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Developing and Assessing Accident Management Plans for Nuclear Power Plants

Development Process and Criteria

Prepared by
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EG&G Idaho, Inc.

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ABSTRACT

This document is the first volume of a two-volume NUREG/CR. It describes a four-phase approach for developing criteria that can be used for assessing the adequacy of severe accident management plans for nuclear power plants. The general attributes of accident management plans (Phase 1) are identified, and a process for developing and implementing severe accident management plans (Phase 2) is described. This process is based on a prototype process described in NUREG/CR-5543. The prototype process was revised using results from an evaluation of this process (Phase 3), which is documented in Volume 2. General criteria for assessing the adequacy of accident management plans are also presented (Phase 4). These criteria were based on process specific criteria presented in Volume 2 and NUREG/CR-5543.

FIN B5723—Accident Management Framework

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EXECUTIVE SUMMARY

Accident Management is an essential element of the Nuclear Regulatory Commission (NRC) Integration Plan for the closure of severe accident issues. This element will consolidate the results from other key elements, such as the Individual Plant Examination, the Containment Performance Improvement, and the Severe Accident Research programs, in a form that can be used to enhance the safety programs for nuclear power plants. The NRC is currently conducting a program that will aid in defining the scope and attributes of accident management. The fundamental objective of the program is as follows:

> Each NRC licensee shall implement for each nuclear plant an 'Accident Management Plan' that provides a framework for evaluating information on severe accidents, including that developed through conduct of the Individual Plant Examinations, for preparing and implementing severe accident operating procedures, and for training operators and managers in these procedures.

The NRC staff, including the Office of Nuclear Regulatory Research (RES), received instructions from the Commission and the Executive Director for Operations to work with the nuclear utility industry to define the scope and content of accident management plans and to develop guidance on these plans. In accordance with these instructions, RES is conducting a research program to establish those attributes of a plant severe accident management plan that are necessary to ensure effective response to credible severe accidents and recommend criteria that can be used to assess the adequacy of accident management plans.

To assist in this program, an approach comprising four phases has been developed to identify the important attributes of a severe accident management plan and, based on these attributes, to produce assessment criteria. The primary objective for each phase follows:

> Phase 1. Identify the general attributes that an implemented accident management plan should include, based on the stated accident management objectives and other pertinent information.
>
> Phase 2. Integrate the identified general attributes into a prototype process that includes the steps necessary to develop and implement an accident management plan with the capability to provide severe accident management at a plant.
>
> Phase 3. Validate the capabilities of the process through an application that uses information expected to be available at a nuclear power plant. This application is intended to identify discrepancies. Improvements will be developed to correct them.
>
> Phase 4. Identify criteria, based on the important characteristics of the validated process, that can be used to assess the adequacy of accident management plans.

All phases of this approach have been completed. Initial results, including a prototype process and preliminary criteria, were documented in NUREG/CR-5543. Volume 2 of this NUREG/CR presents results from the validation of the prototype process (Phase 3) and a set of process-specific assessment criteria that were developed. The process was modified to reflect the results of the validation phase and a set of more general criteria were produced (Phase 4). This report updates NUREG/CR-5543 to incorporate these results in Phases 1, 2, and 4.

We have used information from the following sources to identify the general attributes that an accident management plan should have: the objectives for accident management described in NRC correspondence (SECY-012-89), the five accident management framework elements identified by the NRC, and the processes involved in the development of the currently used design-basis approach for classifying and analyzing potential accidents. We identified nine attributes by assessing and integrating the information obtained from these three sources. We believe an implemented accident management plan should have the following general attributes:

1. Adequate information to understand the *capabilities and potential limitations* of the plant, including both equipment and personnel

2. A clearly identified set of accident management *strategies* that will effectively prevent or mitigate undesirable accident consequences

3. *Procedures and guidelines* implemented at all appropriate levels in the organization for executing the strategies

4. *Engineered methods* (necessary systems and equipment) identified for the proper implementation of strategies

5. Indication that adequate *plant status information* is available to monitor all plant safety functions and is available to select and to assess the effectiveness of all strategies

6. Clearly delineated lines of *decision making authority and responsibility*

7. Provision for adequate *training* of all personnel involved in accident management

8. *Validation* of the performance of the implemented accident management plan

9. A formal mechanism in place to *identify and incorporate new information* into the implemented accident management plan as it becomes available.

Our process is based on these attributes. Figure ES-1 illustrates the eight steps of the process.

