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TECHNICAL REPORT

LINKAGE OF PRA MODELS —
PHASE I RESULTS

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*Prepared for the
U.S. NUCLEAR REGULATORY COMMISSION*

Lockheed
Idaho Technologies Company

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Linkage of PRA Models - Phase I Results

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ABSTRACT

The goal of the Phase I work of the "Linkage of PRA Models" project was to postulate methods of providing guidance for U. S. Nuclear Regulator Commission (NRC) personnel on the selection and usage of probabilistic risk assessment (PRA) models that are best suited to the analysis they are performing. In particular, methods and associated features are provided for (a) the selection of an appropriate PRA model for a particular analysis, (b) complementary evaluation tools for the analysis, and (c) a PRA model cross-referencing method. As part of this work, three areas adjoining "linking" analyses to PRA models were investigated: (a) the PRA models that are currently available, (b) the various types of analyses that are performed within the NRC, and (c) the difficulty in trying to provide a "generic" classification scheme to groups plants based upon a particular plant attribute.

EXECUTIVE SUMMARY

For Phase I of the "Linkage of PRA Models" project, three coupled "analysis aids" were postulated that could possibly assist the U. S. Nuclear Regulatory Commission (NRC) in their probabilistic risk assessment (PRA) analysis tasks. The three postulated analysis aids and the assistance that each would provide are shown below.

Postulated analysis aid	Assistance provided by method
Selection of an appropriate PRA model for a particular analysis	Assist the analyst in choosing an appropriate PRA model for the analysis being performed.
Complementary evaluation tools for the analysis	Assist the analyst in performing an analysis by providing relevant information for the analysis, setting up the problem in the appropriate PRA model, performing the analysis after the analyst finishes setting up the problem, and providing results needed by the analyst.
Cross-referencing method	Assist the analyst in extrapolating results to other "like" plants or in performing analysis for models similar between plants. A comprehensive cross-referencing method would alleviate the need to attempt to group plants according one set of plant response "characteristics"

The first postulated PRA assistance aid is a tool to provide guidance on the selection of a PRA model best suited to the analysis being performed. After interviewing knowledgeable NRC personnel, it was deemed to be unproductive to categorize each analysis area with one type of PRA model. Given that we can not provide a "blanket categorization" of models to NRC analyses, other methods of identifying appropriate PRA models need to be suggested. Consequently, six ways to assist in the selection of appropriate PRA models were postulated:

- (1) Leaving the decision of which model to use and why to use it up to the knowledgeable PRA analyst. Consequently, it would be required that the analyst be familiar with the attributes of the various PRA models in order to make an informed decision. This is the "status quo" option.
- (2) Providing a hard copy of PRA model attributes and letting the PRA analyst fit the particular analysis at hand to the model attributes. This method is like (1) above except the hard copy of the model attribute information would be available to help supplement the inherent knowledge of the PRA analyst.

- (3) Developing an *electronic* database of the model attribute information could be an alternative presentation method of item (2). Computerizing the attribute information would allow for efficient presentation, manipulation, updating, and searching of the model information.
- (4) Providing a hard copy of a decision-based flow chart with questions designed to help the PRA analyst "focus-in" or select the most appropriate PRA model for the particular analysis being performed. Since the decision-based questions would require knowledge of the PRA model attributes, this method would probably require that either method (2) or (3) be completed to provide the model attribute information.
- (5) Developing an *electronic* version of the decision-based flow chart (programmed as an expert system) could be an alternative (and probably preferred) presentation method of item (4). An electronic version of the expert system would be able to be linked with an electronic database of model attributes and possibly analysis tools to provide an integrated analysis package. Since the decision-based questions would require knowledge of the PRA model attributes, this method would probably require that method (3) be completed in order to have access to the model attribute information.
- (6) Assigning a "value" function to the various analysis attributes to determine the most appropriate model to be used for a particular analysis. There may be some difficulty in assigning the value function for the analysis attributes. This method would probably still require some type of decision-based flow chart [e.g., method (4) or (5)] in order to determine how and where to apply these "value" functions to the decision process.

Of the six postulated tools above, it was judged that option (5) would be the most useful and is possible to implement using available software tools. Pros and cons for each tool were generated and are discussed in this report. If option (5) were to be implemented, an ideal framework for its presentation would be similar to the concept of "wizards" in Microsoft Word™ or "coaches" in Novell WordPerfect™. These two software "agents" guide the analyst in performing a certain action by asking relevant questions for the action.

To demonstrate option (5), an example decision-based flow chart was generated and is shown in this report. It should be noted that this flow chart is simplified in that some of the "branching" questions would need additional information or detail in order to actually answer the "branching" question. An example of this simplification would be for the boxes labeled "Is the scenario modeled adequately in the model?" It may take further information concerning the model in question along with a PRA analyst evaluating the model in order to actually answer the question. Specifically, an electronic database of the PRA model attributes would (presumably) contain information pertinent to answering the question of "Is the scenario modeled adequately in the model?". An example was also provided demonstrating how software could be used (with the flow chart) to assist the analyst with typical types of analyses. Obviously, we can not computerize the analysis process to the point where the analyst is virtually not needed. In fact, it is envisioned that the analyst would be an integral part of the process.

The second analysis aid that was postulated was a set of complementary evaluation tools. Several example evaluation tools are listed below.

Evaluation tool	Tool function
Analysis "mapping" tool	The tool would assist the analyst in "mapping" a particular condition into the chosen PRA model. Examples of the functions of this tool are: (1) helping select specific basic events affected by the analysis, (2) modifying modeling assumptions particular to the analysis, (3) changing basic event parameters such as common cause events, and (4) determining system dependencies/shared components particular to the analysis.
Electronic model information tool	The tool would help the analyst by providing information relevant to analysis in a computerized fashion. Advanced information display techniques such as visualization and hypertext could help to present applicable PRA model information. For example, modeling documentation for a high pressure injection system could be seamlessly linked to P&IDs, a dependency matrix, applicable fault trees, applicable event trees, failure data, and basic event parameters. Having this tool would reduce the burden on the analyst of trying to "wade" through the substantial amount of PRA-related information that is available when performing a particular analysis.
Analysis "assistant" tool	The tool would serve to provide an analysis assistant so that various types of analysis can be quickly and efficiently performed. The tool would be tailored to the various types of analysis being performed at the NRC. The tool would be aimed at personnel who do not frequently use the available analysis tools and consequently are not familiar with the required nuances to use these current tools. Thus, the tool would try to be as user-friendly as possible while performing the mechanics of an analysis.
Results presentation tool	The tool would be linked to the analysis assistant tool in order to make sure that the appropriate analysis results (for the analysis being performed) were calculated by the assistant. Once the results are available, the results presentation tool would automatically output the results in whatever format is required by the analyst.
Decision criteria tool	The tool would assist the analyst in using the results of the analysis in making a decision for the particular analysis. Successful implementation of such a tool would require a defined set of criteria for the various types of analyses that are performed. Potential features of the tool could be: (1) contrasting results to comparable analyses that have been previously performed, (2) regulatory guidance for the particular analysis, and (3) assistance in estimating weakness/strengths of the analysis.

The last of the three postulated PRA assistance aids is a cross-referencing feature. Use of this cross referencing function would help to alleviate the need for a PRA model classification scheme. While classification schemes such as the ASP classification are useful to provide a coarse grouping of somewhat like plant models, the plant-to-plant variation seen in U.S. nuclear power plants do not provide for a convenient "one-type-fits-all" classification scheme.

Consequently, a model-driven cross-referencing scheme could provide a dynamic method in which groups of "similar" plants are identified depending on the particular criteria specified by the analyst. Thus, as the analysis varies, the plant groupings will vary and will be specific to the particular analysis attributes specified by the analyst.

Phase II of the "Linkage of PRA Models" project was designated as attempting to demonstrate the potential for worthwhile concepts from the Phase I work. While the three postulated PRA assistance methods cover a wide range of topics, they are all relevant to the goal of trying to make PRA analysis easier for NRC personnel. Consequently, efforts spent demonstrating these methods may prove to be beneficial.

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ACRONYMS

AEOD	Office of Analysis and Evaluation of Operational Data
ALWR	advanced light water reactor
AOT	allowable outage time
ASEP	Accident Sequence Evaluation Program
ASP	Accident Sequence Precursor
BWR	boiling water reactor
B&W	Babcock and Wilcox
CCDF	conditional core damage frequency
CCDP	conditional core damage probability
CDF	core damage frequency
CDP	core damage probability
CE	Combustion Engineering
EPRI	Electric Power Research Institute
GE	General Electric
HRA	human reliability analysis
HVAC	heating, ventilation, and air conditioning
IPE	individual plant examination
LER	licensee event report
LOCA	loss-of-coolant accident
LOOP	loss of offsite power
NMSS	Office of Nuclear Material Safety and Safeguards

NRC	Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation
PRA	probabilistic risk assessment
PWR	pressurized water reactor
RES	Office of Nuclear Regulatory Research
SAPHIRE	Systems Analysis Programs for Hands-on Integrated Reliability Evaluations

Linkage of PRA Models - Phase I Results

1. INTRODUCTION

For the "Linkage of PRA Models" project, the overall goal was to first evaluate both (a) analysis attribute data for the types of analysis performed by the U.S. Nuclear Regulatory Commission (NRC) and (b) probabilistic risk assessment (PRA) model attribute data from available electronic models. Using this attribute data, a unified PRA classification scheme will be postulated which "links" NRC analysts' evaluation needs to appropriate PRA models. Thus, the focus of the Phase I work was to postulate methods of providing guidance for NRC personnel on the selection and usage of PRA models that are best suited to the analysis they are performing. This "linking" process is graphically illustrated below.

While in general the attributes of a particular analysis may be numerous and quite complex, this project focuses on the important attributes that drive a particular analysis. Examples of some of these analysis attributes include: (a) desired PRA measures (i.e., result of the analysis), (b) the end use of PRA results, and (c) time constraints (results in minutes versus days). The PRA models have attributes that are related to the analysis attributes. Some of these model attributes include: (a) the risk measures that a PRA model gives as a result, (b) the modeling level of detail that exists within a PRA, and (c) the uncertainty analysis included in a PRA.

The body of this report discusses some of the postulated methods that could help the NRC to "link" their analysis needs to the available models. Specifically, options and related details are provided for (a) the selection of an appropriate PRA model for a particular analysis, (b) complementary evaluation tools for the analysis, and (c) a cross-referencing method. Definitions and discussions of these three topics are contained in Section 2.

As part of the Linkage of PRA Models Task I work, several areas adjoining "linking" analyses to PRA models were investigated. In particular, three areas were investigated and are discussed in the appendices of this report. First, Appendix A contains information on the PRA models (both simplified and detailed) that are currently available. Attribute information from these models was used to generate the postulated "linkage" methods. Second, Appendix B contains information on the various types of analyses that are performed within the NRC by the Offices of Analysis and Evaluation of Operational Data (AEOD), Nuclear Reactor Regulation (NRR), and Nuclear Regulatory Research (RES). This information was used to tailor the postulated "linkage" methods to a particular type of analysis. And last, Appendix C discusses the difficulty in trying to provide (and use) a "generic" classification scheme that groups plants based upon a particular attribute (e.g., response to certain initiating events). This information was used to propose a cross-referencing scheme that would better fit the various types of analyses performed by the NRC. For additional details on any of these three adjoining areas, the reader is referred to the appropriate appendix.

2. POSTULATED ANALYSIS AIDS TO PROVIDE PRA ASSISTANCE

This section provides details for three coupled "analysis aids" or methods that could possibly assist the NRC in their PRA analysis tasks. The word "coupled" implies that the three methods provide for different analysis assistance and could be completely separate from each other, but would be most effective if the three were combined into a single analysis package. The three postulated methods and the assistance that each would provide are shown below.

Postulated method	Assistance provided by method
Selection of an appropriate PRA model for a particular analysis	Assist the analyst in choosing an appropriate PRA model for the analysis being performed.
Complementary evaluation tools for the analysis	Assist the analyst in performing the analysis by providing relevant information for the analysis, setting up the problem in the appropriate PRA model (as much as possible), performing the analysis after the analyst finishes setting up the problem, and providing results needed by the analyst.
Cross-referencing method	Assist the analyst in extrapolating results to other "like" plants or in performing analysis for models similar (for the particular analysis) among plants. A comprehensive cross-referencing method would alleviate the need to attempt to group plants according to certain "characteristics" (e.g., the ASP classification scheme).

2.1 Selection of Appropriate PRA Model for Particular Analysis

This section provides an overview of potential methods for identifying a PRA model appropriate for the various types of analyses performed by the NRC. These methods were developed using the information gathered during meetings with NRC personnel knowledgeable about the types of analyses they perform and the attributes of those analyses.

After collecting the analysis attribute data from NRC personnel, it became apparent that it may be futile to generically categorize each analysis area as using one particular type of PRA model (e.g., either a detailed or simplified PRA model). For the most part, the decision on which PRA model to use is a function of several factors, including the type of analysis, the time available, the desired level of detail, the need for an uncertainty analysis, the requirement of plant specificity, etc. Also, the decision on which PRA model to use could, in general, be a function of the specific issue or scenario being analyzed. Thus, to attempt to categorically label particular analysis areas as needing either a detailed PRA model or a simplified PRA model does not capture all the nuances that are encountered while performing the various types of NRC analyses.

So, if it is unproductive to categorize each analysis area with one type of PRA model, what are other potential methods of identifying appropriate PRA models? Possible methods could include:

- (1) Leaving the decision of which model to use and why to use it up to the knowledgeable PRA analyst. Consequently, it would be required that the analyst be familiar with the attributes of the various PRA models in order to make an informed decision.
- (2) Providing a hard copy of PRA model attributes and letting the PRA analyst fit the particular analysis at hand to the model attributes. This method is like (1) above except the hard copy of the model attribute information would be available to help supplement the inherent knowledge of the PRA analyst.
- (3) Developing an *electronic* database of the model attribute information could be an alternative presentation method of item (2). Computerizing the attribute information would allow for efficient presentation, manipulation, updating, and searching of the model information.
- (4) Providing a hard copy of a decision-based flow chart with questions designed to help the PRA analyst "focus-in" or select the most appropriate PRA model for the particular analysis being performed. Since the decision-based questions would require knowledge of the PRA model attributes, this method would probably require that either method (2) or (3) be completed to provide the model attribute information.
- (5) Developing an *electronic* version of the decision-based flow chart (programmed as an expert system) could be an alternative (and probably preferred) presentation method of item (4). An electronic version of the expert system would be able to be linked with an

electronic database of model attributes and possibly analysis tools to provide an integrated analysis package. Since the decision-based questions would require knowledge of the PRA model attributes, this method would probably require that method (3) be completed in order to have access to the model attribute information.

- (6) Assigning a "value" function to the various analysis attributes to determine the most appropriate model to be used for a particular analysis. There may be some difficulty in actually assigning the value function for the analysis attributes. This method would probably still require some type of decision-based flow chart [e.g., method (4) or (5)] in order to determine how and where to apply these "value" functions to the decision process.

