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Regulatory Analyses for Severe Accident Issues: An Example

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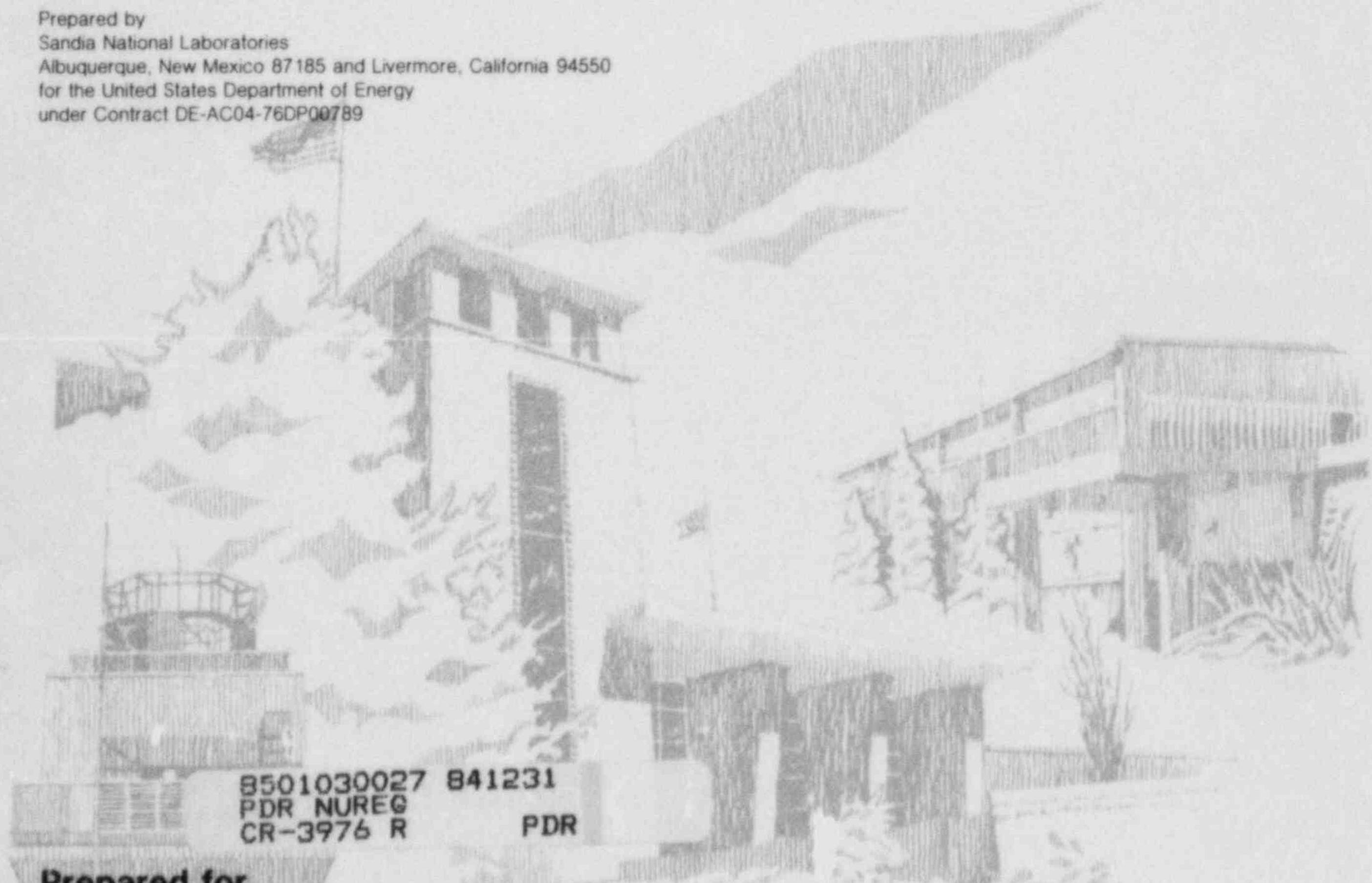

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REGULATORY ANALYSES FOR SEVERE ACCIDENT ISSUES: AN EXAMPLE

ABSTRACT

This report presents the results of an effort to develop a regulatory analysis methodology and presentation format to provide information for regulatory decision-making related to severe accident issues. Insights and conclusions gained from an example analysis are presented. The example analysis draws upon information generated in several previous and current NRC research programs (the Severe Accident Risk Reduction Program (SARRP), Accident Sequence Evaluation Program (ASEP), Value-Impact Handbook, Economic Risk Analyses, and studies of Vented Containment Systems and Alternative Decay Heat Removal Systems) to perform preliminary value-impact analyses on the installation of either a vented containment system or an alternative decay heat removal system at the Peach Bottom #2 plant. The results presented in this report are "first-cut" estimates, and are presented only for illustrative purposes in the context of this document. This study should serve to focus discussion on issues relating to the type of information, the appropriate level of detail, and the presentation format which would make a regulatory analysis most useful in the decisionmaking process.

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PREFACE

This report is part of an ongoing program in the NRC Division of Risk Analysis and Operations addressing regulatory decisionmaking and policy analysis. The program is focused on the flow of information from the NRC research programs to regulatory decisionmakers addressing specific issues.

The regulatory decisionmaking and policy analysis program will benefit both the technical analysts involved in NRC research programs and the regulatory decisionmakers who use technical information to form judgements and opinions on particular regulatory issues. Through exploration and clearer definition of the interface between research programs and regulatory decisionmaking, the individuals involved in ongoing NRC research programs can be made more acutely aware of the information needs and desires of NRC decisionmakers and can orient or modify their efforts appropriately. Similarly, NRC decisionmakers can become knowledgeable in the types of information which the research programs can provide, and perhaps more importantly, become familiar with the methodologies and results from the research programs and the degree of confidence or certainty which should be associated therewith. The benefits of the program to both technical and regulatory programs should feedback to assure better transfer and utilization of technical information for regulatory decisionmaking purposes.

The objective of the study for which this report was written was to identify problems in the research program-decisionmaker interface by performing an example "regulatory analysis." The regulatory analysis is the vehicle by which results of technical analyses can be moved into the regulatory environment for consideration in decisionmaking on specific issues. The purpose of this study was not to perform the final regulatory analysis and form a decision rationale on a specific issue, but rather to uncover through an example analysis the problems which are likely to be incurred in the performance of future regulatory analyses. The methodology and presentation format used in the example regulatory analysis (Appendix A of this report) were developed using guidance from previous NRC documents (NUREG/BR-0058 and the Value/Impact Handbook) to the degree possible and are not recommended as the format for all regulatory analyses on all issues.

The methodology chosen in performing the example regulatory analysis was to rely on technical information from previously completed research programs to the extent possible. In situations in which the available technical information was inadequate or incomplete, an attempt was made to develop the necessary information with a minimum of effort. Normally this involved utilizing information from ongoing research programs or draft reports, or using engineering judgement to complete portions of the analyses. Because of the objectives of this program, an explicit attempt was made to not expend any significant effort developing new technical information. This philosophy and methodology proved to be useful for pointing out many problems which will be incurred in performing regulatory analyses based on the results of previously completed technical programs. These problems are discussed in detail in the main report, and are being addressed further in current NRC programs.

The methodology chosen in performing the example regulatory analysis in this report places some important limitations on the use of the technical information contained herein. Since an attempt was made to fill information gaps with results from ongoing programs, draft reports, and engineering judgement, the technical analyses contained in the example regulatory analysis may not be of sufficient quality to draw conclusions beyond those drawn in the example itself. The information base may be dated, incomplete, technically inaccurate, and will be superceded by information from ongoing research programs in certain instances. Therefore, the example regulatory analysis in this report is in no way intended to serve as the final decision rationale for the example issues presented.

Many of the shortcomings in the example regulatory analysis in this report are likely to be problems in future regulatory analyses unless significant strides are made to improve the researcher-decisionmaker interface. Despite the possible shortcomings in the technical aspects of this effort, the interface problems identified in the main report have proven to be illuminating to both researchers and NRC decisionmakers. Also, many of the lessons learned from this effort have been fed directly back to research programs and NRC decisionmakers to rectify some of the problems identified. Finally, this effort and the lessons learned have helped to guide the continuation of the Regulatory Decisionmaking and Policy Analysis Program on the resolution of problems in the researcher-decisionmaker interface.

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1.0 INTRODUCTION

The Reactor Safety Study [1] predicted that severe accidents beyond the design basis, specifically core melt accidents, dominate the public health risks from commercial LWR operation in the U.S. The accident at Three Mile Island in 1979 demonstrated that severe accidents resulting in core damage can have very significant financial impacts on both LWR plant licensees and consumers served with electricity from an LWR plant. In recognition of these circumstances, the NRC has responded by examining the technical bases that have been used in the past for developing regulations for the operation of commercial LWR plants. Part of this response has been the development of a Severe Accident Research Plan (SARP). This plan is described in NUREG-0900 [2], which states that

> ". . . it is the intent of the SARP to establish a sound technical basis on which an evaluation of the need for changes in nuclear power plant design and operation can be made. . . .
>
> The plan presented here includes work to identify those factors that are most important in developing a sound decisionmaking capability and reduce, as needed, the levels of uncertainty."

A number of programs are currently underway as part of SARP, or are developing information that will be useful in meeting the goals of SARP. These include the Severe Accident Risk Reduction Program (SARRP), which is examining various preventive and mitigative mechanisms which could be used to reduce severe accident risks, the Accident Sequence Evaluation Program (ASEP), which should identify important accident sequences for specific classes of U.S. LWR plants, several code development programs such as MELCOR and CONTAIN, as well as experimental programs examining the physical processes which might occur during severe accidents.

The new information developed in these and other programs may lead to revised designs of future plants, possible modifications to operating procedures in new and existing plants, suggestions for backfits to existing plants, and possibly new approaches to the regulation of the nuclear industry. In addition, the NRC is attempting to provide a basis for examining these issues through the development of safety goals which addresses the question, "how safe should plants be?" Information generated in SARP can be used to help determine how safe existing (or planned) plants are, and if the level of safety is determined to be inadequate, what alternative actions to improve plant safety are available and cost effective.

Several efforts are being carried out by NRC and its contractors to facilitate the integration of the information being developed as part of research programs into the regulatory structure and decisionmaking process. A Value-Impact Handbook has been developed to establish a consistent approach for the performance of value-impact (or cost-benefit) analyses for use in NRC decisionmaking [3]. The program for which this report was written, the Regulatory Decisionmaking and Policy Analysis Program, seeks to establish methods for incorporation of information from a broad range of research programs and to develop suitable presentation formats for providing guidance to decisionmakers on specific issues. Some of the questions which have been raised and addressed to some degree as part of this program include the following:

- What questions do decisionmakers need to answer? (What decisions need to be made now and in the future?)
- What information do decisionmakers need (or feel is necessary) to answer these questions?
- Is the desired information available from past or ongoing research programs?
- How can research programs which generate risk-related information be performed differently to provide more appropriate information?
- What subset of all available information should be provided to the decisionmaker?
- What are the most appropriate and efficient methods for presentation of the information required in the decisionmaking process?

Clearly these questions are very broad in nature and difficult to answer because they address issues related to communication and regulatory decisionmaking rather than specific technical issues. The approach employed in this study to address these issues was to perform an example regulatory analysis on a representative topic of interest using information which is currently available. Appendix A of this report contains the example regulatory analysis on the implementation of a vented containment system or an alternative decay heat removal (ADHR) system at Peach Bottom Unit 2. Again, it is important to note that the example regulatory analysis is not intended to provide the final decision rationale for these issues, but rather to identify the problems which will be encountered as the information from the SARP is incorporated into the decision process. The technical information employed in the example regulatory analysis has been extracted from previous studies to the extent possible, and an attempt was made to avoid, as much as possible, developing new technical information. As a result, some of the information in the example regulatory analysis may be quite dated, and NRC has ongoing research programs which will provide improved information related to containment venting and ADHR systems (specifically the SARRP and TAP A-45 programs). Thus, the primary purpose of the example regulatory analysis is to point out the problems which will be incurred in the incorporation of information from research programs into the NRC decisionmaking process in the future. This effort has also been used to provide an interface, related to the use of information in the decisionmaking process, among many of the programs being carried out as part of the overall SARP effort.

The regulatory analysis is the tool that NRC intends the staff to use to present to a decisionmaker all the relevant technical as well as non-technical information necessary for the resolution of a selected issue. The guidelines for performing a regulatory analysis outlined in NUREG/BR-0058 [4] and the cost-benefit approach developed in the Value-Impact Handbook [3] have been employed to the extent possible in the evaluation of the risk reduction alternatives in this report. The development of an example regulatory analysis served as a field test of the guidance and rules laid out in NUREG/BR-0058, as well as a test of the directions in the Value-Impact Handbook on performing a cost-benefit analysis. It has helped identify potential problems in performing such analyses, particularly with regard to gathering data from ongoing or past research programs. The example is also helping to resolve issues related to breadth of content, level of detail, and methods for presentation of information that are appropriate in a regulatory analysis.

This main report describes the experiences and problems encountered in performing an example regulatory analysis on the backfitting of either a vented containment system or an ADHR system to Peach Bottom Unit 2. Section 2 contains a synopsis of the example, including a description of the issues, the candidate systems, and the sources of information used in developing the example analysis. Section 3 discusses issues related to the gathering and application of information that is developed in research programs. Section 4 is devoted to the impacts of uncertainties on performing a regulatory analysis, and a discussion of the impacts of uncertainties on the ability to make decisions based on traditional cost-benefit guidelines. Finally, Section 5 covers the display of information to the decisionmaker and the problems of communicating very complex technical information for decisionmaking on specific issues. Following the main report are a series of appendices that contain the example regulatory analysis and the information that would normally support an analysis of a severe accident issue, including appendices on the calculation of baseline risk and risk reduction, as well as detailed descriptions of the proposed systems and their basis for selection. It is important to emphasize that the information presented in this example analysis, while developed using methods that would be appropriate to a final regulatory analysis, is nonetheless tentative and should not be used for purposes beyond demonstrating the techniques being developed in the example regulatory analysis.

2.0 SYNOPSIS OF THE EXAMPLE REGULATORY ANALYSIS

A number of alternatives which reduce the probability of core melt accidents or the probability of containment failure in the event of core melt accidents have been studied for possible implementation as backfits at operating plants. Two of these are the use of (filtered) vents from containment and alternative decay heat removal (ADHR) systems. The example regulatory analysis in Appendix A examines the impact on public risk and the costs of these two systems. The format of this analysis is based on the guidelines contained in NUREG/BR-0058 [4].

The first section of the example regulatory analysis discusses the objectives achieved by implementation of either alternative under consideration. The containment vent system is effective in reducing the probability of containment failure for certain overpressure events and provides fission product scrubbing in the suppression pool for some accident sequences, and therefore mitigates the consequences for certain core melt accidents. More importantly for the Peach Bottom plant, by preserving containment integrity, the vented containment serves to reduce the probability of accidents for which core melt follows containment failure. The accident prevention provided by the vent system under consideration is predicted to be more important than the consequence mitigation effect of the vent system for the Peach Bottom plant. The ADHR system reduces core melt probability by increasing the probability that decay heat removal will be achieved following reactor shutdown. Thus the ADHR system is predicted to provide only reduction in the core melt frequency and no significant consequence mitigation effects are provided. Both alternatives serve to reduce public health and financial risks, and both may have some impact on the risks associated with external events and special emergencies.

The discussion of the objectives is followed by descriptions of the specific design alternatives under consideration. For venting systems this involves the comparative advantages of high versus low volume vents and filtered versus unfiltered vents. A short argument for the selection of the unfiltered vent from the wetwell is given, and is followed by a description of the vent design. A detailed description of the various venting alternatives and the selection criteria are contained in an appendix to the example. The ADHR system is similarly treated. The key variable in the choice of ADHR systems relates to the capabilities of the system to remove decay heat under various reactor coolant system pressure conditions. The choices are followed by a listing of the five screening criteria which had formed the basis for selecting among the candidate ADHR systems in previous technical analyses. A low pressure makeup and suppression pool cooling train is the alternative considered in the example analysis, and is fully described and diagrammed, as was the vent. The selected ADHR system is described in detail in an appendix to the example. Several alternatives that were not studied in detail in the example are described in the sections following the descriptions of the two main alternatives.

The third major section of the example regulatory analysis discusses the consequences of implementation of the alternatives. The main body of this section is the cost-benefit analysis that was carried out according to the format developed in the Value-Impact Handbook. The first step in the development of the cost-benefit analysis is the summarization of information related to baseline and averted risks. The development of the risk estimates appears mostly in an appendix to the example, rather than in the section itself. The risk estimates are based on a variety of sources in order to develop baselines and risk reductions for the two alternatives that are directly comparable. While these estimates were developed to the degree possible in this limited study, the results are preliminary estimates. Therefore, they should not be used outside the example context of the regulatory analysis. In addition to the value-impact statement, this section also contains cursory discussions of additional (non-quantifiable) impacts such as impacts on special emergencies and external events.

The next major section of the report is the decision rationale. The first part of this section is a summarization of the conclusions from the value-impact analyses. The major conclusions regard the role of uncertainties, the cost-benefit balance and the effects of the alternatives on external events and special emergencies. These conclusions are followed by more general conclusions relating to the uncertainties again, as well as issues regarding the development of the data. The section ends with a recommended course of action. Following the section on the decision rationale, the last section of the example regulatory analysis is the implementation plan for recommendations from the analyses.

From the regulatory analysis presented in Appendix A, the following conclusions emerged regarding the implementation of the containment venting system at the Peach Bottom plant:

1. The uncertainties in the estimates of baseline risk and the risk reduction potential of the vented containment system make it currently impossible to definitively prove or disprove the cost-effectiveness of the system at the Peach Bottom plant. However, the vent is predicted to reduce a significant fraction of the internally-initiated accident risk from Peach Bottom operation due mostly to the prevention of core melt in specific accident sequences, and is clearly in the range of cost effectiveness.

2. The dominant attributes (contributors to costs and/or benefits) in the value-impact analysis for the vented containment system are the risk reduction for internally-initiated accidents and the industry cost of implementation. The conclusions from the value-impact analysis are not sensitive to assumptions regarding the other attributes considered in the analysis.

3. Improved information regarding the costs of vent installation could enhance our ability to decide whether or not the vent is cost-effective, particularly using central estimates. Also, further risk information could result in better quantification and possibly reduction of the uncertainties in the analysis. However, it is likely that significant uncertainties will still have to be dealt with in the final decisionmaking process.

4. The use of $1000/person-rem as a measure of public health or total impacts results in larger estimates of benefit on this issue than the use of actual averted property damage and health effects impacts.

5. The vent may have negative impacts on station blackout accidents, indicating that other venting options may be more appropriate for consideration at plants with high station blackout frequencies. However, since the Peach Bottom station blackout frequency is relatively low [5], this had little impact on the value-impact portion of the example regulatory analysis.

In summary, the vent fares reasonably well in the value-impact analysis for the Peach Bottom plant, achieving potentially large risk reductions for relatively small costs. This is due to the nature of the system, preventing core melt from occuring in specific accident sequences at the Peach Bottom plant. These results are strongly dependent upon the two accident sequences which are the dominant contributors to the core melt frequency at the Peach Bottom plant: transient-initiated accidents with failure to achieve decay heat removal (group TW sequences), and anticipated transients without scram (group TC sequences). The vent could look substantially worse at plants with high station blackout frequencies or different containment designs.

Based on the analysis performed for the ADHR system, the following conclusions can be drawn:

1. The ADHR system considered in the example regulatory analysis is unlikely to be cost-effective based on reduction of internally-initiated severe accident risks at the Peach Bottom plant. The system is predicted to result in reduction of the risk from accident sequences which result in core melt due to loss of the decay heat removal function. However, the large cost of the system (on the order of tens of millions of dollars) makes the net benefit of implementation negative.

2. Like the vented containment, the dominant attributes in the value-impact analysis for the ADHR system are the risk reduction for internally-initiated accidents, and the industry cost of implementation. The conclusions from the value-impact analysis are not sensitive to assumptions regarding other attributes considered.

3. It is unlikely that improved information regarding the internally-initiated accident risk reduction of the ADHR system would change the conclusions from the value-impact analyses. Information improvement for this system should focus on additional considerations like special emergencies or potential constraints to implementation of the system at Peach Bottom.

4. As with the vented containment system, the use of $1000/person-rem as a measure of public health or total impacts results in larger estimates of benefit on this issue than the use of actual averted property damage and health effects impacts.

In summary, the ADHR system is not likely to be cost-effective based on the value-impact analysis performed for internally-initiated accidents at the Peach Bottom plant. The ADHR system is predicted to result in risk reduction for core melt accidents resulting from loss of the decay heat removal function (group TW sequences), but the benefits from this risk reduction are not large enough to outweigh the large implementation costs for this system. Improvement of information for decisionmaking regarding the ADHR system, if desired, should focus on additional considerations rather than the attributes considered in the value-impact analysis in this study.

Several important general conclusions have resulted from the performance of the example regulatory analysis and the value-impact studies of the vented containment system and the ADHR system. Among some of the important general conclusions are:

1. The central estimates of the mean internal accident risks for the remainder of plant life at LWR plants are in the range of a few million dollars based on estimates of property damage and health effect costs. Thus, it is extremely unlikely that modifications with costs ranging from several million to hundreds of millions of dollars could be justified purely based on cost-benefit analyses. Because baseline risk estimates are relatively low, detailed cost-benefit analyses should focus on the options with relatively low implementation costs. Analyses of the more expensive options might be focused more effectively on considerations other than traditional cost-benefit analyses.

2. There may be important negative synergistic effects on the benefits achieved through implementation of more than one risk reduction modification at a given plant. For example, the net benefit achieved through installation of both the vented containment system and the ADHR system at the Peach Bottom plant is far less than the sum of the net benefits of each individual system. Therefore, it is important to consider the costs and benefits of risk reduction modifications relative to one another, in addition to examination of the cost-effectiveness of any one system. This comparison should result in selection of "the best" alternative or alternatives rather than an alternative which is only "acceptable."

3. Uncertainties are likely to reappear as the most difficult issue to cope with effectively in future regulatory analyses. There is a strong need for a significant improvement in methods for both quantification of uncertainties and communication of uncertainties within a decisionmaking framework.

4. There is substantial difficulty associated with the collection and use of the results of previous technical analyses in a consistent regulatory analysis framework. Some of the difficulties arise from analyses performed at different times, using different base assumptions, or from the unavailability of necessary information for decisionmaking purposes. It is useful for regulatory

analysis purposes to have as much information as possible available. Also, very simple value-impact calculations can often identify information which will be necessary for a final regulatory analysis.

Again, it is important to point out that the purpose of the example regulatory analysis was to identify potential problems and information needs which are likely to be required in the decisionmaking process for severe accident issues rather than to provide a definitive decision rationale for the specific issues addressed. Based on this objective, and since ongoing research programs will provide improved technical information related to these specific issues, it is recommended that final decisions on these issues be delayed until the improved information from ongoing research programs is available. However, it is recommended that the problems in the regulatory analysis and decisionmaking process identified in this study should be addressed by the NRC to assure that an appropriate and efficient mechanism exists for incorporating future technical information into the regulatory process.

3.0 INFORMATION CONTENT ISSUES AND INSIGHTS

One of the goals of the Regulatory Decisionmaking and Policy Analysis Program was to uncover, through development of the example analysis, the problems which may be encountered in the performance of a regulatory analysis. These problems can be divided into several major topic areas, each of which will be discussed separately. In general, the topics all relate to the availability and communication of information.

3.1 Lack Of Information

One important problem which might arise in the performance of a regulatory analysis for severe accident issues is a lack of appropriate or technically-based information. This problem was encountered frequently in carrying out the example analysis, mainly because the results of previous technical studies were applied to specific issues for which the technical information was not appropriately developed. For example, the backfit of the ADHR system had been studied in detail for a BWR plant, although not the Peach Bottom plant. Thus, a lot of the necessary information is available for a reactor of similar design, but the adaptation of some of that data, and the closure of areas in which data are missing is a difficult task. This type of problem which was encountered in the example regulatory analysis demonstrates the need to clearly identify the information which is likely to be required in the decisionmaking process either before or during the course of research programs which would provide the desired information.

In some other cases it may be possible to perform a regulatory analysis using simple assumptions to bound possible ranges in cases where appropriate information does not exist. For example, in the example regulatory analysis, the NRC costs of development and implementation of the ADHR system are shown to be small relative to industry implementation costs.

Another problem faced in the development of the regulatory analysis is the lack of information related to uncertainties reflecting a general lack of knowledge, as in the source term. Like most other studies, we have adopted the approach of making "bounding" assumptions to appropriately reflect the uncertainties associated with the risk and risk reduction measures. These assumptions were employed to reflect the uncertainties in developing the high, nominal (best), and low estimates as outlined in the Value-Impact Handbook [3].

A potential problem was also identified relating to the unavailability of some non-technical information. Since research programs are often oriented towards addressing the technical issues associated with a proposed modification to the plant, change in operating procedures, or improvement in the state of knowledge, there is usually little if any discussion of the non-technical implications of the possible changes. Examples of issues for which information is clearly required as part of a thorough regulatory analysis include the consistency of the recommendations with past regulatory behavior, the legal ramifications of the suggestions, or the nature of the hearing processes which may be required to implement a specific suggestion.