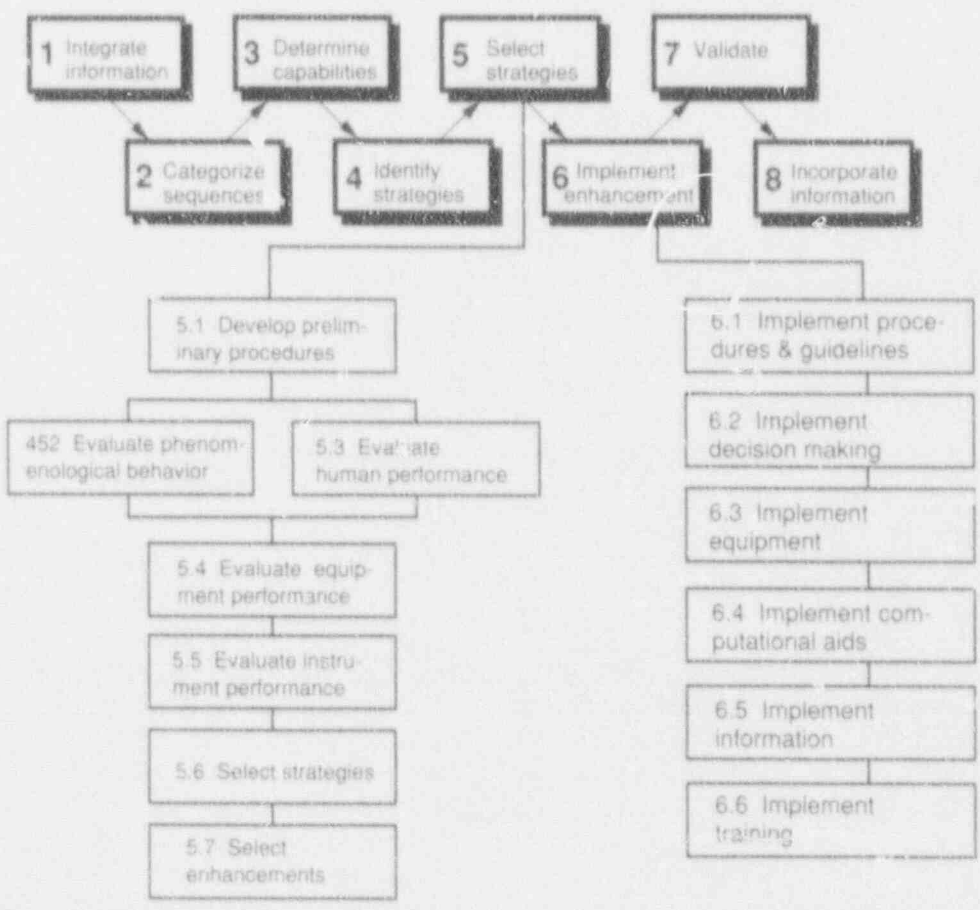


Figure ES-1. Process for developing an accident management plan.

Step 1. Assemble the existing information needed to understand plant capabilities and limitations during severe accidents. Examples of such information are individual plant examination (IPE) results, plant-specific design and operations information, and results from severe accident research.

Step 2. Categorize the severe accident sequences identified by the IPE or PRA into assessment categories having similar accident characteristics and challenges to safety functions. These assessment categories will guide the remaining steps in determining what plant capabilities exist to enhance accident management and what accident management strategies would be beneficial.

Step 3. Identify plant-specific accident management capabilities having the potential to be effective for the assessment categories identified in Step 2. We recommend a structured question-answer format for the following areas: procedures and guidance, training, instrumentation, equipment, and decision-making responsibility and authority. These accident management capabilities are used in Steps 4 and 5 to identify and evaluate strategies.

Step 4. Identify strategies that have the potential to prevent or mitigate the consequences for the assessment categories identified in Step 2. Use the answers to questions developed in Step 3 to accomplish this objective, by identifying accident management actions that intervene in the accident sequences, placing emphasis on the use of existing plant equipment and personnel. Strategies identified for similar plants or identified from other investigations should also be considered.

Step 5. Evaluate the potential strategies identified in Step 4 and select those that will be most effective. Initially, develop preliminary procedures that list in detail the tasks needed to implement each potential strategy. Then, evaluate the details of the strategy in four different but interrelated areas: phenomenological behavior, human performance, equipment performance, and instrument performance. The results of these evaluations can then be used to select strategies that will effectively address the sequence categories. Once you have selected strategies, you can identify the accident management enhancements necessary for implementing all selected strategies. Enhancements are those changes in the plant hardware and operations necessary to implement the selected strategies.

Step 6. Use the information developed in the five previous steps to implement your accident management enhancements. Though each plant will likely have a unique process for implementation, the areas where changes will be made are common: (a) procedures and guidance, (b) delineation of decision-making responsibility and authority, (c) equipment and engineered systems, (d) computational aids, (e) instrumentation, and (f) training programs.

Step 7. Validate your implemented accident management plan, including the strategies, procedures, guidance, computational aids, engineered methods, decision-making structure, and training. The methods are similar to the validation tasks identified in NUREG-0899 for implementation of the symptom-based emergency operating procedures (EOPs).

Step 8. Identify and incorporate new severe accident information in the implemented accident management plan. This is accomplished by (a) identifying new severe-accident information that has not been considered in the implemented accident management plan, (b) determining how this new information influences the implemented accident management plan, and (c) identifying needed improvements, if any.

A set of general assessment criteria were developed that can be used to assess the adequacy of methods suggested for developing severe accident management plans or to examine the capability of plans that are completed. Note that both our recommended process and our assessment criteria have not been extensively reviewed or approved by the NRC staff.

ACKNOWLEDGMENTS

We express appreciation to Donald E. Solberg, the NRC Project Manager, and to those within the NRC who have offered ideas and suggestions for improving the approach and content of this document. We also acknowledge the creative efforts of David R. Pack who formatted and provided technical editing for the document.

EXPLANATION OF KEY TERMS

Accident management or severe accident management — Actions taken during the course of an accident by the plant operating and technical staff to prevent core damage, terminate any progress of core damage and retain the core within the reactor vessel, maintain containment integrity as long as possible, and minimize offsite releases. Accident management is separate from, but coordinated with, emergency preparedness, which is concerned with the response to a release of radioactive material to the environment.

Accident management plans — Plans and actions undertaken by a nuclear plant staff prior to an accident to ensure that adequate plant hardware capability exists and that plant personnel with responsibilities for accident management are adequately prepared to take effective onsite actions to prevent, or mitigate the consequences of, a severe accident.

Computational aid — Precalculated analyses, nomographs, or easily used computer aids available to plant staff during an accident for estimating the occurrence and timing of key plant phenomena and for evaluating the efficacy of candidate strategies.

Decision making — The process of solving a problem through the conscious acts of consideration and resolution.

Emergency operating procedures (EOPs) — Plant procedures that direct licensed operators' actions necessary to mitigate the consequences of transients and accidents that have caused plant parameters to exceed reactor protection system set points or engineered safety feature set points, or other established limits.

Engineered methods — Methods that use plant hardware that can be used in accident management strategies to prevent or mitigate the consequences of severe accidents. Examples are spool pieces that provide a cross tie between water sources for units at multiple unit sites, or nonsafety-grade pumps capable of supplying water to the containment spray systems.

Event-oriented EOPs (emergency operating procedures) — Event-oriented EOPs providing operating instructions that are very effective but require that an operator diagnose the specific event causing the transient or accident in order to mitigate the consequences of that transient or accident.

Framework — Those elements of an accident management plan needed to ensure it is effective yet flexible enough to accept new information. The framework currently consists of five elements: organization and decision making, strategies and procedures, guidance and computational aids, instrumentation, and training.

Function-oriented EOPs — EOPs that provide operator guidance on how to verify the adequacy of critical safety functions and how to restore and maintain those functions when they are degraded. Function-oriented emergency operating procedures are written in a way that the operator need not diagnose an event, such as a LOCA, to maintain a plant in a safe condition.

Industry guidance — Information provided to nuclear utilities (for example, by NRC and NUMARC) to aid in development of an accident management plan.

Interfacing system loss-of-coolant accidents (ISLOCAs) — A class of accidents initiated by hardware failures or human errors that result in the overpressurization and rupture of systems that interface with the reactor coolant system. Significant risk may be attributed to ISLOCAs that occur outside of the containment building.