It is the opinion of the authors that method (5) would best serve the needs of the NRC to select an appropriate PRA model for a particular analysis. Some justification for this opinion is provided below (in Table 1) via a list of "pros and cons" for each option.

Table 1. "Pros and cons" for each of the postulated PRA model selection methods.

Option	"Pros"	"Cons"
(1) Leaving the decision of which model to use and why to use it up to the PRA analyst.	Does not require any additional work. This is the "do nothing" option. Would not require a computer and software.	Does not assist the NRC with their need of providing analysis tools to further the "in-house" use of PRA. Relies on having experienced PRA analysts with knowledge of the various models (and their respective attributes).
(2) Providing a hard copy of PRA model attributes and allowing the PRA analyst to fit the analysis to the model attributes.	Shows the analyst what attributes are in the models. Would not require a computer and software.	Analyst must be able to decide if the attributes fit the analysis being performed. The model attributes will have to be determined and collected in order to document them. Outdated hard copy reports will have to be discarded and replaced with new reports as PRA models change over time.
(3) Developing an <i>electronic</i> database of the model attribute information could be an alternative method of item (2).	Allows analyst a quick method to see what models contain attributes complementary to the analysis being performed.	Analyst must be able to decide if the attributes fit the analysis being performed. The model attributes will have to be determined and collected in order to document them. Requires development of a computer program.
(4) Providing a hard copy of a decision-based flow chart designed to help the analyst select the most appropriate PRA model.	Provides guidance to analyst for selecting most appropriate model. Will show analyst the criteria for selecting a particular model. Would not require a computer and software.	May be time consuming flipping through pages to follow flow chart. Some decisions on flow chart may require additional information, requiring multiple, cross-references sources of information.

Option	"Pros"	"Cons"
(5) Developing an <i>electronic</i> version of the decision-based flow chart (programmed as an expert system) could be an alternative presentation method of item (4).	Provides guidance to analyst for selecting most appropriate model more efficiently than (4). A program diagram, if developed, will show analyst the criteria for selecting a particular model.	Requires development of a computer program. Only assists the analyst in selecting a model--some interaction by the analyst will be required.
(6) Assigning a "value" function to the various analysis attributes to determine the most appropriate model for a particular analysis.	Provides guidance to analyst for selecting most appropriate model using more refined "judgement" and option (5). A program diagram, if developed, will show analyst the criteria for selecting a particular model.	Only assists the analyst in selecting a model--some interaction by the analyst will be required.

2.1.1 Decision-Based Flow Diagram Overview

To further discuss method (5), an example of one possible model-identification flow diagram is provided (see Figure 1). These eight pages of flow diagrams attempt to question a PRA analyst in order to provide the most appropriate PRA model for the answers that are given.

If this concept of a decision-based flow diagram were to be computerized, an ideal framework for its presentation would be similar to the concept of "wizards" in Microsoft Word™ or "coaches" in Novell WordPerfect™. These two software "agents" guide the analyst in performing a certain action by asking relevant questions for the action. To illustrate this concept, a simple example will be presented following a brief overview of the flow diagram itself.

It should be noted that this flow diagram is simplified since some of the "branching" questions would need additional information or detail to be answered. An example of this simplification would be for the boxes labeled "Is the scenario modeled adequately in the model?" It may take further information concerning the model in question along with a PRA analyst evaluating the model in order to actually answer the question. Specifically, an electronic database of the PRA model attributes would (presumably) contain information pertinent to answering the question of "Is the scenario modeled adequately in the model?". Nonetheless, it is useful to evaluate the flow diagram in order to understand the potential complexity that occurs when trying to choose a particular PRA model for use on an analysis.

Some clarification on the flow diagram may be provided by discussing the "branching" questions that are not straightforward. The following provides additional issues that would influence the answers to three different "branching" questions that are found in the flow diagram.

Figure 1. Example decision-based flow diagram to assist in the selection of an appropriate PRA models.

Note: Loops to go back to obtain the "next best" model are repeated until all models meeting the desired modeling attributes are exhausted. Once models are exhausted, goto (J).

Figure 1. (cont.)

Figure 1. (cont.)

Figure 1. (cont.)

Figure 1. (cont.)

Figure 1. (cont.)

Figure 1. (cont.)

Figure 1. (cont.)

Is the scenario modeled adequately in the model? Issues that must be addressed when answering this question may be very qualitative rather than quantitative. Determining whether a PRA adequately models a scenario may require answering one or more qualitative questions. For example, one could ask whether (1) a particular system/component failure is in the PRA; (2) a particular sequence of events is modeled via event trees; (3) common-cause events are included in the system failure modeling; (4) basic event data appears to be reasonable; (5) accepted PRA practices were employed to develop the model; (6) support systems are modeled; (7) operator actions (including dependencies) are appropriate; (8) system success criteria is accurate (especially considering the analysis being performed); and (9) scenario is "artificially" truncated from results (e.g., turning off particular accident sequences).

Can we incorporate the scenario into the model? Issues that must be addressed when answering this question include: (1) the time available for the modification to the model; (2) the modeling ability of the analyst for the particular issue being analyzed (or, alternatively, the availability of other knowledgeable analysts); and (3) applicability to include scenario into available model (e.g., full power models may be of little use for shutdown events).

List the models that best match the desired modeling attributes. Issues that must be addressed when performing this action include: (1) a quantitative method of ranking the models would be required (if it was desirable to obtain the "best" model); (2) different models may have different features that are desirable (e.g., simplified model may be easier to use but detailed model has better operator recovery modeling); and (3) some model attributes may be much more important than other attributes for a particular analysis.

An additional issue that is not directly addressed by the flow diagram is, if two or more models were available that met the analysis criteria, how would one prioritize the models such that the "best" one was selected for use. Also, some of the paths through the flow diagram lead to the statement that we "cannot directly quantify the issue with PRA methodology." This statement is included to indicate that not every problem fits neatly within a PRA framework.

While evaluating the flow diagram shown in Figure 1, there are several assumptions to keep in mind. These assumptions are listed below.

1. For the entire diagram, it was assumed that it is preferable to choose a simple PRA model over a detailed model, given that the simple model will be sufficient (i.e., use as complex a model as needed, but no more so). It may be possible to assign a "weighting" function to this assumption that could impact the decision of a particular PRA model. For example, if a particular analyst were more interested in detailed models than simplified model, she could give more "weight" to the decision criteria that favored the detailed models. But, this concept of a "weighting" function for the branching questions is left as a possible area for further thought and research.

2. For those occasions when the available analysis time is *short*, three items are assumed:
 - (a) There is not enough time to regenerate cut sets for detailed models. As the analysis codes improve along with increases in computing power, this assumption may begin to diminish in importance.
 - (b) None of the released simple models have uncertainty parameters in them. Currently (as of July 1995), only a couple of "demonstration" simplified models have uncertainty parameters in them.
 - (c) Time is not available to put uncertainty data into a simple model. It is further assumed that sensitivity studies would probably not be possible in the time available.
3. For those occasions when the available analysis time is long, three items are assumed:
 - (a) Enough time is available to become familiar with a detailed model.
 - (b) There may be time to incorporate uncertainty parameters into a simple model
 - (c) It is preferable to evaluate several potential models for their applicability to the problem being analyzed rather than build a new model from scratch.

Given the assumptions listed above, an analyst could use the flow diagram to begin to "focus in" to a particular PRA model. It should be pointed out that any realization of the flow-diagram concept may deviate somewhat from the example flow diagram presented in this report. It is assumed that an actual computerized flow diagram would contain additional detail not shown in the example flow diagram. Examples of the additional detail that would be needed include the attributes for the types of analyses performed by the NRC, PRA model information and attributes, and modeling information such as success criteria.

It may be possible that this decision-based flow diagram method could be made "dynamic" in that questions asked could vary depending on the particular type of analysis being performed. The concept of software "agents" to guide the analyst in answering the questions needed to decide upon an appropriate model would use this "dynamic" technique.

2.1.2 Software Agent to Assist in Flow Diagram Implementation

One way to computerize the decision-based flow diagram method would be to borrow from the concept of software agents. Software agents essentially guide the analyst through a specific task by asking relevant questions for the task. To illustrate this concept, a simple example is presented. For this simple demonstration, assume that a request has been received to extend a component allowable outage time at Plant X from three days to six days. Assume that you, as the analyst for the problem, have less than a day to respond to the request. Thus, you "fire up" your computer and start the software agent "PRA-ASSISTANT." The following is a hypothetical example of what could happen.

Welcome to PRA-ASSISTANT

PRA-ASSISTANT is designed to assist you in selecting and using one (or more) of the PRA models that are available.

Please tell me how much time you have to perform the needed analysis. [6 hrs]

First, the agent asks for the time available for the analysis. In this example, we stated that only six hours were available.

Since the decision-based flow diagram shown in Figure 1 has been incorporated into the agent, the agent will determine that six hours falls into the category of "short" time for the analysis.

Looking at page 7 (i.e., the first page of Figure 1), it is obvious that the agent would then need to know if a plant-specific analysis is needed.

===== PRA-ASSISTANT =====

Please tell me what type of analysis you are performing. [request for AOT extension]

One possible way this question could be answered would be to ask for the type of analysis being performed.

Knowing attributes for the types of analyses performed by the NRC, the agent would suggest that, since this is an AOT extension request, the analysis

would fall under the category of "review of requests for discretionary enforcement," which generally require a plant specific analysis. Consequently, the agent would recommend that a plant specific analysis be performed (and it may give reasons why this is so).

===== PRA-ASSISTANT =====

Since the analysis you are performing falls under the category of "review of requests for discretionary enforcement," it is recommended that you perform an analysis using a model specific to a particular plant. Is this OK? [yes]

After we answer "yes" to the question of plant specific analysis, the agent would ask for the plant in question. We would then respond with "Plant X."

Next, we need to determine whether or not an uncertainty analysis is needed. Lets assume that we do not need an uncertainty analysis (we may be able to perform some sensitivity analyses time permitting). (The question of whether we need an uncertainty evaluation could possibly be "built-in" to the assistant for those analyses that have a defined need (or lack of) for an uncertainty evaluation.)

===== PRA-ASSISTANT =====

For this analysis, is an uncertainty evaluation required? [no]

So, when asked by the agent, we would indicate that we did not need an uncertainty analysis.

At this point, the agent would need to determine whether there is a simplified model available for Plant X.

===== PRA-ASSISTANT =====

A simplified model is available for Plant X.

I am currently retrieving the model from the LAN server...please wait...

For this example, lets assume that there is a simplified model available for Plant X.

The agent would then go search the appropriate location(s) to find the latest version of the simplified model for Plant X.

Once the model is retrieved, the agent would assist us in determining whether the situation we want to model is represented "adequately" in the simplified

model for Plant X.

===== PRA-ASSISTANT =====

I need to know some details for the analysis you are performing to assist you in determining whether the simplified model for Plant X will be adequate.

Since you are performing an AOT extension evaluation, is only a single component AOT going to be extended? [yes]

First, the agent would ask for details of the analysis.

Since the agent would know what type of analysis we are performing, only questions relevant to the particular type of analysis would be asked.

For the example, let's assume that the turbine driven auxiliary feedwater pump is inoperable and the extension request is for this pump.

===== PRA-ASSISTANT =====

Which component does the requested AOT extension pertain to? [turbine driven AFW pump]

[List Basic Events] [Show P&IDs] [Show Fault Trees]
[Show Event Trees] [Display Model Notebook]

We could view several types of information before we entered the component. This information could include basic events, P&IDs, fault trees, event trees, model notebooks, and electronic links to the NRC Plant Information Books.

After entering "turbine driven AFW pump," the agent would first determine which component we were discussing.

===== PRA-ASSISTANT =====

You specified "turbine driven AFW pump." I believe that the appropriate components in the model are:

AFW-TDP-FC-P17
AFW-PMP-CF-ALL

[Show event descriptions]
[List Basic Events] [Show P&IDs] [Show Fault Trees]
[Show Event Trees] [Display Model Notebook]

Then, the agent would indicate the basic event(s) that it inferred were relevant to the component that we specified. In order to make this inference, the agent would have to have access to the model and attribute information (e.g., component naming scheme, fault tree logic, basic event information).

===== PRA-ASSISTANT =====

It appears as if the two basic events and their associated fault trees/event trees will be adequate to evaluate the turbine driven AFW pump AOT extension request. Do you agree? [yes]

[List Basic Events] [Show P&IDs] [Show Fault Trees]
[Show Event Trees] [Display Model Notebook]

After reviewing the notebooks, P&IDs, fault trees, and basic events, we determine that these two basic events are all we need to modify to "map" the analysis into the model.

Consequently, when asked if we agree with the agent that the scenario we are modeling is represented adequately in the model, we would say "yes."

===== PRA-ASSISTANT =====

For this particular analysis, I believe that we should calculate an "event importance" using the GEM code. Do you agree? [yes]

[List Basic Events] [Show P&IDs] [Show Fault Trees]
[Show Event Trees] [Display Model Notebook]

At this point, we would begin our analysis.

The agent could help us set up the analysis by suggesting that we calculate an "event importance" using the GEM code.

===== PRA-ASSISTANT =====

I recommend that the basic events be set to:

AFW-TDP-FC-P17 = TRUE
AFW-PMP-CF-ALL = 0.0134

[See Assumptions and Calculations]

[List Basic Events] [Show P&IDs] [Show Fault Trees]
[Show Event Trees] [Display Model Notebook]

The agent could further suggest that the component AFW-TDP-FC-P17 be set to a TRUE house event (to simulate its failure during the AOT duration). Also, component AFW-PMP-CF-ALL could be set to a new common-cause probability. (The agent could estimate a new probability if it had knowledge of the cause of the component outage, the system success criteria, basic event failure probabilities, and common-cause model parameter values.)

===== PRA-ASSISTANT =====

Would you like me to map the recommended basic event settings into the GEM code and run the analysis for you? [yes]

[List Basic Events] [Show P&IDs] [Show Fault Trees]
[Show Event Trees] [Display Model Notebook]

We could then tell the agent to run the analysis and give us the results.

If formal, documented decision criteria were available for the analysis we are performing, the agent would then be able to inform us of the results and how they compare with the decision criteria.

As part of the result, the assumptions, calculations, and mappings that were performed by the agent would be printed. This print-out would be needed in order for the analyst to be comfortable with the overall results (that is, to know what is going on "behind the scenes" rather than just having a black box displaying a number).

While this example was somewhat simplified and some of the detail actually needed was hidden, it does provide an illustration of how the concept of a decision-based flow diagram could be implemented to assist the analyst with typical types of analyses. Obviously, we can not computerize the analysis process to the point where the analyst is virtually not needed. In fact, it is envisioned that the analyst would be an integral part of the process.

2.2 Complementary Evaluation Tools for Analysis

This section discusses some potential evaluation tools that would complement the model selection "agent" discussed in the previous section. The last couple of steps in the agent example from Section 2.1 alluded to some of these evaluation tools. To summarize these tools, Table 2 below lists some potential analysis tools and their respective functions.

Table 2. A list of potential evaluation tools that would complement the model selection "agent."