3.2 Non-comparable Information

Since the method of performance and content of a probabilistic risk assessment (PRA) are determined, at least in part, by its anticipated application, the methods used and topics covered vary from one PRA to the next. This can lead to a variety of problems. Since a regulatory analysis may typically cover a number of alternatives, as did the example, one might have to rely on the results of several different studies in order to gather all required information. The differences in the assumptions employed in risk studies often lead to noncomparable information. For example, the development of risk estimates, a fundamental contribution of the PRA to the regulatory analysis, may involve estimates based on release categories, as was the case in WASH-1400 [1] and NUREG-0773 [6], or it may be based on specific accident sequence information as was the case in the study of conceptual designs for containment venting [5]. Even when consistent release categories are used, differences in presentation might still occur. The analyses performed in NUREG-0773 resulted in shifting certain accident sequences to smaller release categories. In addition, the different vintages of PRAs lead to different results, reflecting improvements in the state of knowledge.

Use of a common approach will not necessarily resolve all the differences. Studies made for different purposes may concentrate on different areas. For example, the containment venting study was obviously more concerned with accident sequences for which the vent might prevent core melt or mitigate accident consequences than with the decay heat related sequences which are the focus of ADHR studies. Thus, even though the analysis approaches may be similar, the different scopes of coverage might make attempts at comparison of the two sets of results difficult when trying to establish risk baselines or comparisons of risk reduction.

The performance of a PRA requires a considerable number of assumptions to be made. Unfortunately, the assumptions can vary considerably from one PRA to the next. These differences include assumptions about the nature of the base plant design (fixes not yet made or mandated may be assumed to exist), assumptions about frequencies of accident initiators, and assumptions used for modeling physical processes and accident phenomena.

The measures calculated in the risk studies may vary as well. Not all studies report the same risk measures, and there is no standardized nomenclature for the measures, so similarly named measures may not be comparable. Person-rem, for example, may be measured over all exposed population, or may refer to the 50 mile radius suggested in some interpretations of the Commission's proposed safety goals [7]. Measurement of the dollar value of health effects is a subject of continual controversy, and the measurement of offsite damage is subject to a number of interpretations. Onsite damage, which is frequently a dominant factor in economic consequences, is also subject to a variety of approaches to calculation, or even the question as whether to include it at all.

3.3 Summary And Recommendations On Information Content Issues

The performance of the example regulatory analysis, and the lessons learned with regard to information gathering and development, served to reinforce our perceptions of the importance of programs such as SARRP which will develop risk information for a wide variety of alternative modifications for each plant under consideration. Because the information is being generated as part of one program, the risk and risk reduction information developed is likely to be as consistent as is currently possible for different modifications at different plants. Also, SARRP will be able to provide a comparison of risk reduction alternatives for a given plant, so that the "best" alternatives are clearly identified, rather than merely "acceptable" alternatives.

Another important lesson that has come out of this example is the importance of insuring that the researchers carrying out PRAs or other programs understand the intended application of their work. Much of the work used in support of the example regulatory analysis had been carried out as part of previous research programs. However, much of the work was not designed in a way that maximized its contribution in resolving current regulatory issues. In some cases this occurred because the researchers were not adequately aware of (and could not be expected to anticipate) the current regulatory needs.

In order to insure consistency between existing data and future research programs, and to facilitate calculations based on existing data, it would be very desirable to establish a data base system containing the assumptions and results of risk assessment research performed to date, as well as a mechanism for updating and manipulating the data. This data base would allow future analysts to quickly evaluate the impacts of changes in assumptions and to perform comparative studies of existing PRAs. This kind of information base could prove to be extremely useful for the staff within the NRC in developing insights into the impacts of assumptions and an improved understanding of severe accident issues. Some data bases of risk related information are planned for development as part of the SARR program.

4.0 IMPACTS OF UNCERTAINTIES

Current studies on uncertainties indicate that the uncertainties associated with all aspects of PRA, while better understood, will continue to be large, frequently so large as to preclude the use of a strict cost-benefit criterion in determining whether to adopt a proposed fix or other suggestion. Sometimes the uncertainties will make it impossible to determine whether or not a proposal results in a net reduction in the overall risk.

A number of other problems arise from the current uncertainty analyses. The uncertainties themselves are very uncertain, are often estimated subjectively, and are frequently expressed as scale factors or even orders of magnitude which indicates the imprecision with which the estimates are derived. The degree of completeness of the uncertainty analysis, and the method used, can vary radically from one analysis to another. Together these differences and shortcomings create considerable problems for the author of a regulatory analysis; new uncertainty estimates may have to be made, and considerable effort may be devoted to make the results of previous analyses comparable so that they can appear in the same regulatory analysis. Finally, the uncertainties, almost regardless of the manner in which they are estimated, will often rule out clear cut cost-benefit decisions on many issues of importance.

5.0 COMMUNICATIONS AND DISPLAY OF RESULTS

In developing the example regulatory analysis, a number of issues were raised related to the level and extent of information to be presented to the decisionmaker and the best methods to display that information. For issues such as the backfit of a vented containment or an alternative decay heat removal system, there is a broad array of technical information that is relevant to the issue, particularly risk-related material. That information needs to be synthesized and summarized in a manner making it useful to the decisionmaker.

Appendix C, Baseline Risk and Risk Reduction Estimates with Uncertainties, contains a substantial volume of information used in developing the risk and risk reduction estimates employed in the value-impact portion of the example regulatory analysis. This information, which is already a condensation of a larger amount of information that appears in other reports combined with various assumptions used to bound uncertainties, needs to be further condensed and more efficiently presented if a decisionmaker is to be aided by the information. In the example regulatory analysis, an attempt was made to synthesize and present the information that would be most useful and appropriate in the regulatory decisionmaking context. Included are summary measures such as the core melt frequency per reactor-year of operation, risk measured for the remaining lifetime of the plant (measured in 3 different ways, 1) damages measured using $1000 per person-rem of offsite exposure, 2) offsite damage including health effect costs using the dollar values selected for NUREG/CR-2723 [8], and 3) total onsite and offsite damages), and averted risk for the remaining lifetime of the plant. Numerous other measures could be shown, such as early fatalities, latent cancer fatalities, interdicted land area, and so on. The summary measures presented in the example regulatory analysis were chosen on the basis that they would be the most useful measures for a hypothetical decisionmaker for the particular issues addressed in the example. While the selection did involve deliberate and careful choice, it is important to emphasize the example nature of the regulatory analysis. Therefore any measures which were not included, but are desired, can certainly be added in future analyses. Also, the choice of summary measures presented in a regulatory analysis should be closely linked to the attributes which are important to the specific issues under consideration.

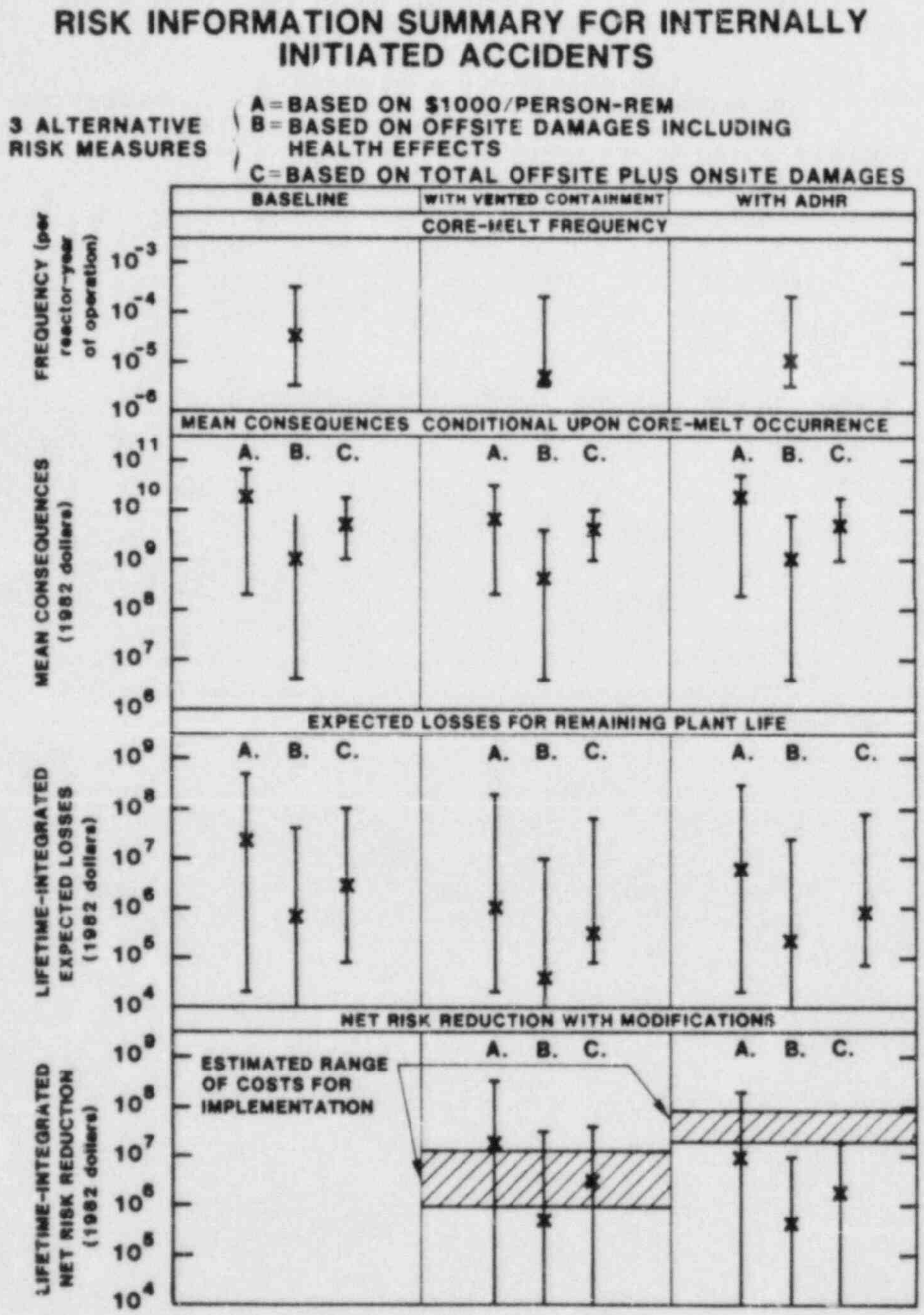
5.1 General Display Issues

Much attention has been focused on the selection of graphical presentation techniques for the data in the example regulatory analysis. Graphs are desirable for several reasons; conciseness, simplification of complex data or relationships, ease of comparison, and speed of communication. However, there are several drawbacks to the use of graphical presentations. Graphs almost always exclude some of the available information, they tend to oversimplify complex issues and relationships, the choice of representation can distort the observer's perception of the content of the graph, and the use of graphs can lead to overconfidence in the observer, leading him to believe that he understands the issues or data more clearly than he really does. All of these issues were considered in trying to develop the graphical presentation of the data that appears in the example regulatory analysis.

Figure 1 shows the graph employed in the example regulatory analysis to summarize risk and risk reduction information for the vented containment and ADHR systems including the estimated uncertainties in each of the measures. This graph presents information on the core melt frequency per reactor-year of operation, the mean consequences (presented in the three summary measures) conditional upon core melt accident occurrence, the risk integrated for the remaining plant lifetime (again presented for the three measures), and the risk averted for the remaining plant lifetime through implementation of either the vented containment system or the ADHR system. This graph is intended to display most of the information related to the internally-initiated risk from plant operation both prior to and after implementation of either risk reduction system which might be of interest to a decisionmaker including the overall uncertainties associated with each section of the analyses. The information related to core melt frequency shows the accident prevention effects of each system and also provides information

Figure 1

HYPOTHETICAL EXAMPLE



related to the estimated uncertainties in the frequency estimates. The mean consequences conditional upon core melt accident occurrence presented in the second box of the figure are based on averaging over many accident sequences, radioactive material release categories, wind directions, and weather conditions. This portion of the display is intended to show the consequence mitigation effects of particular risk reduction measures. The third box of the display shows the lifetime-integrated risk from plant operation for each of the three summary measures. This information is presented to show the effects of integrating over plant life and discounting. Finally, the fourth and final box of the figure shows the net risk reduction (again for the remaining plant lifetime) which would be afforded by the implementation of either risk-reduction system. This averted risk information, including uncertainties, summarizes the information which is used in the value-impact analyses. The shaded area in the fourth box is the estimated cost range for implementation of each system from the value-impact analyses.

The intent of the presentation format in Figure 1 is to summarize concisely most of the information related to the risk from plant operation in which a decisionmaker might be interested. From the display it is clear that there are large uncertainties associated with both the frequency and consequence portions of the analyses, which lead to uncertainties in the lifetime risk and averted risk values which are employed in the value-impact analyses. The display also demonstrates that there are several additional calculations and assumptions required to step from core melt frequency into risk measures. The display is also useful in that it is easy to compare core melt frequency, mean consequence, and lifetime risk measures (with uncertainties) both before and after the implementation of either system. The display also encourages the comparison of alternative measures through the stages of the analysis. Finally, the display format of Figure 1 is useful because it summarizes a tremendous amount of information related to core melt frequency, consequences, and risk in a very small space.

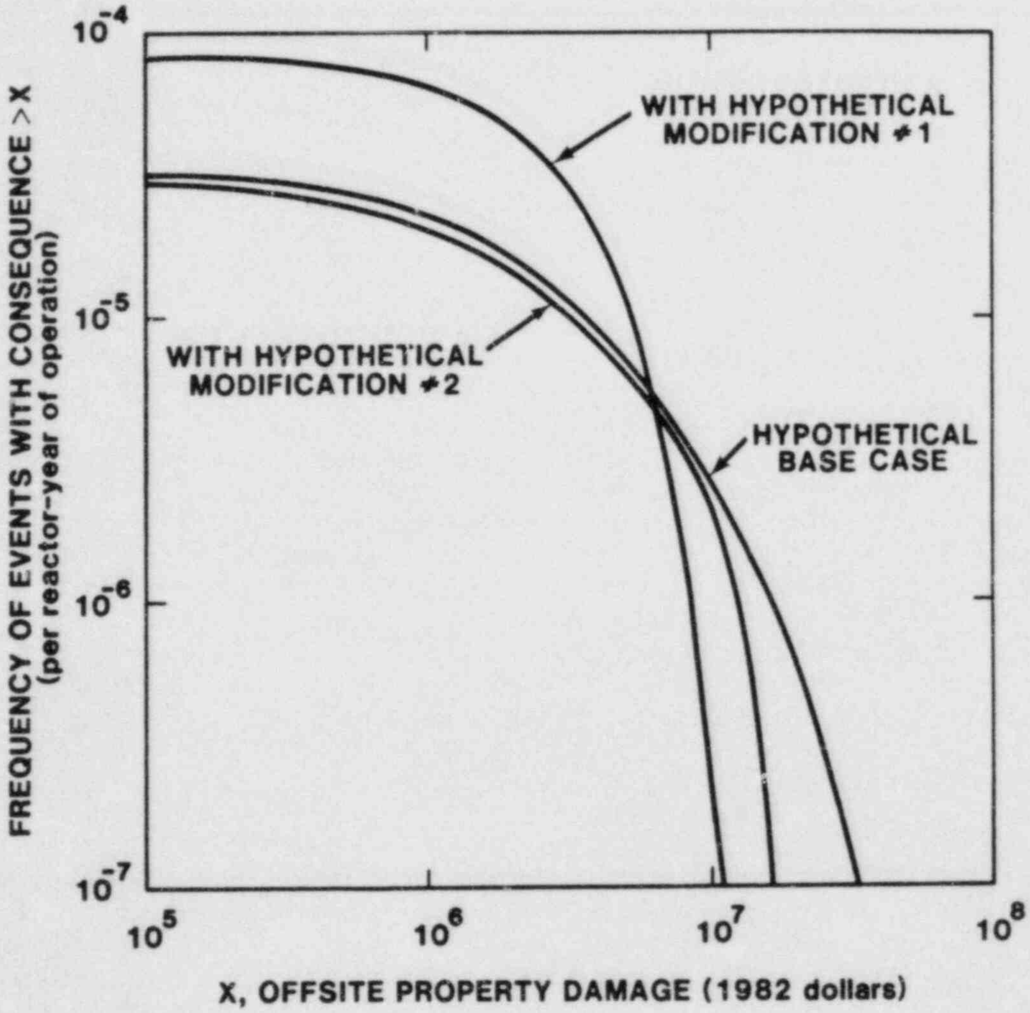
Although the presentation format used in Figure 1 has many advantages, there are several problems which have also been identified for this display. One problem regards the amount of information presented in Figure 1 related to severe accident frequency and risk measures. The intent of the display was to provide all of the information related to risk which might be of interest to individual decisionmakers. However, to achieve this objective, values are presented from several stages of the analyses, which leads to complexity in the communication and interpretation of information. For example, the exact process by which "mean consequences conditional upon core melt accident occurrence" are calculated is likely to be unclear to a decisionmaker who is not intimately familiar with risk and consequence analyses. Any confusion which might exist regarding mean consequences is likely to cause further confusion in interpretation of the lifetime-integrated risk measures. It is possible that Figure 1 may be too heavily oriented towards technical information which would not prove fruitful for decisionmaking at high levels. This example display format demonstrates well the problems incurred in striking a balance between providing adequate information to satisfy decisionmaking needs and simplification of presentations through elimination of unnecessary technical details.

There are several additional problems which have been identified with the display format in Figure 1. Although the figure displays the overall uncertainties from the analyses, it does not demonstrate well the major contributors to the uncertainties. The display requires interpretation and comparisons across logarithmic scales which can be difficult and confusing for those not familiar with this type of presentation. The display of mean consequences does not show the potential severity of low probability events, which may be an important attribute for consideration in regulatory decisionmaking. Also, because there is so much information displayed, the figure often provides different insights to different individuals. For example, some individuals felt that this figure primarily demonstrated the large magnitudes of uncertainties, while others focused mainly on the strengths and weaknesses of the various measures demonstrated in the figure. Presentation of such a large amount of information in a single display tends to detract from the ability to communicate any single important point in one figure. Individuals tend to focus on the information presented which they best understand rather than any single argument which the authors intend the figure to support.

To demonstrate the potential problems with information which is omitted from presentation in Figure 1, Figure 2 presents hypothetical CCDFs (Complementary Cumulative Distribution Functions) for offsite property damage from core melt accidents. CCDFs are also presented for offsite property damage risk after the implementation of two hypothetical risk reduction measures. The values presented in Figure 2 are not based on any specific risk reduction measures but are intended to clearly demonstrate the types of information which cannot be inferred from Figure 1. The CCDF for risk reduction modification #1 in Figure 2 shows a dramatic change in the complexion of the risk profile compared to that shown for the base case in Figure 2. The probability of low consequence events is raised by the system, while the probability of very high consequence events is significantly lowered. This may be an important attribute for consideration in severe accident decisionmaking, yet this point

Figure 2

HYPOTHETICAL COMPLEMENTARY CUMULATIVE DISTRIBUTION FUNCTIONS FOR OFFSITE PROPERTY DAMAGE



would not be demonstrated well using the display format of Figure 1, since the mean consequences, conditional upon core melt accident occurrence, would show little change. Also, because high consequence events often contribute very little to the mean consequence, it is possible that a mitigation feature which lowers only the consequences near the peak of the CCDF would not significantly affect the mean consequence. This case is demonstrated in the CCDF for risk reduction modification #2 in Figure 2, which has approximately the same mean as the base case. Finally, it is important to note that although Figure 2 does provide some additional insights related to accident consequences which may be obscured by the display format of Figure 1, Figure 2 does not provide any information related to the uncertainties associated with the analyses.

The experiences gained in the example regulatory analysis point out some important benefits to be gained through a uniformity of style in the presentation of results of technical analyses for use in the decisionmaking process. For example, individuals who are familiar with accident consequences can extract much information from results presented using CCDFs because they constantly present the results of their analyses in this format. Conversely, presentation of results in a CCDF format can obscure information for those individuals who are unfamiliar with risk or consequence analyses. Similarly, the individuals involved in this study became very familiar and comfortable with the display format in Figure 1 after several repetitions of the analyses and discussions. However, this display format, which is rich in technical information, could also be somewhat confounding to decisionmakers unfamiliar with the style of display.

Figure 3 presents a duplicate of the value-impact summary graph from the example regulatory analysis in Appendix A. This display demonstrates the ease of comparison and perceptions which can be induced by the selection of the appropriate style of graph. Figure 3 shows that the significant contributors to the value-impact portion of the analysis are the values of the risk averted and the industry costs of implementation. This is in large part due to the magnitude of the uncertainties associated with these two attributes, and the relatively small contributions of other attributes even based on bounding assumptions. The display format in Figure 3 is also very successful in making clear that the net benefits might be negative; since the scale is linear, the zero point is included on the y-axis. However, a change in the style of the graph can have a radical impact on the viewer's perception. Figure 4 shows the graph in Figure 3 redrawn with a logarithmic scale (this requires defining the impacts as negative dollars since we can't have negative values on a log scale). The values and impacts with uncertainties which stood out as being so obviously dominant in Figure 3 are obscured by the logarithmic scale in Figure 4.

Figure 3

HYPOTHETICAL EXAMPLE

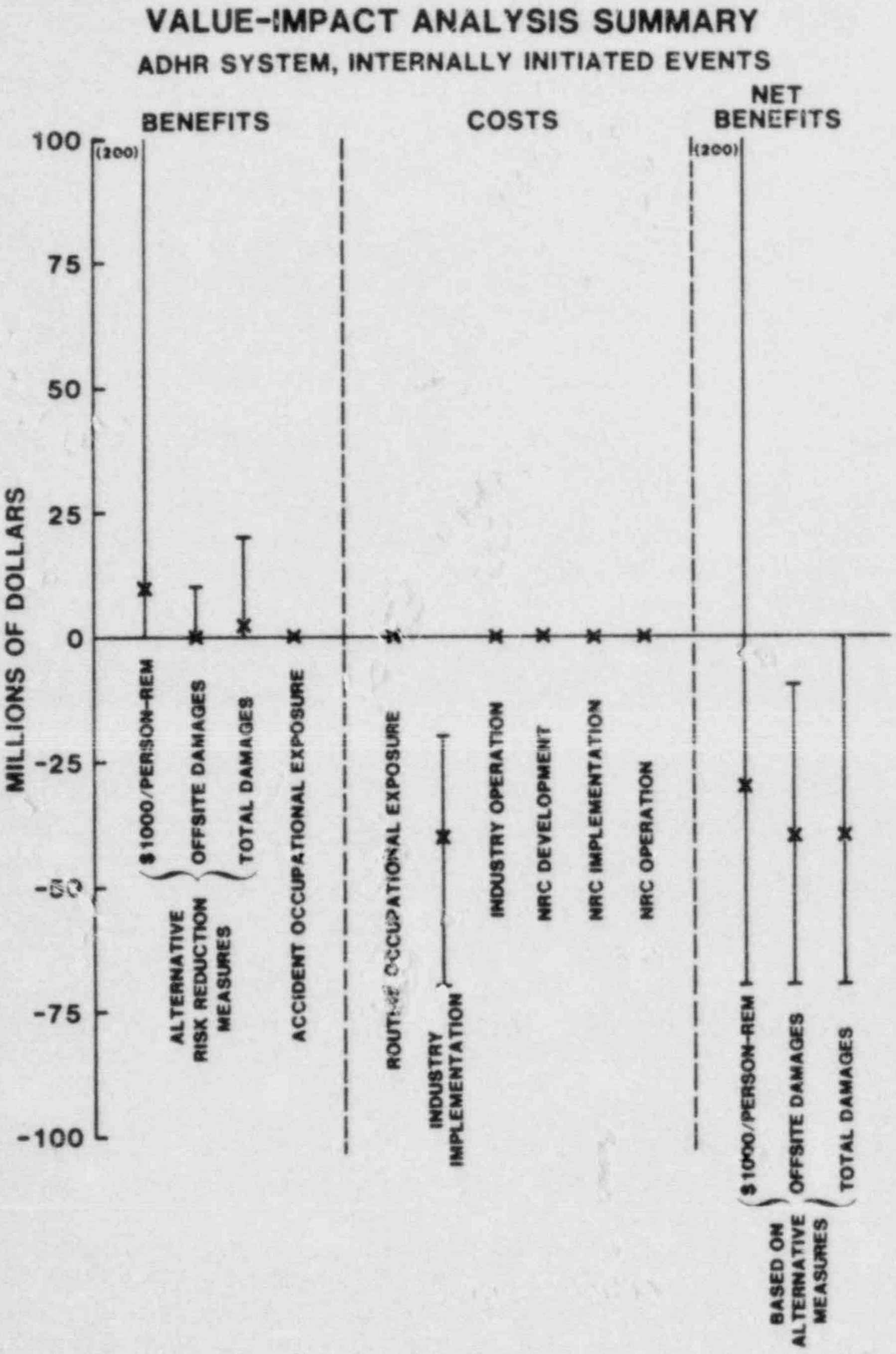
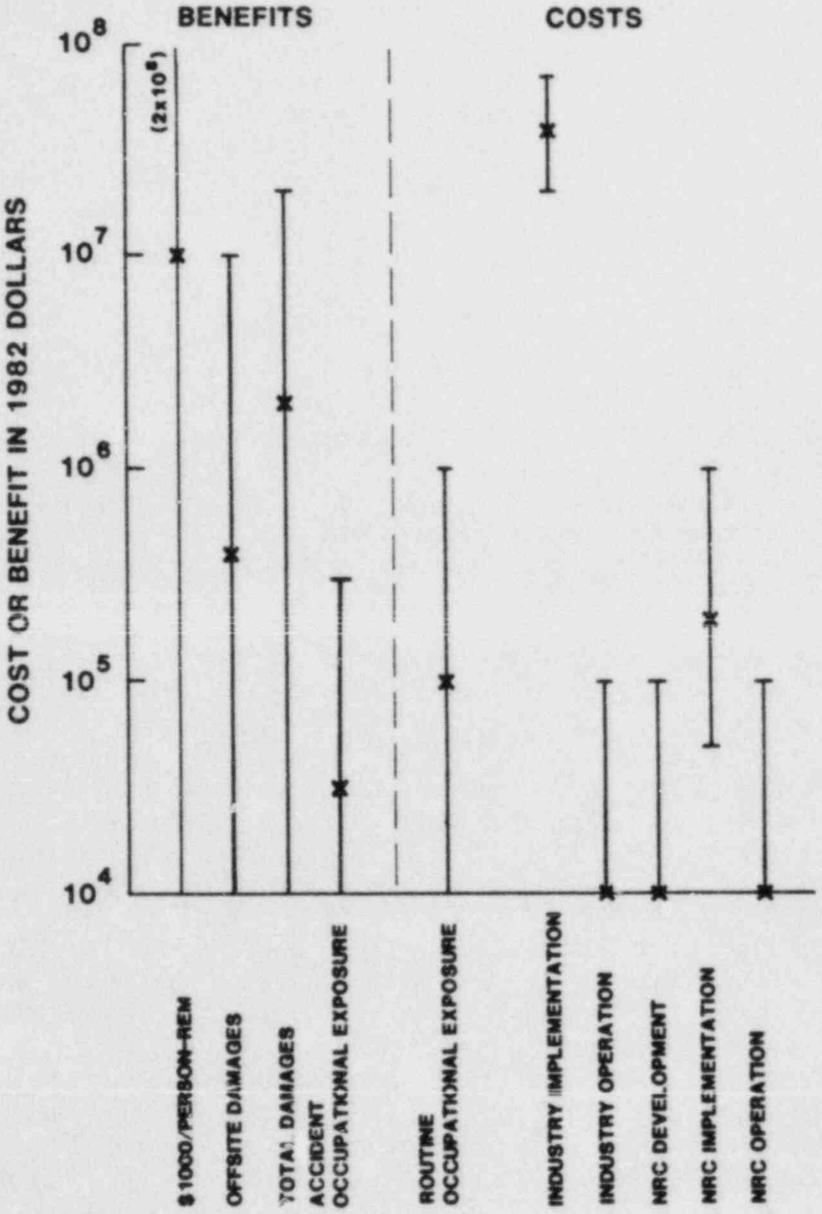


Figure 4

HYPOTHETICAL EXAMPLE

SUMMARY OF BENEFIT AND COST ESTIMATES USED IN ADHR VALUE-IMPACT ANALYSIS



In summary, there are a number of conflicting objectives to be achieved in the display and communication of results of technical analyses for use in the regulatory decisionmaking process. Several specific issues which have been raised through the experience with the example regulatory analysis have been pointed out in this report. The display formats chosen for presentation of results in the example, although not perfect, represent an attempt to achieve the desired objectives for the specific issues under consideration. As will be the case for all the conflicts in choice of presentation techniques for regulatory decisionmaking, the choice will depend on the specific intended audience and the technical arguments to be made. There is no display technique defined to be the 'correct' method applicable to all situations. Hopefully, the example presentations contained in this study will serve as a starting point for discussions to develop more efficient and appropriate methods for communication of technical information in the regulatory environment.