Management — The acts of planning and supervising such that available resources are used to achieve an objective.

Phenomenological behavior—The conditions (for example, temperature, pressure, fuel state) occurring in a nuclear power plant system, containment, and surrounding environment resulting from the thermal, hydraulic, mechanical, radiological, and chemical phenomena.

Procedural Guidance — Plant procedures, guidelines, job descriptions, organizational descriptions, communication and information flow charts, descriptions of the decision making process, etc.

Procedures — Licensee-developed instructions that ensure planned plant staff responses to severe accident conditions.

Safety Function — A function specifically required to keep the plant in a safe condition so that public health and safety will not be endangered. Example safety functions are maintaining core heat removal, maintaining reactor coolant system heat removal, and maintaining containment pressure control.

Strategy, global — A group of strategies or activities at a plant developed with the common objective to prevent or mitigate the effects of severe accidents.

Strategy, specific — One of a set of strategies or group of activities that accomplish a global strategy.

Symptom-based analysis — The concept of analyzing instrument indications of plant conditions and behavior to identify accident symptoms and to select strategies for accident management based on these symptoms.

Technical guidelines — Documents that identify the equipment or systems to be operated and list the steps necessary to mitigate the consequences of transients and accidents and restore safety functions. Technical guidelines represent engineering data derived from transient and accident analyses and translated such that they can be used to write detailed plant procedures, for example, emergency operating procedures. There are two types of technical guidelines, as defined below.

Generic technical guidelines. Guidelines prepared for a group of plants with a similar design.

Plant-specific Technical Guidelines. Plant-specific technical guidelines are one of the following:

- Technical guidelines prepared by plants not using generic technical guidelines
- A description of the planned method for developing plant-specific EOPs from the generic guidelines by including plant-specific information (for example, deviations from generic technical guidelines necessary because of different plant equipment, operating characteristics, or design).

Validation — The processes by which an accident management plan is evaluated against the basic objectives or requirements of that plan. Typically, these objectives address the basic question of whether the various components of the plan are prepared properly, are integrated and well-interfaced, and are workable from both a technical and human factors standpoint.

Verification — The process of determining whether or not the products of a given phase of development meet all of the requirements established during all previous phases.

Writer's guide — A writer's guide details how to prepare text and visual aids for emergency operating procedures so that they are complete, accurate, convenient, readable, and acceptable to control room personnel. Its recommendations address all aspects of writing procedures from a human factors standpoint.

A Systematic Process for Developing and Assessing Accident Management Plans

INTRODUCTION

Significant capabilities for the management of accidents currently exist at nuclear power generating stations in the United States. These capabilities are based on the United States Nuclear Regulatory Commission (NRC) regulations and are generally outlined in Supplement 1 to NUREG–0737, Emergency Response Capability (USNRC 1982)[a] and in NUREG–0654/FEMA-REP-1, Rev. 1, Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants (USNRC 1980). Examples of these capabilities include the following:

- Emergency response facilities
  - Technical support center
  - Operational support center
  - Emergency operations facility
- Function-oriented, symptom-based emergency operating procedures (EOPs)
- Instrumentation in accordance with Regulatory Guide 1.97
- Control rooms with appropriately human engineered equipment
- Safety parameter display system (SPDS)
- Radiological emergency response plans, including
  - Onsite emergency organization
  - Emergency classification
  - Notification and communications
  - Accident assessment
  - Protective response
  - Radiological exposure control
  - Exercises and drills.

a. Reference to sources is by author and date. See the Reference section, page 62, for full citations.

These capabilities are generally directed toward preventing damage to the reactor core, preventing containment failure, and minimizing public health risks. Although some capabilities exist for managing the effects of severe accidents (those that extend beyond core damage), the effectiveness of these capabilities to reduce risk for a broad range of credible severe accidents has not been demonstrated.

The staff of the NRC have concluded that the risk associated with severe core damage accidents can be further reduced through effective accident management. This conclusion was reached based on information from probabilistic risk assessments (PRAs), severe accident research and analysis, and findings from a study conducted through the International Nuclear Safety Advisory Group (INSAG 1988). Examples of potential limitations identified in the current approach to accident management are as follows:

- The emergency operating procedures (EOPs) presently implemented at nuclear power plants are primarily directed at the prevention of core damage, which is the first priority of accident management, and at the maintenance of containment integrity. However, these EOPs may not have sufficient directions for coping with extensive core damage and relocation, failure of the reactor vessel, threats to containment integrity that may derive from severe core damage, or mitigation of fission product release.
- The current provisions for coordination of onsite accident management with offsite, emergency response may need additional definition when managing severe accidents. For example, if containment venting is selected as an accident management strategy, the decision to execute an onsite strategy has potential off-

site consequences, which implies a need for additional communication and consultation with offsite organizations.

Accident Management is, therefore, an essential element of the NRC Integration Plan for the closure of severe accident issues and will provide a means to consolidate the results from other key elements [for example the Individual Plant Examination (IPE), the Containment Performance Improvement, and the Severe Accident Research programs] in a form that can be used to enhance the accident prevention and mitigation capabilities of nuclear power plants. The Accident Management element will ensure that planned actions and preparatory measures are developed that will extend operating procedures, guidelines, and training well beyond plant design-basis accident conditions and that will make effective use of existing personnel, equipment, and information in severe accident situations.

The NRC is currently conducting a program that will aid in defining the scope and attributes of accident management for nuclear power plants. The fundamental objective of the program is as follows:

> Each NRC licensee shall implement for each nuclear plant an 'Accident Management Plan' which provides a framework for evaluating information on severe accidents, including that developed through conduct of the Individual Plant Examinations (IPEs), for preparing and implementing severe accident operating procedures, and for training operators and managers in these procedures (USNRC 1989).

The accident management plan that licensees will develop and implement for each plant is expected to incorporate the four subsidiary objectives (USNRC 1989) listed in Table 1. This plan is intended to promote the most effective use of available utility resources (people and hardware) to prevent or mitigate severe accidents. Its implementation would be achieved through improvements in the existing emergency procedures and training programs, and by additional planning for severe accidents, which could strengthen the support provided to the plant operating staff in case of a severe accident. Extensive hardware changes to reduce the frequency of severe accidents are *not* a central aim of the implementation of this plan, though limited minor modifications may prove beneficial.