Evaluation tool	Tool function
Analysis "mapping" tool	The tool would assist the analyst in "mapping" a particular condition into the chosen PRA model. Examples of the functions of this tool are: (1) helping select specific basic events affected by the analysis, (2) modifying modeling assumptions (such as system success criteria) particular to the analysis, (3) changing basic event parameters such as common cause events, and (4) determining system dependencies/shared components particular to the analysis.
Electronic model information tool	The tool would help the analyst by providing information relevant to analysis in a computerized fashion. Advanced information display techniques such as visualization and hypertext could help to present applicable PRA model information. For example, modeling documentation for a high pressure injection system could be seamlessly linked to P&IDs, a dependency matrix, applicable fault trees, applicable event trees, failure data, and basic event parameters. Having this tool would reduce the burden on the analyst of trying to "wade" through the substantial amount of PRA-related information that is available when performing a particular analysis.
Analysis "assistant" tool	The tool would serve to provide an analysis assistant so that various types of analysis can be quickly and efficiently performed. The tool would be tailored to the various types of analysis being performed at the NRC. The tool would be aimed at personnel who do not frequently use the available analysis tools and consequently are not familiar with the required nuances to use these current tools. Thus, the tool would try to be as user-friendly as possible while performing the mechanics of an analysis.
Results presentation tool	The tool would be linked to the analysis assistant tool in order to make sure that the appropriate analysis results (for the analysis being performed) were calculated by the assistant. Once the results are available, the results presentation tool would automatically output the results in whatever format is required by the analyst.
Decision criteria tool	The tool would assist the analyst in using the results of the analysis in making a decision for the particular analysis. Successful implementation of such a tool would require a defined set of criteria for the various types of analyses that are performed. Potential features of the tool could be: (1) contrasting results to comparable analyses that have been previously performed, (2) regulatory guidance for the particular analysis, and (3) assistance in estimating weakness/strengths of the analysis.

2.3 Cross-Referencing Method.

The last of the three postulated PRA assistance aids is a cross-referencing feature. Use of this cross referencing function would help to alleviate the need for a PRA model classification scheme. While classification schemes such as the ASP classification are useful to provide a coarse grouping of somewhat similar plant models, the plant-to-plant variations seen in U.S. nuclear power plants do not provide for a convenient "one-type-fits-all" classification scheme. Consequently, a model-driven cross-referencing scheme could provide a dynamic method in which groups of "similar" plants are identified depending on the particular criteria specified by the analyst. Thus, as the analysis varies, the plant groupings will vary and will be specific to the particular analysis attributes specified by the analyst. As an example of the types of cross-referencing that could be computerized in this method, three postulated analyses are illustrated below.

2.3.1 Illustration of Cross-Referencing Method

Three cases will be discussed that demonstrate how a cross-referencing method could be used. It should be pointed out that these cases were performed by *manually* searching the available PRA models. It is envisioned that implementation of a cross-reference method would result in a software program with associated model attribute data such that the manual searches would not be required.

Case #1 Assume that we have an analysis where we want to estimate the importance of service water system (SWS) pumps. The first step would be to check the "simplified" models to determine if the SWS is modeled. After performing this step, we find that none of the "simplified" models contain any support systems, and consequently, SWS is not modeled.

The next step is to search the available "detailed" models. The analyst must have access to all of the full-level PRA models in order to explore the models to determine if SWS is modeled in the data base. One method the analyst has to determine how and if the SWS is modeled in the full-level PRA model is to do a search on the fault tree logic. The analyst must search on the fault tree logic since no graphical representations (i.e., P&IDs) are available in IRRAS for the systems to see if the SWS is modeled. From the databases that were reviewed, the SWS was not modeled as a top event but as subtree that are called out by the different system fault trees. This search to understand how the SWS was modeled is very tedious and difficult at times to understand how the SWS was modeled. The reason for the difficulty is because the SWS system is not a top event and the subtree must be searched and marked as top trees in order for the logic to be reviewed. Some of the SWS subtrees are hard to find because of naming conventions.

Once the subtree logic is made accessible, the SWS subtree can be reviewed to determine which pump trains makeup the subtree for the importance study. Another method the analyst has to determine how and if the SWS is modeled in the full-level PRA model is to cross-reference the SWS basic events. This cross-reference will show which system and subsystem

fault trees the basic event is used in. A problem that could arise is if the basic event names are not that easily discernable (i.e., not named according to NUREG/CR-5905). This can make searching out the SWS components difficult. From the review of a few full-level PRA databases, the following lists the database and how the SWS was modeled.

Dresden:	The SWS is modeled as subtree logic with component basic event.
Fitzpatrick:	The SWS is modeled as subtree logic with component basic event.
Sequoyah:	The SWS is modeled as subtree logic with component basic event.
Peach Bottom:	The SWS is modeled as subtree logic with component basic event.
River Bend:	The SWS is modeled as subtree logic with component basic event.
Surry:	The SWS (or CCW) is modeled as subtree logic with component basic event.
San Onofre:	The SWS is modeled as a single basic event.

Case #2 Assume that we have an analysis where we need to investigate the reliability of an auxiliary feedwater (AFW) system that has one motor-driven and one turbine-driven pump. Assume we also wanted the importance of the turbine driven pump. The quickest way to check all of the AFW systems that are modeled in the PWR plants is to look through the ASP notebooks (for the simplified models). The notebooks contain the simplified fault trees for the AFW systems. This will provide the analyst with the information on how many trains of AFW and the different pump driver types the plant uses. The notebook also lists the system success criteria. Therefore, the notebooks will give a quick reference for the number and type of AFW pump trains.

If the analyst *only* has access to the electronic data bases for the ASP PWR plants, the amount of time for the cross-referencing will be greatly increased. Each graphical fault tree must be reviewed to determine if the AFW system for that particular plant contains the appropriate number and type of AFW pump trains. This process is very time consuming since each plant must be opened and the graphic trees must be loaded. The analyst must locate the AFW fault tree and review the tree to see if this plant meets the search requirements.

From reviewing all of the PWR ASP plant notebooks, the following reactor plants contain the type of AFW system that is required for this example.

Prairie Island 1 & 2	PWR Class B
Seabrook Station	PWR Class B
ANO Unit 1	PWR Class D
Crystal River 3	PWR Class D
Palisades	PWR Class G
Fort Calhoun	PWR Class G
ANO Unit 2	PWR Class H

The "simplified" models contain train-level supercomponents for the majority of their basic events. The turbine-driven AFW pump basic events will contain other components along

with their failure modes. The turbine-driven pump basic event will contain the fails to start and fails to run failure modes added together along with any manual, check, or motor-operated valves that can be "rolled up" into the basic event. This can create a problem if the analyst wants to see the importance of just the turbine-driven pump fails to start or run without having the other components being part of the overall basic event.

The "detailed" models were not reviewed for this example case.

Case #3 Assume an inspection item noted that several check valves at Peach Bottom were not being maintained properly, impeding their ability to function. We want to find out which and how many check valves are modeled in the "simplified" and "detailed" plant models.

First, we need the full-level model so that the basic event list can be obtained. Once the data base is loaded, there are many different ways that the number of check valves used in the model can be counted. For example, the analyst can do a report on the basic events and count the basic events that are check valves. These applicable basic events are named ####-CKV-##-#### or ####-TCV-##-#### (in the "detailed" model). Alternatively, the analyst could extract the basic event information into either Word Perfect or Excel where CKV and TCV can be searched and then counted as to how many check valves are used in the model. (Note: The basic event search can be most easily accomplished if the basic events are named according to some consistent criteria.) The total number of check valves in the "detailed" model is 44. Note that this type of search ignored differences between check valves (e.g., design, manufacture).

Counting the number of check valves in the "simplified" model is much different than the "detailed" model, since most of the basic events in the "simplified" model are train level supercomponents. This means that the basic event names will not reference any of the components that are contained within the supercomponent. Therefore, the only way that the analyst can determine how many check valves are being used by the "simplified" model is to review the ASP notebook. The ASP notebook lists all of the basic events used in the model along with what components are used to create the supercomponent. Thus, the analyst must review all of the basic events and count each check valve that is listed as either a single basic event or one that is rolled into a supercomponent. There are a total of 31 check valves that are used in the "simplified" model. Of these 31 check valves only 5 are used as single basic events.

2.3.2 Proposed Framework to Develop Cross-Reference Method

To provide a cross referencing method, a framework will need to be developed that focuses on the attributes of the PRA models and the needs of the analyses that are routinely performed. One potential cross referencing method could be developed according to the following steps:

(1) Examine the available PRA models in order to determine

- How parts of the models could be categorized. Examples include extracting information for:
 - a. Systems/subsystems.
 - b. Accident sequences.
 - c. Event trees.
 - d. Recovery actions/modeling type.
 - e. Size and complexity of model.
 - f. Common-cause modeling and parameters

(2) Once the categorization scheme is determined from (1) above, two parallel paths could be taken.

- Gathering the data for the various categories from each plant PRA model (both simplified and detailed models).
- Prototyping the software that would handle the cross referencing of the model information.

(3) After data is collected and the software is completed, tests could be performed to:

- Test the software.
- Determine potential improvements that could enhance the software.

By computerizing the cross referencing function, the model attributes would be readily available to PRA analysts and would help to identify models applicable to the types of analyses they are performing.

3. CONCLUSIONS

For Phase I of the "Linkage of PRA Models" project, three coupled "analysis aids" were postulated that could possibly assist the NRC in their PRA analysis tasks. The three postulated analysis aids were (1) selection of an appropriate PRA model for a particular analysis, (2) complementary evaluation tools for the analysis, and (3) a cross-referencing method.

The first postulated PRA assistance aid is a tool to provide guidance on the selection of a PRA model best suited to the analysis being performed. After interviewing knowledgeable NRC personnel, it was deemed to be unproductive to categorize each analysis area with one type of PRA model. Given that we can not provide a "blanket categorization" of models to NRC analyses, are other potential methods of identifying appropriate PRA models need to be suggested. Consequently, six ways one could assist in the selection of appropriate PRA models were postulated:

- (1) Leaving the decision of which model to use and why to use it up to the knowledgeable PRA analyst.
- (2) Providing a hard copy of PRA model attributes and letting the PRA analyst fit the particular analysis at hand to the model attributes.
- (3) Developing an *electronic* database of the model attribute information could be an alternative presentation method of item (2).
- (4) Providing a hard copy of a decision-based flow chart with questions designed to help the PRA analyst "focus-in" or select the most appropriate PRA model for the particular analysis being performed.
- (5) Developing an *electronic* version of the decision-based flow chart (programmed as an expert system) could be an alternative (and probably preferred) presentation method of item (4).
- (6) Assigning a "value" function to the various analysis attributes to determine the most appropriate model to be used for a particular analysis.

Of the six postulated tools above, it was judged that option (5) would be the most useful and is possible to implement using available software tools. Pros and cons for each tool were generated and are discussed in this report. To demonstrate option (5), an example decision-based flow chart was generated and is shown in this report. An example was also provided demonstrating how software could be used (with the flow chart) to assist the analyst with typical types of analyses. It was noted that we can not computerize the analysis process to the point where the analyst is virtually not needed. It is envisioned that the analyst would be an integral part of the process.

The second analysis aid that was postulated was a set of complementary evaluation tools. Several example evaluation tools that were listed include: (1) an analysis "mapping" tool, (2) an electronic model information tool, (3) an analysis "assistant" tool, (4) a results presentation tool, and (5) a decision criteria tool.

The last of the three postulated analysis aids is a cross-referencing feature. Use of this cross referencing function would help to alleviate the need for a PRA model classification scheme. While classification schemes such as the ASP classification are useful to provide a coarse grouping of somewhat similar plant models, the plant-to-plant variations seen in U.S. nuclear power plants do not provide for a convenient "one-type-fits-all" classification scheme. Consequently, a model-driven cross-referencing scheme could provide a dynamic method in which groups of "similar" plants are identified depending on the particular criteria specified by the analyst.

Phase II of the "Linkage of PRA Models" project was designated as attempting to demonstrate the potential for worthwhile concepts from the Phase I work. While the three postulated PRA assistance methods cover a wide range of topics, they are all relevant to the goal of trying to make PRA analysis easier for NRC personnel. Consequently, efforts spent demonstrating these methods may prove to be beneficial.

APPENDIX A - Current NRC PRA Models and Classification Schemes

APPENDIX A - Current NRC PRA Models and Classification Schemes

A.1 INTRODUCTION

This appendix presents an overview of probabilistic risk assessment (PRA) classification schemes and available PRA data bases used by the U. S. Nuclear Regulatory Commission (NRC). The focus of the document is similar to that of NSAC-152, *EPRI PRA Repository*,¹ with the exception that this document focuses on existing PRAs easily accessible to the NRC. Consequently, this appendix addresses only PRA data bases that are in SAPHIRE² code format. Also, this appendix presents information for the PRA data bases concerning the level of detail contained in the data bases and the structure of the data base (i.e., how it was constructed). Unlike NSAC-152, this document does not compare similar PRAs nor does it present extended amounts of detail for each PRA data base. Rather, *high-level* information is presented for each PRA data base applicable for deciding which (if any) data base should be used for a particular risk analysis task. If the reader is interested in extra detail for a particular PRA data base, please see the latest copy of the data base in question (whether it be a paper copy or computer file).

In general, the NRC uses two types of models. The first model type represents detailed, full-scope models that could be represented by full PRA or individual plant examination (IPE) data bases. This model type is called *full PRA models*. The second model type represents simplified, train-level models such as those in use by the Accident Sequence Precursor (ASP) program. This model type is called *simplified PRA models*.

This appendix has two major parts. Section A.2 contains an overview of some of the PRA classification schemes currently in use at the NRC. Section A.3 contains information addressing the NRC PRA data bases available in the SAPHIRE computer code. Section A.4 presents conclusions. Section A.5 presents a list of the references called out in the appendix.

A.2 PRA CLASSIFICATION SCHEMES

Two PRA classification schemes are discussed in this section. The first is the scheme used for the ASP simplified models. The second scheme is from the Accident Sequence Evaluation Program (ASEP). These classification schemes are intended to help the analyst divide particular plant PRA data bases into categories of plants with similar characteristics. However, the ASP and ASEP schemes use different grouping criteria to classify plants. In general, the ASP models are classified according to front-line system response (e.g., coolant injection mechanism) whereas ASEP plants are classified according to types of containment. Additional detail for both classification schemes are presented below.

A.2.1 ASP Classification Scheme

The ASP models are first divided into either pressurized water reactor (PWR) or boiling water reactor (BWR) categories. Then, the PWRs are subdivided into six classes according to the decay heat removal mechanism and feed and bleed capabilities. The BWRs are subdivided into three classes according to the decay heat removal mechanism. The nine ASP plant classes are described in Table A-1.

These nine classes were determined by examining the systems required to operate following a reactor trip, loss of offsite power (LOOP), small-break loss-of-coolant accident (LOCA), or steam generator tube rupture. From the *Daily Events Evaluation Manual*,³ the plant classes were determined as follows:

The plant categorization scheme groups plants with similar responses to transients and accidents based on the front-line systems included in the plant design and the availability of alternate mitigative features which also provide for core protection.