5.2 Display Of Uncertainties

The results reported in the example analysis are subject to frequently large uncertainties. Many of the uncertainties contained in the analyses are based on a "lack of knowledge" in specific areas related to severe accident phenomonology. The methods used to present the results in the example do not allow the reader, however sophisticated, to distinguish between these "ignorance" and other data-related or "stochastic" contributions to the uncertainties presented. It is extremely difficult to make clear in any presentation format those portions of the analyses which are very accurately quantified based on statistical data, and those parts which employ some degree of subjective or engineering judgement. No attempt at distinguishing between these two types of information was made in the example regulatory analysis. Displays that distinguish these two types of information might be important in some regulatory applications.

The uncertainties in portions of the example regulatory analysis are displayed in Figure 1 and Figure 3. These formats have the advantage of displaying the overall uncertainties in the results of the analyses, but do not show the major contributors to the uncertainties in the analyses. This may be a desirable attribute for use in the regulatory decisionmaking process, and should be further addressed in studies of alternative display methods.

6.0 SUMMARY

In summary, the performance of the regulatory analysis has pointed out several areas which require further attention to assure that appropriate mechanisms exist for the incorporation of research program results into the regulatory decisionmaking process. It is necessary to make clear to researchers what the needs of the regulatory agency are, and then monitor the research to insure that the information necessary for the agency's needs is being developed by the research program. This approach is clearly preferable to the modification of research results to fit regulatory needs after a research program has been completed. There is a need for recognition within the NRC that there are large uncertainties in the results of risk analyses, and that the uncertainties must be carefully considered and weighed in the regulatory decisionmaking process. Finally, there is a need for improved methods for communication and display of results to decisionmakers since the amount of information related to severe accident issues can become overwhelming.

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APPENDIX A

EXAMPLE REGULATORY ANALYSIS OF VENTED CONTAINMENT SYSTEM AND ALTERNATIVE DECAY HEAT REMOVAL SYSTEM FOR PEACH BOTTOM #2

GLOSSARY

ADHR = Alternative Decay Heat Removal (System)
ATWS = Anticipated Transient Without Scram
DHR = Decay Heat Removal (System)
ECC = Emergency Core Cooling
ECCS = Emergency Core Cooling System
FVCS = (Filtered) Vented Containment System
HPCI = High Pressure Coolant Injection (System)
RCIC = Reactor Core Isolation Cooling (System)
RPS = Reactor Protection System

KEY TO ACCIDENT SYMBOLS

B = Total loss of ac power (i.e., station blackout) for >12 hours
C = Failure of the reactor protection system
Q = Failure of normal feedwater system to provide makeup water
T = Transient event
U = Failure of HPCI or RCIC to provide core make-up water
V = Failure of low pressure ECCS to provide core make-up water
W = Failure to remove residual core heat

A.1 PROBLEM STATEMENT

A.1.1 Introduction

Core melt accidents resulting in containment failure are important contributors to the public health risk from the operation of light-water reactors in the U.S. A number of alternatives have been studied for reducing the probability of core melt and core damage or mitigating the consequences of core melt accidents by eliminating or significantly altering many of the events that lead to core damage or containment failures. Two plant improvements which have been considered to reduce the probability and risks of severe accidents include vented containment systems and alternative decay heat removal systems (ADHR). This regulatory analysis addresses the values and impacts of possible requirements for addition of either a vented containment system or an alternative decay heat removal system at the Peach Bottom #2 plant, a BWR with a Mark I containment system. Information from previous and current NRC programs has been expanded and utilized to estimate probabilistically the values and impacts of these risk reduction modifications. The analyses address primarily the Peach Bottom plant because the costs and benefits of the risk reduction measures are dependent on plant-specific factors including risks before modification and plant design and layout. To the extent possible, the discussion is generalized to draw broad conclusions concerning the costs and benefits of these risk reduction measures for other LWRs, particularly other BWR plants with Mark I containment systems.

A.1.2 Background

A.1.2.1 Vented Containment System -

After the accident at TMI, much interest focused on design studies for systems which add the option of filtered venting or purging of the containment in the event of a severe accident. Several groups which reviewed the TMI accident in detail, including the ACRS, the NRC Lessons Learned Task force, and the Rogovin Commission, expressed interest in the evaluation of the severe accident consequence mitigation potential of conceptual designs for filtered vents. The interest in filtered vent systems focused on the potential for avoiding containment system failure during core melt accidents.

An early value-impact study of vented containment systems performed at Sandia National Laboratories indicated that the systems were likely to be most cost effective on BWR plants with Mark I or Mark III containment systems. A detailed value-impact study of vented containment concepts for Mark I BWR plants is in the final review process [A.1], and a companion report for Mark III plants should be completed shortly. The value-impact study includes estimates of the risk reduction afforded by alternative venting systems at the Peach Bottom plant.

A.1.2.2 Alternative Decay Heat Removal Concept -

As part of the NRC LWR safety program, Sandia National Laboratories recently completed an assessment of the values and impacts of alternative decay heat removal systems (ADHR) for U.S. nuclear plants [A.2]. The study focused on improving decay heat removal system reliability by reducing system vulnerability to hazards which challenge or jeopardize system operation. Several candidate ADHR designs were developed and value-impact analyses were performed for retrofits of the "best" candidate designs to existing LWRs.

Alternative decay heat removal (ADHR) systems achieve severe accident risk reduction by providing additional layers of protection against failure to remove decay heat. The system reduces the frequency of core melt accidents caused by failure of the decay heat removal system and is therefore aimed primarily at prevention of severe accidents rather than consequence mitigation. An ADHR may also be valuable for reducing the plant susceptibilty to "special emergencies" (or external events) by strengthening the capability to remove decay heat during or after sabotage, fires, earthquakes, or other external event challenges.

A.1.3 Outline Of Report

This report is organized using the outline recommended in NUREG/BR-0058 [A.3] and therefore should be consistent with other NRC analyses of proposed regulatory changes. Section A.2 contains a brief discussion of the objectives of the proposed plant modifications including decreased public health risks from severe (core melt) accidents, decreased core melt accident frequencies and/or losses, reduction of the financial risks from plant operation, reduction of the uncertainties in the risks from internally-initiated accidents, and possible reduction of risk from external accident initiators (special emergencies). Section A.3 addresses the risk reduction alternatives which are under consideration in this example regulatory analysis including a brief description of the vented containment and the alternative decay heat removal system designs. Also discussed are possible alternative risk-reduction measures which might achieve the same objectives, including the implementation of alternative venting systems using in-place hardware or minor improvements to existing decay heat removal systems. The consequences of the addition of the vented containment system or the alternative decay heat removal system are discussed in Section A.4 of this report. Value-impact analyses (consistent with NUREG/CR-3568 [A.4]) are presented for both the vented containment and the ADHR, the impacts on other regulatory requirements are discussed, and potential constraints including scheduling, institutional, and policy concerns are identified. Section A.5 presents the salient information from the analyses regarding the decision to accept or reject the proposed plant risk reduction modifications. Included are the summary of the value-impact analysis, a discussion of additional decision considerations, and discussion related to the uncertainties inherent within the analyses. Finally, the conclusions from Section A.5 are related to plans for implementation of regulatory requirements in Section A.6. This discussion identifies additional information which would be desirable in the decision basis and potential sources of additional information within existing NRC research programs.

Summaries of detailed design and technical information related to the vented containment and the alternative decay heat removal system concepts evaluated in this study are included in appendices B-C. Technical information related to the development of baseline risk estimates for Peach Bottom #2, the risk reduction afforded by installation of the vented containment or the ADHR, and information from previous studies of the vented containment and ADHR concepts are included in the appendices.

A.2 OBJECTIVES OF THE PROPOSED PLANT MODIFICATIONS

This section describes the objectives of the addition of either a containment venting system or an alternative decay heat removal system at the Peach Bottom plant. The primary objective of either system is the reduction of public health and economic risks from severe accidents which might occur during plant operation.

A.2.1 Vented Containment System

Previous studies of filtered vent concepts for BWR plants with Mark I containment systems identified the following benefits of a venting system for the Peach Bottom plant [A.1]:

1. The venting system can be used to prevent primary containment failure during core melt accident sequences. Depending on the filtering strategy, this can result in a reduction of the radioactive material release for many accident scenarios.
2. The venting system can be used to prevent core melt from occurring for some scenarios in which core melt follows containment failure. This results in a reduction of the frequency of core melt events.

This system achieves both reduction of the frequency of accidents which release radioactive material to the environment (core melt or radioactive release prevention) and also reduction of the magnitude of the radioactive material release for specific accident conditions (accident consequence mitigation). Thus, the concept has benefits in terms of both severe accident prevention and mitigation.

Because the vented containment concept reduces both accident probabilities and offsite consequences, the concept warrants consideration for achieving the following objectives: reducing the frequency of core melt accidents, reducing public health risks from severe accidents, reducing the onsite and offsite financial risks of severe accidents, reducing the uncertainties in estimates of severe accident consequences and risks, and possibly for reducing the risks from external events or special emergencies (e.g., earthquakes, fires, sabotage). The degree to which the vented containment concept achieves these objectives and is cost-beneficial is evaluated in the value-impact analyses in section A.4 of this example regulatory analysis.

A.2.2 Alternative Decay Heat Removal Concept

The primary benefit of an alternative decay heat removal system for the Peach Bottom plant is a reduction of the probability of the failure to remove decay heat after transient-initiated accidents. The system may also provide benefits by improving capabilities for suppression pool cooling during certain severe accident sequences. The ADHR also might provide reduction of the frequency of core melt accidents caused by fires, sabotage, earthquakes, or other external event challenges. Thus, the benefits of the ADHR result primarily from the prevention of severe accidents rather than consequence mitigation.

The primary objective addressed by the ADHR system is the reduction of the core melt accident frequency, particularly from those accidents caused by failure to remove decay heat. The system can also reduce the uncertainties associated with estimates of the core melt accident frequency. Because the system reduces the frequency of specific severe accident sequences, it also addresses the objectives of reduction of public health and financial risks, and possibly reduces the risks from external events and special emergencies. The ADHR, in contrast to the FVCS, is not expected to provide significant consequence mitigation after core melt events. The core melt frequency and risk reductions achieved by the recommended ADHR at the Peach Bottom plant are evaluated in the value-impact analyses presented in section A.4.

A.3 ALTERNATIVES

The specific vented containment system design and ADHR design under consideration for the Peach Bottom #2 plant are briefly described in this section. Alternative risk-reduction measures which are not considered in detail in this example regulatory analysis are also discussed.

The rationale for the selection of the conceptual designs of the FVCS and ADHR system considered in this regulatory analysis are briefly discussed in this section. More detailed technical descriptions of these two risk reduction systems may be found in Appendix B.

A.3.1 Vented Containment System

A detailed study of conceptual designs for vented containment systems for BWR plants with Mark I containment systems is currently in the final review process [A.1]. Several venting strategies combined with other related plant improvements were evaluated in the study. The major classes of containment venting alternatives can be divided based on two design characteristics, high- versus low-volume vents, and filtered versus unfiltered vents. The advantages of low-volume vents identified in the study are:

1. It may be easier to design a highly reliable valving arrangement that minimizes the chances of spurious leakage.
2. Available containment penetrations of the required size may be easier to find.
3. Filter components would be smaller and therefore easier and less costly to maintain.
4. A stuck-open valve would not be likely to cause rapid depressurization with concomitant suppression pool flashing that could lead to ECC pump damage.

The advantages of high-volume vents outlined in the study are:

1. They can be designed to prevent containment failure from rapid overpressurization during ATWS events (accident sequence type TC).

2. The rate of venting may be sufficient to reduce the peak pressure achieved during the ex-vessel "steam spike" event below the containment failure point.

3. A large volume venting capability enhances the possibility for anticipatory venting if core melting is felt to be imminent. (Anticipatory venting may increase the likelihood of surviving containment pressurization during or after core melting.)

In the balance between filtered versus unfiltered vents, the filtered vents have the advantage of providing additional retention of released fission products, thereby mitigating the consequences of the release. Unfiltered vents are simpler to design and construct, and therefore likely to be more reliable. In addition, there are no filter loading problems in unfiltered vents.

Five major filtering alternatives were considered in the analysis of filter vent containment systems for BWR Mark I plants [A.1]. In addition, other filtering alternatives and total containment were considered, although not in detail. The five major alternatives were:

1. Water Pools

2. Venturi Scrubbers

3. Crushed Rock Filters

4. Submerged Gravel Scrubbers

5. Graded Sand Filters

The other filtering alternatives considered included graded fiberglass filters, high-efficiency particulate attenuation filters, and charcoal filters (both impregnated and unimpregnated). None are satisfactory with regard to the criteria developed for evaluation of alternatives in the study, and as a consequence were not considered in detail [A.1]. The study concluded that the crushed rock filter or a water filter using the suppression pool (i.e., an unfiltered vent from the wetwell) best satisfy evaluation criteria based on risk-reduction potential and cost-effectiveness [A.1]. Detailed risk analyses of various designs and strategies involving crushed rock filters and unfiltered vents from the wetwell indicate that there is no substantial difference in risk reduction between these two approaches for the external event, ATWS, TW sequence, TQUV sequence, and station blackout frequencies estimated for the Peach Bottom plant [A.1]. Since the crushed rock filter would be considerably more expensive to install than the wetwell vent, the unfiltered vent from the wetwell was determined to be the best filtering option and is therefore the only filtering option considered in this regulatory analysis. With certain reactor upgrades, the unfiltered vent from the wetwell was shown to provide a degree of risk reduction comparable to other venting strategies at a considerably lower cost, and with potentially higher reliability than a filtered vent.

A schematic diagram of the recommended venting concept is shown in Figure A.3.1. This vent design includes a high-volume (3 foot diameter) vent from the wetwell atmosphere to the atmosphere [A.1]. The high-volume vent was selected over its low-volume counterpart because the high volume vent provided more risk reduction from ATWS sequences, a higher potential for avoiding "steam spike" containment failures, and reduction of core melt frequency through anticipatory venting for approximately the same cost as the low-volume vent. The high-volume vent is designed to be passively actuated when internal containment pressure exceeds design pressure (56 psig) but below the pressure at which primary system safety/relief valves no longer can be controlled (about 75 psig). A manual shutoff capability is provided to protect against excessive fission product releases when the suppression pool is saturated and the core is degraded.

This vent design and strategy serve to reduce risk by several mechanisms. For certain sequences, atmospheric release requires that released fission products pass through the suppression pool. For these cases, particularly for subcooled pools, the retention of fission products will mitigate the atmospheric release, and hence the offsite consequences of the accident. For other cases, the increased probability of ECCS survival due to prevention of containment failure due to overpressure can prevent core melting, and therefore reduce the probability of the completion of the accident sequence. Finally, for other cases involving core melt, early venting of containment (before fuel melting) followed by vent closure may allow additional time for deposition in containment before eventual containment failure.

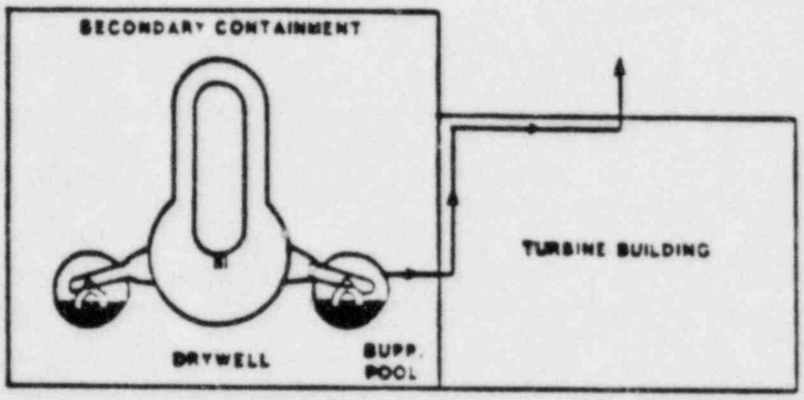

Figure A.3.1 Schematic Diagram of Vented Containment System for Mark I BWR Containment [A.1]

A.3.2 Alternative Decay Heat Removal System

A multiple objective study has recently been completed as part of the NRC LWR safety program to assess the values and impacts of alternative decay heat removal concepts for LWR nuclear power plants [A.2]. Potential inadequacies in current decay heat removal systems were identified and a group of design criteria was established for alternative systems which were intended to rectify these inadequacies. Several candidate alternative decay heat removal system concepts were proposed and value-impact analyses were performed for the most promising systems.

Design criteria for ADHR systems were developed in the study to address the weak points in current LWR decay heat removal system designs. Both internally-initiated accidents and special emergencies (including external events) were considered in the development of the design criteria. Based on these design criteria, three BWR candidate alternative decay heat removal (ADHR) concepts were selected for further consideration in the value-impact study:

1. A low pressure makeup and suppression pool cooling train
2. A high pressure makeup and suppression pool cooling train
3. A controlled/variable pressure makeup and suppression pool cooling train

These three BWR ADHR candidate concepts were then screened based on five major factors:

1. Functional capability
2. Compliance with design criteria
3. Feasibility of construction
4. Potential costs
5. Operational and maintenance difficulties.

A screening process was developed to eliminate those alternatives for which serious questions could be raised regarding the feasibility of implementation as a backfit, and also to eliminate those concepts which would not significantly improve DHR capabilities. The operational expense and system costs were considered to be of secondary importance to other attributes because basic concepts which satisfied the first three criteria could be modified to reduce costs and maintenance problems. Basic concepts with problems relating to the first three criteria would be much more difficult to modify for implementation. Thus, based on engineering judgement of the importance of various attributes, the cost and operational screening factors were weighted by 50 and 20 respectively, while the other three screening criteria were each weighted by 100. The low pressure makeup and suppression pool cooling concept ranked the highest of the three alternative decay heat removal concepts for BWRs in the screening process (scoring 370 of a possible 370), while the other concepts ranked lower (high pressure cooling - 340, controlled depressurization cooling - 305) due mainly to weaknesses in construction feasibility and functional capabilities. Therefore, the low pressure makeup and suppression pool cooling concept was the only BWR candidate analyzed in detail in the decay heat removal study, and is the system discussed in this example regulatory analysis.

A flow diagram of the low pressure makeup and suppression cooling train ADHR is shown in Figure A.3.2 [B.2]. This add-on system relies on the automatic depressurization relief valves or some add-on dedicated relief valves to depressurize the reactor vessel. After depressurization, the method of maintaining inventory resembles the low pressure coolant injection mode of the residual heat removal system. The add-on pumps are modeled after the low pressure coolant injection pumps. The concept is a single train, 100% capacity system, without redundancy or single failure capability. It includes its own fluid system, power supplies, control systems, and instrumentation. Valving to regulate the reactor coolant makeup and suppression pool cooling functions of the system would be provided. Cooling water to the add-on heat exchanger, pump seals, motor bearing coolers, and room coolers would be provided by a dedicated service water system which connects to an ultimate heat sink.

Two important benefits of the low pressure BWR makeup and suppression pool cooling system were identified as:

1. All components are readily available and could be identical to existing components.
2. The system would serve to minimize blowdown from small LOCAs since the system involves reactor depressurization.

Two disadvantages of the low pressure BWR makeup and suppression

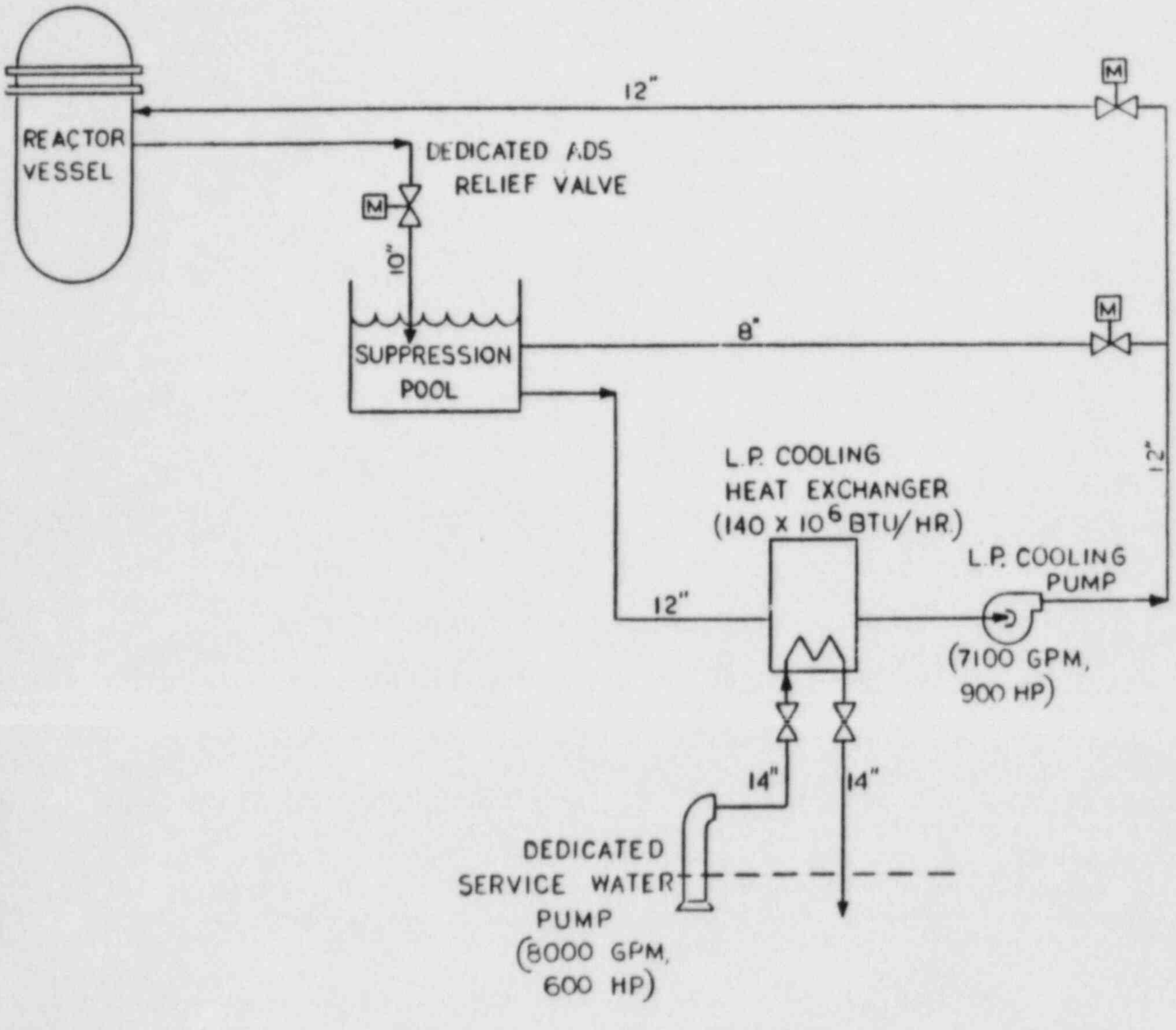

Figure A.3.2 Flow Diagram for Low Pressure Makeup and Suppression Cooling Train [A.2] pool cooling system were identified as:

1. The system has a large number of components which must operate in order for it to function. This would require a routine maintenance and inspection program.