The NRC staff, and the Office of Nuclear Regulatory Research (RES) in particular, received the following instructions from the Commission and the Executive Director for Operations (USNRC 1989):

> The staff will continue to work with NUMARC to define the scope and content of an accident management framework or plan and the means for implementing such a frame-

Table 1. Accident management plan objectives

1. Develop technically sound strategies for maximizing the effectiveness of personnel and equipment in preventing and mitigating potential severe accidents. This includes ensuring that guidelines and procedures to implement these strategies are in place at all plants.

2. Ensure that installed instrumentation and equipment called for in the diagnosis and control of accidents beyond the design basis are identified and assessed to determine their availability and capabilities, and the need for incremental improvements of existing systems to ensure their availability is assessed.

3. Ensure that nuclear plant staff are trained in the procedures and guidelines to follow in the event of an accident beyond the design basis of the plant, and ensure the utility management is trained and prepared to deal with severe accidents.

4. Provide a technical basis for assessing the effectiveness of specific accident management strategies and capabilities.

> work. Through a coordinated effort, the staff will develop guidance on the accident management framework (as part of the accident management research effort). . . .
>
> The NRC will provide guidance to industry on the scope and content of a utility accident management plan or framework in a generic letter on accident management.

Responding to these instructions, RES is conducting a research program to establish those attributes of a plant severe accident management plan necessary to ensure effective response to credible severe accidents and to recommend criteria that can be used to assess the adequacy of accident management plans. Figure 1 illustrates the general approach developed to provide assessment criteria. The rectangles in the figure represent information sources used in the approach, and the circles represent the phases that must be accomplished to carry out the approach. The primary objectives for each phase are as follows:

Phase 1. To use the NRC objectives outlined in SECY-012-89 (USNRC 1989) and other pertinent information to identify the general attributes that an implemented accident management plan should include.

Phase 2. To integrate the identified general attributes into a prototype process that includes the steps necessary to develop and implement an accident management plan with the capability to provide severe accident management at a plant.

Phase 3. To validate the capabilities of the process through an application that uses information typical of that expected to be available at a nuclear power plant. This application is expected to identify discrepancies in the process. Improvements will be developed to correct the discrepancies.

Phase 4. To use the important characteristics of the benchmark process to identify criteria that can be used to assess the adequacy of accident management plans developed and implemented by the nuclear utility industry.

In this report, Volume 1 of a two-volume NUREG/CR, we update the results presented in NUREG/CR-5543 (Hanson et al. 1991) to include

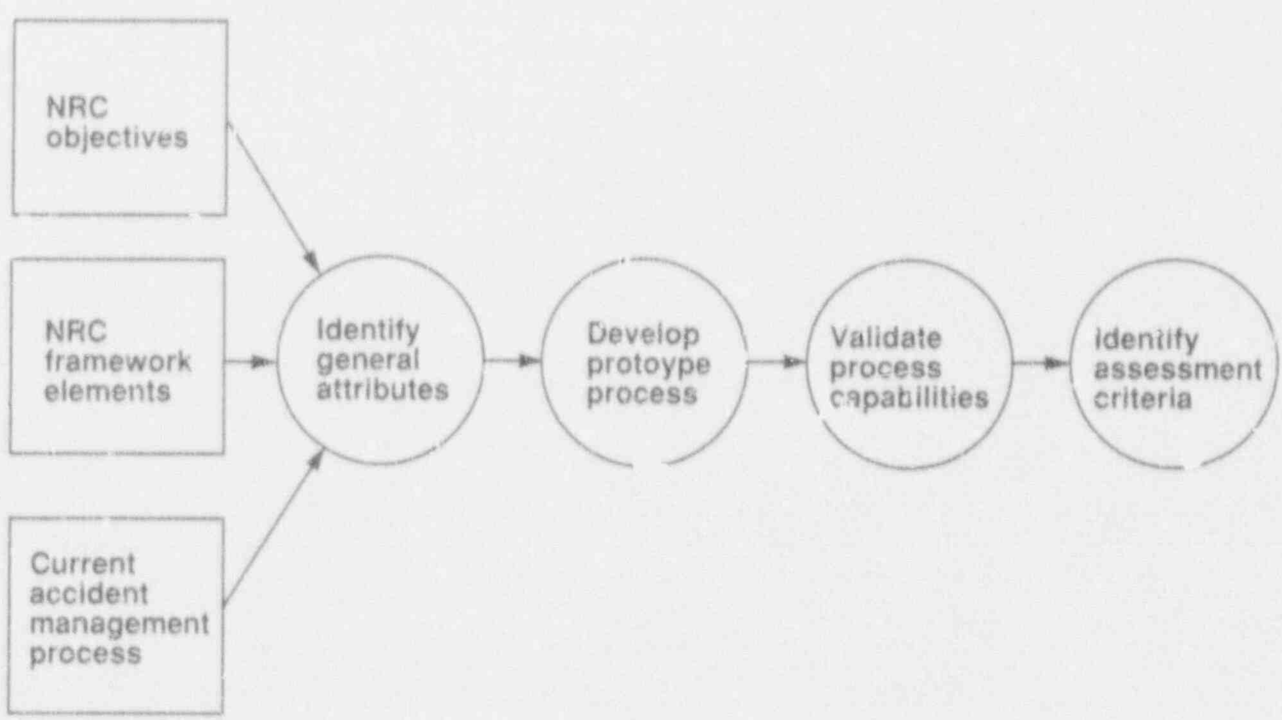


Figure 1. Approach for developing guidance for an accident management plan.

lessons learned during the validation of the prototype process (Phase 3). Results from Phases 1, 2 and 4 are emphasized. Section 2 describes the general attributes developed during the first phase and shows how these attributes were used to outline a prototype process for Phase 2. Section 3 describes in detail the updated process for development and implementation of accident management plans. This process is based on the prototype process developed during Phase 2, and documented in NUREG/CR-5543, and includes improvements identified during the third phase. Section 4 contains a general set of criteria that can be used to assess accident management plans. Volume 2 (Hanson et al. 1991) contains the results from Phase 3 and describes changes to the preliminary criteria documented in NUREG/CR-5543.

Note that both the process and the criteria represent recommendations by the authors that have not been extensively reviewed or approved by the NRC staff.