It should be pointed out that functions concerning the containment integrity and post-accident reactivity removal are not included in the classification scheme within ASP.

Section A.3.3 lists the SAPHIRE data bases available to the NRC sorted by plant class. A total of 100 ASP models are available in the SAPHIRE code format.

Table A-1. ASP classification scheme for the nine plant classes.

ASP plant class	Class description
BWR	
BWR A	Older BWRs with isolation condensers and feedwater coolant injection systems that employ the main feedwater pumps
BWR B	Older BWRs with isolation condensers and high pressure coolant injection systems
BWR C	Newer BWRs with reactor core isolation cooling and high pressure coolant injection (or high pressure core spray) systems
PWR	
PWR A1	Westinghouse PWRs which use recirculation spray for decay heat removal following a LOCA
PWR A2	Westinghouse PWRs which use recirculation spray for decay heat removal following a LOCA
PWR B	Westinghouse PWRs (primarily) which use low-/high-pressure recirculation for decay heat removal following a LOCA.
PWR D	Babcock and Wilcox PWRs (primarily) with high-head high pressure injection systems. Power operated relief valve operability is not required for bleed and feed on these plants.
PWR G	Combustion Engineering PWRs with bleed and feed capability
PWR H	Combustion Engineering PWRs which utilize secondary side depressurization and the condensate system as an alternate to auxiliary feedwater and main feedwater

A.2.2 ASEP Classification Scheme

The ASEP classification scheme is primarily based on the type of containment at the plant. For each plant type (either BWR or PWR), groups are defined by the major containment types (e.g., Mark I versus Mark II). This classification scheme results in eight BWR groups and 17 PWR groups. The BWR groups are shown in Table A-2. The PWRs are shown in Table A-3.

The BWR plants are divided by Mark containment type (i.e., I, II, or III) and production line. The PWR plants are divided into three categories: (1) large dry atmospheric, (2) subatmospheric, and (3) ice condenser. The PWR plants are further divided by nuclear steam system supplier. Within category 1, large dry atmospheric, there are seven types of containments:

- Type 1 Preformed bar, reinforced concrete cylinder, hemispherical dome, flat base, steel liner.
- Type 2 Concrete vertical cylinder with prestressed vertical reinforcement, deformed bar, reinforced concrete hemispherical dome and flat base. Complete steel-lined structure.
- Type 3 Prestressed post-tensioned concrete vertical cylinder dome, deformed bar reinforced flat base steel liner. No buttresses, shallow dome.
- Type 4 Prestressed post-tensioned concrete vertical cylinder dome, deformed bar reinforced flat base steel liner. Three buttresses, hemispherical dome.
- Type 5 Prestressed post-tensioned concrete vertical cylinder dome, deformed bar reinforced flat base steel liner. Three buttresses, shallow dome.
- Type 6 Prestressed post-tensioned concrete vertical cylinder dome, deformed bar reinforced flat base steel liner. Four buttresses, shallow dome.
- Type 7 Prestressed post-tensioned concrete vertical cylinder dome, deformed bar reinforced flat base steel liner. Six buttresses, shallow dome.

Table A-2. ASEP classes for BWR plants.

Group	BWR type	Containment type
1	BWR 2	Mark I
2	BWR 3 (isolation condenser)	Mark I
3	BWR 3 (nonisolation condenser)	Mark I
4	BWR 4	Mark I
5	BWR 4	Mark II
6	BWR 5	Mark II
7	BWR 4/5	Mark II
8	BWR 6	Mark III

Table A-3. ASEP classes for PWR plants.

Group	PWR type (vendor)	Containment type
1	Westinghouse	Large dry atmospheric, Type 1
2	Westinghouse	Large dry atmospheric, Type 2
3	Westinghouse	Large dry atmospheric, Type 4
4	Westinghouse	Large dry atmospheric, Type 5
5	Westinghouse	Large dry atmospheric, Type 7
6	Westinghouse	Subatmospheric
7	Westinghouse	Ice condenser
8	Babcock and Wilcox (B&W)	Large dry atmospheric, Type 1
9	B&W	Large dry atmospheric, Type 4
10	B&W	Large dry atmospheric, Type 5
11	B&W	Large dry atmospheric, Type 6
12	B&W	Large dry atmospheric, Type 7
13	Combustion Engineering (CE)	Large dry atmospheric, Type 1
14	CE	Large dry atmospheric, Type 3
15	CE	Large dry atmospheric, Type 4
16	CE	Large dry atmospheric, Type 5
17	CE	Large dry atmospheric, Type 7

Although the ASEP grouping is shown in this appendix, the ASEP document⁴ points out that the "...grouping is done solely to present and organize the...plant information and does not have any significance towards 'plant grouping'." Consequently, the ASEP grouping scheme may not lend itself to using similar PRA models for plants within the same "group."

A.3 NRC PRA SAPHIRE MODELS

A.3.1 Overview of PRA Models

Two types of models are in use by the NRC. The first model type represents detailed, full-scope models that could be represented by full PRA or IPE data bases. This model type is referred to as "full PRA models." The second model type represents simplified, train-level models such as those in use by the ASP program. This model type is referred to as "simplified PRA models."

The full and simplified PRA models discussed in this report were developed using the SAPHIRE computer code. The models were developed to provide the analyst a means to efficiently manipulate the PRA. The full PRA models use one of two types of logic-modeling (either the large event tree or the fault tree linking methods) to produce accident sequence cutsets. The simplified PRA models use event trees linked to fault tree logic (i.e., fault tree linking method) to produce accident sequence cutsets. The two different types of modeling methods and the level of detail built into the different models are discussed further in Sections A.3.2 and A.3.3.

The main difference between the two types of PRA models (i.e., full or simplified) is the level of detail built into the models. The simplified models contain the same number of event trees for all PWRs and BWRs. Also, for the simplified models, the number of fault trees for each PWR or BWR class depends on the front-line systems needed to prevent core damage. For the full PRA models, the number of event and fault trees contained in the PRA correspond to the source of information used to develop the PRA. The full PRA models consist of more event trees and fault trees than the simplified models. But some full PRA models use sequence logic instead of event trees linked to fault trees when determining the sequence cutsets. The total number of accident sequences is larger for the full models than for the simplified models.

Within each SAPHIRE data base, a report of "summary" information is available. This report can be displayed by entering the REPORTS option, selecting the Family submenu, and then the Statistics option. An example report for the family statistics report is shown in Figure A-1. The statistics report will show various information for the PRA data base, including the number of fault trees, event trees, accident sequences, and basic events. This information can quickly tell the analyst the general level of detail contained in the data base. For example, a typical detailed PRA data base may have 2,500 basic events, whereas a typical simplified data base may have only around 100-150 basic events. The difference in the number of basic events indicates the overall level of detail contained in the logic models for the data base.

FAMILY STATISTICS REPORT			
Family: DEMO			

Fault Trees	2	Basic Events	24
Subtrees	2		
		Event Attributes	
Gates	12	Event Types	7
		Failure Modes	5
Event Trees	1	Locations	7
Subtrees	1	Systems	3
		Trains	0
Sequences	2		
End States	2	Histograms	1
P&IDs	0	Change Sets	0

Figure A-1. Example SAPHIRE output report for the data base statistics.

A.3.2 Full PRA Models

The full SAPHIRE PRA models were developed to correspond to the information given in their respective PRA or IPE. The full PRA models used either the linked fault tree method (i.e., fault tree logic linked to event trees) or sequence logic (i.e., the large event tree method) when determining the accident sequence cutsets shown in the PRA or IPE. The available PRA models are listed in Table A-4. There are a total of 20 fully developed PRA models available in the SAPHIRE code format.

The PRA models were developed as either a SARA-level load, IRRAS-level load, or a combination of both. A SARA-level load is where the sequence cutsets were manually put into the SAPHIRE PRA data base. The reason for manually inputting the cutsets was to duplicate the cutsets shown in the PRA or IPE. An IRRAS-level load allows the sequence cutsets to be generated from either the linked event trees and fault trees or sequence logic.

The modeling method used in developing the PRA models was either a large fault tree/small event tree (FTL) (also known as fault tree linking) method or large event tree/small fault tree (LET) method (also known as the *PLG method*). The FTL method uses small event trees that contain only front-line safety systems analyzed separately using fault trees. These fault trees are generally large and contain most of the system dependencies. The FTL method is also a technique whereby the fault tree logic is combined with the event tree logic (i.e., successes and failures), resulting in a logic expression for each sequence in the event tree. The LET method uses large event trees where most of the information about the support systems and other dependencies are placed in the event trees. Due to the dependency information being placed in the event trees, the front-line system fault trees are generally small. Both types of modeling (FTL or LET) should produce the same results if the assumptions are consistently maintained throughout the analyses.

Table A-4. Detailed PRA data bases loaded into the SAPHIRE code.

Data base	Plant type	SAPHIRE version	Type of data base	PRA source and date	Modeling method ^a	Comments
AP600 (AT-POWER)	Westinghouse advanced light water reactor (ALWR) design	5.0	IRRAS-level	Westinghouse PRA June 1992	FTL	Data base is scheduled to be updated FY 1995.
AP600 (SHUTDOWN)	Westinghouse ALWR design	5.0	IRRAS-level	Westinghouse PRA June 1992	FTL	Data base is scheduled to be updated FY 1995.
CESSAR System 80+	CE ALWR design	5.0	IRRAS-level	CE PRA 1991 and SSAR October 1990	FTL	
Beaver Valley Unit 2	Westinghouse 3-Loop with dry, subatmospheric containment	4.0	SARA-level	PLG PRA/IPE March 1992	LET	Dominant accident sequence cutsets were manually loaded.
Brunswick Unit 1	GE type 4, MARK I containment	5.0	SARA-level	Energy Inc. PRA April 1988	FTL	Dominant accident sequence cutsets were manually loaded.
Brunswick Unit 2	GE type 4, MARK I containment	5.0	SARA-level	Energy Inc. PRA April 1988	FTL	Dominant accident sequence cutsets were manually loaded.
Dresden Units 2 & 3	GE type 3, MARK I containment	5.0	SARA-level	Westinghouse PRA January 1993	FTL	IRRAS-level data base development is currently in progress.
Grand Gulf Unit 1	GE type 6, MARK III containment	5.0	SARA/IRRA S-level ^b	NUREG/CR-4550 Vol. 6 September 1989	FTL	Cutsets were manually loaded for the sequences that could not be duplicated from the PRA.
Indian Point Unit 2	Westinghouse 4-loop with dry, ambient pressure containment	2.5	SARA-level	PL&G PRA 1988	FTL	No current plans to upgrade this data base to version 5.0.

Table A-4. (continued)

Data base	Plant type	SAPHIRE version	Type of data base	PRA source and date	Modeling method ^a	Comments
James A. FitzPatrick Unit 1	GE type 4, MARK I containment	5.0	SARA-level	SAIC PRA August 1991	FTL	Dominant accident sequence cutsets were manually loaded.
Joseph M. Farley Units 1 & 2	Westinghouse 3-loop with dry, ambient pressure containment	5.0	SARA-level	Westinghouse PRA June 1993	LET	IRRAS-level data base development is currently in progress.
LaSalle Unit 2	GE type 5, MARK II containment	5.0	SARA-level	NUREG/CR-4832 1992/1993	FTL	A separate data base exists that includes changes made to the plant high pressure core spray.
Oconee Unit 3	B&W lowered loop with dry, ambient pressure containment	5.0	SARA-level	Duke Power PRA November 1990	FTL	A separate data base exists in that cutsets can be generated for only SGTR and main steamline break event trees.
Oyster Creek Unit 1	GE type 2, MARK I containment	5.0	SARA-level	PLG PRA June 1992	LET	IRRAS-level data base development is currently in progress
Peach Bottom Unit 2	GE type 4, MARK I containment	5.0	SARA/IRRA S-level ^b	NUREG/CR-4550 Vol. 4 August 1989	FTL	Cutsets were manually loaded for the sequences that could not be duplicated from the PRA.
River Bend Unit 1	GE type 6, MARK III containment	5.0	IRRAS-level	Gulf States Utilities Co. PRA January 1993	FTL	Cutsets can be generated for all sequences. This data base uses the latest SAPHIRE 5.0 features.

Table A-4. (continued)

Data base	Plant type	SAPHIRE version	Type of data base	PRA source and date	Modeling method ^a	Comments
San Onofre Units 2 & 3	CE with dry, ambient pressure containment	5.0	IRRAS-level	Southern California Edison Co. PRA May 1993	FTL	Cutsets can be generated for all sequences. This data base uses the latest SAPHIRE 5.0 features.
Sequoyah Unit 1	Westinghouse 4-loop with wet, ice condenser containment	5.0	SARA/IRRA S-level ^b	NUREG/CR-4550 Vol. 5 April 1990	FTL	Cutsets were manually loaded for the sequences that could not be duplicated from the PRA.
Surry Unit 1	Westinghouse 3-loop with dry, subatmospheric containment	5.0	SARA/IRRAS level ^b	NUREG/CR-4550 Vol. 3 April 1990	FTL	Cutsets were manually loaded for the sequences that could not be duplicated from the PRA.
Zion Unit 1	Westinghouse 4-loop with dry, ambient pressure containment	5.0	SARA-level	NUREG/CR-4550 Vol. 7 May 1990	LET	This data base does not contain any fault trees.

a. FTL signifies that the large fault tree/small event tree method (also known as fault tree linking) was used for the data base. LET signifies that the large event tree/small fault tree method (also known as the *PLG method*) was used for the data base.

b. These data bases are scheduled to be developed as full IRRAS-level data bases in 1995.

A.3.3 Simplified PRA Models

The simplified PRA models consist of those models developed and modified by the Idaho National Engineering Laboratory for use by the ASP evaluation program. A total of 75 different models representing most of the operational nuclear power plants in the United States are available in the SAPHIRE code format. Table A-5 lists the available data bases sorted by class type.

There are four event trees for every simplified PWR model: (1) LOOP, (2) small LOCA, (3) SGTR, and (4) transients (with an anticipated transient without scram tree transferred into the transient tree). The *fault tree linking* approach is used in the models. The event trees are considered to be small, but the fault trees are also small since the logic modeling is stopped at the supercomponent or train level. Also, support systems are not modeled at this time. The data bases for BWR plants contain event trees similar to the PWR models with the exception that the SGTR tree is not applicable.

The total number of fault trees in a data base depends on the plant class. The various plant classes require different systems used in the event trees in order to prevent core damage. The simplified models contain only front-line safety systems (e.g., high pressure injection, residual heat removal). No support systems are modeled (e.g., such as component cooling water, service water system). Although no support systems are currently included in the simplified models, work toward adding some support system dependencies is in progress. The support systems and other improvements to be added to the models are discussed below.

The support systems to be added to the simplified models deal with all the cooling water systems (e.g., component cooling water, service water system). The other support systems or modeling changes to be included are the emergency electrical power (based upon electrical buses instead of diesel generators for power). Also, some heating, ventilation, and air conditioning (HVAC) system dependencies will be added.