2. Three large containment and drywell penetrations are required. These may not be available as spares, especially in older plants.

As originally envisioned, the recommended ADHR concept would have consisted of an automatic depressurization, low pressure core spray, and RHR functions. However, in order to perform the low pressure core spray function immediately following a scram, the ADHR concept proved to be too large to be retrofitted into existing plants. Therefore, the ADHR conceptual design was revised to account for reactor core isolation cooling (RCIC) system operation during the first two hours following a scram, allowing a reduction in the size of the ADHR components. This design approach implicitly assumes that the RCIC can be relied upon to operate for two hours with only DC power available (i.e., two hour battery capacity). However, some key components of the RCIC may require AC power to function properly [A.2]. Despite these shortcomings, the two hour delayed operation of the add-on system was chosen as the design basis for evaluation of the recommended ADHR concepts [A.2]. Despite this and possible additional shortcomings of the recommended concept, the detailed design effort supported the conclusion of the screening process that the low pressure makeup and suppression cooling concept is preferable to the other two ADHR concepts considered.

A.3.3 Alternatives Not Addressed In Detail

In addition to the requirement for the vented containment and ADHR systems considered in this example regulatory analysis, there are several other regulatory options which might be chosen to achieve similar objectives. Several of these options are discussed in this section.

A.3.3.1 Venting Options Using Existing Hardware -

Some degree of containment venting or purging capability could possibly be achieved by utilizing existing piping and containment penetrations (particularly the containment purge lines) and developing procedures to avoid containment failure due to overpressurization during severe accident conditions. This approach, which is likely to have significantly lower costs than installation of the containment vent design of Figure A.3.1, was not considered in the technical analysis of containment venting strategies [A.2]. Implementation of this concept might require only that modifications be made to plant emergency operating procedures, or it may be most beneficial to make relatively minor plant hardware modifications to augment the ability to purge the primary containment.

This option of containment venting using existing BWR Mark I plant hardware is not addressed in this regulatory analysis. Technical information regarding the risk reduction potential of this option is not currently available and is likely to be strongly dependent on plant-specific characteristics. The industry cost of implementation for such an option could be less than the costs estimated for the high-volume wetwell vent. However, to evaluate both the values and impacts of such an option it would be necessary to estimate the risk reduction potential of venting using existing systems. Recommendations concerning the value of such information are contained in section A.5.

A.3.3.2 Upgrades To Existing Decay Heat Removal Systems -

It may be possible to improve the reliability of DHR systems by upgrading existing systems rather than adding another completely independent ADHR train. The costs of minor DHR system modifications to improve system reliability are likely to be much smaller than those estimated for retrofitting the system concept in Figure A.3.2 into an existing plant. The selection of the most cost-effective DHR system modifications would vary from plant to plant based on the overall reliability and the most susceptible components of the existing DHR systems. The effectiveness of modifications would also be dependent on the contribution of DHR failures to core melt accidents for a given plant.

The option of achieving risk reduction through minor modifications to existing DHR hardware in BWR Mark I plants is not addressed in this regulatory analysis. Information regarding the most useful DHR system modifications, the risk reduction achieved, and the costs of modification will be strongly dependent on plant-specific design characteristics. Detailed plant-specific technical evaluations of DHR upgrading alternatives are necessary for performing value-impact evaluations for these options. Although complete technical information is not currently available, NRC programs which might supplement the information available for consideration of minor DHR system improvements are discussed in section A.5.

A.3.3.3 No Action -

The option to take no definitive action based on a lack of cost-effectiveness or a lack of sufficient information is also available. Selection of this option has the advantage of allowing for improved information to be considered in the severe accident risk reduction decisionmaking process. However, the option also implies further plant operation at existing public health and economic risk levels. This option is discussed further in section A.5 based on the conclusions and information available in the value-impact analyses.

A.4 CONSEQUENCES OF IMPLEMENTATION

The consequences of implementation of either the vented containment system or the alternative decay heat removal system at the Peach Bottom plant are discussed in this section. The risk and risk reduction information developed using information from previous technical analyses is briefly summarized to show the range of risk reduction (for internal event initiators) used in the value-impact analyses. More detailed information regarding the derivation of the risk and risk reduction estimates is provided in appendix C. The risk information is then used together with additional cost and benefit information to perform value-impact analyses in section A.4.2 on both the vented containment system and the alternative decay heat removal system. Section A.4.3 contains discussion of additional considerations for implementation of the vented containment or ADHR related to special emergencies and external events. Finally, potential constraints to implementation of these risk reduction measures and impacts on other requirements are discussed in section A.4.4.

A.4.1 Summary Of Risk And Risk Reduction Information

One of the primary goals addressed by the implementation of either the vented containment system or the ADHR system at Peach Bottom #2 is the reduction of both health and economic risks from internally-initiated severe accidents. Information related to internally-initiated severe accident risk before implementation of any risk reduction measures and after installation of either risk reduction concept is discussed in this section. More detailed information related to the derivation of the values presented is contained in appendix C. Risk from externally initiated accidents is not included in the risk values presented but is discussed in section A.4.3.

Table A.4.1 summarizes the information related to the core melt frequency from internally initiated accidents at the Peach Bottom #2 plant for the baseline case and after the addition of either the vented containment or the ADHR concept. Low, central, and high estimates are shown which include uncertainties in the data for initiating event frequencies and failure-related data. The table shows that both the ADHR and the vent are expected to reduce the core melt frequency at Peach Bottom, the vent by reducing the frequency of many accident sequences in which core melt occurs after or as a result of containment failure, and the ADHR system by reducing the frequency of core melt accidents which result from a failure to remove decay heat. Using the low

HYPOTHETICAL EXAMPLE

Table A.4.1 - Summary of Core Melt Frequency Information for Internally Initiated Accidents (Peach Bottom #2 plant, per reactor-year of operation)

	Baseline	With Vented Containment	With ADHR System
Low Estimate	$3x10^{-6}$	$3x10^{-6}$	$3x10^{-6}$
Central Estimate	$3x10^{-5}$	$4x10^{-6}$	$1x10^{-5}$
High Estimate	$3x10^{-4}$	$2x10^{-4}$	$2x10^{-4}$

baseline estimate of core melt frequency for Peach Bottom #2, it is unlikely that either system would provide a large reduction of the core melt frequency because many sequences usually contribute to small frequencies rather than one large dominant sequence. Using the high estimate of baseline core melt frequency, it is possible that single accident sequences become dominant which are not effectively removed by either system. The variation in the factor of core melt frequency reduction achieved by either system between the low, central, and high estimates results because both modifications under consideration only reduce the frequency of specific accident sequences, not all accident sequences.

Table A.4.2 shows estimates of the mean health consequences of a core melt accident at the Peach Bottom #2 plant conditional on accident occurrence. The low, central, and high estimates of consequences are shown for total early fatalities, early injuries, total latent cancer fatalities, and total offsite person-rem (all consequences shown are totals for all offsite locations). The values shown are the means (or expected values) of consequences considering the probabilities of weather conditions, wind direction, and various emergency response scenarios at the time of accident occurrence. The central estimates of consequences are based on the NUREG-0773 [A.5] source terms and the modeling and reference case assumptions described in the documentation of the CRAC2 code [A.6]. The low estimates are based on lower bound estimates of source terms (assumed to be approximately a factor of 50 reduction from NUREG-0773 source terms) combined with low estimates of mean consequences considering the uncertainties in consequence analyses for the various measures. The high estimates are based on the NUREG-0773 source terms with high estimates for consequences considering the uncertainties in the consequence analyses. The mean estimates of early fatalities and early injuries conditional on core melt accident occurrence are effectively reduced to zero (even in the baseline case) based on lower bound source term values. The vented containment system is predicted to provide some consequence mitigation based on the central estimate since the system reduces the magnitude of the radionuclide release for some accident sequences, and reduces the probability of certain accidents in which core melt follows containment failure. The ADHR system does not provide significant consequence mitigation since the system only reduces the frequency of core melt accidents caused by failure of existing decay heat removal systems.

Table A.4.3 summarizes the information regarding public health risk from internally-initiated accidents at the Peach Bottom 2 plant. Total societal early fatality risks, early

HYPOTHETICAL EXAMPLE

Table A.4.2 - Mean Health Consequences* Conditional Upon Core Melt Accident Occurrence (Peach Bottom #2 plant)

		Early Fatalities	Early Injuries	Latent Cancer Fatalities	Offsite Person-Rem
	Low Estimate	~0	~0	$7x10^{0}$	$1x10^{5}$
Baseline	Central Estimate	$1x10^{-1}$	$2x10^{1}$	$1x10^{3}$	$2x10^{7}$
	High Estimate	$5x10^{-1}$	$1x10^{2}$	$1x10^{4}$	$7x10^{7}$
	Low Estimate	~0	~0	$7x10^{0}$	$1x10^{5}$
With Vent	Central Estimate	$5x10^{-2}$	$1x10^{1}$	$5x10^{2}$	$8x10^{6}$
	High Estimate	$3x10^{-1}$	$5x10^{1}$	$5x10^{3}$	$3x10^{7}$
	Low Estimate	~0	~0	$7x10^{0}$	$1x10^{5}$
With ADHR	Central Estimate	$8x10^{-2}$	$2x10^{1}$	$1x10^{3}$	$2x10^{7}$
	High Estimate	$5x10^{-1}$	$1x10^{2}$	$1x10^{4}$	$5x10^{7}$

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* Mean consequences for all accident scenarios, emergency response scenarios, wind directions, and meteorological conditions.

HYPOTHETICAL EXAMPLE

Table A.4.3 - Summary of Offsite Health Risk Information for Internally Initiated Accidents (Peach Bottom #2 plant, per reactor-year of operation)

		Early Fatalities	Early Injuries	Latent Cancer Fatalities	Offsite Person-Rem
	Low Estimate	~0	~0	2×10^{-5}	<1
Baseline	Central Estimate	3×10^{-6}	7×10^{-4}	4×10^{-2}	6×10^{2}
	High Estimate	2×10^{-4}	4×10^{-2}	4×10^{0}	2×10^{4}
	Low Estimate	~0	~0	2×10^{-5}	<1
With Vent	Central Estimate	2×10^{-7}	4×10^{-5}	2×10^{-3}	3×10^{1}
	High Estimate	5×10^{-5}	1×10^{-2}	1×10^{0}	5×10^{3}
	Low Estimate	~0	~0	2×10^{-5}	<1
With ADHR	Central Estimate	8×10^{-7}	2×10^{-4}	1×10^{-2}	2×10^{2}
	High Estimate	1×10^{-4}	2×10^{-2}	2×10^{0}	1×10^{4}

injury risks, latent cancer fatality risks, and offsite person-rem risks are shown per reactor-year of operation for the baseline case and after installation of either the vent or the ADHR. Uncertainties in core melt accident frequencies, source terms, and offsite consequences have been included in the formation of the low and high estimates of the risks from internal events. The uncertainties in the various health risk estimates are estimated to cover between 2 and 5 orders of magnitude and thus must be considered carefully in estimating the risk reduction afforded by the systems. Table A.4.3 shows that neither the vent nor the ADHR would definitely provide substantial health effect risk reduction if lower bound baseline estimates of risk are employed. Both the vent and the ADHR are likely to result in some decrease in public health effect risks if central or high estimates of baseline risk are employed.

Table A.4.4 presents the mean economic consequences conditional on core melt accident occurrence at the Peach Bottom #2 plant. Economic consequences are shown based on (1) $1000/person-rem of offsite exposure, (2) offsite property damage (including evacuation costs, agricultural product costs, and land and property decontamination/interdiction costs), (3) offsite health effects costs based on NUREG-2739 [A.7] (using $1,000,000 per early fatality, $100,000 per early injury, and $100,000 per latent cancer fatality), (4) onsite property damage (including replacement power costs, physical plant losses, and plant decontamination costs), and (5) total onsite and offsite costs (the summation of 2, 3, and 4). Uncertainties in source terms and consequences conditional on core melt accident occurrence are included in the low and high estimates. Table A.4.4 shows that onsite costs are the dominant contributors to the expected total costs conditional on core melt occurrence.

Table A.4.5 summarizes the economic risks from internal events integrated over the remaining life of the Peach Bottom #2 plant. Again, risks are shown based on $1000/person-rem, offsite property damage, offsite health effects, onsite property damage, and total offsite plus onsite costs. All of the integrated economic risk measures (except the $1000/person-rem values) have been discounted at 4%/year over the remaining plant life. Uncertainties in core melt accident frequencies, source terms, and economic consequences have been included in the low and high estimates in the table.

Information related to the risk reduction afforded by installation of either the vented containment system or the ADHR system at the Peach Bottom plant is presented in Table A.4.6. Shown are low, central, and high estimates of the risk averted

HYPOTHETICAL EXAMPLE

Table A.4.4 - Mean Economic Consequences* Conditional Upon Core Melt Accident Occurrence (Peach Bottom #2 plant)

		Costs @ $1000 Per Person-Rem	Offsite Property Damage Costs**	Offsite Health Effects Costs***	Onsite Losses	Total (Onsite+ Offsite) Costs
	Low Estimate	$\$2\times10^{8}$	$\$4\times10^{6}$	$\$2\times10^{5}$	$\$1\times10^{9}$	$\$1\times10^{9}$
Baseline	Central Estimate	$\$2\times10^{10}$	$\$1\times10^{9}$	$\$1\times10^{8}$	$\$4\times10^{9}$	$\$5\times10^{9}$
	High Estimate	$\$6\times10^{10}$	$\$6\times10^{9}$	$\$1\times10^{9}$	$\$1\times10^{10}$	$\$2\times10^{10}$
	Low Estimate	$\$2\times10^{8}$	$\$4\times10^{6}$	$\$2\times10^{5}$	$\$1\times10^{9}$	$\$1\times10^{9}$
With Vent	Central Estimate	$\$8\times10^{9}$	$\$4\times10^{8}$	$\$6\times10^{7}$	$\$4\times10^{9}$	$\$4\times10^{9}$
	High Estimate	$\$3\times10^{10}$	$\$3\times10^{9}$	$\$6\times10^{8}$	$\$1\times10^{10}$	$\$1\times10^{10}$
	Low Estimate	$\$2\times10^{8}$	$\$4\times10^{6}$	$\$2\times10^{5}$	$\$1\times10^{9}$	$\$1\times10^{9}$
With ADHR	Central Estimate	$\$2\times10^{10}$	$\$1\times10^{9}$	$\$1\times10^{8}$	$\$4\times10^{9}$	$\$5\times10^{9}$
	High Estimate	$\$5\times10^{10}$	$\$6\times10^{9}$	$\$1\times10^{9}$	$\$1\times10^{10}$	$\$2\times10^{10}$

* Mean consequences for all accident scenarios, emergency response scenarios, wind directions, and meteorological conditions.

** Offsite damages based on CRAC2 calculations.

*** Offsite health effects costs based on values described in NUREG/CR-2739 [C.3].

HYPOTHETICAL EXAMPLE

Table A.4.5 - Summary of Economic Risk Information for Internally Initiated Accidents (Peach Bottom #2 plant, risks in 1982 dollars for remaining plant lifetime)

		Costs @ \$1000 Per Person-Rem*	Offsite Property Damage Costs**	Offsite Health Effects Costs***	Onsite Losses	Total (Onsite+ Offsite) Costs
Baseline	Low Estimate	$\$2\times10^{4}$	$\$2\times10^{2}$	$\$1\times10^{1}$	$\$7\times10^{4}$	$\$7\times10^{4}$
	Central Estimate	$\$2\times10^{7}$	$\$5\times10^{5}$	$\$7\times10^{4}$	$\$2\times10^{6}$	$\$3\times10^{6}$
	High Estimate	$\$5\times10^{8}$	$\$3\times10^{7}$	$\$7\times10^{6}$	$\$7\times10^{7}$	$\$1\times10^{8}$
With Vent	Low Estimate	$\$2\times10^{4}$	$\$2\times10^{2}$	$\$1\times10^{1}$	$\$7\times10^{4}$	$\$7\times10^{4}$
	Central Estimate	$\$9\times10^{5}$	$\$3\times10^{4}$	$\$4\times10^{3}$	$\$3\times10^{5}$	$\$3\times10^{5}$
	High Estimate	$\$2\times10^{8}$	$\$8\times10^{6}$	$\$2\times10^{6}$	$\$5\times10^{7}$	$\$6\times10^{7}$
With ADHR	Low Estimate	$\$2\times10^{4}$	$\$2\times10^{2}$	$\$1\times10^{1}$	$\$7\times10^{4}$	$\$7\times10^{4}$
	Central Estimate	$\$6\times10^{6}$	$\$2\times10^{5}$	$\$2\times10^{4}$	$\$8\times10^{5}$	$\$1\times10^{6}$
	High Estimate	$\$3\times10^{8}$	$\$2\times10^{7}$	$\$4\times10^{6}$	$\$5\times10^{7}$	$\$8\times10^{7}$

* Lifetime economic risks based on \$1000 per person-rem and no discounting in future years.

** Lifetime offsite damage risks based on CRAC2 economic calculations and real discount rate of 4%.

*** Health effects costs based on values described in NUREG/CR-2739 [C.8] and a real discount rate of 4%.

HYPOTHETICAL EXAMPLE

Table A.4.6 - Summary of Risk Reduction Estimates Used in Value-Impact Analyses
(in dollars for remaining plant lifetime)

		Costs Based on $1000/Person-Rem	Offsite Costs	Total Costs (Onsite+Offsite)
	Low Estimate	~0	~0	~0
With Vent	Central Estimate	$\$2\text{x}10^{7}$	$\$5\text{x}10^{5}$	$\$3\text{x}10^{6}$
	High Estimate	$\$3\text{x}10^{8}$	$\$3\text{x}10^{7}$	$\$4\text{x}10^{7}$
	Low Estimate	~0	~0	~0
With ADHR	Central Estimate	$\$1\text{x}10^{7}$	$\$4\text{x}10^{5}$	$\$2\text{x}10^{6}$
	High Estimate	$\$2\text{x}10^{8}$	$\$1\text{x}10^{7}$	$\$2\text{x}10^{7}$

over the remaining lifetime of the plant. Averted risk is shown based on $1000/person-rem, total offsite costs, and total (onsite plus onsite) costs. The low, central, and high estimates are based on the public health and economic risk information presented in previous tables. Table A.4.6 shows that the uncertainties in core melt accident frequencies, source terms, and consequences result in a large range of possible averted risk ranging from very small values to hundreds of millions of dollars.

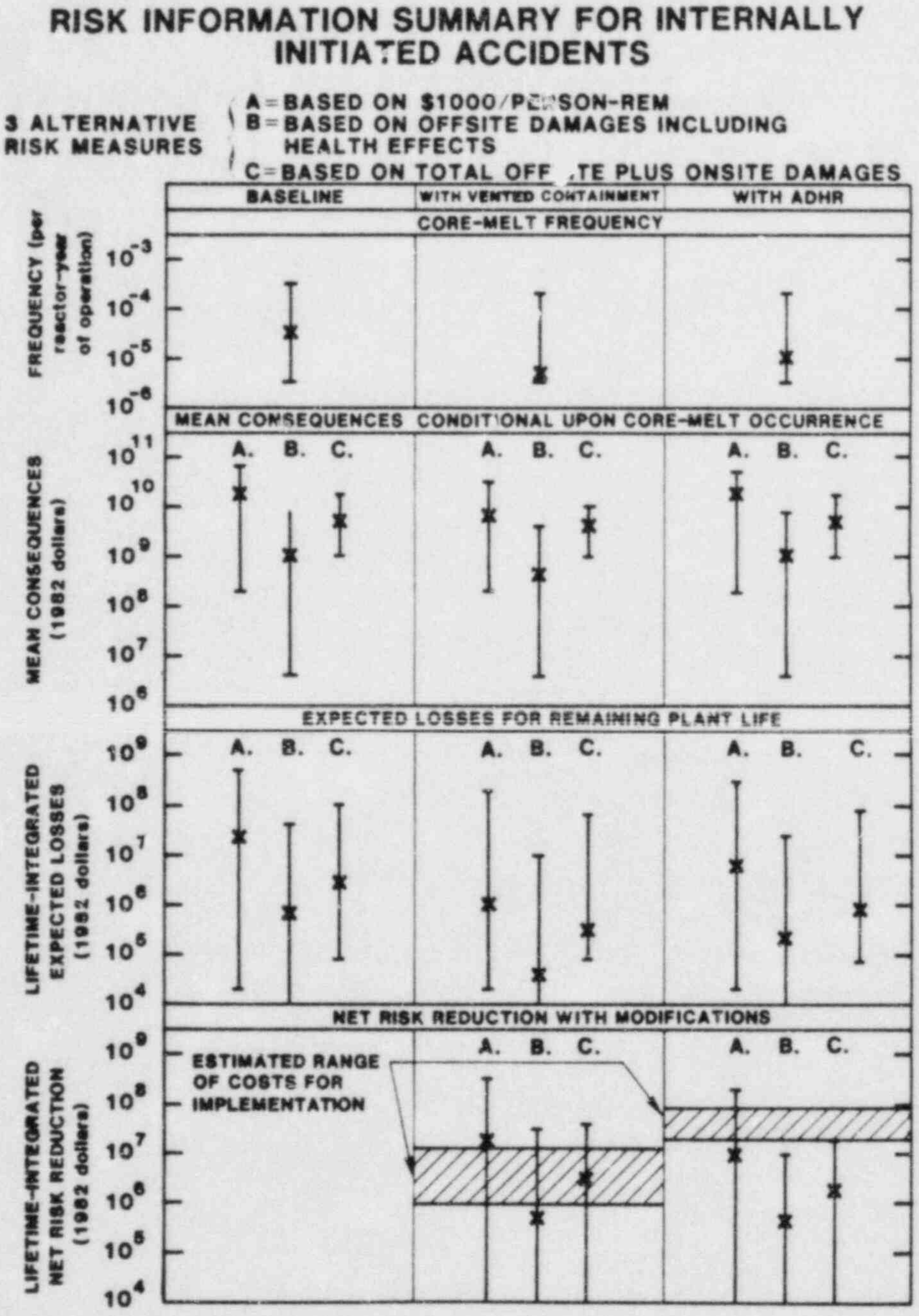
A summary of the risk-related information for the Peach Bottom #2 plant is displayed in Figure A.4.1. This figure shows the core melt frequency, the mean consequences conditional on core melt occurrence, the lifetime-integrated risks, and the net lifetime-integrated risk reduction afforded by the vented containment or the ADHR system. Low, central, and high estimates are shown for the core melt frequency which consider the uncertainties in the accident sequence frequencies. Low, central, and high estimates of consequences conditional upon accident occurrence reflect uncertainties in both source terms and accident consequence modeling. The low, central, and high estimates of lifetime integrated risks and net risk reduction include uncertainties in accident sequence frequencies, source terms, and accident consequences. The risks are displayed based on three measures: (A) $1000/person-rem, (B) Offsite costs including health effects, and (C) Total onsite plus offsite costs. The estimates of lifetime-integrated net risk reduction (measured in dollars) are used in the value-impact analyses for internal events which follow.

A.4.2 Value-Impact Analyses

The quantified values and impacts of a requirement for installation of either the vented containment system or the ADHR system at the Peach Bottom plant are discussed in this section. The value-impact analyses are based on internally-initiated accidents only, and do not include external events and special emergencies which are discussed in Section A.4.3. The table below summarizes the attributes examined in the value-impact analyses for the vented containment and ADHR systems. (These attributes are based on the Value-Impact Handbook, NUREG/CR-3568 [A.4]).

Figure A.4.1

HYPOTHETICAL EXAMPLE



Checklist for attributes affected by installation of a vented containment system or an ADHR system:

Attribute	Quantified Change	Unquantified Change*	No Change
Public Health (Offsite) Risks	X		
Offsite Property (Economic) Risks	X		
Onsite Property (Economic) Risks	X		
Occupational Exposure (accidental)	X		
Occupational Exposure (routine)	X		
Regulatory Efficiency			X
Improvements in Knowledge		X	
Industry Implementation Cost	X		
Industry Operation Cost	X		
NRC Development Cost			X
NRC Implementation Cost	X		
NRC Operation Cost	X		

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* In this context, "unquantified" means not readily estimated in dollars.

Each of the attributes is discussed in this section, and a summary table of costs and benefits is developed. The uncertainties and sensitivities in the risk and cost estimates are also discussed.

A.4.2.1 Benefits Of Implementation -

A.4.2.1.1 Estimated Reductions In Risk From Internally-Initiated Accidents -

The vented containment system and ADHR have important impacts on the estimated public health risks, offsite economic risks, and onsite economic risks from severe (core damage or core melt) accidents. Estimates of core melt frequency, source terms, and consequences of severe accidents both before and after installation of either system are developed in appendix C. The resulting estimates of the risk reduction afforded by the vented containment system (for internally initiated events only) with associated uncertainties which are discussed in section A.4.1 are employed in the value-impact analyses. The table below shows high, central, and low estimates of the risk reduction afforded by the installation of the vent based on consideration of uncertainties relating to core melt frequency, severe accident source terms, and accident consequences. The net risk reduction over the remaining plant life (presented in dollars) is shown based on $1000/person-rem, offsite costs (including health effects), and onsite cost measures.