2. IDENTIFICATION OF GENERAL ATTRIBUTES AND AN OUTLINE OF A PROCESS

In this section we present results from the first of the four phases illustrated in Figure 1, the identification of general attributes that should be inherent in accident management plans. We also present an outline of a process, based on the identified attributes, that could be used for developing an accident management plan.

Identifying General Attributes

We used the information from the three major sources shown in the rectangles in Figure 1 to identify the general attributes an accident management plan should have. The NRC objectives, shown in the first rectangle and discussed in Section 1, describe the outcome expected from the development and implementation of an accident management plan, which provide insights for identifying several key attributes. Example attributes are (a) technically sound strategies, (b) expanded guidelines and procedures, (c) adequate instrumentation, (d) improved equipment use, and (e) expanded training. From the second source of information, the NRC has identified five accident management framework elements considered essential for accident management (listed in Table 2). These framework elements are discussed both in SECY-012-89 (USNRC 1989) and in the material related to the Individual Plant Evaluation (IPE) program (Palla 1989). The third source of information is based on the processes involved in developing the currently used design-basis approach for classifying and analyzing potential accidents.

We identified the general attributes of an accident management plan by assessing and integrating information obtained from the three sources. As expected, there was good correspondence between the attributes derived from the NRC objectives and the NRC framework elements. We also identified additional attributes that complemented those identified from the other two sources, based on the review of current accident management approaches. From all sources, we identified a total of nine general attributes. Table 3 presents an overview of the attributes.

The nine attributes can be considered as representing three broad areas that relate to the preparation, implementation, and long-term monitoring of an accident management plan. The first attribute relates to the information necessary to prepare accident management plans. Attributes 2 through 7 are important during the preparation and implementation of accident management plans. Attributes 8 and 9 are necessary to ensure that an established accident management plan is validated and properly maintained. Justification of each of the attributes follows:

1. *Adequate information to understand the capabilities and potential limitations of the plant, including both equipment and personnel.*

   An understanding of potential accidents, and the capabilities that exist to prevent or mitigate these accidents, is important during the planning phases of accident management and also during the response phase, should an accident occur. Much of the information leading to this understanding would be acquired during the development of an IPE or PRA. Additional understanding will rely on a detailed knowledge of the design and operation of the plant. For example, an understanding of the capabilities and availability of non-safety grade equipment and other resources is necessary to ensure the most effective response to potential severe accidents.

2. *A clearly identified set of accident management strategies that will effectively prevent or mitigate undesirable accident consequences.*

   Preplanned actions (strategies) should be developed when the time for reaction to accident conditions is relatively short or when the consequences of an accident are considered to be high. Strategies for nuclear power plants

Table 2. NRC accident management framework elements

- Accident Management Strategies
- Training
- Guidance and Computational Aids
- Instrumentation
- Delineation of Decision-making Responsibilities

should be aimed at preventing core damage, preventing reactor vessel failure, preventing containment failure, and mitigating fission product release for the identified potential vulnerabilities of the plant.

3. *Procedures and guidelines implemented at all appropriate levels in the organization for executing the strategies.*

Procedures and guidelines must be available to aid the personnel involved in accident management. Additional procedures and guidelines may be needed for severe accidents to ensure that all personnel involved in accident management will successfully implement proper preventive or mitigative measures. Guidelines may be most appropriate for personnel located at the technical support center or in utility corporate offices. All procedures and guidelines should be based on evaluations of the tasks personnel must perform.

4. *Engineered methods (necessary systems and equipment) identified for the proper implementation of strategies.*

Some strategies may rely on the use of existing equipment in new or innovative ways or may rely on rapid assessment of accident conditions and rapid response. Engineered methods may therefore be in the form of either software or hardware. For example, we would consider identifying innovative system alignments, fabricating necessary spool pieces to allow the use of alternate pumps or coolant sources, and developing computational aids to project system conditions into the future to identify the need for immediate implementation of a specific strategy all as development and use of engineering methods.

Table 3. The nine general attributes of accident management

1. Adequate information to understand the capabilities and potential limitations of the plant, including both equipment and personnel
2. A clearly identified set of accident management strategies that will effectively prevent or mitigate undesirable accident consequences
3. Procedures and guidelines implemented at all appropriate levels in the organization for executing the strategies
4. Engineered methods (necessary systems and equipment) identified for the proper implementation of strategies
5. Indication that adequate plant status information is available to monitor all plant safety functions and is available to select and to assess the effectiveness of all strategies
6. Clearly delineated lines of decision making authority and responsibility
7. Provision for adequate training of all personnel involved in accident management
8. Validation of the performance of the implemented accident management plan
9. A formal mechanism in place to identify and incorporate new information into the implemented accident management plan as it becomes available

5. *Indication that adequate plant status information is available to monitor all plant safety*

functions and is available to select and to assess the effectiveness of all strategies.

Identification and diagnosis of accident conditions and selection, implementation, and assessment of the effectiveness of prevention or mitigation measures must all be based on the information supplied by the plant measurement systems. The measurement systems must supply accurate information over the full range of the expected accident conditions and must survive the harsh severe accident environments to ensure that accident management responses are adequate.

6. *Clearly delineated lines of decision making authority and responsibility.*

   Lines of authority and responsibility for decision making must be clearly defined during the planning phase of accident management to ensure timely, well-thought-out decisions, and that the decisions will be honored at all levels within the accident management structure during the response to an accident.

7. *Provision for adequate training of all personnel involved in accident management.*

   Personnel involved in accident management must be properly trained to ensure high likelihood they will successfully manage an accident. The extension of accident management into the severe accident regime may require that personnel involved in accident management possess additional skills, knowledge, and abilities (SKA). The desired SKAs and appropriate training must be identified.

8. *Validation of the performance of the implemented accident management plan.*

   Once an accident management plan is developed and implemented, a validation process should be used to ensure that all parts of the system work together to provide the desired level of accident management capability. Validation could be accomplished using such means as simulation, review, exercise, or drill.

9. *A formal mechanism in place to identify and incorporate new information into the implemented accident management plan as it becomes available.*

   Following the development and implementation of an accident management plan, new information on accident initiators, accident phenomena, or prevention and mitigation capabilities may become available. A means must be included for identifying and understanding the impact of this information, together with a means of modifying the implemented accident management plan if the new information could have significant impact on the identification, prevention, or mitigation of accidents.