The simplified model improvements will incorporate uncertainty to the basic events. Other improvements to the models include updated human reliability modeling and improved common cause failure modeling. The original simplified data bases were developed in SAPHIRE version 4.16. All 75 data bases will be converted to version 5.0 during 1995.

The basic events in the fault tree models represent supercomponents or trains wherever possible. The basic event nomenclature uses the recommended naming scheme from NUREG/CR-5905⁵ for systems, components, and most failure modes. The simplified models contain an average of 100 total basic events per data base.

Table A-5. ASP PRA data bases sorted by plant class.

Plant	ASP class
Big Rock Point	BWR A
Millstone 1	BWR A
Nine Mile Point 1	BWR A
Oyster Creek	BWR A
Dresden 2 and 3	BWR B
Browns Ferry 1, 2, and 3	BWR C
Brunswick 1 and 2	BWR C
Clinton 1	BWR C
Cooper Station	BWR C
Duane Arnold	BWR C
Enrico Fermi 2	BWR C
Fitzpatrick	BWR C
Grand Gulf 1	BWR C
Hatch 1 and 2	BWR C
Hope Creek 1	BWR C
LaSalle 1 and 2	BWR C
Limerick 1 and 2	BWR C
Monticello	BWR C
Nine Mile Pt. 2	BWR C
Peach Bottom 2 and 3	BWR C
Perry 1	BWR C
Pilgrim 1	BWR C
Quad Cities 1 and 2	BWR C
River Bend 1	BWR C
Susquehanna 1 and 2	BWR C
Vermont Yankee	BWR C
Washington NP 2	BWR C
Beaver Valley 1	PWR A1
North Anna 1 and 2	PWR A1
Surry 1 and 2	PWR A1
Beaver Valley 2	PWR A2
Millstone 3	PWR A2
Braidwood 1 and 2	PWR B
Byron 1 and 2	PWR B
Catawba 1 and 2	PWR B
Commanche Peak 1 and 2	PWR B
Cook 1 and 2	PWR B
Davis-Besse 1	PWR B

Table A-5. (cont.)

Plant	ASP class
Diablo Canyon 1 and 2	PWR B
Farley 1 and 2	PWR B
Ginna	PWR B
Haddam Neck	PWR B
Harris 1	PWR B
Indian Point 2	PWR B
Indian Point 3	PWR B
Kewaunee	PWR B
Maine Yankee	PWR B
McGuire 1 and 2	PWR B
Pt. Beach 1 and 2	PWR B
Prairie Island 1 and 2	PWR B
Robinson 2	PWR B
Salem 1 and 2	PWR B
Seabrook 1	PWR B
Sequoyah 1 and 2	PWR B
South Texas 1 and 2	PWR B
Summer 1	PWR B
Turkey Point 3 and 4	PWR B
Vogtle 1 and 2	PWR B
Watts Bar 1 and 2	PWR B
Wolf Creek 1	PWR B
Zion 1 and 2	PWR B
ANO 1	PWR D
Crystal River 3	PWR D
Oconee 1, 2, and 3	PWR D
TMI 1	PWR D
ANO 2	PWR G
Calvert Cliffs 1 and 2	PWR G
Fort Calhoun 1	PWR G
Millstone 2	PWR G
Palisades	PWR G
St. Lucie 1 and 2	PWR G
Palo Verde 1, 2, and 3	PWR H
San Onofre 2 and 3	PWR H
Waterford 3	PWR H

A.4 CONCLUSIONS

An overview is presented for both PRA classification schemes and the available PRA data bases used by the NRC. Within this overview, information is presented for the PRA data bases concerning the level of detail contained in the data bases and the structure (i.e., how it was constructed) of the data base.

Two classification schemes are investigated and summarized. The first is the ASP classification scheme, the second is the ASEP classification scheme.

- The ASP models are first divided into either PWR or BWR categories. Then, the PWRs are divided into six classes, subdivided by decay heat removal mechanism and feed and bleed capabilities. The BWRs are divided into three classes, subdivided by decay heat removal mechanism. The nine ASP categories are shown in Table A.1.
- The ASEP classification scheme is primarily based on the type of reactor containment. For each plant type (either BWR or PWR), groups are defined by the major containment types (e.g., Mark I versus Mark II). This type of classification scheme results in eight BWR groups and 17 PWR groups. The BWR groups are shown in Table A.2. The PWR groups are shown in Table A.3. Although the ASEP grouping is shown in this report, the ASEP document⁴ points out that the "... grouping is done solely to present and organize the . . . plant information and does not have any significance towards 'plant grouping'." Consequently, the ASEP grouping scheme may not lend itself to using similar PRA models for plants within the same "group."

In general, the NRC uses two types of models. The first model type represent detailed, full-scope models that could be represented by full PRA or IPE data bases. This model type is called *full PRA models*. The second model type represents simplified, train-level models such as those in use by the ASP program. This model type is called *simplified PRA models*. Details are provided for both types of data bases available in the SAPHIRE format. Specifically, 20 full PRA data bases are available, whereas 75 simplified PRA data bases are available. Items such as the plant type, version number of the data base (e.g., developed in SAPHIRE 4.0), and modeling type (e.g., large event tree versus fault tree linking) are presented for each data base.

A.5 REFERENCES

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2. Idaho National Engineering Laboratory, *Systems Analysis Programs for Hands-on Integrated Reliability Evaluations (SAPHIRE)*, Version 5.0, September 1994.
3. Science Applications International Corporation, *Daily Events Evaluation Manual*, 1-275-03-336-01, January 1992.
4. Sandia National Laboratory, *Accident Sequence Evaluation Program*, (interim report), September 1984.
5. A. Trusty and D. P. Mackowiak, *Revisions and Development of Common Nomenclature for Naming and Labeling Schemes for Probabilistic Risk Assessment*, NUREG/CR-5905, August 1992.

**APPENDIX B - Attributes for the Types of Probabilistic Risk
Assessments Performed by Selected Offices Within the Nuclear
Regulatory Commission**

APPENDIX B - Attributes for the Types of Probabilistic Risk Assessments Performed by Selected Offices Within the Nuclear Regulatory Commission

B.1 INTRODUCTION

B.1.1 Program Overview

For the "Linkage of PRA Models" project, the overall goal is to collect (1) analysis attribute data for the types of analysis performed by the NRC, and (2) probabilistic risk assessment (PRA) model attribute data from available models. Ultimately, these two sets of data and a unified PRA classification scheme will be "linked" to provide guidance for NRC personnel on the selection of PRA models that are best suited to the analysis they are performing. This "linking" process is graphically illustrated below.

Examples of analysis attributes include: (a) desired PRA measures (i.e., result of the analysis), (b) the end use of PRA results, and (c) time constraints (results in minutes versus days). The PRA models have attributes that are related to the analysis attributes. Some of these model attributes include: (a) the measures that a PRA model gives as a result, (b) the modeling level of detail that exists within a PRA, and (c) the uncertainty analysis included in a PRA.

This appendix provides details concerning the collection of information from Nuclear Regulatory Commission (NRC) personnel pertaining to the types of analysis they perform and attributes for those analyses. The information presented herein was primarily gathered during a series of meetings with knowledgeable personnel from the Offices of Analysis and Evaluation of

Operational Data (AEOD), Nuclear Reactor Regulation (NRR), Nuclear Regulatory Research (RES), and contractors.

A list of applicable definitions for this project are provided in this section of the appendix. The remainder of this appendix is divided into four sections. Section B.2 lists the types of analysis that are performed by the various offices within the NRC. Section B.3 presents the attribute data for those types of analysis identified. Section B.4 gives some limitations that may be encountered when performing analyses within the various offices (including NRC contractor viewpoints on these limitations). Section B.5 presents conclusions for this appendix.

B.1.2 Definitions

This section contains definitions of terms and phrases that are used throughout this appendix. These definitions are provided in order to alleviate potential misinterpretations of the information presented in this report.

OFFICE — An **office** represents one of the NRC Offices (e.g., AEOD, NRR, RES).

AREA — An **area** represents an analysis domain within an **office**. A list of **offices** (and their respective areas) that are addressed include:

(NRR) (1) events assessment, (2) issues assessment, (3) review of significance of inspection findings, (4) review of requested modifications to licenses and technical specifications, (5) review of requests for discretionary enforcement, (6) review of issues that may warrant regulatory action, (7) inspection planning.

(AEOD) (1) events assessment, (2) issues assessment.

(RES) (1) generic issue prioritization, (2) generic issue resolution.

TYPE OF ANALYSIS — The **type of analysis** refers to the kinds of analyses performed within each of the analysis **areas**. As an example of a **type of analysis**, assume a utility requests a one-time allowable outage time (AOT) extension for a failed auxiliary feedwater pump. Under the **area** of "review of requests for discretionary enforcement" within the **office** of NRR, some type of risk-based analysis or evaluation would be performed. This **type of analysis** would be used to assist in the determination of whether to allow the utility to extend the AOT.

MODEL — A **model** represents a PRA data base (e.g., NUREG-1150 data bases, ASP simplified data bases) coupled with an appropriate analysis tool (e.g., FRANTIC, IRRAS, SARA, GEM). A **model** may be as simple as a list of failure cut sets for a safety system (in the SARA code) or as complex as the full Peach Bottom NUREG-1150 data base (in the IRRAS code).

ATTRIBUTE — An **attribute** is a particular characteristic or trait of the **type of analysis** and the **model**. Examples of **attributes** include:

(Analysis) What is the desired PRA result for the analysis? What are the time constraints? What is the level of modeling detail needed for the analysis? Is an uncertainty analysis required?

(Model) What measures does a PRA model give as a result? What modeling level of detail exists within the PRA? Is an uncertainty analysis included in the PRA? Can the PRA models be grouped according to a classification scheme that will allow for grouping of "like" plant models.

ATTRIBUTE DATA — Specific information for a particular **analysis attribute**. The **attribute data** are the answers to the **attribute** questions such as "what are the time constraints" and "is an uncertainty analysis required."

LIMITATION — A **limitation** represents a weakness that may exist as part of either the **type of analysis** or the **model**. Examples of **limitations** include:

- (1) PRA models have not been put to a particular use before (e.g., risk-based scheduling for preventative maintenance).
- (2) Initial information for and familiarity with the **type of analysis** to be performed may be limited (e.g., LER information for an event assessment may not be detailed enough to satisfy data requirements for human reliability models).

B.2 NRC ANALYSIS AREAS

This section describes the analysis areas that exist within the NRC. These analysis areas include the major types of PRA analysis performed within the three NRC offices AEOD, NRR, and RES.

The various analysis areas for AEOD, NRR, and RES are listed in Table B-1. While other analysis areas exist within the NRC (e.g., adequacy of regulation), only those areas shown in Table B-1 are within the scope of work for the "Linkage of PRA Models" project. These areas presented in Table B-1 constitute the majority of the PRA analysis performed by the NRC. Included in Table B-1 are brief descriptions for each of the analysis areas. These descriptions were provided by the NRC personnel interviewed for each of the respective Offices.

Two areas of analysis, licensing of fuel cycle and materials and regulation of fuel cycle and materials, are also not included within the scope of work for this project. These two areas are primarily contained within the Office of Nuclear Material Safety and Safeguards (NMSS).

As discussed in NUREG-1489,¹ the general breakdown of the PRA reactor analyses for the NRC are divided into two fields: (1) licensing of reactors and (2) regulation of reactors. A brief description of each field is provided below.

Licensing of reactors - PRA uses in this category include the review of analyses submitted as part of advanced reactor design certification applications, as well as plant-specific licensing actions such as technical specification modifications or justifications for continued operations. The principal responsibility for this work is in NRR, with support provided in some instances by RES.

Regulation of reactors - PRA is used in many aspects of reactor regulation, including monitoring operations (with risk-based inspections); screening events for significance (including operational event screenings, generic safety issue screenings, and facility screening risk assessment); analyses of events and issues (including operational events analyses, component and system failure data analyses and trends, reliability monitoring that is now developing as a result of the maintenance rule, generic safety issue analyses, and severe accident research studies); facility analyses (both those performed by the staff such as NUREG-1150 and by licensees in the individual plant examination (IPE) process; and in regulatory analyses supporting regulatory actions such as backfits. These types of PRA analyses are performed by NRR, AEOD, and RES.

Table B-1. NRC analysis areas.

Analysis	Description
NRR	
Events assessment	A quick evaluation to determine if the event warrants further investigation or analysis. The analysis is not necessarily for publication and is usually performed in response to daily phone calls.
Issues assessment	An evaluation to determine (from a risk perspective) the importance of a particular issue. Important issues may be given to RES as a generic issue.
Review of significance of inspection findings	A quick evaluation of inspection items that appear interesting from a risk perspective.
Review of requested modifications to licenses and technical specifications	An evaluation that is part of the approval process for a license or technical specification modification.
Review of requests for discretionary enforcement	A very quick evaluation of licensee request for discretionary relief from a technical specification requirement before required shutdown action must be taken.
Review of issues that may warrant regulatory action	An evaluation that provides supplementary documentation to support issuing a regulatory action (such as a Generic Letter).
Inspection planning	An evaluation to direct the efforts of an inspection team or the Resident Inspector based upon risk perspective.
AEOD	
Event assessment	Accident Sequence Precursor (ASP) evaluation of event processed through the ASP screening method. The analysis is more formalized than the NRR events assessments, however, the same PRA models are typically used for both.
Issues assessment	An evaluation to determine (from a risk perspective) the importance of a particular issue. Important issues may be given to RES as a generic issue.
RES	
Generic issue prioritization	High level evaluation to determine ranking (e.g., high, medium, low, drop) for a particular issue. Simplified Level 3 risk and cost-benefit analysis are performed.
Generic issue resolution	Detailed evaluation (requiring PRA and engineering analysis) which is usually performed by a contractor. The evaluation includes detailed Level 3 risk and cost-benefit analysis.

B.3 ANALYSIS ATTRIBUTE DATA

For the various analysis areas that are listed in Table B-1, analysis attributes were identified that would indicate a particular model or models to be used for the analysis. This section presents the data for these analysis attributes that were collected during a series of meetings with knowledgeable NRC personnel. NRC personnel who were interviewed included: (NRR) Steve Long and Millard Wohl; (AEOD) Dale Rasmuson and Pat O'Reilly; and (RES) Ron Emrit, Craig Hrabal, and Chris Rourk. Also included is a brief introduction of the analysis area (borrowing upon information collected during the personnel interviews, NRC task analyses, and NUREG-1489). The primary attributes that were discussed in the NRC meetings and an explanation of each attribute are shown below.

Figure of merit — The figure of merit is the analysis measure or measures that are used to assist in the decision making process for a particular type of analysis. Thus, the figure of merit is the result of an analysis. Examples of PRA figures of merit could include: change in core damage frequency (CDF), population dose, conditional core damage probability (CCDP), or change in system availability.