ESTIMATES OF RISK REDUCTION AFFORDED BY PLANT MODIFICATIONS
INTERNALLY INITIATED EVENTS ONLY

VENTED CONTAINMENT SYSTEM

	HIGH	CENTRAL	LOW
\$1000/PERSON-REM	$\$3x10^8$	$\$2x10^7$	~0
OFFSITE COSTS	$\$3x10^7$	$\$5x10^5$	~0
TOTAL COSTS	$\$4x10^7$	$\$3x10^6$	~0

ALTERNATIVE DECAY HEAT REMOVAL CONCEPT

	HIGH	CENTRAL	LOW
\$1000/PERSON-REM	$\$2x10^8$	$\$1x10^7$	~0
OFFSITE COSTS	$\$1x10^7$	$\$4x10^5$	~0
TOTAL COSTS	$\$2x10^7$	$\$2x10^6$	~0

The values presented in this table cover a very wide range due to the consideration of uncertainties in baseline risk and risk reduction estimates as outlined in Appendix C. Information was derived from a variety of sources to develop the central estimates and the uncertainty bounds. The risk reduction estimates contained in the above tables are for internal initiators only. The potential impact of the modifications on externally initiated accidents is discussed in section A.4.3.

A.4.2.1.2 Accidental Occupational Exposure -

As recommended in the Value-Impact (V-I) Handbook, the estimates of occupational exposure after a core melt accident are based on the experience with the TMI-2 cleanup and recovery program. However, new information concerning the TMI-2 recovery program has recently become available to update the values recommended in the V-I Handbook [A.4]. The TMI-2 cleanup is currently projected to result in approximately 50,000 person-rem over the duration of the cleanup program. This is employed as the central estimate of occupational exposure conditional upon core melt accident occurrence for the V-I analysis. A high estimate of twice the central estimate, or ~$1x10^5$ person-rem, is employed and could occur for specific core melt accidents which breach the reactor vessel and result in worse contamination of the containment building than the TMI-2 accident. For less severe core damage accidents, the resulting occupational exposure could be much lower; an estimate of 2000 person-rem, conditional on a core melt accident is used as a lower estimate based on the work of Murphy and Holter who analyzed core damage accidents resulting in only small releases of radioactive material from the core [A.8].

Estimated Core Melt Accident Occupational Exposure
(Person-Rem, Conditional on Accident Occurrence)

High	Central	Low
1×10^{5}	5×10^{4}	2×10^{3}

The estimates of occupational exposure conditional upon core melt accident occurrence are combined with estimates of the net reduction of core melt frequency provided by each system to develop estimates of the net benefit in terms of accidental occupational exposure avoided for the remaining plant life. The table below summarizes the low, central, and high estimates of net reduction in core melt frequency afforded by the vent and ADHR:

Estimated Net Reduction in Core Melt Frequency
(Per Reactor-Year of Operation)

System	High	Central	Low
Vented Containment	1×10^{-4}	2×10^{-5}	~0
ADHR	1×10^{-4}	2×10^{-5}	~0

The net benefit provided by the reduction in accidental occupational exposure for each system is estimated by integrating the expected exposure reduction over the remaining 30 year plant life assuming a $1000 per person-rem conversion factor. Ranges of conversion factors from $100/person-rem to $5000/person-rem could be justified with arguments regarding the economic costs of health effects or the costs of manpower loss to the plant licensee (including costs of employee benefits, etc.). However, as will be shown in the conclusion of the value-impact analyses, occupational dose is a very minor contributor to the overall benefits, and considerable increases in the estimates of the person-rem incurred, or in the value in dollars per person-rem, would have to occur before accidental occupational dose would affect the outcome of the value-impact analysis. Therefore, no further effort to improve the estimates of accidental occupational exposure costs or benefits is warranted in this example.

Benefit from Reduction of Accidental Occupational Exposure
(Integrated for 30 Year Plant Life, $1000/person-rem)

System	High	Central	Low
Vented Containment	$\$3\times10^5$	$\$3\times10^4$	~0
ADHR	$\$3\times10^5$	$\$3\times10^4$	~0

A.4.2.2 Costs Of Implementation -

A.4.2.2.1 Occupational Exposures (Routine) -

The routine occupational exposure can be divided into two components, the one-time exposure that occurs during the installation of the vent, and the ongoing exposure that occurs during routine maintenance during the remainder of the plant life. For the vented containment system, the one-time exposure during installation is estimated based on the construction time estimate contained in [A.1]. The time to install the parts of the vent in exposure zones is estimated to be between 250 and 4000 person-hours, with a central estimate of approximately 1000 person-hours. The average dose field is estimated to be between 10 and 100 mrem/hour, with a central estimate of 50 mrem/hour. Installation of the ADHR system is estimated to require between 500 and 8000 person-hours in exposure areas, with a central estimate of approximately 2000 person-hours. The dose field estimates are roughly the same as those for the installation of the vent.

No sources of estimates for inspection and maintenance time are available for the systems under consideration, but it is expected that either the vented containment or the ADHR would require between 2 to 100 person-hours per year, with a central estimate of 10 person-hours per year, in a dose field estimated to be between 10 and 100 mrem/hour, with a central estimate of 5 mrem/hour.

The costs of occupational exposure during installation and routine maintenance are estimated using $1000/person-rem of exposure. The exposure values estimated for these systems are only rough estimates, but further efforts are not justified based on the conclusions of the value-impact analyses which show that these costs are not important relative to other attributes in the analysis. The tables below summarize the cost estimates for both exposure during installation and exposure from routine operation and maintenance for the vent and the ADHR:

Cost of Occupational Exposure During System Installation
(Based on \$1000/person-rem of exposure)

System	Low	Central	High
Vented Containment	$\$3x10^3$	$\$5x10^4$	$\$4x10^5$
ADHR	$\$5x10^3$	$\$1x10^5$	$\$8x10^5$

Cost of Occupational Exposure from
Routine Inspection and Maintenance
(Integrated for 30 year plant life, \$1000/person-rem)

System	Low	Central	High
Vented Containment	$\$6x10^2$	$\$2x10^4$	$\$3x10^5$
ADHR	$\$6x10^2$	$\$2x10^4$	$\$3x10^5$

Total Costs of Occupational Exposure During
Construction, Inspection and Maintenance
(For remaining plant life plant life, \$1000/person-rem)

System	Low	Central	High
Vented Containment	$\$4x10^3$	$\$7x10^4$	$\$7x10^5$
ADHR	$\$6x10^3$	$\$1x10^5$	$\$1x10^6$

A.4.2.2.2 Industry Costs Of Implementation -

Industry implementation costs for the vented containment system are based on information from [A.1]. A study by an architect engineering firm has provided a set of drawings, parts lists, and labor estimates for the installation of a filtered vent at Peach Bottom Unit #2. A major determinant of the cost of installing the vent is the amount of downtime that will be incurred. The estimates in [A.1] call for the vent to be installed during a refueling outage in order to minimize downtime. However, because of the frequently busy schedules of activity during scheduled outages, there is some doubt as to whether it would be possible to perform the necessary work during the refueling. Estimates provided by the architect engineering firm state that the extra downtime could be as much as 15 days depending upon the venting strategy chosen. The costs quoted in [A.1] (~$\$1x10^6$) do not include any allowance for plant downtime during installation, and therefore should be viewed as a lower estimate. Several other factors could contribute to raising the high estimate well above that provided in [A.1]. Costs such as overhead expenses could be higher than those included in the estimates provided by the architect/engineering firm. In addition to the hardware costs, there are a number of other costs associated with the installation of the vent. Because the venting strategy might allow deliberate atmospheric radioactive releases, it is possible that hearings regarding the installation of the vent would be required. Costs will be incurred in the development of operating and maintenance procedures for the vent and/or additional staff training in the new accident response options available with the vent. To incorporate these factors, the high estimate for the installation cost is based on 15 days of additional downtime, and significant additional overhead costs (~$\$1.5\text{x}10^7$). The central estimate is based on the hardware and labor costs from [A.1] plus 2 days of additional outage time with significant additional overhead or cost overruns (~$\$3\text{x}10^6$). Finally, the cost estimate for hardware and labor from [A.1] is used as the low estimate.

More detailed cost estimates for installation of an ADHR system at six operating U.S. LWR plants were developed as part of the study of ADHR conceptual designs [A.2]. The cost estimates for implementation of the system were remarkably similar for all three BWR plants considered in the analyses. The cost estimates include provisions for substantial downtime (~15 days) due to the work required for backfitting an ADHR system to an existing plant. The low estimate of the industry implementation costs for the value-impact analysis is based on the hardware and labor costs from [A.2] and the assumption that all work can be done during previously scheduled plant outages (~$\$2\text{x}10^7$). The central estimate of the industry implementation costs is based on the hardware and labor costs combined with costs for 15 days of outage duration and minor cost overruns during system installation (~$\$4\text{x}10^7$). Finally, the high estimate of industry implementation costs for the ADHR system is based on hardware and labor costs, 30 days of additional outage duration, and major cost overruns during system installation (~$\$7\text{x}10^7$). The estimates of industry implementation costs for the vent and the ADHR system are summarized in the table below:

Estimated Costs of Industry Implementation ($)

System	Low	Central	High
Vented Containment	$\$1\text{x}10^6$	$\$3\text{x}10^6$	$\$2\text{x}10^7$
ADHR	$\$2\text{x}10^7$	$\$4\text{x}10^7$	$\$7\text{x}10^7$

A.4.2.2.3 Industry Operation Cost -

Ongoing costs to the industry arise primarily from the requirements for testing and maintenance of the components comprising the vent or the ADHR system. The components of both systems include valves, control systems, sensors, and instrumentation. Since either modification would be an important contributor to the overall plant safety system, the components would be subject to periodic testing and maintenance. Even summed over the remaining life of the plant, these costs would be small, (a few percent of the low estimate of cost of installation), especially considering that the costs of exposure are already included in the routine exposure cost estimates. Therefore, the industry operation costs are small even relative to other low cost estimates, and no detailed estimate of these costs is developed for this value-impact analysis.

A.4.2.2.4 NRC Development Cost -

Development costs for the NRC arise from the need to prepare documents, conduct a legal search, publish rulemaking notices, hold public hearings, prepare responses to public comments, and draft a final regulation. Since the proposed actions affect only one plant, and no rulemaking is anticipated for this one plant, the marginal NRC costs would be fairly small. Because these costs will be small compared to the major costs already discussed (again, at most a few percent of the industry implementation cost), no detailed estimate is developed. If the proposed action were extended to include additional plants for consideration, then NRC costs could become substantially larger, and any additional research to support the action should be included as development costs. (Research costs in support of the current proposed action may also be considered as development costs. However, as the research has already been performed, in this case the costs are already sunk, and therefore should not be considered as a cost of adopting the alternative.)

A.4.2.2.5 NRC Implementation Cost -

The cost to implement either proposed action stems from the effort necessary to review the utilities plans for the retrofit, monitor the construction, approve the as-built configuration, and approve the revised procedures and technical specifications. The central estimate of the effort necessary to perform these tasks is two person-years at $100,000 per person-year, including overhead. The low estimate is based on a total time requirement of 1/2 person-year, and our high estimate is based on 10 person-years required.

Costs of NRC Implementation

System	Low	Central	High
Vented Containment	$\$5x10^4$	$\$2x10^5$	$\$1x10^6$
ADHR	$\$5x10^4$	$\$2x10^5$	$\$1x10^6$

A.4.2.2.6 NRC Operating Cost -

After either modification is installed, there may be recurring costs to the NRC from the need for additional inspections, procedure reviews, or other activities necessary to insure compliance. These costs should be very small (no more than a few percent of the estimated cost of installing either system), and therefore no detailed cost estimate is developed for the value-impact analysis.

A.4.2.3 Value-Impact Analysis Summary -

Table A.4.7 summarizes the information from the value-impact analyses for the installation of the vented containment system. The table shows low, central, and high estimates of the benefits, costs, and net benefits of implementation of the vented containment system. The value-impact analysis considers only risk reduction for internally initiated accidents. Industry operation costs, NRC development costs, and NRC operating costs are small relative to other costs and are therefore not explicitly estimated. The range of net benefits has been estimated by combining high benefit estimates with low cost estimates, and low benefit estimates with high cost estimates to make clear the large uncertainties in the analyses. The central estimates of net benefits are based on central estimates carried throughout the analysis. All of the values in the table are presented with "single digit accuracy" to reflect the quality of the information in the analyses. Estimated risk reduction is shown in the table for three measures: (1) $1000/person-rem (offsite), (2) Offsite costs, (3) Total (Onsite plus Offsite) Costs. The basis for the risk reduction estimates are discussed in section A.4.1 and Appendix C. The table shows that the dominant cost component is the industry implementation cost, and

HYPOTHETICAL EXAMPLE

Table A.4.7 - Summary of Value-Impact Analysis for Installation of Vented Containment System

Benefits

		Low	Central	High
Alternative Risk Reduction Measures	\$1000/Person-Rem	~0	$\$2x10^{7}$	$\$3x10^{8}$
	Offsite Damages	~0	$\$5x10^{5}$	$\$3x10^{7}$
	Total Damages	~0	$\$3x10^{6}$	$\$4x10^{7}$
Accident Occupational Exposure		~0	$\$3x10^{4}$	$\$3x10^{5}$

Costs

	High	Central	Low
Routine Occupational Exposure	$\$7x10^{5}$	$\$7x10^{4}$	$\$4x10^{3}$
Industry Implementation	$\$2x10^{7}$	$\$3x10^{6}$	$\$1x10^{6}$
Industry Operation	*	*	*
NRC Development	*	*	*
NRC Implementation	$\$1x10^{6}$	$\$2x10^{5}$	$\$5x10^{4}$
NRC Operating	*	*	*

Net Benefits

		Low	Central	High
Based on Alternative Risk Measures	\$1000/Person-Rem	$-\$2x10^{7}$	$\$2x10^{7}$	$\$3x10^{8}$
	Offsite Damages	$-\$2x10^{7}$	$-\$3x10^{6}$	$\$3x10^{7}$
	Total Damages	$-\$2x10^{7}$	$-\$2x10^{5}$	$\$4x10^{7}$

* Contribution to total costs is small, therefore no detailed cost estimates were developed.

the dominant benefits (for all except the low case in which benefits are negligible) result from core melt accident risk reduction. The largest estimates of net benefits for vent implementation result from using the $1000/person-rem measure.

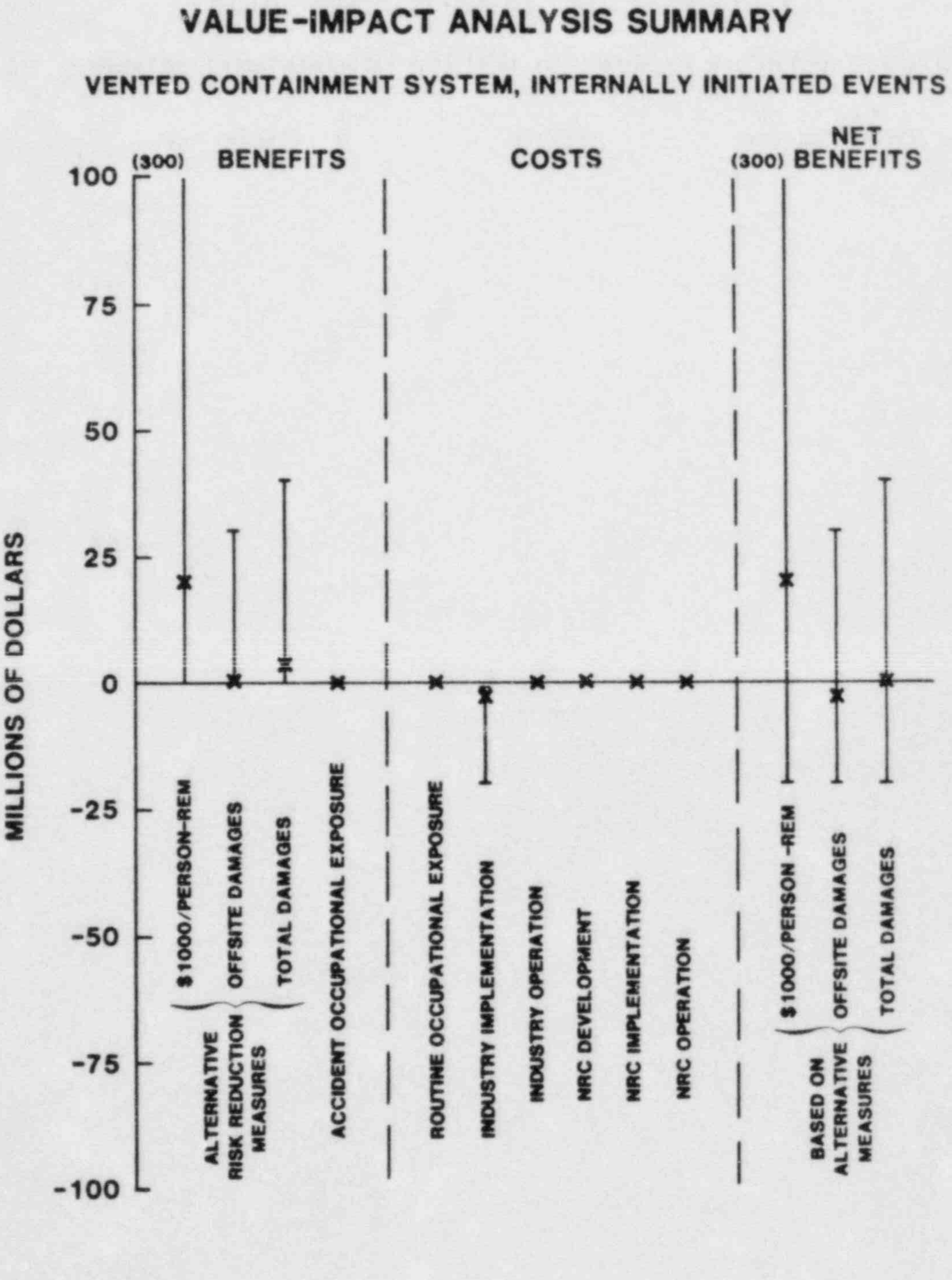
Figure A.4.2 summarizes the results of the value-impact analyses for the vented containment system. The figure shows low, central, and high estimates of each attribute considered in the V-I analysis. The figure shows that the uncertainties in core melt frequency, source terms, and consequence calculations result in wide bands of estimated risk reduction. The figure clearly demonstrates that considering the uncertainties in the analyses, the only important contributors are the risk reduction benefits and the industry implementation costs for the vent. The conclusions of the analysis would not be sensitive to assumptions regarding the values of other attributes. The net benefits column shows that it is not possible to conclude from the current analysis that the vent definitely is or is not cost-effective (based on internal risk information) based on any of the three risk measures chosen ($1000/person-rem, offsite costs, or total costs). However, based on central estimates, the vent results in positive net benefits based on $1000/person-rem, and negative net benefits based on offsite costs or total costs. Based on central estimates the value-impact analyses show that the vent is in the range of generally cost-effective actions. Possible improvements in the value-impact analyses using central estimates should focus attention on the risk reduction estimates and industry implementation costs, as demonstrated in the figure.

Table A.4.8 summarizes the information from the value-impact analyses for the installation of the ADHR system. Again, the value-impact analysis considers only risk reduction for internally-initiated accidents. Industry operation costs, NRC development costs, and NRC operating costs are small relative to other costs and are therefore not explicitly estimated. The basis for the risk reduction estimates shown in the table are discussed in section A.4.1 and Appendix C. The table shows that as with the vented containment, the dominant cost component is the industry implementation cost, and the dominant benefits result from core melt accident risk reduction. Thus, cost estimates for the other attributes included in the analysis are generally less important. As with the vent, the largest estimates of net benefits for ADHR result from using the $1000/person-rem measure.

Figure A.4.3 summarizes the results of the value-impact analyses for the ADHR system. The figure shows low, central, and high estimates of each attribute considered in the V-I analysis.

Figure A.4.2

HYPOTHETICAL EXAMPLE



HYPOTHETICAL EXAMPLE

Table A.4.8 - Summary of Value-Impact Analysis for Installation of Alternative Decay Heat Removal System

Benefits

		Low	Central	High
Alternative Risk Reduction Measures	\$1000/Person-Rem	~0	$\$1x10^{7}$	$\$2x10^{8}$
	Offsite Damages	~0	$\$4x10^{5}$	$\$1x10^{7}$
	Total Damages	~0	$\$2x10^{6}$	$\$2x10^{7}$
Accident Occupational Exposure		~0	$\$3x10^{4}$	$\$3x10^{5}$

Costs

	High	Central	Low
Routine Occupational Exposure	$\$1x10^{6}$	$\$1x10^{5}$	$\$6x10^{3}$
Industry Implementation	$\$7x10^{7}$	$\$4x10^{7}$	$\$2x10^{7}$
Industry Operation	*	*	*
NRC Development	*	*	*
NRC Implementation	$\$1x10^{6}$	$\$2x10^{5}$	$\$5x10^{4}$
NRC Operating	*	*	*

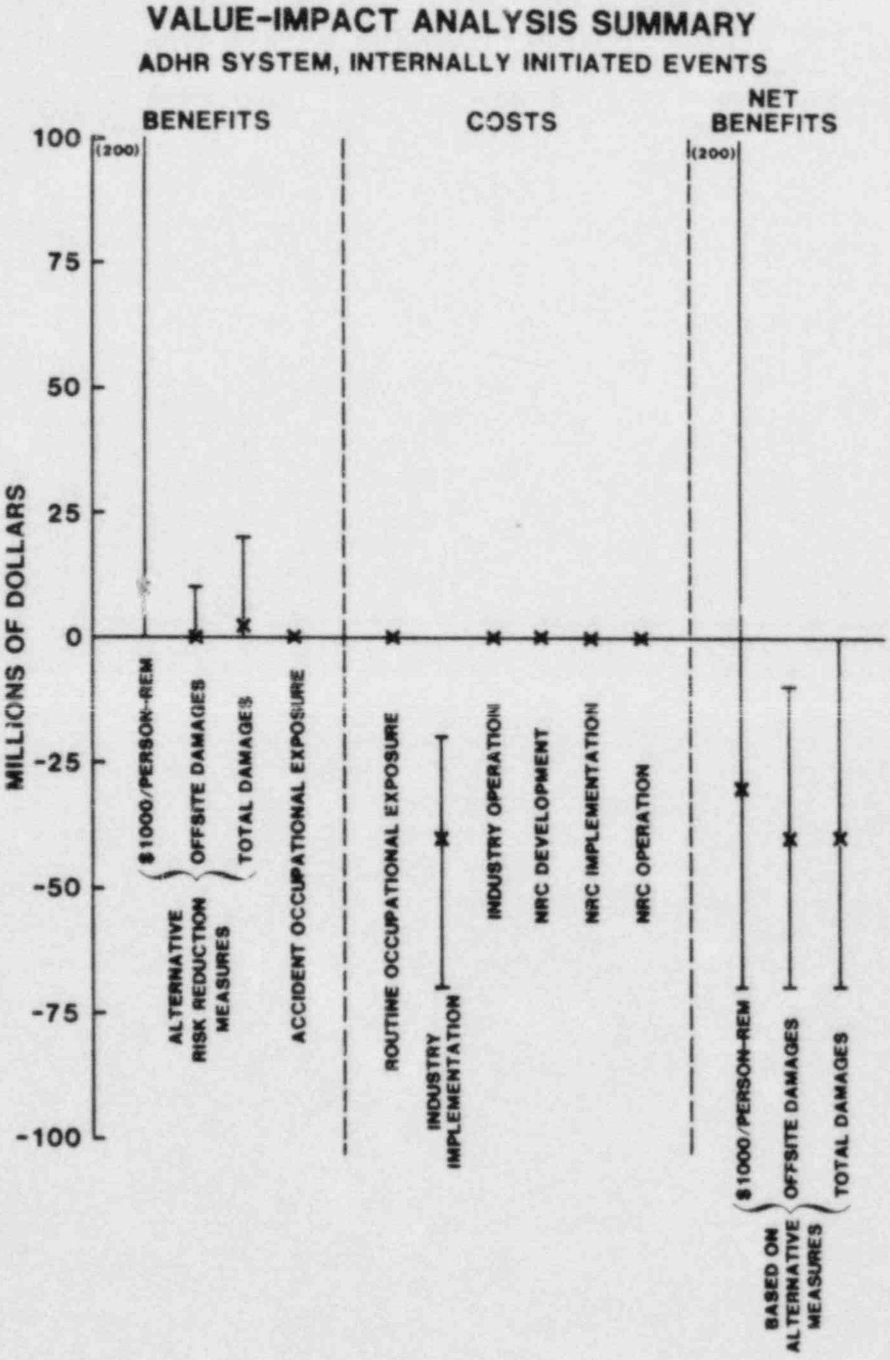
Net Benefits

		Low	Central	High
Based on Alternative Risk Measures	\$1000/Person-Rem	$-\$7x10^{7}$	$-\$3x10^{7}$	$\$2x10^{8}$
	Offsite Damages	$-\$7x10^{7}$	$-\$4x10^{7}$	$-\$1x10^{7}$
	Total Damages	$-\$7x10^{7}$	$-\$4x10^{7}$	$-\$3x10^{4}$

* Contribution to total costs is small, therefore no detailed cost estimates were developed.