Process Steps

Using the attributes described above, we have developed a process to produce an accident management plan. Figure 2 presents the steps of this process. Figure 3 presents the relationship between the previously described attributes and the steps and substeps of the process. We briefly describe the process now and provide additional detail in Section 3.

The first step in the process involves assembling the information needed to understand the capabilities and limitations of the plant. Resources that should be available at the beginning of this process include descriptions of plant design and operations, results from the IPE or the probability risk assessment (PRA), and severe accident information. Information should be plant-specific, though generic information can be used if it is determined to be directly applicable to the plant. Although most of the information would be readily available from an IPE or PRA, examples of important additional information are generic information from studies or evaluations of similar plants, recent NRC information Notices, and results from Generic Issue studies. Once you have assembled information you should incorporate it into the plant-specific database on severe accidents and make it accessible from strategic plant locations (such as at the technical support center and control room) where it can be used as a resource during the development phase of the acci-

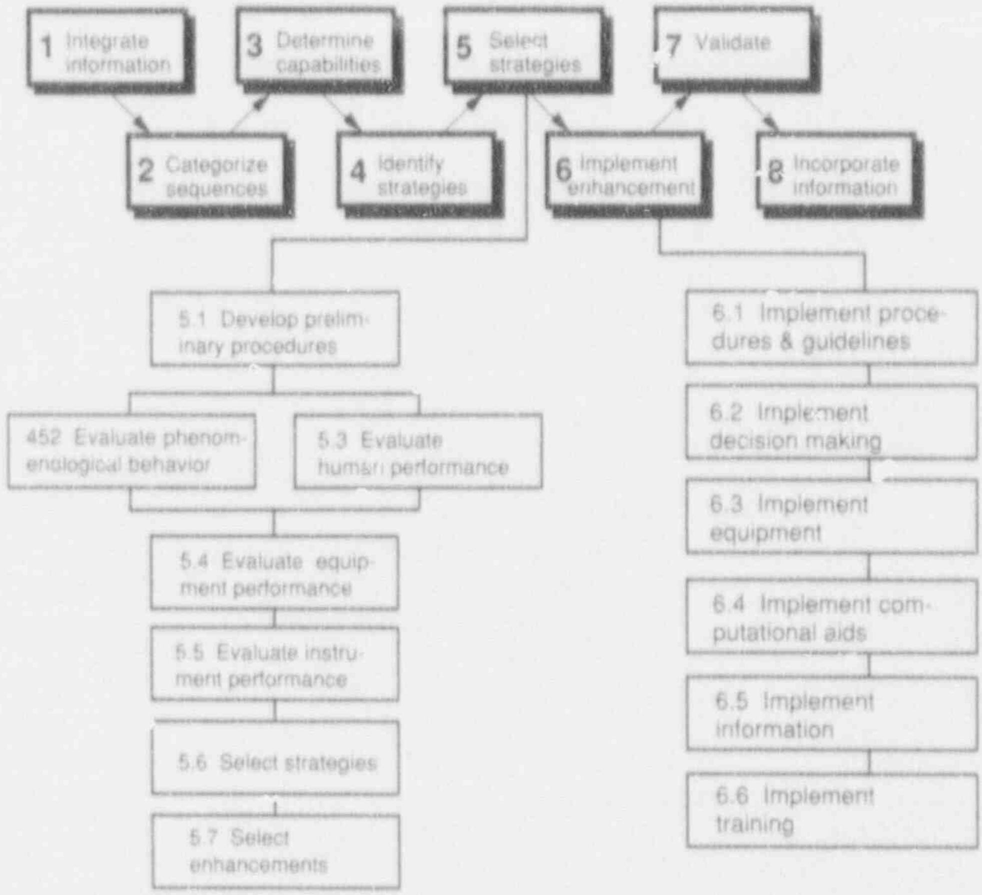


Figure 2. Process for developing an accident management plan.

dent management plan, during training and during response to an accident.

The objective of the second step of the process is to categorize the severe accident sequences identified by the IPE or PRA based on similarities in the characteristics of these sequences. Since there may be a large number of potentially different sequences, it is important to select characteristics that are broadly based, such as plant safety functions. For example, sequences that result in similar mechanisms that cause challenges to plant safety functions can be grouped together into categories. These categories, called assessment categories, are used throughout the remaining process steps to provide a basis for identifying potential accident management strategies and assessing their capabilities to prevent or mitigate severe accidents.

The third step is intended to identify and describe specific hardware and personnel capabilities that can be used as the basis for strategies that effectively prevent or mitigate severe accidents. Search for these additional capabilities must include several broad areas: procedures and guidelines, training, instrumentation, equipment, and decision making authority and responsibility. A broad examination of each area is necessary to ensure comprehensive results. For example, in the area of equipment you should identify non-safety grade equipment with the capability to perform the function of safety grade equipment. You would also determine what equipment could be repaired on site and the time required for its repair. A question-answer format is used to focus this examination.

The fourth step is a method to identify potential strategies that can intervene in the progress of a severe accident to prevent or mitigate its consequences. The first substep is to determine where there would be opportunities for intervention for