Decision criteria — The decision criteria are the standard by which the figure of merit is used to assist in the decision making process. The standard could be a comparison between the analysis CDF results and a stated numerical value (e.g., the NRC safety goals). For example, an analysis for a particular issue could yield a CDF value of $3 \times 10^{-4}/\text{yr}$ which would be compared against a stated goal of $1 \times 10^{-4}/\text{yr}$.

End use — The end use indicates the intended end use of the results of the analysis. The end use indicates the desired objective of the analysis. The objective could help decide what PRA models should be used for an analysis.

Time constraints — The time constraints refer to the time limitations that may be present, if any, for a particular type of analysis. Some analyses that are performed by the NRC allow a very limited amount of time for analysis (e.g., a couple of days or less). These types of time constraints may preclude a particular PRA model from being used due to the time required to exercise the model.

Level of detail — The level of detail is a measure of the complexity needed in the PRA models to give what is considered to be an adequate analysis answer. Some PRA models stop the logic modeling at the train or supercomponent level. Other models continue the logic modeling down to subcomponents (e.g., contacts on relays).

Uncertainty considerations — Uncertainty considerations indicate to what extent an uncertainty analysis is needed. Typically, point estimate results are readily available from the PRA models. An uncertainty analysis may not be available from some PRA models. Given that the uncertainty is required to be known, various results of the uncertainty analysis may be needed. For example, it may be desirable to know the mean value and 95th percentile for a particular analysis. Alternatively, uncertainty considerations may include the potential for sensitivity studies.

Plant-specific/generic analysis — Plant-specific/generic analysis refers to the types of PRA models that are needed for a particular analysis. If an issue is being evaluated that focuses on a specific feature of a certain nuclear power plant then it may be necessary that a PRA model exist for the plant in question (i.e., plant-specific analysis). Other types of issues may be applicable to every plant or to a large group of plants. Rather than trying to perform an analysis using models from each plant, it may be desirable to perform a couple of analyses using models that are applicable to a large group of plants (i.e., generic analysis).

Human performance issues — Human performance issues indicates the type of human reliability assessment (HRA) models that are needed for the particular analysis. This attribute attempts to provide information concerning the intended use of applicable HRA models within the PRA model being used for the analysis.

External events — External events refer to the potential need for an external events assessment during a particular analysis. Some analyses may be sensitive to issues related to external events. For these types of analyses it would be advantageous to have external event models along with the internal event models.

Low power and shutdown — Low power and shutdown refers to the potential need for a low power and shutdown operations assessment during a particular analysis. Some analyses may be sensitive to issues related to low power and shutdown operations. For these types of analyses it would be advantageous to have low power and shutdown models along with the full power models.

B.3.1 Analysis Areas for the Office of NRR

B.3.1.1 Events assessment

Events assessment provides an initial screening of operational events for safety significance by considering a number of factors, including significance to core damage frequency. The initial screening process uses the ASP program or simple PRA models to obtain an estimate of conditional core damage probability (CCDP), given that an event has occurred.

Figure of merit — Δ CDF, CCDP, or both.

Decision criteria — Not documented, but is related to the safety goals (e.g., frequency of core damage 10^{-4} /yr, 10^{-1} conditional containment failure probability, 10^{-6} /yr large release frequency). A particular event does not cause much concern if the CCDP is less than 10^{-5} . Low CCDP events could get increased attention if the event occurs on numerous occasions. Events with CCDP of 10^{-4} or greater command much more attention.

End use — The end use is to evaluate notifications, LERs, inspection findings, and daily “telephone calls” to evaluate and decide on their risk significance. An average of 20 “events” per day may be reported. Informal prescreening does take place.

Time constraints — The available time for the analysis ranges from hours to a couple of days.

Level of detail — Since time is a major driver on NRR event assessment, simplified models are generally preferred due to their ease of use.

Uncertainty considerations — Uncertainty propagation is not routinely performed. Some sensitivity analyses are performed.

Plant-specific/generic analysis — Plant-specific analysis is performed, but analyst may think about the general applicability of a particular event.

Human performance issues — HRA issues are normally not addressed.

External events — Generally classified as “impractical to analyze.” May be evaluated on an ad hoc basis.

Low power and shutdown — May be evaluated on an ad hoc basis.

B.3.1.2 Issues assessment

Issues assessment is the evaluation of operational events but requires a more detailed understanding of the event and its quantitative "risk" impact as part of an evaluation of possible regulatory action. The PRA modeling includes event trees and fault trees specific to classes of plants, generic recovery actions, and estimates of conditional core damage probabilities for the events. The plant-specific nature of the event should be incorporated into the analysis as much as possible, including any assumptions of equipment operability.

Figure of merit — Δ CDF for issues. For an "event type" of analysis, CCDP or Δ CDF.

Decision criteria — Not documented, but is related to the safety goals (e.g., frequency of core damage 10^{-4} /yr, 10^{-1} conditional containment failure probability, 10^{-6} /yr large release frequency). A particular event does not cause much concern if the CCDP is less than 10^{-5} . Low CCDP events could get increased attention if the event occurs on numerous occasions. Events with CCDP of 10^{-4} or greater command much more attention.

End use — Primarily used for the disposition of issues into one of three categories: (1) regulatory action, (2) no regulatory action, or (3) continued detailed research into issue.

Time constraints — Ranges from a couple of days ("event assessment" type) to a couple of years (issues that "evolve"). Typical time constraint is 3-6 weeks.

Level of detail — Attempt to use simplified models when possible. "Full-level" models are used occasionally. Try to get results to within an order of magnitude.

Uncertainty considerations — The uncertainty should be used to "ground" the results in reality.

Plant-specific/generic analysis — Typically use a "class-of-plant" approach, which is quasi-generic analysis. Would like results to be applicable to as many plants as possible.

Human performance issues — A simplified approach to address HRA is now used. More complex approaches may be used in the future as models become available.

External events — External events are typically not addressed adequately. Usually just rely on expertise to provide engineering judgement.

Low power and shutdown — May be evaluated on an ad hoc basis. Will occasionally attempt to model important events.

B.3.1.3 Review of significance of inspection findings

Review of significance of inspection findings is a brief analysis and review of inspection items that appear interesting from a risk perspective. Findings from onsite inspection activities may be evaluated to determine their potential risk significance.

Figure of merit — Δ CDF, conditional core damage frequency (CCDF).

Decision criteria — No set criteria. Decisions are made subjectively.

End use — To determine whether to discontinue or expand a particular type of inspection.

Time constraints — A couple of months.

Level of detail — Generally, the analysis demands detailed models. The type of inspection may determine the model that is needed.

Uncertainty considerations — Uncertainty propagation is not routinely performed. Some sensitivity analyses are performed.

Plant-specific/generic analysis — Plant-specific analysis may be needed to point out vulnerabilities.

Human performance issues — Not routinely performed.

External events — Not routinely performed.

Low power and shutdown — Inspection findings were evaluated in conjunction with the low power and shutdown study performed through RES (NUREG/CR-6143, NUREG/CR-6144). Not routinely performed.

B.3.1.4 Review of requested modifications to licenses and technical specifications

Review of requested modifications to licenses and technical specifications is an evaluation that is part of the approval process when a modification (to a license or technical specification) is requested from a utility. These types of requests include permanent modification to equipment AOTs, extensions for surveillance testing intervals, and increases to calibration intervals.

Figure of merit — Δ CDF and the change in the core damage probability (Δ CDP). Public dose calculations are sometimes (but rarely) performed.

Decision criteria — Limit Δ CDP to 5×10^{-7} . This criterion arose informally and is not documented.

End use — To check PRA submittal for the requested modification. Currently, personnel at the NRC do not perform analysis to check submittal. If submittal appears to be adequate, the request may be granted.

Time constraints — For an individual plant request, 5-6 weeks. For an owners group request, 7-8 months.

Level of detail — Was not acquired.[†]

Uncertainty considerations — Was not acquired.[†]

Plant-specific/generic analysis — Typically, plant-specific items are addressed. IPE insights may be useful.

Human performance issues — Was not acquired.[†]

External events — Was not acquired.[†]

Low power and shutdown — Was not acquired.[†]

[†] NRC personnel did not feel qualified to set standards or provided detailed information for these attributes. Analysis may be generally performed by contractors. NRC reviews of these types of analysis may have been to infrequent to provide detailed information concerning the analysis attributes.

B.3.1.5 Review of requests for discretionary enforcement

Review of requests for discretionary enforcements is a very quick evaluation of licensee request for relief from a technical specification requirement before a required action (generally plant shutdown) must be taken. These types of requests usually take the form of a one-time increase in an equipment AOT.

Figure of merit — Δ CDF multiplied by the duration of allowed outage.

Decision criteria — No formal criteria exists. Review typically questions what is the percentage increase in overall CDF (which may be compared to the NRC safety goals).

End use — To either grant or deny request for discretionary enforcement (e.g., increased AOT).

Time constraints — Typically on the order of hours, but could be a day or two.

Level of detail — In-house analysis is limited by the time constraints.

Uncertainty considerations — If performed, it is used to judge the quality of the results.

Plant-specific/generic analysis — It is important to capture plant-specific vulnerabilities. But, generic insights may be useful. Ad hoc plant-to-plant comparisons are occasionally performed.

Human performance issues — Do not typically address HRA issues.

External events — Do not typically address.

Low power and shutdown — Improved analysis may be needed for low power and shutdown evaluations.

B.3.1.6 Review of issues that may warrant regulatory action

This area is an outgrowth of events and issues assessment. Consequently, the attribute data for most of those sections are applicable for this area. For those analyses that result in an information notice issuance, the original analysis that is performed is generally adequate. For some analysis (i.e., those resulting in issuance of a generic letter), RES may perform a cost-benefit analysis based on the original NRR risk analysis. Issuance of a generic letter may also require additional and more formal risk analysis. In general, there are not any real time constraints for this area.

B.3.1.7 Inspection planning

The objective of PRA use in inspections is to provide risk-based insights as guides for efficient use of limited staff inspection resources. Inspection applications are primarily based on ranking plant systems, components, and operations according to significance to core damage frequency. The process calls for the identification of dominant accident sequences and the use of importance measures. The specific importance measures used for ranking are risk reduction, risk achievement, Fussell-Vesely, and relative ranking importance measures.

Figure of merit — Fractional changes in CDF or large release frequency. Importance measures are also used.

Decision criteria — Importance originally grouped by high, medium, and low. Now may be grouped by important and not-so-important. May try to look for "clustering" in the list.

End use — To provide to the inspector a list of components or systems to be inspected. Contribution of overall failures is important.

Time constraints — When planning for a particular inspection, a couple of months. Risk-based inspection guides generally have no time constraint.

Level of detail — Generally need a lot of detail.

Uncertainty considerations — Uncertainty propagation is not routinely performed. Some sensitivity analyses are performed.

Plant-specific/generic analysis — Plant-specific analysis are needed to point out plant-specific vulnerabilities.

Human performance issues — May check training of operators for dominant accident sequence concerns. May also check procedures. Importance measures may be available for human actions.

External events — Not much analysis has been performed in this area.

Low power and shutdown — Not much analysis has been performed in this area.

B.3.2 Analysis Areas for AEOD

B.3.2.1 Events assessment

The purpose of events assessment is to provide an initial screening of operational events (LERs) for safety significance by considering a number of factors. The screening process uses a computerized prescreening and, for events passing the prescreening stage, simple PRA models to obtain an estimate of conditional core damage probability, given that the event has occurred or condition has existed for a certain duration.

Figure of merit — CCDP.

Decision criteria — Initial screening, engineering judgement, and "impractical to analyze" grouping will remove a majority of the events that are reported. An initial analysis is performed. If the CCDP is less than 10^{-6} then reject event. Events that are not rejected receive a more refined analysis. The criteria and screening process are all documented in the ASP NUREG/CR-4674 reports.

End use — Attempting to estimate the risk significance for operational events. Trying to answer what can be learned from reactor experience.

Time constraints — The preliminary analysis will take approximately four weeks.

Level of detail — Simplified models are currently in use. Models with additional plant-specific detail will probably be used in the future. The need is for reasonable, detailed results. Currently, development of the models is ahead of the quality of data available.

Uncertainty considerations — No uncertainty is currently evaluated. Uncertainty analysis is needed.

Plant-specific/generic analysis — Plant-specific analysis is used as much as possible. The improved models are plant-specific, but the component data may be generic. May eventually perform plant-to-plant comparisons, but probably no generic analysis.

Human performance issues — Currently trying to improve this analysis area. The models are getting more sophisticated than the data we have available from documentation of the event.

External events — Not currently evaluated.

Low power and shutdown — Events that occur during low power/shutdown operations are evaluated if they appear to be risk significant. It is currently difficult to analyze these events due to lack of models for low power/shutdown configuration. Such evaluations now entail developing custom models for each event analyzed.

B.3.2.2 Issues assessment

The objective of the analysis of operational events is a more detailed understanding of the event and its quantitative "risk" impact as part of an evaluation of possible regulatory action. This use of PRA methodology include event trees and fault trees specific to class of plants, generic recovery actions, and estimates of conditional core damage probabilities for the event (which currently turn out to be the same models used for events assessments). The plant-specific nature of the event should be incorporated into the analysis as much as possible, including any assumptions of equipment operability.

Figure of merit — CDF, CDP, CCDF, or CCDFP.

Decision criteria — No objective criteria are documented. Management decision may refer back to NRC safety goal.

End use — It is desirable to see if certain initiatives are effective.

Time constraints — In general, no real time constraints. Responsiveness may be a couple of months.

Level of detail — Simplified models are currently in use. Models with additional plant-specific details will probably be used in the future. The need is for reasonable, detailed results.

Uncertainty considerations — Need uncertainty evaluation in order to get the statistical significance.

Plant-specific/generic analysis — Plant-specific insights may be highlighted. Generic analysis is usually performed. As the number of available plant models increases, more plant-specific analysis might be performed.

Human performance issues — HRA issues are important.

External events — Primary focus is on internal events.

Low power and shutdown — Some of these issues may be evaluated.

B.3.3 Analysis Areas for Office of RES

B.3.3.1 Generic issue prioritization

The generic safety issues are prioritized for this study and three main objectives of the risk assessment are listed below: (1) to provide a systematic and disciplined framework that forces the analyst to explicitly define the issue and its relationship to risk, (2) to screen out the issues that do not merit further attention because they have no or very little risk significance, and (3) to provide a quantitative measure for placing the remaining issues in order of priority.

Figure of merit — Δ CDF and \$/person-rem ratio (discussed in NUREG-0933²).

Decision criteria — The decision criteria is well defined and is given in NUREG-0933. Essentially, a table is given where the Δ CDF and \$/person-rem ratio are used to categorize an issue as either high, medium, low, or drop.

End use — The end use is to provide for a conservation of resources to do technical analysis. It is not desirable to expend resources on non-risk significant issues.

Time constraints — A matter of months, typically 4-6 months. No maximum length of time. Some issues may have shorter time constraints.

Level of detail — Only as much model detail as needed to solve the problem being evaluated. The level of detail needed does vary according to the issue being evaluated.

Uncertainty considerations — Uncertainty is used when possible. For low and drop issues, uncertainty is used to make sure the issue is not risk significant.