Figure A.4.3

HYPOTHETICAL EXAMPLE



The figure shows that the uncertainties in core melt frequency, source terms, and consequence calculations result in wide bands of estimated risk reduction for the $1000/person-rem measure. However, uncertainties in the benefit estimates for offsite costs and total costs are considerably smaller. The figure clearly demonstrates that as with the analysis for the vented containment system, the only important contributors to the value impact analyses are the risk reduction benefits and the industry implementation costs. The conclusions of the analysis would not be sensitive to assumptions regarding the values of other attributes. The net benefits column shows that it is not possible to conclude from the current analysis that the ADHR definitely is or is not cost-effective (based on internal risk information) based on the $1000/person-rem measure. However, for offsite costs and total costs, even the highest estimates of net benefits are negative. For all three of the risk measures chosen ($1000/person-rem, offsite costs, or total costs) the central estimate of net benefits is negative. Thus, based on the value-impact analyses, the particular ADHR system considered in this analysis is unlikely to be cost-effective at the Peach Bottom plant. The analysis also shows that possible improvements in information related to the value-impact analysis are unlikely to change the conclusions since the absolute magnitude of the net benefits is fairly large.

The results of the value-impact analyses for internally-initiated accidents show that the vented containment system is in the range of cost-effectiveness based on central estimates carried throughout the analyses. However, the uncertainties in the current analyses, especially related to risk reduction, are very large and prohibit any definitive statement regarding the cost-effectiveness of the vent. The value-impact analyses for internally-initiated accidents show that the ADHR system under consideration is not cost-effective for the Peach Bottom plant based on central estimates. The ADHR system might be cost-effective based on the $1000/person-rem measures, considering the large uncertainties in the analyses. The value-impact analyses show that for both systems the most important attributes are related to risk reduction and the cost of implementation. Thus, the conclusions of the analysis are not sensitive to assumptions regarding other attributes. Improvements in information regarding the risk reduction or construction cost of the vented system might be useful to improve central estimates or eliminate part of the broad uncertainty bands for net benefits. However, the uncertainties are not likely to be reduced to the point where cost effectiveness could be proven. For the ADHR system, improved analyses are not likely to change or improve any of the conclusions which can be drawn for this particular plant. Efforts to improve information regarding this ADHR system for Peach Bottom should not focus on value-impact analyses for internally-initiated accidents, but should focus on additional considerations and attributes not considered in this analysis.

A.4.3 Special Emergencies/External Events

In addition to the values and impacts which have been quantified in section A.4.2, there are supplementary considerations which might have important impacts on the decision to implement or reject a regulatory alternative. The contribution of external events to risk from plant operation and the potential impact of the risk reduction modifications on external event risks are not quantified in the value-impact analyses. A qualitative discussion of information related to the impact of the vented containment system and the ADHR on risk from these events is contained in this section.

External events and special emergencies like earthquakes, hurricanes, and fires can be significant contributors to the core melt frequency at nuclear power plants. Unfortunately, methodologies to evaluate the risks from external events and special emergencies are not as well developed as those for internally initiated severe accidents. Although quantitative analysis of all external event risks is not possible, the impacts of plant modifications on external event risks must be weighed carefully in the decisionmaking process.

A wide variety of plausible external events could have impacts on nuclear power plant operation and thus contribute to the risks from external events. However, the frequency of most of the external events is strongly dependent on location of the plant site. A review of all of the commercial U.S. nuclear plant sites can be used to quickly eliminate the most bizarre external events from risk considerations (e.g., frazil, avalanche, airborne insects, ship collisions, seiches, ice jams, aquatic organisms, drought). The following initiating events cannot be ruled out based on site considerations and could be important contributors to U.S. LWR plant risks:

Aircraft Impact
Hurricanes
Fires
Seismic Activity
External Flooding
Internal Flooding
Lightning
Sabotage
Extreme Winds and Tornadoes
Pipe Whip, Turbine Missiles, etc.

The degree to which these events are a concern is strongly dependent on plant-specific characteristics.

A.4.3.1 Vented Containment System -

The effectiveness of the vented containment system was evaluated for various loss of offsite power frequencies and external event frequencies in the study of vented containment conceptual designs [A.1]. The consideration of external events can have some important impacts on the benefits of the vented containment system.

The high volume vent from the wetwell considered in this regulatory analysis (and, any venting strategy with no filters) may actually increase the risk from loss of offsite power events (>12 hour loss) because the suppression pool is predicted to be saturated for this scenario (no suppression pool cooling is available). Thus, the use of the vent would not enhance the depletion of fission products through suppression pool scrubbing. Since the vent generally reduces the amount of deposition in the primary containment and reduces the effect of the auxiliary building retaining fission products, the high volume wetwell vent led to a slight increase in the risk from offsite power loss (>12 hours) accidents in the study [A.1].

Because the probability of the loss of offsite power accident (TB) was determined to be low for the Peach Bottom plant (station blackout frequency was determined to be about $5x10^{-7}$ per reactor-year of operation due to the four diesels shared between Peach Bottom Units 2 and 3 [A.1]), the effect of the venting system on loss of offsite power events is not important and does not significantly influence the cost-effectiveness of the system. However, the NRC-sponsored generic station blackout study estimated station blackout frequencies on the order of $1\text{-}3x10^{-5}$ per reactor-year. The containment venting conceptual study concluded that the high volume vent from the wetwell was probably not cost-effective for plants with station blackout frequencies of $>5x10^{-5}$, and that passive, unfiltered venting systems should <u>not</u> be considered in areas where the station blackout probability is high [A.1].

The study of vented containment conceptual designs [A.1] also included a cursory analysis of external events and the risk reduction afforded by various strategies. The preliminary analysis indicated that the high volume vent from the wetwell would have neither strong positive or negative effects on the risk from externally initiated accidents. If external events represented the dominant contributor to the overall core melt frequency, then risk reduction factors of 10 or greater were not predicted to be achievable by any of the vented containment designs. However, the vent systems could still be cost-effective based on reduction of internally initiated accident risks even if external events are the dominant contributor to core melt frequency.

In summary, the vented containment may have negative impacts on the risk from loss of offsite power events at Mark I BWR plants. Since the frequency of this event is predicted to be relatively low for the Peach Bottom plant, the value-impact analysis is not adversely impacted by this conclusion. However, the high-volume vent from the wetwell looks considerably less beneficial for plants with high station blackout frequencies. Alternative venting strategies may be appropriate for these plants. Also, based on the cursory analyses in [A.1], the high volume vent from the wetwell has neither strong positive or negative impacts on external event risks. However, even if external events dominate the core melt frequency, the vent still may be cost-effective based on reduction of internally initiated accident risks.

A.4.3.2 Alternative Decay Heat Removal System -

The analyses of ADHR conceptual designs included some qualitative analysis of the impact of the systems on the risk from special emergencies and internal events [A.2]. Unfortunately, one of the most important conclusions from the analyses was that the impact on external event risk is very plant-specific. Because Peach Bottom was not included in the plants considered in the ADHR study, none of the specific recommendations regarding external event risk are applicable to the case under consideration. However, some general conclusions from the analyses of external events for the ADHR system are applicable.

A detailed analysis of an ADHR system concept on the risk from fires was carried out as part of the ADHR study for the Crystal River #3 plant. The conclusion of the analysis was that it would be more cost-effective to improve existing systems through the use of fire barriers rather than installing a new system to address the fire problem. The study concluded that a decision to add on a completely new system or to improve an existing system must be made on a case-by-case basis for any power plant or special emergency being evaluated.

Another important conclusion which resulted from the ADHR study [A.2] related to the construction layouts of the ADHR systems installed as backfits. Based on design experience of the ADHR systems for the example plants it was concluded that the ADHR system piping configuration often was constrained by other considerations (e.g., lack of available containment penetrations) to be routed along the same path as piping for existing systems. This is an important consideration for sabotage risk, since one of the primary methods of mitigating this risk is through physical separation. Thus, it is unlikely that large benefits in the reduction of sabotage risk could be achieved through the installation of the ADHR system as a backfit because of considerations related to separation of piping.

The study of ADHR system concepts [A.2] designed the add-on concepts in combination with existing systems to handle all special emergencies as dictated by current design guidelines including fire, flood, earthquake, sabotage, and airplane crash. For example, the service water system for the low pressure add-on system is based on a split-case horizontal pump rather than the more typical vertical turbine pump to eliminate the need for a separate intake structure and to make the system less susceptible to sabotage. Obviously, consideration of special emergencies should be part of the final detailed design process for any ADHR system for the Peach Bottom #2 plant.

Little additional information related to the impact of the ADHR system under consideration on the risk from special emergencies at the Peach Bottom plant is currently available. Since the system essentially provides and additional means of decay heat removal, it may provide benefits in those situations in which the existing DHR systems are susceptible to special emergencies which would not result in common-mode failure of the add-on ADHR system. As discussed in the ADHR study [A.2], it is necessary to consider the impact on special emergencies on a case-by-case basis for specific plants and specific events. This analysis has not yet been performed for the ADHR at the Peach Bottom plant.

A.4.3.3 Conclusions-Special Emergencies/External Events -

The cursory analyses which have been previously performed [A.1] of the impact of the vented containment system on the risk from external events and special emergencies showed that the vent may have negative impacts on specific loss of offsite power sequences (as might any venting strategy without filters). However, since the loss of offsite power frequency at Peach Bottom was estimated to be low in the vented containment study, this was not an important problem. Improved information regarding the potential negative impacts of the vent could aid in the final decisionmaking process. The analyses did not predict that the vent would result in significant benefits or problems related to other external events. Thus, regardless of the frequency of the external events upon which the vent has little impact, it may be cost effective based on internal event considerations as demonstrated in the value-impact analyses.

Little information is currently available regarding the possible benefits of the ADHR system on special emergency risk at the Peach Bottom plant. Improved information in this area might prove useful for regulatory decisionmaking, especially in light of the conclusions from the value-impact analyses for internally-initiated accidents.

A.4.4 Impacts On Other Requirements/Potential Constraints

Because the implementation of either action is limited specifically in this case to a single plant, it is likely that impacts on other regulatory requirements would be small and could be dealt with in a timely manner in the regulatory process. There is one potential impact on future requirements which should be pointed out, however. It is important that all severe accident risk reduction measures under consideration be compared in the decisionmaking process so that the best regulatory options are chosen rather than merely acceptable options. Implementation of any requirement which reduces the risk from severe accidents makes it more likely that future (and possibly better) alternative risk reduction measures would not be cost-effective. Therefore, it is important that all alternatives available at a given point in time be compared to assure that the best option is chosen in the decisionmaking process.

There are some potential constraints related to the implementation of the requirements which have not yet been addressed in this analysis. These constraints relate mainly to installation of the ADHR system at the Peach Bottom plant. The study of ADHR conceptual designs identified many problems in the actual construction of add-on ADHR systems at existing plants. For example, one common problem was the lack of available containment penetrations for retrofitting the ADHR system, which could cause the need to reduce the size of the piping or eliminate the possibility of installing the system at all. These issues have not been addressed in this study, and would have to be addressed before any requirement for an ADHR system at Peach Bottom could be adopted.

A.5 DECISION RATIONALE

The conclusions and recommended course of action based on the analyses performed are discussed in this section. The rationale for the decisions and the alternatives which were not selected are also discussed.

A.5.1 Conclusions From Analyses Of The Vented Containment And ADHR

A.5.1.1 Vented Containment System -

Based on the analyses performed for the vented containment system, the following conclusions can be drawn:

1. The uncertainties in the estimates of baseline risk and the risk reduction potential of the vented containment system make it currently impossible to definitively prove or disprove the cost-effectiveness of the vent system at the Peach Bottom plant. However, the vent is predicted to reduce a significant fraction of the internally-initiated accident risk from Peach Bottom operation, and is clearly in the range of cost effectiveness. This result is strongly dependent upon the estimated frequencies of the TC and TW accident sequences at the Peach Bottom plant.

2. The dominant attributes (contributors to costs or benefits) in the value-impact analyses for the vented containment system are the risk reduction for internally-initiated accidents and the industry cost of implementation. The conclusions from the value-impact analyses are not sensitive to assumptions regarding other attributes considered.

3. It seems unlikely that further information regarding the risk from Peach Bottom operation and the high-volume wetwell vent risk reduction would result in the ability to definitively prove the cost effectiveness of the option. However, further information regarding the source term and phenomonological uncertainties could result in the ability to prove the vent is not cost-effective. Improved information regarding the costs of vent installation could improve our ability to decide whether or not the vent is cost-effective, particularly using central estimates. Further risk

information could result in better quantification and possibly reduction of the uncertainties in the analysis. However, it is likely that significant uncertainties will still have to be dealt with in the final decisionmaking process.

4. The use of $1000/person-rem as a measure of public health or total impacts results in larger estimates of benefit on this issue than the use of actual averted property damage and health effects impacts.

5. The vent may have negative impacts on station blackout events or special events which result in station blackout, indicating that other venting options may be more appropriate for consideration at plants with high station blackout frequencies. However, since the Peach Bottom station blackout frequency is relatively low [A.1], this had little impact on the value-impact analyses in this regulatory analysis.

6. The cursory consideration of external events in [A.1] indicates that the vent has neither strong positive or negative impacts on the risks from externally-initiated accidents. If external events were the dominate contributor to core melt frequency, the vent would result in smaller reduction factors in risk. However, the vent may be cost-effective based on internally-initiated events alone, independent of the externally-initiated core melt frequency.

In summary, the vent fares well in the value-impact analyses for the Peach Bottom plant, achieving potentially large risk reductions for relatively small costs. This is due to the nature of the system, achieving substantial reductions in the size of the radioactive material release for many internal accident initiators. The vent could look substantially worse at plants with high station blackout frequencies or different containment designs.

A.5.1.2 Alternative Decay Heat Removal System -

Based on the analyses performed for the ADHR system, the following conclusions can be drawn:

1. The ADHR system considered in this analysis is unlikely to be cost-effective based on reduction of internally-initiated severe accident risks at the Peach Bottom plant. The system is predicted to result in reduction of the risk from accident sequences which result in core melt due to loss of the decay heat removal function, but the large cost of the system (on the order of tens of millions of dollars) makes the net benefit of implementation negative. The uncertainties in the analyses do not affect this conclusion for internally-initiated accidents except when the $1000/person-rem measure is used as the measure of risk reduction. The large uncertainties lead to the possibility that the system is cost-effective using this measure.

2. Like the vented containment, the dominant attributes in the value-impact analyses for the ADHR system are the risk reduction for internally initiated accidents, and the industry cost of implementation. The conclusions from the value-impact analyses are not sensitive to assumptions regarding other attributes considered.

3. It is unlikely that improved information regarding the internally-initiated accident risk reduction of the ADHR system would change the conclusions from the value-impact analyses. Information improvement for this system should focus on additional considerations like special emergencies or potential constraints to implementation of the system at Peach Bottom.

4. As with the vented containment system, the use of $1000/person-rem as a measure of public health or total impacts results in larger estimates of benefit on this issue than the use of actual averted property damage and health effects impacts.

5. There is very little information available related to the impact of the ADHR system on external events or special emergencies at the Peach Bottom plant. However, the system was designed to work in conjunction with other systems to meet existing design requirements for special emergencies like fires, floods, and airplane crashes. The analyses which have been performed to date indicate that there is a need to consider the ADHR system impacts on a case-by-case basis for specific plants and specific events.

In summary, the ADHR system is not likely to be cost-effective based on the value-impact analyses performed for internally-initiated accidents at the Peach Bottom plant. The ADHR is predicted to result in risk reduction for core melt accidents resulting from loss of the DHR function, but the benefits from this risk reduction are not large enough to outweigh the large implementation costs for this system. Improvement of information for decisionmaking regarding the ADHR system, if desired, should focus on additional considerations rather than the attributes considered in the value-impact analyses.

A.5.2 General Conclusions From The Regulatory Analysis

Several important general conclusions have resulted from the performance of this regulatory analysis and the value-impact studies of the vented containment and the ADHR systems. These conclusions are discussed in more detail in the main report which discusses the regulatory analysis and decisionmaking processes. Among some of the important general conclusions are:

1. The central estimates of the internal accident risks for the remainder of plant life at LWR plants are in the range of a few million dollars based on estimates of property damage and health effect costs. Thus, it is extremely unlikely that modifications with costs ranging from several million to hundreds of millions of dollars could be justified purely based on cost-benefit analyses. Because the baseline risk estimates are relatively low, detailed cost-benefit analyses should focus on the options with relatively low implementation costs. Analyses of the more expensive options might be focused more effectively on considerations other than cost-benefit analyses.

2. There are important synergistic effects on the benefits achieved through implementation of more than one risk reduction modification at a given plant. For example, the net benefit achieved through installation of both the vented containment and the ADHR at the Peach Bottom plant is far less than the sum of the net benefits of each individual system. Therefore, it is important to consider the costs and benefits of risk reduction modifications relative to one another, in addition to examination of the cost-effectiveness of any one system. This comparison should result in selection of "the best"

alternative or alternatives rather than an alternative which is only "acceptable."

3. Uncertainties are likely to reappear as the most difficult issue to cope with effectively in future regulatory analyses. There is a strong need for a significant improvement in methods for both quantification of uncertainties and communication of uncertainties within a decisionmaking framework. Because of the complexity of this problem, it is likely that substantial efforts will be required to significantly improve capabilities in this area.

4. There is a substantial difficulty associated with collection and use of the results of previous technical analyses in a consistent regulatory analysis framework. Some of the difficulties arise from analyses performed at different times, using different base assumptions, or from a lack of availability of necessary information for decisionmaking purposes. It is useful for regulatory analysis purposes to have as much information as possible available. Also, very simple value-impact calculations can often identify information which will be necessary for a final regulatory analysis.

A.5.3 Recommendations

A.5.3.1 Recommended Course Of Action -

Based on the analyses performed for the vented containment system and the alternative decay heat removal system, the following recommendations are made:

1. The analyses of the vented containment indicate that the concept definitely warrants further consideration. NRC's SARR program will provide further cost-benefit analyses of the vented containment system for a broader range of LWR plants. Also, additional information should be gathered related to the spectrum of low-cost venting options for BWR plants. In particular, the risk reduction potential of venting using existing hardware needs to be evaluated. If the risk reduction potential is similar to that for the option evaluated in this regulatory analysis, it would clearly be a most desirable alternative.

2. It would seem imprudent to force an early decision on the vented containment issue given the plans and schedules for current programs which will generate additional information related to venting at BWR Mark I plants. The needs for the decisionmaking process on this issue should be clearly identified as soon as possible to assure that current research programs will generate all of the information which will be required.

3. Implementation of the ADHR system at Peach Bottom currently cannot be recommended based on cost-benefit analyses for internally-initiated accidents. Information development for decisionmaking on this issue should focus on additional considerations rather than improved value-impact analyses. Very little information is currently available concerning the impact of an ADHR system on special emergencies or external events at the Peach Bottom plant.

4. There is a need to better define the interface between the NRC decisionmaking process and the role of research programs to provide necessary technical information. Also, increased emphasis needs to be placed on identification of information which is required for decisionmaking, and methods for efficient display and communication of this information to decisionmakers.

5. There is a general need for improved uncertainty analysis techniques for use in value-impact and regulatory analyses. Failure to achieve improvements in this area could result in regulatory analyses of limited usefulness and a decisionmaking process constantly hampered by uncertainty issues.

A.5.4 Discussion Of Other Alternatives

In addition to the requirement of the vented containment or the ADHR system discussed in this report, several other options are available. The options are reviewed and discussed in this section.

A.5.4.1 Venting Options Using Existing Hardware -

Additional information should be developed related to the spectrum of possible venting options using existing plant hardware or only minor plant modifications. The value-impact analyses show that only low-cost options are likely to be proven cost-effective due to the small absolute magnitude of the baseline risk at the Peach Bottom plant. The estimates of the risk reduction benefits of such venting options should be developed and compared to those for the vent design considered in this regulatory analysis.

A.5.4.2 Upgrades To Existing Decay Heat Removal Systems -

Current NRC programs, specifically related to Task Action Plan A-45, will develop information related to a broader range of alternatives for improving existing DHR systems at U.S. LWRs. This information should provide a basis for determining whether or not there are significant cost-effective modifications which should be made at existing U.S. plants.

A.5.4.3 No Action -

This regulatory analysis has recommended that action on the vented containment system and the ADHR at the Peach Bottom plant be delayed until the improved information from current research programs becomes available. However, a strong recommendation is made to take actions to identify the information which is necessary to make decisions, assure that it is being appropriately generated, and develop techniques for processing and communicating this information in an efficient manner to the decisionmakers. The costs of delaying the final decisions until the appropriate information is available are likely to be outweighed by the benefits of improved information and confidence.

A.6 IMPLEMENTATION PLAN

Because no specific recommendations regarding the implementation of final requirements are made in this regulatory analysis, a detailed implementation plan is not appropriate. The coordination of information generation from existing programs and timely incorporation into the decisionmaking process should occur internally within the NRC.

A.7 REFERENCES

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APPENDIX B

DETAILED DESCRIPTION OF RISK REDUCTION ALTERNATIVES

B.1 VENTED CONTAINMENT SYSTEM

A detailed study of conceptual designs for vented containment systems for BWR plants with Mark I containment systems is currently in the final review process [B.1]. Several venting stategies combined with other related plant improvements were evaluated in the study. The major classes of containment venting alternatives can be divided along two axes, high- versus low-volume vents, and filtered versus unfiltered vents. The advantages of low-volume vents identified in the study are:

1. It may be easier to design a highly reliable valving arrangement that minimizes the chances of spurious leakage.
2. Available containment penetrations of the required size may be easier to find.
3. Filter components would be smaller and therefore easier and less costly to maintain.
4. A stuck-open valve would not be likely to cause rapid depressurization with concomitant suppression pool flashing that could lead to ECC pump damage.

The advantages of the high-volume vent outlined in the study are:

1. It may be capable of preventing containment failure from rapid overpressurization during ATWS events (accident sequence type TC).
2. The rate of venting may be sufficient to reduce below the failure point the peak pressure achieved during the ex-vessel "steam spike".

3. A large volume venting capability enhances the option of anticipatory venting if core melting is felt to be imminent. (Anticipatory venting may increase the likelihood of surviving containment pressurization during or after core melting.)

Hybrids of these systems, high-low volume vents, combine some of these advantages, although at the cost of increased complexity, and therefore a probable decrease in reliability. With a hybrid system, high-volume venting is actuated only when low-volume venting is not adequate, and filter components are not needed in the high-volume vent path because the vent automatically closes before core melting can occur. In the balance between filtered versus unfiltered vents, the filtered vents have the advantage of providing additional retention of released fission products, therefore mitigating the consequences of the release. Unfiltered vents are simpler to design and construct, and therefore likely to be more reliable. In addition, there are no filter loading problems in unfiltered vents.

Five criteria were established, based on consideration of the risk dominant accident sequences, to evaluate the relative merits of alternative filtering and venting schemes [B.1]. The criteria were defined to maximize the risk reduction afforded by venting concepts based on consideration of the physical progression of various accident sequences for a BWR Mark I plant [B.1]. The criteria are not based directly on any NRC regulations or regulatory guides. The functional criteria for the venting concepts identified in [B.1] are:

1. The filter system should be capable of tolerating a steady flow of superheated steam for an indefinitely long period of time, and the filter should retain a reasonable fission product capturing efficiency. (Relates to transient induced accidents with loss of residual heat removal capability (TW-type events).)

2. The filter should be capable of operating passively (without ac or dc power) and withstanding decay heat for 24 hours or more. (Relates to transient-induced accidents with long-term loss of offsite power (TB type events).)

3. The filter should be able to withstand high aerosol mass loadings without plugging up. (Relates to TB- and TW-type accidents.)

4. The filter should be resistant to impulse loading (Ex-vessel steam explosions).

5. If intended for transient-induced accidents with failure to scram the reactor (TC type), the system must be able to tolerate extraordinarily high heat loads, in the form of superheated steam, for an indefinite amount of time.

Five major filtering alternatives were considered in the analysis of vented containment systems for BWR Mark I plants [B.1]. In addition, other filtering alternatives were considered, although not in detail. The five major alternatives were:

1. Water Pools
2. Venturi Scrubbers
3. Crushed Rock Filters
4. Submerged Gravel Scrubbers
5. Graded Sand Filters

The other filtering alternatives considered included graded fiberglass filters, high-efficiency particulate attenuation filters, and charcoal filters (both impregnated and unimpregnated). None are satisfactory with regard to all of the criteria listed above, and as a consequence were not studied in detail. The study concluded that the crushed rock filter or a water filter using the suppression pool (i.e., an unfiltered vent from the wetwell) best satisfy the five criteria [B.1].

Detailed risk analyses of various designs and strategies involving crushed rock filters and unfiltered vents from the wetwell indicate that there is no substantial difference in risk reduction between these two approaches. Since the crushed rock filter would be considerably more expensive to install than the wetwell vent, the unfiltered vent from the wetwell was determined to be the best filtering option and is therefore the only filtering option considered in this analysis. A schematic diagram of this venting concept is shown in Figure B.1. With certain reactor upgrades, the unfiltered vent from the wetwell provides a degree of risk reduction comparable to other venting strategies at considerably lower cost, and with potentially higher reliability than a filtered vent.