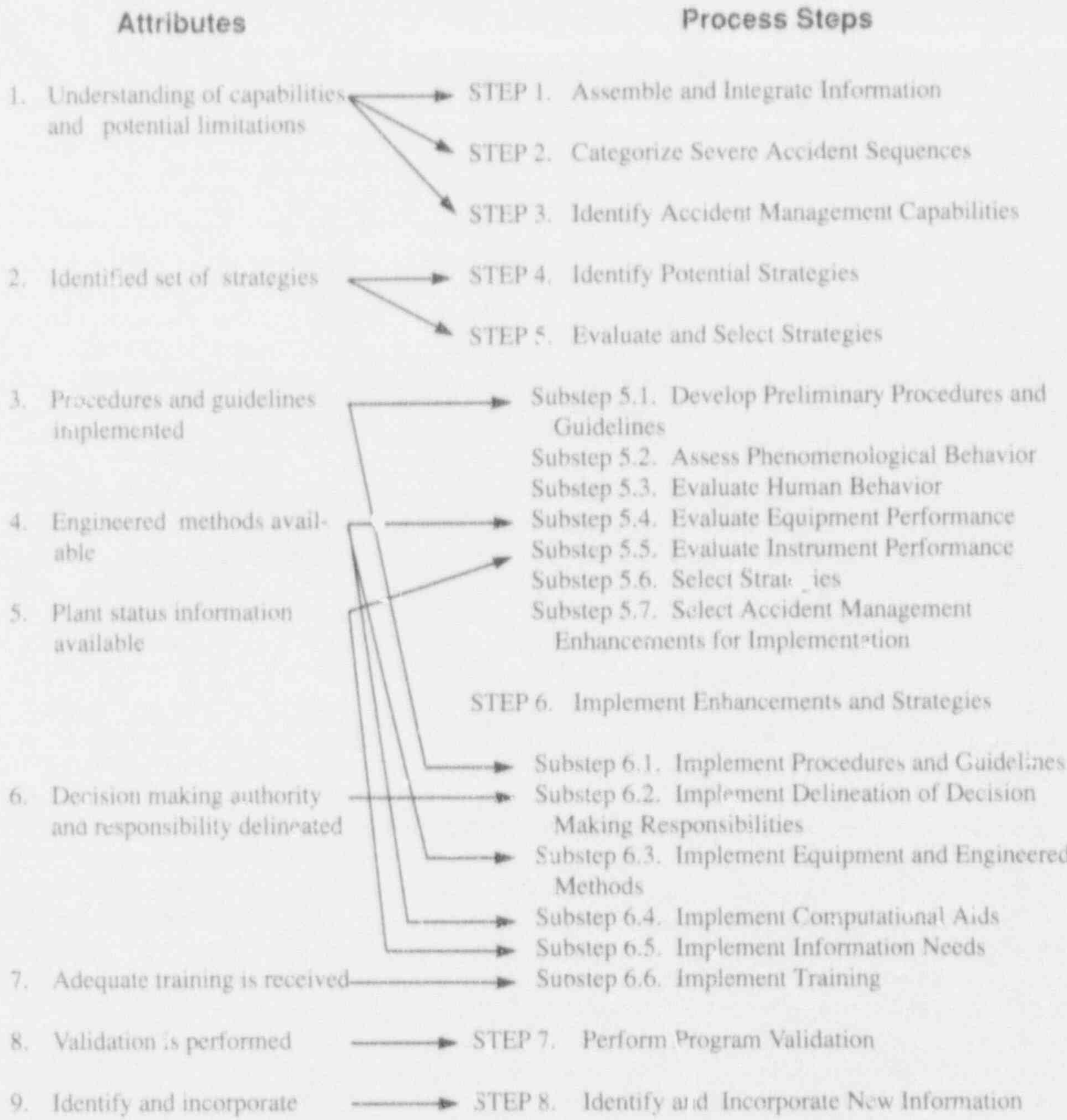


Figure 3. Relationship between attributes and process steps.

each assessment category, based primarily on the answers to the questions developed in Step 3. Potential strategies are then proposed to capitalize on these opportunities for intervention. In the second substep, identify potential strategies by examining the applicability of strategies from sources outside of the plant, for example, strategies recommended by the NRC or strategies found to be effective at similar plants. For the final substep, describe each proposed strategy in sufficient detail that an evaluation of the effectiveness of the strategy can be performed.

The objective of the fifth step is to evaluate the potential strategies and select those that would be the most effective, and to identify enhancements that should be implemented. Enhancements may be either strategy specific or general. Examples of enhancements are modifications to procedures needed to implement a strategy, or additional training on the expected plant response during severe accidents to ensure that personnel will respond properly. Figure 2 illustrates the process for executing this step. The substeps are designed to accomplish the following:

- Develop preliminary procedures and guideance to carry out the proposed strategies so that a detailed evaluation can be performed.

- Perform a coordinated analysis of each potential strategy to assess strategy performance and to determine whether there are additional needs for training, computational aids, instrumentation, and decision making. The analysis includes an evaluation of phenomenological behavior, human performance, equipment performance, and instrument performance.

- Select strategies based on a set of criteria that ranks the strategies based on such considerations as strategy effectiveness and likelihood of successful implementation.

- Select enhancements for implementation at the plant based on the results of the preceding substeps.

In the sixth step, implement the accident management enhancements selected in the previous step at the plant. These enhancements are modifications or additions to the plant in the following areas: procedures and guidelines, delineation of decision-making responsibility and authority, equipment and engineered systems, computational aids, instrumentation, and training programs. The process for implementation is general in some of these areas, for example, equipment and engineered systems, because the processes for modifying or adding equipment will be well-defined and plant specific. Additional detail in the areas of procedures and guidelines, and decision making responsibility and authority, are provided in this step since the enhancements needed for severe accident management in these areas may be less clear.

The seventh step of the process includes the work necessary to validate the accident management plan, including the strategies, procedures, guidelines, computational aids, engineered methods, decision making structure, and training. The role of validation is similar to the validation tasks identified in NUREG-0899 (USNRC 1982) for implementation of the system-based EOPs. The initial substep is a simple walkthrough of the procedures and aids to identify and correct any deficiencies in a given strategy. The second substep is a full, operational test of the strategy, which includes all parts of the organization involved in the accident. Periodic drills may be needed to ensure the implemented plan continues to be valid.

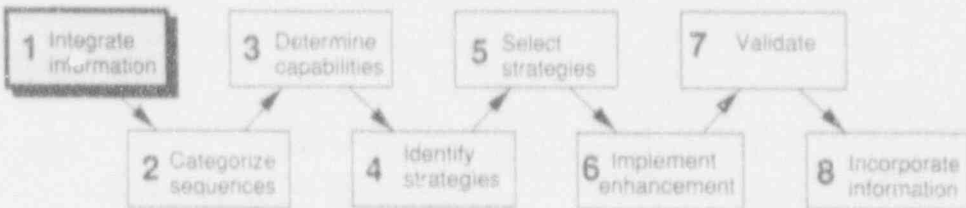
In the eighth step, identify new severe accident information that becomes available after the accident management programs have been put in place and consider how it might influence the implemented accident management plan. This information may improve your understanding of severe accident phenomena or quantify the effects of personnel or equipment performance during severe accidents, which could allow strategies to be eliminated, invalidate portions of existing procedures or strategies, or create the need for new strategies. To properly incorporate new information as it becomes available, identify important new information and evaluate its impact on the current accident management program. If changes are deemed advisable, use Steps 2 through 7 of the process described above for assessing and implementing the changes.

3. PROCESS FOR DEVELOPING AN ACCIDENT MANAGEMENT PLAN

This section describes the steps that make up the process in detail. Steps 2, 3, and 4 of the process were modified extensively based on the validation work performed during Phase 3.