Plant-specific/generic analysis — Typically get plant-specific results and then try to apply the results to other plants. Attempt is to use the models as generically as possible. May try to make the results applicable to certain classes of plants.

Human performance issues — Try to use existing models and values in available PRAs as much as possible.

External events — Lack of available models has precluded this type of analysis. Primarily use engineering judgement and available expertise.

Low power and shutdown — Lack of available models has precluded this type of analysis. Primarily use engineering judgement and available expertise.

B.3.3.2 Generic issue resolution

A generic safety issue is defined as a possible deficiency in the design, construction, or operation of a class of NRC-licensed installations or activities. This analysis must be capable of supporting a decision on whether the potential change in risk is sufficient to justify regulatory action. The use of PRA for these issues include: (1) an assessment of the CDF impact associated with the issue; (2) calculation of the consequences and risk to the public (in person-rem averted) in addition to CDF; (3) an uncertainty analysis that permits the calculation of mean values for comparisons with decision criteria (which are in mean values), so as not to overlook or dismiss potentially risk-significant issues prematurely; (4) applicability to the set of affected plants (meaning that more than one PRA may be needed to cover the entire spectrum of plants under consideration); and (5) integration of related issues under study to avoid piecemeal evaluation of issues.

Figure of merit — Δ CDF and \$/person-rem ratio.

Decision criteria — Use the \$1000/person-rem to make regulatory decisions.

End use — To resolve generic issues. Most resolution analysis is not performed within the NRC (i.e., subcontracted), but this may change in the future.

Time constraints — Practically no time constraints. Analysis phase should be limited to two years.

Level of detail — Only as much model detail as needed to solve the problem being evaluated. The level of detail needed does vary according to the issue being evaluated. In general, more detail is needed than in the prioritization phase.

Uncertainty considerations — No consistent guidelines, but probably need to evaluate uncertainty. Uncertainty is probably more important in resolution than in prioritization.

Plant-specific/generic analysis — Plant-specific analysis is typically used generically to apply to a group of plants.

Human performance issues — Since the analysis is not typically performed in house, information on this attribute is not available. But, human performance issues may be as important as hardware related issues.

External events — This analysis gets moved into the IPE external events process.

Low power and shutdown — Since the analysis is not typically performed in house, information on this attribute is not available. Occasionally though, these analyses are performed.

B.3.4 Ranking of Key Attributes

For the attribute information that was collected, it was determined that some attributes could be ranked as to their relative priority or importance for a particular type of analysis. Consequently, for each analysis area, information was ranked for the attributes of: (1) time constraints, (2) level of detail, (3) uncertainty considerations, and (4) plant-specific or generic analysis. Table B-2 shows the ranking of these attributes for each of the analysis areas.

Table B-2. Analysis priority ranking of key attributes.

Analysis	Time constraints	Level of detail	Uncertainty considerations	Plant-specific analysis
NRR				
Events assessment	high	driven by time constraints	low	important to broaden results to generic applicability
Issues assessment	high	low	high	important to broaden results to generic applicability
Review of significance of inspection findings	low	issue dependent	high	medium
Review of requested modifications to licenses and technical specifications	not ranked	not ranked	not ranked	not ranked
Review of requests for discretionary enforcement	high	driven by time constraints	low	high
Review of issues that may warrant regulatory action	not ranked	not ranked	not ranked	not ranked
Inspection planning	low	high	low	high
AEOD				
Event assessment	high	high	low	high
Issues assessment	medium	high	medium	high
RES				
Generic issue prioritization	low	high	low	high
Generic issue resolution	low	high	high	high

B.4 ANALYSIS LIMITATIONS

During the collection of analysis attribute information, additional limitation data was gathered from most of the NRC personnel interviewed previously (for Section 3) and NRC contractors. This data concerning potential analysis limitations that may be encountered when performing the various types of analysis. These limitations are presented in this section. Table B-3 lists some of the limitations that were discussed for the various analysis areas. Some of these limitations may ultimately be useful in assisting the analysis in selecting and using a particular PRA model. Other limitations may point out deficiencies in current PRA models.

Limitations that were found to be generic to all the areas discussed above include:

- Event tree accident sequence endpoints for success may not be stable.
- Cumulative PRA effects (e.g., multiple changes) need to be better accounted for in the analyses.
- PRAs do not model complex errors of commission.
- Human reliability modeling is problematic.
- Focusing on core damage frequency rather than a dose or risk value (e.g., person-rem) may be misleading depending on the particular issue being evaluated?
- Lack of shutdown risk models may be a limitation for several areas?

Table B-3. Limitations of the analyses performed listed by analysis areas.

Analysis	Limitations or analysis concerns
NRR	
Events assessment	The analyst needs to consider potential multiple equipment outages. Long term risk average models and data are used for short-term risk evaluation.
Issues assessment	Non-PRA analysis (e.g., engineering evaluation, data analysis) may be needed to supplement PRA analysis.
Review of significance of inspection findings	Better human reliability models are needed (e.g., fire barriers).
Review of requested modifications to licenses and technical specifications	Need to consider risk from change in operating mode. Need to consider potential multiple equipment outages. Long term risk average models and data are used for short-term risk evaluation.
Review of requests for discretionary enforcement	Need to consider risk from changes in operating mode. Long term risk average models and data are used for short-term risk evaluation. Quick analysis time precludes detailed modeling.
Review of issues that may warrant regulatory action	
Inspection planning	Better human reliability models are needed (e.g. fire barriers).
Adequacy of regulation	Difficulty in (1) deciding how a regulation might affect a PRA (2) reconstructing past risk profile.
AEOD	
Event assessment	Need to consider potential multiple equipment outages. Long term risk average models and data are used for short-term risk evaluation.
Issues assessment	Non-PRA analysis (e.g., engineering evaluation, data analysis) may be needed to supplement PRA analysis.
RES	
Generic issue prioritization	Not enough complex models for some types of plants. Lack of automatic consequence mapping. Need better mapping for consequences. Better human reliability models are needed (e.g. fire barriers)? External events models are not available.
Generic issue resolution	Not enough complex models for some types of plants. Lack of automatic consequence mapping. Need better mapping for consequences. Non-PRA analysis (e.g., engineering evaluation, data analysis) may be needed to supplement PRA analysis.

Other related issues that were raised can be grouped into a couple of categories.

Analysis Concerns

- Lack of risk based planning for preventative maintenance is a PRA application shortcoming (not of the models).
- The adequacy-of-regulation issue may be difficult (or impossible) to address due to the historical data collection that would be needed. Much of the data that would need to be evaluated for this type of analysis may not even exist (e.g., plant configuration 10 years ago).
- For event analysis, the information that is provided for the event may not be detailed enough to perform a "detailed" human reliability assessment (e.g., the stress level may not be known).
- An analyst's familiarity with a PRA model to be used for a particular analysis could be a concern (but this is not a model limitation). This item is more of a management concern.
- PRA evaluation criteria may depend on the particular issue being evaluated (e.g., conditional core damage probability for event assessment, $(\Delta CDF)(AOT) \leq 5 \times 10^{-7}$ for AOT evaluations). Some types of analysis may require multiple types of results (e.g., core damage frequency along with offsite dose).
- For some types of analysis, there should be a link between the person doing the PRA analysis and the people who raised the issue. This issue occurs in areas such as generic issue resolution.
- Some desire to have detailed models "back-up" simplified models was expressed. These more detailed models would be used to validate the simplified models that were being used.
- The analysis for discretionary enforcement needs to be performed very quickly. It may be impossible to attempt to build model structure (e.g., fault trees, event trees) to get an answer. Also, some detailed models may take too long to be evaluated using current computing power.
- For some types of analysis, 79 different plant models would be useful. But realistically, a representative cross section of models would probably be adequate. This cross section could be defined by a classification scheme such as that used for the ASP models.

PRA Modeling Concerns

- Design errors are typically not addressed in the PRA models (this may be a model uncertainty type of limitation).
- Concerns with phenomena were discussed for several issues (e.g., hot shorts, smoke damage during fires).
- If regulations or documentation (e.g., QA activities) are relaxed due to risk-based arguments, how do we know we will not introduce a new failure mode? Data collection may help to identify any areas where new failure modes were introduced.
- The initial conditions for a particular event could drive the short term risk profile. Such time dependent risk analysis is not routinely performed. The PRA models currently in use average the operational data (e.g., maintenance and testing outage duration) over long periods of time.
- No library of external event models are available for generic studies. Limited detailed fire and seismic models are available (e.g., NUREG-1150).
- Indicators that tell if a model is realistic, complete, and applicable for the analysis are needed. This is related to identifying model characteristics necessary for use in a particular area.
- The PRA/IPEs that were performed by the industry may not be consistent as a group. The ASP models may be more consistent as a group. Consistency may be important when comparing results between types or groups of plants.
- It may be beneficial to have a list of the applications and changes that were made using a particular PRA model to assist future PRA analysis. If we knew how a model was used and for what, this information may help the guidance for particular PRA models.

Miscellaneous Items

- Suggestions were made concerning other PRA models (e.g., IREP, foreign PRAs) that may be available and may be useful for use in generic issue prioritization.
- Most of the PRA analysis is performed at Headquarters. The regional offices may increase the amount of PRA they do in the future.

- For some analysis, the analyst may be able to “trick” the PRA models to handle items not specifically modeled in the PRA. But, for this type of analysis, the user must be sophisticated enough to handle the issue. For example, if a component is not specifically modeled in the PRA but impacts or fails a component that is in the model, it may be possible to fail this second component and obtain the desired result as if the first component were actually modeled.

B.5 CONCLUSIONS

Presented primarily in this appendix are details concerning the collection of information from NRC personnel pertaining to the types of analysis they perform and attributes for those analysis. This work was performed under the "Linkage of PRA Models" project, FIN W6301. The collected information presented herein was primarily gathered during a series of meetings with knowledgeable personnel from the offices of AEOD, NRR, and RES.

Specific data were presented for the types of analysis performed by the NRC. For these areas of analysis, several attributes were identified. These analysis attributes include:

Figure of merit	Decision criteria
End use	Time constraints
Level of detail	Uncertainty considerations
Plant-specific/generic analysis	Human performance issues
External events	Low power and shutdown

Detailed information were collected and are documented for the analysis areas of:

NRR

- Events assessment
- Issues assessment
- Review of significance of inspection findings
- Review of requested modifications to licenses and technical specifications
- Review of requests for discretionary enforcement
- Review of issues that may warrant regulatory action
- Inspection planning

AEOD

- Event assessment
- Issues assessment

RES

- Generic issue prioritization
- Generic issue resolution

Lastly, prioritization of important attributes by NRC personnel were provided. Also, information concerning limitations and analysis problems (as identified by NRC personnel and contractors) that are encountered were presented.

B.6 REFERENCES

1. U. S. Nuclear Regulatory Commission, *A Review of NRC Staff Uses of Probabilistic Risk Assessment*, NUREG-1489, March 1994.
2. R. Emrit et al., *A Prioritization of Generic Safety Issues*, NUREG-0933, Main Report and Supplements 1-12, U. S. NRC. July 1991.

APPENDIX C - Cross Reference Classification for PRA Models

APPENDIX C - Cross Reference Classification for PRA Models

This appendix provides information used in determining if developing a cross-reference classification scheme would allow an analyst to use a "similar" full level detailed PRA model for plants that do not have a full level, detailed model. This classification would have to allow the analyst the flexibility to focus on the appropriate parts of the PRA models (e.g., system fault trees, accident sequences) as needed.

One potential classification scheme that is currently used to group similar plants is the Accident Sequence Precursor (ASP) classification scheme. The ASP models are first divided into either pressurized water reactor (PWR) or boiling water reactor (BWR) categories. Then, the PWRs are subdivided into six classes according to the decay heat removal mechanism and feed and bleed capabilities. The BWRs are subdivided into three classes according to the decay heat removal mechanism. The nine ASP plant classes are described in Table C-1.

These nine classes were determined by examining the systems required to operate following a reactor trip, loss of offsite power (LOOP), small-break loss-of-coolant accident (LOCA), or steam generator tube rupture. From the *Daily Events Evaluation Manual*,¹ the plant classes were determined as follows:

The plant categorization scheme groups plants with similar responses to transients and accidents based on the front-line systems included in the plant design and the availability of alternate mitigative features which also provide for core protection.

It should be pointed out that functions concerning the containment integrity and post-accident reactivity removal are not included in the classification scheme within ASP.

To determine the potential usefulness of the ASP classification to group "similar" plants, a PWR ASP class (PWR B) and a BWR ASP class (BWR C) were evaluated to ascertain the similarities between plants within each class. For the PWR B class, the following plant models were evaluated: Byron 1&2, Catawba 1&2, Diablo Canyon 1&2, Indian Point 2&3, Kewaunee, Maine Yankee, Robinson 2, Salem 1&2, Seabrook 1, Sequoyah 1&2, South Texas 1&2, Turkey Point 3&4, and Watts Bar 1&2. For the BWR C class, the following plants models were evaluated: Browns Ferry 1,2&3, Brunswick 1&2, Clinton, Fitzpatrick, Fermi 2, La Salle 1&2, Monticello, Peach Bottom 2&3, River Bend, and Susquehanna 1&2

Table C-1. ASP classification descriptions for the nine plant classes.

ASP plant class	Class description
BWR	
BWR A	Older BWRs with isolation condensers and feedwater coolant injection systems that employ the main feedwater pumps
BWR B	Older BWRs with isolation condensers and high pressure coolant injection systems
BWR C	Newer BWRs with reactor core isolation cooling and high pressure coolant injection (or high pressure core spray) systems
PWR	
PWR A1	Westinghouse PWRs which use recirculation spray for decay heat removal following a LOCA
PWR A2	Westinghouse PWRs which use recirculation spray for decay heat removal following a LOCA
PWR B	Westinghouse PWRs (primarily) which use low-/high-pressure recirculation for decay heat removal following a LOCA.
PWR D	Babcock and Wilcox PWRs (primarily) with high-head high pressure injection systems. Power operated relief valve operability is not required for bleed and feed on these plants.
PWR G	Combustion Engineering PWRs with bleed and feed capability
PWR H	Combustion Engineering PWRs which utilize secondary side depressurization and the condensate system as an alternate to auxiliary feedwater and main feedwater

For each of the plants previously listed, the front-line system modeling (i.e., those models in the ASP plant PRA models) were evaluated to determine the characteristics of the front-line system. Tables C-2 through C-10 shows the results of the evaluation. Tables C-2 through C-5 provide results for the PWR plants while Tables C-6 through C-10 provide results for the BWR plants.

Table C-2 displays the specific characteristics of six front-line systems for each PWR plant. Table C-3 regroups the PWR plants based upon plants having similar AFW systems. Table C-4 regroups the PWR plants based upon plants having similar emergency power systems. Table C-5 regroups the PWR plants based upon plants having similar high pressure injection systems.

Table C-6 displays the specific characteristics of seven front-line systems for each BWR plant. Table C-7 regroups the BWR plants based upon plants having similar emergency power systems. Table C-8 regroups the BWR plants based upon plants having similar high pressure core injection systems. Table C-9 regroups the BWR plants based upon plants having similar low pressure core injection systems. Table C-10 regroups the BWR plants based upon plants having similar low pressure core spray systems.