The analysis of BWR Mark I venting concepts resulted in recommendations for several modifications to be made at the Peach Bottom plant independent of the installation of a venting system. These include the implementation of an auxiliary boiler tie-in to the steam-air ejectors in the main condenser and upgrading the cross-tie between the high pressure service water system (HPSW)

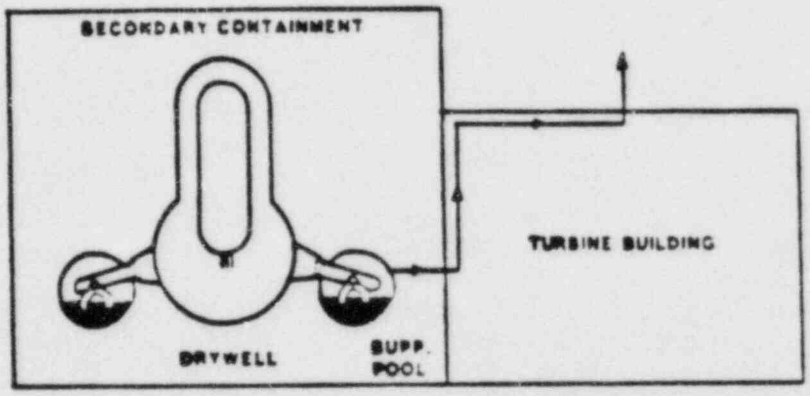

Figure B.1 Schematic Diagram of Vented Containment System for Mark I BWR Containment [B.1] and the low pressure coolant injection system (LPCI) to safety grade standards. The auxiliary boiler tie-in helps assure that condenser vacuum can be reestablished following a transient-induced LOCA requiring containment isolation, and is predicted to result in approximately a factor of 5-10 reduction in the core-melt frequency. The HPSW-LPCI cross-tie is useful in situations where the residual heat removal pumps are unavailable due to cavitation or overheating, the suppression pool is being depleted, or additional heat removal capacity is needed to delay containment overpressurization. The tie-in is particularly useful when the suppression pool is saturated and containment is either leaking or being intentionally vented.

The recommended venting option includes a high-volume (3 foot diameter) vent from the wetwell atmosphere to the atmosphere [B.1]. The vent is designed to be passively actuated when internal containment pressure exceeds design pressure (56 psig) but below the pressure at which primary system safety/relief valves no longer can be controlled (about 75 psig). A manual shutoff capability is provided to protect against excessive fission product releases when the suppression pool is saturated and the core is degraded.

This vent design and strategy serve to reduce risk by several mechanisms. For certain sequences, atmospheric release requires the aerosol to pass through the suppression pool. For these cases (specifically for subcooled pools) the retention of fission products will mitigate the atmospheric release, and hence the offsite consequences of the accident. For other cases, the increased probability of ECCS survival due to prevention of containment failure from overpressure can prevent core melting, and therefore reduce probability of the completion of the accident sequence. Finally, for other cases involving core melt, early venting of containment (before fuel melting) followed by vent closure may allow additional time for deposition in containment before eventual containment failure.

B.2 ALTERNATIVE DECAY HEAT REMOVAL SYSTEM

A multiple objective study has recently been completed as part of the NRC LWR safety program to assess the values and impacts of alternative decay heat removal concepts for LWR nuclear power plants [B.2]. Potential inadequacies in current decay heat removal systems were identified and a group of design criteria were established for alternative systems which addressed the current system inadequacies. Several candidate alternative decay heat removal system concepts were proposed and value-impact analyses were performed for the most promising alternative systems.

The design criteria developed for alternative decay heat removal systems divide the range of LWR events into two categories:

1. Initiating events and system failures which have been observed to occur and for which industry data allows a quantitative assessment of reliability improvements.

2. Special emergencies which have been postulated as potential threats to decay heat removal operations but for which a lack of experience permits only a qualitative assessment of reliability improvements (e.g., fire, earthquake, tsunami, hurricane, flood, sabotage).

Operating experience and reliability estimates indicated that the large majority of transients which interrupt normal heat removal via the power conversion system and which require the operation of decay heat removal systems can be classified as either loss of main feedwater events, loss of main feedwater in conjunction with a loss of offsite power, or loss of main feedwater in conjunction with a loss of both onsite and offsite alternating current (AC) power sources. For the purpose of choosing candidate ADHR concepts for subsequent evaluation, probabilistically oriented design criteria intended to cope with the above transients were selected from criteria being used in the U.S. and abroad and from the findings of a number of reliablity studies [B.2, Refs. 3,5,11,12,16,17]:

1. Alternatives shall be able to function without both offsite and onsite electricity for power and control; alternative electrical sources should be self-contained.

2. Alternatives shall be independent and separate from all existing plant systems whose functions they duplicate, except that the capability may be provided to manually crossconnect the alternatives to the existing onsite emergency electrical system as a backup.

3. Alternatives shall be designed to prevent exposure to pressures and temperatures which exceed their design limitations.

4. Alternatives shall be designed to permit inspection and testing on a periodic basis under conditions as close to design requirements as practical.

5. Alternatives and their supporting subsystems shall be designed to the same criteria and shall be designed to not interfere with or jeopardize other safety systems during normal or abnormal conditions.

6. Alternatives need not be designed to perform their functions during loss of coolant accidents which are sufficiently large to ensure adequate decay heat removal via operation of the emergency core cooling system.

7. Alternatives shall initiate automatically if system operation is required within 30 minutes. However, automatic actuation should not cause or exacerbate accident conditions.

8. Alternatives shall operate automatically for 10 hours once initiated. Manual termination and control should be possible to override system malfunctions or to reactivate other decay heat removal systems.

These criteria are not directly based on the NRC USI-A-45 criteria or any other regulations or regulatory guides. Based on a review of existing design criteria in the U.S. and abroad for special emergencies, and the assumption that existing regulatory guidelines adequately define the design requirements for specific special emergencies, the following alternative decay heat removal system design criteria were defined:

1. Alternatives shall be able to withstand industrial sabotage as defined in 10 CFR 73.55, "Requirements for Physical Protection of Licensed Activities in Nuclear Power Reactors Against Industrial Sabotage;" Regulatory Guide 1.17, "Protection of Nuclear Power Plants Against Sabotage;" ANSI N18.17-1973, "Industrial Security for Nuclear Power Plants."

2. Alternatives shall be able to withstand earthquakes as defined in Regulatory Guide 1.29, Seismic Design Classification."

3. Alternatives shall be located or protected so that simultaneous loss of existing systems and the alternatives cannot occur as a result of fire, missile, flood, sabotage, and pipe whip, as defined in applicable regulatory documents.

4. Alternatives shall be able to withstand extreme pressure loading from hurricanes, tornadoes, and external explosions as defined in applicable regulatory documents.

5. Alternatives shall be located or protected so that simultaneous loss of existing systems and the alternatives cannot occur as a result of airplane crash or ship collision.

6. Alternatives need not be designed to withstand the simultaneous occurrence of more than one special emergency, unless more than one condition can credibly occur simultaneously or in sequence (e.g., aircraft crash followed by an explosion and fire).

Based on the above design criteria, three BWR candidate alternative decay heat removal (ADHR) concepts were proposed in the value-impact study:

1. A low pressure makeup and suppression pool cooling train.

2. A high pressure makeup and suppression pool cooling train.

3. A controlled/variable pressure makeup and suppression pool cooling train.

These three BWR candidate concepts were screened based on five major factors:

1. Functional capability

2. Compliance with design criteria

3. Feasibility of construction

4. Potential costs

5. Operational and maintenance difficulties.

A screening process was developed to eliminate those alternatives for which serious questions could be raised regarding the feasibility of implementation as a backfit, and also to eliminate those concepts which would not significantly improve DHR capabilities. The operational expense and system costs were considered to be of secondary importance to other attributes because basic concepts which satisfied the first three criteria could be modified to reduce costs and maintenance problems. Basic concepts with problems relating to the first three criteria would be much more difficult to modify for implementation. Thus, based on engineering judgement of the importance of various attributes, the cost and operational screening factors were weighted by 50 and 20 respectively, while the other three screening criteria were each weighted by 100. The low pressure makeup and suppression pool cooling concept ranked the highest of the three alternative decay heat removal concepts for BWRs in the screening process (scoring 370 of a possible 370), while the other concepts ranked lower (high pressure cooling - 340, controlled depressurization cooling - 305) due mainly to weaknesses in construction feasibility and functional capabilities. Therefore, the low pressure makeup and suppression pool cooling concept was the only BWR candidate analyzed in detail in the decay heat removal study, and is the system discussed in this report.

A flow diagram of the low pressure makeup and suppression cooling train is shown in Figure B.2 [B.2]. The add-on system relies on the automatic depressurization relief valves or some add-on dedicated relief valves to depressurize the reactor vessel. After depressurization, the method of maintaining inventory resembles the low pressure coolant injection mode of the residual heat removal system. The add-on pumps are modeled after the low pressure coolant injection pumps. The concept is a single train, 100% capacity system, without redundancy or single failure capability. It includes its own fluid system, power supplies, control systems, and instrumentation. Valving to regulate the reactor coolant makeup and suppression pool cooling functions of the system would be provided. Cooling water to the add-on heat exchanger, pump seals, motor bearing coolers, and room coolers would be provided by a dedicated service water system which connects to an ultimate heat sink.

The major benefits of the low pressure BWR makeup and suppression pool cooling system were identified as:

1. All components are readily available and could be identical to existing components.
2. The system would serve to minimize blowdown from small LOCAs since the system involves reactor depressurization.

The major disadvantages of the low pressure BWR makeup and suppression pool cooling system were identified as:

1. The system has a large number of components which must operate in order for it to function. This would require a routine maintenance and inspection program.
2. Three large containment and drywell penetrations are required. These may not be available as spares, especially in older plants.

The low pressure makeup and suppression pool cooling train was originally designed to be able to perform the core spray function immediately after a scram. Unfortunately, to meet this requirement the add-on low pressure concept proved to be too large to be retrofitted into an existing plant. Therefore, the

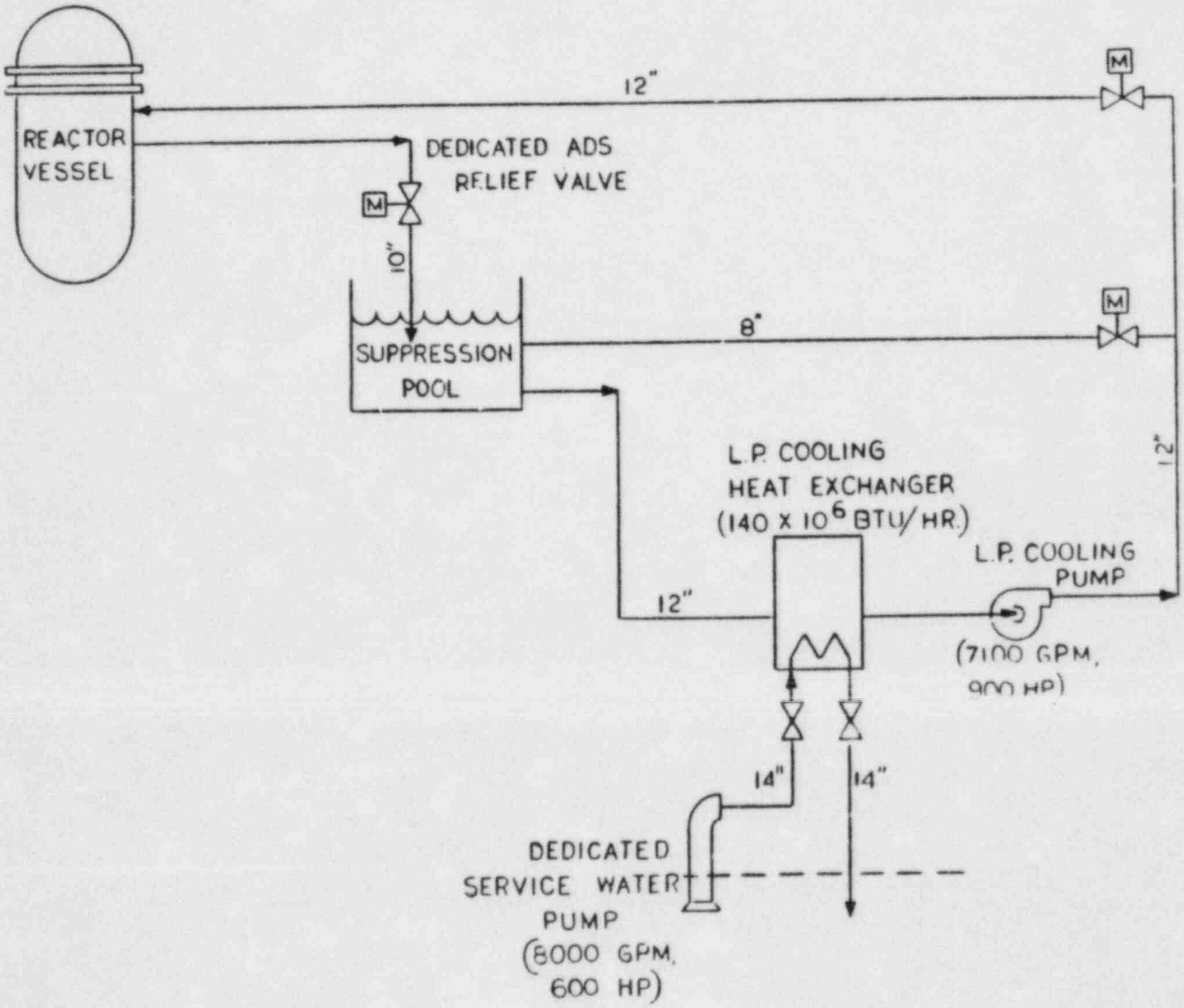

Figure B.2 Flow Diagram for Low Pressure Makeup and Suppression Cooling Train [B.2] concept was revised to take credit for reactor core isolation cooling system operation during the first two hours following a scram. This implicitly assumes that the RCIC can be relied upon to operate for two hours with only DC power available (i.e., two hour battery capacity). However, some key components of the RCIC may require AC power to function properly. Despite these shortcomings, the two hour delayed operation of the add-on system was chosen as the design criterion in the study of alternative heat removal concepts [B.2].

B.3 REFERENCES

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APPENDIX C

BASELINE RISK AND RISK REDUCTION ESTIMATES WITH UNCERTAINTIES

The information regarding risk from the operation of the Peach Bottom plant before modification and after the installation of either the vent or the ADHR is summarized in this section. The discussion focuses on estimates of core melt frequency, accident health and economic consequences, and health and economic risks from plant operation. Estimates of mean risk before and after plant modification are developed based on information gathered from a variety of previous studies. Assumptions used to estimate the ranges of uncertainties for all values presented are also discussed.

In order to form estimates of the core melt frequency and risk for use in the value-impact portion of the example regulatory analysis, it proved necessary to draw technical information from a variety of sources. Much of the information is based on the results of previous research programs which employed different assumptions and techniques in estimating severe accident frequencies and consequences. Because the purpose of this program was not to perform additional research but rather to draw on existing information, in certain cases it was necessary to combine results from analyses performed using inconsistent assumptions and methodologies in order to provide the input information for the value-impact analyses. Because the numerical values presented in this section are based on the combination of previous results and engineering judgement, all values are estimated and presented to one significant figure. This presentation reflects the imprecision which is inherent in the methodologies used to estimate the values. Unfortunately, problems with handling incompatible information or generating additional information are likely to be incurred in performing future regulatory analyses which draw heavily on information from previously completed research programs. This again emphasizes the need to define clearly the anticipated products of research efforts for future regulatory analyses on severe accident issues.

C.1 CORE MELT FREQUENCY

Estimates of the core melt frequency at the Peach Bottom plant were originally developed as part of the RSS in 1975. Since that study, several improved assessments of the core melt frequency at Peach Bottom have been developed [C.1, C.2]. Also, information on the approximate factors of uncertainty in the core melt frequency estimates from internally-initiated accidents have been developed [C.3].

A study has been performed to summarize and rebaseline the RSS risk estimates using information available regarding source terms as of 1981 (NUREG-0773) [C.2]. As part of that study, the core melt frequency at the Peach Bottom plant was assessed using improved accident phenomonology codes and information developed since the RSS. The "central estimate" of core melt frequency from this study is 3×10^{-5} per reactor-year of operation. This estimate agrees very well with the RSS estimate of the Peach Bottom core melt frequency [C.4]. Detailed estimates of the uncertainties associated with the core melt frequency estimates were not developed as part of the RSS or NUREG-0773.

The baseline core melt frequency at the Peach Bottom plant was also evaluated as part of the study of vented containment concepts. The study developed "conservative" and "non-conservative" estimates of the core melt frequency based on bounding assumptions regarding failure rates and the physical progression of core melt accident sequences. The "conservative" estimate of the core melt frequency from the vented containment study is $\sim 2 \times 10^{-5}$ per reactor-year of operation, and the "non-conservative" estimate is approximately 7×10^{-6} per reactor-year. The assumptions employed in the vented containment study to calculate "conservative" and "non-conservative" bounds are numerous and complex, and the interested reader is referred to [C.1] for more detailed information.

The estimate of core melt frequency from NUREG-0773 (3×10^{-5} per reactor-year) is used as the central estimate of baseline core melt frequency in this study. The low and high estimates of the core melt frequency at Peach Bottom are based on the uncertainty factors for internally-initiated accidents estimated as part of the PRA Reference Document (NUREG-1050, Draft). The authors of this report estimated that typically the uncertainties in internally-initiated accident core melt frequencies are approximately factors of 6-10 around the central estimate. The high estimate of baseline core melt frequency employed in this study is a factor of 10 greater than the NUREG-0773 central estimate ($3x10^{-4}$ per reactor-year). The low estimate of baseline core melt frequency is a factor of 10 lower than the central estimate ($3x10^{-6}$). The range from low to high estimates spans both the "conservative" and "non-conservative" estimates of the baseline core melt frequency from the vented containment study [C.1].

The core melt frequency at Peach Bottom after installation of the vented containment system is estimated using the baseline core melt frequency estimates from above with information from the vented containment study [C.1]. The venting option under consideration was estimated to result in a factor of 7-8 reduction in the "conservative" core melt frequency in the vented containment study. Thus, this reduction factor is applied to the central estimate of baseline core melt frequency in this study (which roughly corresponds to the "conservative" estimate of core melt frequency from the vented containment study) to develop the central estimate of the core melt frequency after the installation of the vent at the Peach Bottom plant. The high estimate of core melt frequency after vent installation is based on the high estimate of the baseline core melt frequency, with the assumption that the vent provides the same net reduction in core melt frequency as in the central estimate. This is based on the assumption that the accident sequences for which the vent prevents core melt are not increased in frequency in the high baseline estimate (a pessimistic assumption for estimating net core melt frequency or risk reduction). The low estimate of core melt frequency after installation of the vent is based on the low estimate of the baseline core melt frequency with the assumption that the vent does not prevent core melt for most sequences which are important contributors to the core melt frequency. This low estimate is justified based on two arguments: 1) If the baseline core melt frequency is in the range of the low estimate, experience indicates that many accident sequences will contribute a small amount to this frequency, rather than very few accident sequences which each contribute a large fraction of the total core melt frequency. Since the vent only prevents core melt for certain accident sequences, it is unlikely to provide significant core melt frequency reduction in this case. 2) The low estimate of the baseline core melt frequency is in the range of the estimated frequency of accident sequences for which the vent does not prevent core melt. Thus, based on low estimates of the baseline core melt frequency, it is likely that the vent does not provide significant core melt frequency reduction.

The central estimate of the core melt frequency at Peach Bottom after the installation of the ADHR system is based on elimination of the TW accident sequence from the baseline core melt frequency estimate of NUREG-0773 [C.2]. This results in a central estimate of core melt frequency after ADHR installation of 1×10^{-5} per reactor-year of operation. This estimate is not sensitive to the range of plausible assumptions regarding the effectiveness of the ADHR system in performing the decay heat removal function for transient-induced accidents. The high estimate of the core melt frequency after installation of the ADHR system results from the assumption that the TW accident sequence has the same estimated frequency in the high baseline core melt frequency estimate as in the central baseline core melt frequency estimate (a pessimistic assumption for estimating net core melt frequency reduction). Thus, the ADHR results in the same net reduction in core melt frequency for the high estimate of core melt frequency, resulting in an estimate of core melt frequency after ADHR installation of 2×10^{-4} per reactor-year of operation. The low estimate of core melt frequency after ADHR installation shows no net reduction in the core melt frequency from the low estimate of baseline risk. This results because the ADHR only prevents certain core melt accident sequences, and it is unlikely that these sequences are dominant contributors to a very low total core melt frequency (see arguments above for low estimate of core melt frequency after vent installation).

Table C.1 summarizes the information related to the baseline core melt frequency for the Peach Bottom plant and the estimates of core melt frequency after installation of either the vented containment system or the ADHR system (This table is identical to Table A.4.1 in the example regulatory analysis). The low and high estimates should adequately reflect all of the uncertainties in internally-initiated accidents which are important for the the value-impact analyses in Appendix A.

C.2 HEALTH RISKS

The rationale for the estimates of health risks from Peach Bottom operation both before and after installation of either the vented containment system or the ADHR system are discussed in this section. The estimates must incorporate uncertainties related to both severe accident source terms and consequences in addition to those related to core melt frequencies. The

HYPOTHETICAL EXAMPLE

Table C.1 - Summary of Core Melt Frequency Information for Internally Initiated Accidents (Peach Bottom #2 plant, per reactor-year of operation)

	Baseline	With Vented Containment	With ADHR System
Low Estimate	3×10^{-6}	3×10^{-6}	3×10^{-6}
Central Estimate	3×10^{-5}	4×10^{-6}	1×10^{-5}
High Estimate	3×10^{-4}	2×10^{-4}	2×10^{-4}

estimated health risks have wider bands of uncertainties since there is little data from experience which can be used to directly support the results of the analytical analyses.

The estimated health risks from operation of the Peach Bottom plant are summarized in Table C.2 (identical to Table A.4.3 in the example regulatory analysis). The table shows the mean risks per reactor-year of operation for four attributes related to public health and safety at offsite locations: 1)Early Fatalities, 2)Early Injuries, 3)Latent Cancer Fatalities, and 4)Total Person-Rem Incurred at Offsite Locations. All of the values for public health risks are based on the total impacts which occur at all offsite locations after an accident. It should be pointed out that this list of attributes does not represent all public health consequences of an accident (e.g., genetic effects, thyroid nodules are not included), but it does cover many of the attributes which have been considered most important for decision-making purposes. Low, central, and high estimates of baseline risk and risk after plant modifications are shown in the table.

The central estimates of baseline public health risks shown in Table C.2 are based on accident frequency estimates from NUREG-0773 and consequence calculations performed for the BWR1-BWR4 release categories using the CRAC2 computer code. The consequence analyses are based on the standard CRAC2 "reference case" [C.5] assumptions including "summary" emergency response. The central estimates in the table are based on the mean consequences for each of the BWR1-BWR4 release categories for the Peach Bottom reactor and the population distribution at the Peach Bottom site, with 100 weather sequences sampled from Washington, D.C. National Weather Service data. Thus, the values shown are based on averaging over many accident sequences, containment failure modes and releases, weather sequences, and wind directions.

The low and high estimates of health risks from Peach Bottom operation are developed in this study using assumptions to bound the range of uncertainties in source terms and accident consequences. For the high estimates, the source terms employed are identical to those used in the central estimates. This assumption is made because the central estimates are based on NUREG-0773 source terms (which are very similar to WASH-1400 source terms), and the source terms are so large that no appreciable factor increase is considered to be likely. For low estimates, it is assumed that the source terms are reduced by approximately a factor of 50 from those used in the central estimates. This reduction factor is based on the large

HYPOTHETICAL EXAMPLE

Table C.2 - Summary of Offsite Health Risk Information for Internally Initiated Accidents (Peach Bottom #2 plant, per reactor-year of operation)

		Early Fatalities	Early Injuries	Latent Cancer Fatalities	Offsite Person-Rem
	Low Estimate	~0	~0	$2x10^{-5}$	<1
Baseline	Central Estimate	$3x10^{-6}$	$7x10^{-4}$	$4x10^{-2}$	$6x10^{2}$
	High Estimate	$2x10^{-4}$	$4x10^{-2}$	$4x10^{0}$	$2x10^{4}$
	Low Estimate	~0	~0	$2x10^{-5}$	<1
With Vent	Central Estimate	$2x10^{-7}$	$4x10^{-5}$	$2x10^{-3}$	$3x10^{1}$
	High Estimate	$5x10^{-5}$	$1x10^{-2}$	$1x10^{0}$	$5x10^{3}$
	Low Estimate	~0	~0	$2x10^{-5}$	<1
With ADHR	Central Estimate	$8x10^{-7}$	$2x10^{-4}$	$1x10^{-2}$	$2x10^{2}$
	High Estimate	$1x10^{-4}$	$2x10^{-2}$	$2x10^{0}$	$1x10^{4}$

uncertainties regarding the source term, and the lack of information available from ongoing research programs. Also, the conclusions of the analyses using low estimates are not affected by reduction factors of greater than 50 for source term values. The conclusions of the analyses using low estimates might be changed for much smaller source term reduction factors (e.g., less than a factor of ten), but such small factors are not representative of the true lack of knowledge on this issue.