As can be seen in Tables C-2 through C-10, plants within the same ASP class can have widely differing system designs. Consequently, the calculated system unreliability (via system fault trees) can have varying values. Figures C-1 through C-3 show the system unreliability for select ASP PWR class B plants for the high pressure recirculation, high pressure injection, and emergency power systems, respectively.

From Figure C-1, the largest difference in high pressure recirculation unreliability (from the select PWR plants) is about a factor of four (between South Texas and Turkey Point). Figure C-2 shows a larger difference between the unreliability for the high pressure injection system. Over an order of magnitude difference exist between the high pressure injection system for Robinson compared to Sequoyah. Figure C-3 illustrates the differences between the various emergency power systems that exist between the PWR class B plants. Essentially, the plants that have two diesel generators exhibit the higher unreliability while plants that have three diesel generators have the lower unreliability.

It is evident that simply choosing a plant model based upon the ASP classification will not necessarily guarantee a PRA model applicable to the analysis that is being performed. The analyst will generally need to focus on specific attributes of the models rather than on a generic classification scheme.

Table C-2. PWR plants with associated front-line systems.

PWR Class B Plants (Vendor & No. of loops)	Front-line Systems					
	AFW	EP	F&B (# of PORVs)	HPI	HPR	RHR
Byron 1&2 (West 4-loop)	1 MDP 1 EDP	2 diesel generators	2 PORVs	2 SI pumps 2 Charging pumps	2 SI pumps 2 Charging pumps 2 RHR pumps	2 RHR pumps
Catawba 1&2 (West 4-loop)	1 TDP 2 MDP	2 diesel generators	3 PORVs	2 SI pumps 2 Charging pumps	2 SI pumps 2 Charging pumps 2 RHR pumps	2 RHR pumps
Diablo Canyon 1&2 (West 4-loop)	1 TDP 2 MDP	3 diesel generators	3 PORVs	2 SI pumps 2 Charging pumps	2 SI pumps 2 Charging pumps 2 RHR pumps	2 RHR pumps
Indian Point 2&3 (West 4-loop)	1 TDP 2 MDP	3 diesel generators	2 PORVs	3 SI pumps	3 SI pumps 2 RHR pumps 2 Recirc pumps	2 RHR pumps
Kewaunee (West 4-loop)	1 TDP 2 MDP	2 diesel generators	2 PORVs	2 SI pumps	2 SI pumps 2 RHR pumps	2 RHR pumps
Maine Yankee (CE 2-loop)	1 TDP 2 MDP	2 diesel generators	2 PORVs	3 SI pumps	3 SI pumps 2 RHR pumps	2 RHR pumps
Robinson 2 (West 3-loop)	1 TDP 2 MDP	2 diesel generators	2 PORVs	3 SI pumps	3 SI pumps 2 RHR pumps	2 RHR pumps
Salem 1&2 (West 4-loop)	1 TDP 2 MDP	3 diesel generators	2 PORVs	2 SI pumps 2 Charging pumps	2 SI pumps 2 Charging pumps 2 RHR pumps	2 RHR pumps
Seabrook 1 (West 4-loop)	1 TDP 1 MDP	2 diesel generators	2 PORVS	2 SI pumps 2 Charging pumps	2 SI pumps 2 Charging pumps 2 RHR pumps	2 RHR pumps
Sequoyah 1&2 (West 4-loop)	1 TDP 2 MDP	2 diesel generators	2 PORVs	2 SI pumps 2 Charging pumps	2 SI pumps 2 Charging pumps 2 RHR pumps	2 RHR pumps
South Texas 1&2 (West 4-loop)	1 TDP 3 MDP	3 diesel generators	2 PORVs	3 SI pumps	3 SI pumps which take suction directly from the sump. 3 LPI pumps which take suction directly from the sump but no cross tie from LPI to HPI.	3 RHR pumps (these are not the same as the LPI pumps)

PWR Class B Plants (Vendor & No. of loops)	Front-line Systems					
	AFW	EP	F&B (# of PORVs)	HPI	HPR	RHR
Turkey Point 3&4 (West 3-loop)	3 TDP	2 diesel generators	2 PORVs	2 SI per Unit which are shared between both Units during HPI.	Each Units 2 SI pumps 2 RHR pumps	2 RHR pumps
Watts Bar 1&2 (West 4-loop)	1 TDP 2 MDP	2 diesel generators (designated to each Unit and one swing diesel that can replace any one diesel if it fails)	2 PORVs	2 SI pumps 2 Charging pumps	2 SI pumps 2 Charging pumps 2 RHR pumps	2 RHR pumps

Table C-3. Auxiliary feedwater front-line system components for PWRs.

	Components (type of drivers on the AFW pumps)				
	1 EDP 1 MDP	1 TDP 2 MDP	1 TDP 1 MDP	1 TDP 3 MDP	3 TDP
Plants	Byron 1&2	Catawba 1&2 Diablo Canyon 1&2 Indian Point 2&3 Kewaunee Maine Yankee Robinson 2 Salem 1&2 Sequoyah 1&2 Watts Bar 1&2	Seabrook 1	South Texas 1&2	Turkey Point 3&4

Table C-4. Emergency power front-line system components for PWRs.

	Components (# of emergency diesel generators per Unit)		
	2 DGs	3 DGs	2 DGs with 1 swing DG
Plants	Byron 1&2 Catawba 1&2 Kewaunee Maine Yankee Robinson 2 Seabrook 1 Sequoyah 1&2 Turkey Point 3&4	Diablo Canyon 1&2 Indian Point 2&3 Salem 1&2 South Texas 1&2	Watts Bar 1&2

Table C-5. High pressure injection front-line system components for PWRs.

	Components			
	2 Safety injection pumps 2 Charging pumps	safety injection pumps	3 Safety injection pumps	2 Safety injection pumps shared between both Units
Plants	Byron 1&2 Catawba 1&2 Diablo Canyon 1&2 Salem 1&2 Seabrook 1 Sequoyah 1&2 Watts Bar 1&2	Kewaunee	Indian Point 2&3 Maine Yankee Robinson 2 South Texas 1&2	Turkey Point 3&4

Table C-6. BWR plants with associated front-line systems.

BWR Class C Plants	HPCI	RCIC	EPS	LPCI	LPCS	RHR			HSW
						SDC	SPC	CSS	
Browns Ferry 1,2&3	1 TDP	1 TDP	4 DGs	4 MDPs (used for RHR system)	4 MDPs	n/a	4 MDPs (LPI pumps)	n/a	2 MDPs
Brunswick 1&2	1 TDP	1 TDP	4 DGs	4 MDPs (used for RHR system)	2 MDPs	n/a	4 MDPs (LPI pumps)	n/a	2 MDPs
Clinton	(HPCS) 1 MDP	1 TDP	3 DGs	3 MDPs (used for RHR system)	1 MDP	n/a	2 MDPs (LPI pumps)	n/a	(SSW) 1 MDP
Fitzpatrick	1 TDP	1 TDP	4 DGs	4 MDPs (used for RHR system)	2 MDPs	4 MDPs (use the LPI pumps at the different possible RHR modes)			2 MDPs
Fermi 2	1 TDP	1 TDP	4 DGs	4 MDPs (used for RHR system)	4 MDPs	4 MDPs (use the LPI pumps at the different possible RHR modes)			2 MDPs
La Salle 1&2	(HPCS) 1 MDP	1 TDP	3 DGs	3 MDPs (used for RHR system)	1 MDP	2 MDPs (use 2 LPI pumps at the different possible RHR modes)			(SSW) 1 MDP
Monticello	1 TDP	1 TDP	2 DGs	4 MDPs (used for RHR system)	2 MDP	4 MDPs (use the LPI pumps at the different possible RHR modes)			(SSW) 2 MDPs
Peach Bottom 2&3	1 TDP	1 TDP	4 DGs	4 MDPs (used for RHR system)	4 MDPs	4 MDPs (use the LPI pumps at the different possible RHR modes)			2 MDPs
River Bend	(HPCS) 1 MDP	1 TDP	3 DGs	3 MDPs (used for RHR system)	1 MDP	2 MDPs (use 2 LPI pumps at the different possible RHR modes)			(SSW) 4 MDPs
Susquehanna 1&2	1 TDP	1 TDP	4 DGs	4 MDPs (used for RHR system)	4 MDPs	4 MDPs (use the LPI pumps at the different possible RHR modes)			(SSW) 2 MDPs

Table C-7. Emergency power front-line system components for BWRs.

	Components (# of emergency diesel generators per Unit)		
	2 DGs	3 DGs	4 DGs
Plants	Monticello	Clinton La Salle 1&2 River Bend	Browns Ferry 1,2,&3 Brunswick 1&2 Fitzpatrick Fermi Peach Bottom 2&3 Susquehanna 1&2

Table C-8. High pressure core injection front-line system components for BWRs.

	Components	
	HPCI (HPCI is performed with a TDP)	HPCS (HPCS is performed with a MDP)
Plants	Browns Ferry 1,2,&3 Brunswick 1&2 Fitzpatrick Fermi 2 Monticello Peach Bottom 2&3 Susquehanna	Clinton La Salle 1&2 River Bend

Table C-9. Low pressure core injection front-line system components for BWRs.

	Components (# of motor-driven pumps per Unit)	
	3 MDPs	4 MDPs
Plants	Clinton La Salle 1&2 River Bend	Browns Ferry 1,2,&3 Brunswick 1&2 Fitzpatrick Fermi 2 Monticello Peach Bottom 2&3 Susquehanna 1&2

Table C-10. Low pressure core spray front-line components for BWRs.

	Components (# of motor-driven pumps per Unit)		
	1 MDP	2 MDPs	4 MDPs
Plants	Clinton La Salle 1&2 River Bend	Brunswick 1&2 Fitzpatrick Monticello	Browns Ferry 1,2,&3 Fermi 2 Peach Bottom 2&3 Susquehanna 1&2

Figure 1. High pressure recirculation system unreliability for select ASP PWR class B plants.

Figure 2. High pressure injection system unreliability for select ASP PWR class B plants

Figure 3. Emergency power system unreliability for select ASP PWR class B plants

Further analysis evaluated two full-level, detailed PRA models from plants that have very similar design. The two plants meeting this criteria were Peach Bottom and Fitzpatrick. Both of these plants are BWR/4, Mark I, designs. Table C-11 shows an overview of select system attributes for these two plants. The majority of the systems in these two plants are similar, with the possible exception of the low pressure core spray (LPCS) and the emergency service water (ESW) systems. Electric power is different for the two plants since Peach Bottom is a two unit site while Fitzpatrick is a individual unit. While the two plants are similar, the end results of the PRA models [i.e., core damage frequency (CDF)] were slightly different. Peach Bottom has a reported CDF of 3.6E-6 while Fitzpatrick has a reported CDF of 1.9E-6.

Modeling differences factor into the variation of the CDF between the two plants. For example, Table C-12 list some of the common cause failure probabilities and their respective beta factors for the two plant models. These data difference along with modeling difference determine the overall results of the PRA model. Also, the detailed PRA models differ considerably in the number of events in the models (Peach Bottom has less than 1000 events while Fitzpatrick has more than 6500 events). Consequently, even for PRA models that are very similar, the analyst should be aware of the specifics of the models in order to use them for a variety of analyses.

Table C-11. Comparison of select Peach Bottom and Fitzpatrick systems

System	Peach Bottom	Fitzpatrick
LPCS	Two loops. Four motor driven pumps (3125 g.p.m. @ 105 psig, 4160 Vac/125 Vdc control). Suction: suppression pool, condensate storage tank. Actuation: Reactor low level, drywell high pressure, reactor vessel low pressure.	Two loops. Two motor driven pumps (4700 g.p.m. @ 116 psig, 4160 Vac/125 Vdc control). Suction: suppression pool, condensate storage tank. Actuation: Reactor low level, drywell high pressure, reactor vessel low pressure.
RCIC	Turbine driven pump (600 g.p.m. @ 1135 psig). Suction: Suppression pool, CST. Actuation: Reactor low level.	Turbine driven pump (400 g.p.m. @ 1120 psig). Suction: Suppression pool, CST. Actuation: Reactor low level.
HPCI	Single train, turbine driven pump (5000 g.p.m. @ 1135 psig). Actuation: Reactor low level, drywell high pressure Suction: Suppression pool, CST.	Single train, turbine driven pump (4250 g.p.m. @ 1120 psig) Actuation: Reactor low level, drywell high pressure. Suction: Suppression pool, CST.
ESW	Two pumps in parallel. Vertical, single stage (8000 g.p.m. @ 132 ft). Two booster pumps supply cooling tower (8000 g.p.m. @ 100 psig). ECW pumps are the same as the ESW pumps. Suction from cooling tower. Actuation: DG start signal, drywell low level pressure, drywell high pressure.	Two independent loops, one pump per loop (3250 g.p.m. @ 80 psia). Actuation: DG start signal, reactor closed cooling system lower pressure.

Table C-12. Comparison of common cause event values for Peach Bottom and Fitzpatrick

Description	Peach Bottom		Fitzpatrick	
	Prob.	Beta	Prob.	Beta
CCF of DGs to start	3.900E-005	0.013	1.500E-005	0.13
CCF of two CSS injection valves	7.800E-005	0.026	2.150E-004	0.088
LCS pumps CCF	1.470E-004	0.049	2.500E-004	0.088
CCF of injection valves to open	1.470E-004	0.049	8.710E-005	0.088
SLC pumps fail due to CCF	6.300E-004	0.21	7.350E-005	0.15
CCF of SPC injection valves	1.470E-004	0.049	6.610E-005	0.088

Since it has been demonstrated that a classification scheme (e.g., the ASP classification scheme) that broadly groups plants may not indicate the most appropriate model for a particular analysis, an alternative approach may be desirable. This alternative approach should be able to effectively suggest an applicable PRA model depending on the particulars of the analysis being performed. In order to do this, a cross referencing scheme will need to be developed that focuses on the attributes of the PRA models and the needs of the analyses that are routinely performed. One potential cross referencing scheme could be developed according to:

- (1) "Dissect" the available PRA models in order to determine
 - How pieces of the models could be categorized. Examples include the extracting information for:
 - a. Systems/subsystems.
 - b. Accident sequences.
 - c. Event trees.
 - d. Recovery actions.
 - e. Size and complexity of model.
- (2) Once the categorization scheme is determined from (1) above, two parallel paths could be taken.
 - Gathering the data for the various categories from each plant PRA model (both simplified and detailed models).
 - Prototyping the software that would handle the cross referencing of the model information.
- (3) After data is collected and the software is completed, tests could be performed to:
 - Debug the software.
 - Determine potential improvements that could improve the software.

By computerizing the cross referencing function, the model attributes would be readily available to PRA analysts and would help to identify models applicable to the types of analyses they are performing.

1. Science Applications International Corporation, *Daily Events Evaluation Manual*, 1-275-03-336-01, January 1992.