The ranges of uncertainties on mean accident consequences for a given source term are based on expert judgement and are used in developing low and high estimates of mean public health risks [C.3, C.5]. Estimates of mean early fatalities and injuries for a given source term could be a factor of approximately 5 higher than the central estimates due to uncertainties in the estimation of accident consequences. Estimates of the lower values for these attributes due to uncertainties in consequence estimation were not necessary for the purposes of this study. Estimates of mean total latent cancer fatalities are estimated to be factors of plus or minus 10 due to uncertainties in modeling consequences. Finally, estimates of mean offsite person-rem are estimated to contain uncertainties of plus or minus factors of 3 in the consequence estimates. It should be emphasized that these uncertainty factors are very rough estimates based only on expert judgement. Improved estimates of the uncertainties related to accident physical progression, source terms, and accident consequences are a primary emphasis of the MELCOR code development program. When completed, the MELCOR code system should provide a very useful tool for identification and propagation of uncertainties in all of these areas.

The low estimates of baseline health risks shown in Table C.2 are based on the low core melt frequency estimate from Table C.1 and propagation of the uncertainty factors for accident source terms and consequences outlined above. For early fatalities and early injuries, this results in a low estimate of baseline risk of approximately zero. This is consistent with the "non-conservative" estimate of baseline risk for these attributes from the vented containment study [C.1]. The low values for latent cancer fatalities and offsite person-rem are based on the assumption that mean consequences for these attributes vary approximately linearly with source term magnitudes [C.7] (this is not an unreasonable assumption since there are no threshold effects for these attributes). The high estimates of baseline public health risks are based on the high estimate of baseline core melt frequency (see Table C.1) combined with the approximate uncertainty factors for consequences as outlined above. Again, the high estimates are based on the same source term estimates as used in the analyses for central estimates (i.e., NUREG-0773 source terms).

The central estimates of the public health risks from Peach Bottom operation after installation of the venting system are based on rough risk reduction factors taken from the vented containment study for the specific venting option under consideration [C.1]. The low estimates for risk after vent installation are based on the "non-conservative" estimates from the vented containment study with one minor modification. For latent cancer fatality and offsite person-rem risks, the vent is likely to provide very little reduction from the low baseline estimates. This results from the noble gases which are significant contributors to the lower bound (factor of 50 reduced) source terms employed in this study. Since the vent system described in Appendix B does not significantly reduce the release of noble gases during severe accidents, the vent would not provide significant risk reduction for lower bound source terms. Hence the low estimates of baseline risk and risk after installation of the venting system are equivalent. The high estimates of risk after installation of the vent are based on the high estimate of core melt frequency from Table C.1, and the uncertainty factors for accident consequences as described above.

The central estimates for public health risks after installation of the ADHR system are based on the NUREG-0773 accident sequence and release category frequencies after removal of the TW sequence, and consequence calculations performed with the CRAC2 computer code. This analysis was simplified considerably from that of the vented containment system since the ADHR only affects the frequencies of specific release categories, and does not result in reduced source terms for specific accidents (i.e., it has no significant mitigation effects). The low estimates of public health risk after ADHR installation are equivalent to the low estimates of baseline risk at Peach Bottom. This occurs because the ADHR affects only severe accident sequences in which decay heat removal is a problem. The low estimates of baseline risk have a negligible contribution from these sequences. The high estimate of health risks after installation of the ADHR system are based on the high estimates of core melt frequency (see Table C.1), with the uncertainty factors for each of the health risk attributes as described above.

It should be emphasized that there is a tremendous amount of information summarized in Tables C.1 and C.2 related to core melt frequencies, severe accident source terms, and accident health consequences. The discussion above briefly summarizes the multitude of calculations and assumptions which must be employed in an attempt to blend information from a variety of previous technical studies performed for different purposes. The problems with these analyses are discussed more fully in the section of the main report related to problems with information. Also, the lack of information in specific areas often forces the problem solution to be inferred indirectly. This leads to difficulties in avoiding tremendous complexity in discussion and display of information.

Table C.3 summarizes information related to the mean (or expected) health consequences (for the four attributes) conditional upon core melt accident occurrence at the Peach Bottom site (Table C.3 is identical to Table A.4.2 in the example regulatory analysis). The values in the table represent averages for all core melt accident sequences, source terms, weather sequences, and wind directions at the time of accident occurrence. The values in Table C.3, with few exceptions, can be derived by dividing the risk values in Table C.2 by the corresponding core melt frequency estimates in Table C.1. The exceptions result from the incompatibility of information between the various sources used. The information in Table C.3 does not show the distribution of potential consequences for core melt accidents, but this information could be displayed (in those cases where it is currently available) using the complementary cumulative distribution function (CCDF) of consequences. This is discussed further in the main report on the display of information. The values presented in Table C.3 represent only the mean of the CCDF.

C.3 ECONOMIC RISKS

The rationale for the economic risk estimates employed in the example regulatory analysis are discussed in this section. The value-impact analyses are performed using three alternative economic measures to represent the risk reduction afforded by each of the modifications under consideration: 1)Total risk for remaining plant life evaluated at $1000/person-rem of offsite public exposure, 2)Total risk for remaining plant life using offsite economic cost estimates for property damage and health effects, 3)Total risk for remaining plant life including both onsite and offsite costs of property damage, replacement power costs, and health effects. The values derived for each of these measures with uncertainties is discussed in this section.

HYPOTHETICAL EXAMPLE

Table C.3 - Mean Health Consequences* Conditional Upon Core Melt Accident Occurrence
(Peach Bottom #2 plant)

		Early Fatalities	Early Injuries	Latent Cancer Fatalities	Offsite Person-Rem
	Low Estimate	~0	~0	7×10^{0}	1×10^{5}
Baseline	Central Estimate	1×10^{-1}	2×10^{1}	1×10^{3}	2×10^{7}
	High Estimate	5×10^{-1}	1×10^{2}	1×10^{4}	7×10^{7}
	Low Estimate	~0	~0	7×10^{0}	1×10^{5}
With Vent	Central Estimate	5×10^{-2}	1×10^{1}	5×10^{2}	8×10^{6}
	High Estimate	3×10^{-1}	5×10^{1}	5×10^{3}	3×10^{7}
	Low Estimate	~0	~0	7×10^{0}	1×10^{5}
With ADHR	Central Estimate	8×10^{-2}	2×10^{1}	1×10^{3}	2×10^{7}
	High Estimate	5×10^{-1}	1×10^{2}	1×10^{4}	5×10^{7}

---

* Mean consequences for all accident scenarios, emergency response scenarios, wind directions, and meteorological conditions.

Table C.4 summarizes the information related to the economic risk from internally-initiated severe accidents for the remaining lifetime of the Peach Bottom #2 plant (Table C.4 is identical to Table A.4.5 in the example regulatory analysis). All values are shown in constant 1982 dollars. The attributes shown in the table are economic risks evaluated using 1) $1000/person-rem of offsite exposure, 2) offsite property damage as calculated with an economic consequence model (CRAC2), 3) offsite health effect economic risks based on NUREG/CR-2739 [C.8] costing of health effects (i.e., $1,000,000 per early fatality, $100,000 per early injury, and $100,000 per latent cancer fatality), 4) onsite damage including replacement power costs, plant capital losses, and plant decontamination costs as calculated with the newly developed economic consequence models, and 5) total onsite plus offsite costs (the summation of costs 2, 3, and 4). The values presented in the table represent mean risks based on averaging over all accident sequences, source terms, and offsite weather conditions at the time of accident occurrence.

The uncertainties in the estimates of economic risks from Peach Bottom operation are based on the uncertainties in core melt frequency, source terms, and health consequences which were discussed previously combined with uncertainty estimates for onsite and offsite property damages. The uncertainties in offsite property damage for a defined source term have been estimated to be approximately factors of plus or minus five based on uncertainties in the costs and effectiveness of property decontamination techniques and uncertainties in post-accident population protective measure implementation criteria related to land interdiction [C.6]. Uncertainties in total onsite property damage have been estimated to be approximately plus or minus factors of three based on uncertainties mainly related to replacement power costs and cleanup costs.

The first column in Table C.4 shows the economic risks for the remaining plant life (which is 30 years based on a forty year plant lifetime) evaluated based on $1000/person-rem of offsite exposure. All of the values are based on the corresponding risks for offsite person-rem in Table C.2 multiplied by 30 years (the remaining plant lifetime) and $1000/person-rem. All of the uncertainties related to the values in this column are discussed above related to the offsite person-rem measure of risk.

The baseline estimates of offsite property damage are based on the baseline core melt frequency estimates and consequence calculations for the Peach Bottom site performed with the CRAC2 code. The low estimates are based on a factor of 50 reduction in source terms, and a factor of 5 uncertainty in offsite damages

HYPOTHETICAL EXAMPLE

Table C.4 - Summary of Economic Risk Information for Internally Initiated Accidents (Peach Bottom #2 plant, risks in 1982 dollars for remaining plant lifetime)

		Costs @ \$1000 Per Person-Rem*	Offsite Property Damage Costs**	Offsite Health Effects Costs***	Onsite Losses	Total (Onsite+ Offsite) Costs
	Low Estimate	$\$2\mathrm{x}10^{4}$	$\$2\mathrm{x}10^{2}$	$\$1\mathrm{x}10^{1}$	$\$7\mathrm{x}10^{4}$	$\$7\mathrm{x}10^{4}$
Baseline	Central Estimate	$\$2\mathrm{x}10^{7}$	$\$5\mathrm{x}10^{5}$	$\$7\mathrm{x}10^{4}$	$\$2\mathrm{x}10^{6}$	$\$3\mathrm{x}10^{6}$
	High Estimate	$\$5\mathrm{x}10^{8}$	$\$3\mathrm{x}10^{7}$	$\$7\mathrm{x}10^{6}$	$\$7\mathrm{x}10^{7}$	$\$1\mathrm{x}10^{8}$
	Low Estimate	$\$2\mathrm{x}10^{4}$	$\$2\mathrm{x}10^{2}$	$\$1\mathrm{x}10^{1}$	$\$7\mathrm{x}10^{4}$	$\$7\mathrm{x}10^{4}$
With Vent	Central Estimate	$\$9\mathrm{x}10^{5}$	$\$3\mathrm{x}10^{4}$	$\$4\mathrm{x}10^{3}$	$\$3\mathrm{x}10^{5}$	$\$3\mathrm{x}10^{5}$
	High Estimate	$\$2\mathrm{x}10^{8}$	$\$8\mathrm{x}10^{6}$	$\$2\mathrm{x}10^{6}$	$\$5\mathrm{x}10^{7}$	$\$6\mathrm{x}10^{7}$
	Low Estimate	$\$2\mathrm{x}10^{4}$	$\$2\mathrm{x}10^{2}$	$\$1\mathrm{x}10^{1}$	$\$7\mathrm{x}10^{4}$	$\$7\mathrm{x}10^{4}$
With ADHR	Central Estimate	$\$6\mathrm{x}10^{6}$	$\$2\mathrm{x}10^{5}$	$\$2\mathrm{x}10^{4}$	$\$8\mathrm{x}10^{5}$	$\$1\mathrm{x}10^{6}$
	High Estimate	$\$3\mathrm{x}10^{8}$	$\$2\mathrm{x}10^{7}$	$\$4\mathrm{x}10^{6}$	$\$5\mathrm{x}10^{7}$	$\$8\mathrm{x}10^{7}$

* Lifetime economic risks based on \$1000 per person-rem and no discounting in future years.

** Lifetime offsite damage risks based on CRAC2 economic calculations and real discount rate of 4%.

*** Health effects costs based on values described in NUREG/CR-27[illegible]9 [C.8] and a real discount rate of 4%.

for a given source term. The high estimates are based on the same source terms as used to derive the central estimates, and a factor a 5 uncertainty in the offsite property damage for a given source term. After installation of the vent, the central estimates of offsite property damage are based on the rough risk reduction factor estimates from the vented containment study [C.1]. The high estimates are based on the high estimate of the core melt frequency after vent installation and a factor of 5 uncertainty in offsite property damage estimates for a defined source term. The source terms were the same for both the central and high estimates. The low estimate of offsite property damage risk after vent installation is the same as in the baseline case, since most of this cost results from evacuation costs during core melt accidents, and is likely to be unchanged even after installation of the vent. The central estimate of offsite property damage risks for the ADHR is based on NUREG-0773 accident frequencies after removal of the TW accident sequence and consequence calculations performed with the CRAC2 computer code. The high estimate is based on the high estimate of core melt frequency after ADHR installation from Table C.1 and uncertainty estimates of a factor of 5 for offsite property damages for a defined source term. The low estimate is based on the baseline estimate with the assumption that evacuation would still occur during an accident event even if the ADHR were in place. All of the offsite property damage risks in Table C.4 have been integrated over the 30 year remaining plant life and discounted using a 4% real discount rate. Choice of a 10% real discount rate would reduce all offsite property damage risks by a factor of 2, and choice of a 0% discount rate would increase all risk estimates by a factor of 2. Thus, the results of the analyses are not significantly sensitive to a plausible range of values for discount rates.

The third column in Table C.4 shows the economic risks for offsite health effects based on the NUREG-2723 [C.8] costing of public health effects. These values are based on the risk values for early fatalities, early injuries, and latent cancer fatalities from Table C.2 multiplied by costs of $1,000,000/early fatality, $100,000/early injury, and $100,000/latent cancer fatality. The risks have also been integrated over the 30 year remaining plant life and discounted at 4%. The low and high estimates again include all of the uncertainty factors which were discussed in relation to the health effect risks in Table C.2. Changes in the discount rate between 0-10% would result in less than a factor of 2 variation in all of the estimates of economic risks for offsite health effects.

The estimates of onsite property damages in Table C.4 are based on the corresponding core melt frequencies from Table C.1, with onsite cost estimates for core melt accidents at the Peach Bottom site calculated with the new economic consequence models described in [C.6]. Neither the vent nor the ADHR system is predicted to have a very significant effect on the onsite losses after a core melt accident. All of the low and high estimates of onsite damages are based on the corresponding low and high core melt frequencies from Table C.1 with uncertainty factors of plus or minus three for onsite consequences conditional upon core melt accident occurrence. The onsite property damage risks in Table C.4 have been integrated over the remaining 30 year plant lifetime using a 4% per year discount factor

Finally, the risk estimates based on total costs in Table C.4 are a summation of the corresponding costs in columns 2, 3, and 4 of the table. The low and high estimates of total costs therefore reflect all of the uncertainties in offsite property damages, offsite health effects, and onsite property damages which have been considered in the analyses.

Again, it is important to note that all of the values in Table C.4 represent the mean economic risks integrated over the remaining 30 year lifetime of the plant for various attributes considered in the analysis. The analysis based on $1000/person-rem of offsite exposure is treated separately from the other onsite and offsite cost attributes in the value impact analyses. The three attributes of costs based on $1000/person-rem, offsite costs only, and total costs are carried throughout the value-impact analyses in the example regulatory analysis for comparative purposes to show weaknesses and strengths of each measure.

Table C.5 shows the mean economic consequences conditional upon core melt accident occurrence at the Peach Bottom plant for all of the attributes considered in the analyses (Table C.5 is identical to Table A.4.4 in the example regulatory analysis). The values based on $1000/person-rem and offsite health effects costs (per NUREG-2723) can be derived from Table C.3 by multiplying the mean health effects (or person-rem) by the appropriate dollar values. The values for offsite and onsite damages in Table C.5 are derived from CRAC2 analyses, information in the vented containment study, and calculations performed with the new onsite consequence models [C.6] for the Peach Bottom #2 plant. Table C.5 does not show information related to the distribution of possible economic impacts conditional upon core melt accident occurrence at the Peach Bottom #2 plant, but rather is based on the means of those distributions. Information

HYPOTHETICAL EXAMPLE

Table C.5 - Mean Economic Consequences[*] Conditional Upon Core Melt Accident Occurrence (Peach Bottom #2 plant)

		Costs @ $1000 Per Person-Rem	Offsite Property Damage Costs[**]	Offsite Health Effects Costs[***]	Onsite Losses	Total (Onsite+ Offsite) Costs
	Low Estimate	$\$2\times10^{8}$	$\$4\times10^{6}$	$\$2\times10^{5}$	$\$1\times10^{9}$	$\$1\times10^{9}$
Baseline	Central Estimate	$\$2\times10^{10}$	$\$1\times10^{9}$	$\$1\times10^{8}$	$\$4\times10^{9}$	$\$5\times10^{9}$
	High Estimate	$\$6\times10^{10}$	$\$6\times10^{9}$	$\$1\times10^{9}$	$\$1\times10^{10}$	$\$2\times10^{10}$
	Low Estimate	$\$2\times10^{8}$	$\$4\times10^{6}$	$\$2\times10^{5}$	$\$1\times10^{9}$	$[illegible]
With Vent	Central Estimate	$\$8\times10^{9}$	$\$4\times10^{8}$	$\$6\times10^{7}$	$\$4\times10^{9}$	$\$4\times10^{9}$
	High Estimate	$\$3\times10^{10}$	$\$3\times10^{9}$	$\$6\times10^{8}$	$\$1\times10^{10}$	$\$1\times10^{10}$
	Low Estimate	$\$2\times10^{8}$	$\$4\times10^{6}$	$\$2\times10^{5}$	$\$1\times10^{9}$	$\$1\times10^{9}$
With ADHR	Central Estimate	$\$2\times10^{10}$	$\$1\times10^{9}$	$\$1\times10^{8}$	$\$4\times10^{9}$	$\$5\times10^{9}$
	High Estimate	$\$5\times10^{10}$	$\$6\times10^{9}$	$\$1\times10^{9}$	$\$1\times10^{10}$	$\$2\times10^{10}$

[*] Mean consequences for all accident scenarios, emergency response scenarios, wind directions, and meteorological conditions.

[**] Offsite damages based on CRAC2 calculations.

[***] Offsite health effects costs based on values described in NUREG/CR-2739 [C.8].

displayed using CCDF's (where information is available) as discussed in the main report.

C.4 SUMMARY - RISK REDUCTION INFORMATION

Table C.6 summarizes the low, central, and high estimates of risk reduction afforded by the venting system or the ADHR system at the Peach Bottom #2 plant (Table C.6 is identical to Table A.4.6 in the example regulatory analysis). The estimates are derived by subtraction of the integrated economic risk values presented in Table C.4 after installation of the vent or the ADHR from the baseline estimate of integrated economic risks in Table C.4 (e.g., low estimate after installation subtracted from low baseline estimate, central estimate after installation subtracted from central baseline estimate, etc.). Values are shown for economic risks based on $1000/person-rem of offsite exposure, offsite costs (including property damage and health effects), and total costs (including onsite and offsite property damage, and health effect costs). All values presented in Table C.6 are in constant 1982 dollars and have been integrated over the plant lifetime (30 years) in the analyses. The values are the low, central, and high estimates of the benefits from risk reduction afforded by the vent or the ADHR in the value-impact analyses.

The values presented in Table C.6 are means based on averaging over accident sequences, source terms, and accident consequences for the Peach Bottom plant. An attempt has been made to quantify the magnitudes of the uncertainties in the analyses in the low and high estimates. Generally, this was performed by propagating factors and where appropriate incorporating information from previous technical analyses. Clearly, there is a strong need for improved uncertainty analysis techniques for regulatory analyses, and several programs currently underway, including SARRP and MELCOR, should offer significant contributions in this area.

Finally, the information related to the risk reduction afforded by either the vent or the ADHR system at Peach Bottom is summarized in Figure C.1 (this is identical to Figure A.4.1 in the example regulatory analysis). The figure shows the low, central, and high estimates of core melt frequency, mean accident consequences conditional upon core melt occurrence, lifetime integrated risk, and lifetime integrated net risk reduction for the vent and the ADHR using the $1000/person-rem, offsite cost,

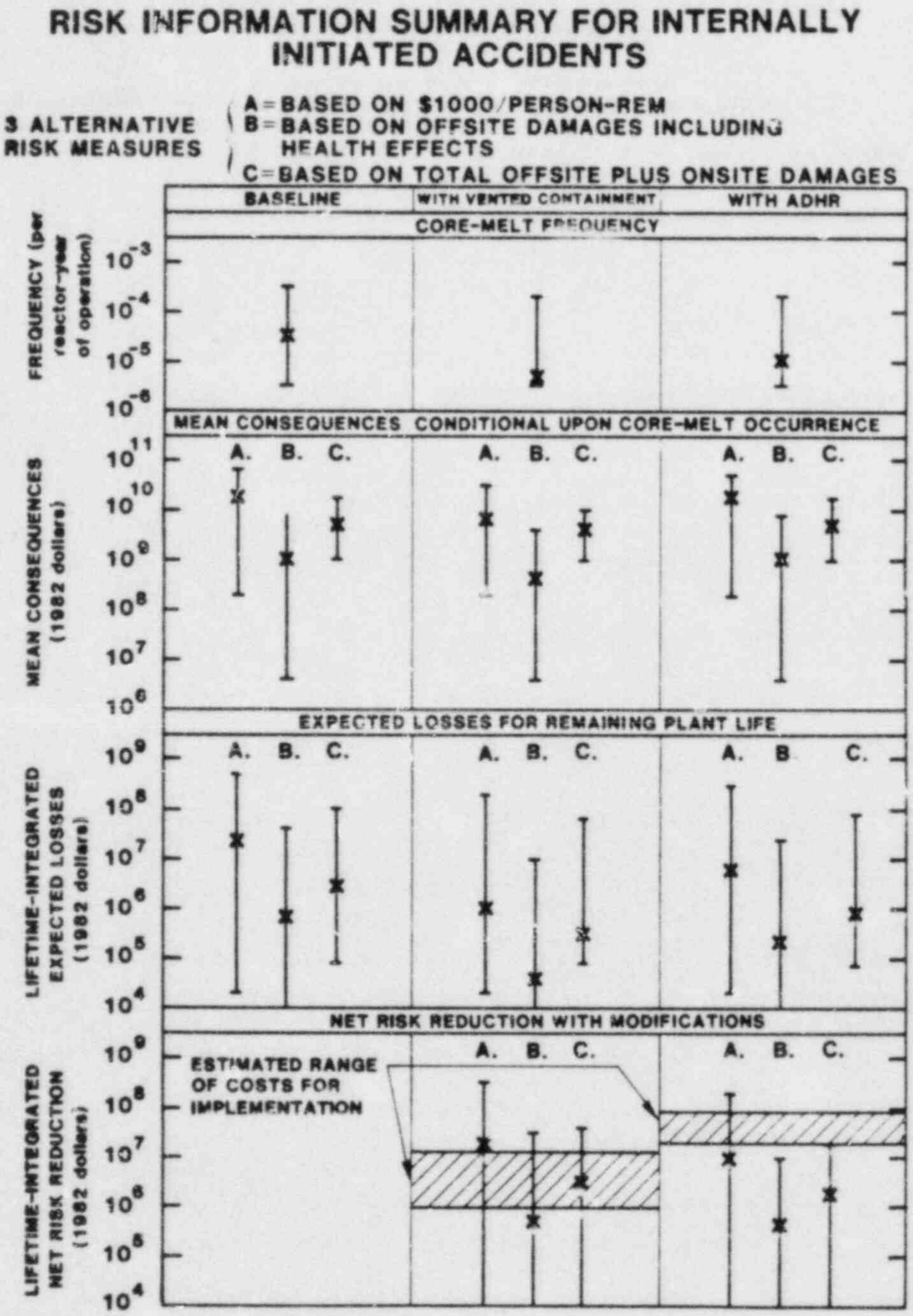
HYPOTHETICAL EXAMPLE

Table C.6 - Summary of Risk Reduction Estimates Used in Value-Impact Analyses (in dollars for remaining plant lifetime)

		Costs Based on $1000/Person-Rem	Offsite Costs	Total Costs (Onsite+Offsite)
With Vent	Low Estimate	~0	~0	~0
	Central Estimate	$\$2\text{x}10^{7}$	$\$5\text{x}10^{5}$	$\$3\text{x}10^{6}$
	High Estimate	$\$3\text{x}10^{8}$	$\$3\text{x}10^{7}$	$\$4\text{x}10^{7}$
With ADHR	Low Estimate	~0	~0	~0
	Central Estimate	$\$1\text{x}10^{7}$	$\$4\text{x}10^{5}$	$\$2\text{x}10^{6}$
	High Estimate	$\$2\text{x}10^{8}$	$\$1\text{x}10^{7}$	$\$2\text{x}10^{7}$

Figure C.1

HYPOTHETICAL EXAMPLE



RISK INFORMATION SUMMARY FOR INTERNALLY INITIATED ACCIDENTS and total cost measures. The estimated low, central, and high costs of implementation of the vent and the ADHR system at the Peach Bottom plant are shown shaded in the figure for comparison to the net risk reduction estimates. This comparison is appropriate since net risk reduction and implementation costs are the most important attributes identified in the value-impact analyses.

This completes the summarization of information related to risk reduction which is used in the value-impact analyses in the example regulatory analysis. Discussion of issues related to the type of information used, the information not presented in the analyses, and possible additional information requirements are discussed further in the main report.

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12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

This report presents the results of an effort to develop a regulatory analysis methodology and presentation format to provide information for regulatory decision-making related to severe accident issues. Insights and conclusions gained from an example analysis are presented. The example analysis draws upon information generated in several previous and current NRC research programs (the Severe Accident Risk Reduction Program (SARRP), Accident Sequence Evaluation Program (ASEP), Value-Impact Handbook, Economic Risk Analyses, and studies of vented containment Systems and Alternative Decay Heat Revmoval Systems) to perform preliminary value-impact analyses on the installation of either a vented containment system or an alternative decay heat removal system at the Peach Bottom #2 plant. The results presented in this report are "first-cut" estimates, and are presented only for illustrative purposes in the context of this document. This study should serve to focus discussion on issues relating to the type of information, the appropriate level of detail, and the presentation format which would make a regulatory analysis most useful in the decisionmaking process.

14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS
Regulatory analysis, economic risk, accident costs, information communication, value-impact analysis

b. IDENTIFIERS/OPEN ENDED TERMS

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