We recommend that a team approach be used to execute the process steps. The team should be composed of personnel with knowledge and experience in the following areas: plant operations, emergency response facility operations, both safety and non-safety grade equipment, instrumentation, IPE or PRA results, severe accident analysis, human factors, and training.

Step 1. Assemble and Integrate Information



Assemble and review information on the capabilities and limitations of the plant and personnel during severe accidents to ensure that it provides sufficient detail to

- Understand the plant-specific behavior for severe accident conditions
- Understand the plant operational and hardware limitations that can affect the initiation of severe accidents or prevent their mitigation
- Identify the capabilities of plant personnel, equipment, and resources that could support severe accident management.

Major sources of information on plant-specific behavior and on current capabilities and limitations are individual plant evaluations (IPEs) or probabilistic risk assessments (PRAs). They identify the dominant accident sequences that lead to core damage and potential radiological releases. Other important sources of information that should be available to supplement understanding of plant limitations and capabilities are listed in Table 4.

Table 4 lists information sources in three categories: (a) Plant and Related Information, (b) IPE/PRA Results, and (c) Severe Accident Information. Plant and Related Information lists many sources of plant operational data and design-basis accident analysis results, including generic research studies, which provide a database of current plant capabilities. IPE/PRA results represent the IPE and Level 1 and 2 PRAs that identify existing plant capabilities and limitations with regard to accidents that progress beyond the design-basis accidents or into severe accidents. Severe Accident Information provides a source of severe accident phenomenological behavior and risk assessment analysis results. For example, the list of NRC Accident Management A strategies for reducing plant risk should also be included in the severe accident information.

Developing and implementing an accident management plan will be enhanced if you understand the following:

- The severe accident sequences that could occur at the plant should be identified and their estimated frequency of occurrence and possible consequences should be understood. This understanding should include those accident sequences that dominate the core melt frequency and those sequences that result in significant radiological releases, even if their

Table 4. Additional sources of information

Plant and Related Information

- Event notifications for power facilities
- Plant incident reports
- Licensee event reports
- Technical specifications
- Guidelines and EOPs
- Nuclear Review Board meeting minutes
- Plant Operations Review Committee meeting minutes
- Safety system functional inspections
- Plant audits
- INPO and SALP ratings reports
- INPO significant event reports
- Significant operations experience reports
- Final safety analysis reports
- 10 CFR 50.59 reviews
- Regulatory guides
- Vendor reports and analyses (response to TMI action items, generic safety issues)
- NSSS service bulletins
- Best-estimate analyses for simulator or operator training programs
- NRC information notices, bulletins, generic letters
- LOCA and non-LOCA Research

IPE/PRA Results

- Level 1 & 2 PRA
- IPE

Additional Severe Accident Information

- Severe accident research
- Generic PRA studies (NUREG 1150, NUREG 0396/0654)
- EPRI/NSAC/INPO reports
- IDCOR results
- NUREG and other research reports
- Assessment of information needs of operating staffs for management of severe accidents (assessment of accident management safety objectives)
- Accident Management A Strategies from SECY-012-89

probability is low. The IPE/PRA results should provide sufficient information to develop the necessary understanding.

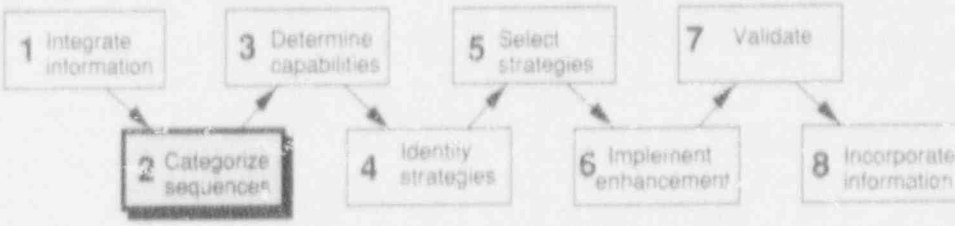
- For each sequence, the key plant phenomenological behavior should be identified and understood. Included should be key sequence events and their timings, system thermal and hydraulic response, important fuel behavior events, key radiological and chemical processes, and the expected physical behavior of the hardware. IPE/PRA information, together with additional severe accident information, could be used to supply the needed information.

- The plant equipment and instrument response for the sequences should also be identified and the availability, capability, effectiveness, and limitations of key plant systems understood, using the plant and related information.

- The expected human performance for key activities should be identified (key operator actions and technical support center inputs) and the capability and effectiveness of personnel understood. Both the positive and negative aspects of the operator actions and the technical support center should be considered. The plant and related information could be used in developing this understanding.

Note that no new information is to be developed in the process described. Assembling the information should familiarize you with expected plant behavior and capabilities during severe accidents. The information is a collection of reference material for use as a resource for the development of the severe accident plan, for use by the technical support staff in the event of an accident, and for training. The information assembled should be used to establish a database that can be conveniently accessed, either as indexed and cross-referenced hardcopy at appropriate locations or as a computerized system.

Step 2. Categorize Severe Accident Sequences



The objective of Step 2 is to organize the information on the plant severe accident sequences into categories that can be used during subsequent process steps to simplify the evaluation of the accident management capabilities and the identification of plant enhancements. The prototype process proposed three substeps for categorizing sequences. However, the Phase 3 validation results indicated that the proposed substeps did not accomplish the objective specified for this step.

Three alternative methods of categorizing sequence information were developed during the evaluation of the prototype process (Phase 3). The first method uses the events on the PRA or IPE event trees as categories because all severe accident sequences comprise a series of these events. Examples of categories based on events are Failure of HPI Systems, Failure to Depressurize RCS, High-Pressure Melt Ejection, Preexisting Containment Leak, and Steam Generator Tube Rupture. This method can be used to assess the current accident management capabilities and develop potential strategies to prevent or mitigate the events. We chose to call these categories assessment categories rather than sequence categories because they are not tied directly to a sequence or group of sequences but are a tool to aid in assessing and enhancing a plant's accident management capabilities.

The second method uses plant safety functions to identify appropriate categories. The concept of plant safety functions, which is already incorporated in the current symptom-based EOPs, can be used as the basis for categorizing severe accident sequences. The first task is to examine the plant safety functions currently used in the EOPs to assess their applicability during severe accidents and to identify additional safety functions or eliminate those that may not apply during severe accidents. This method of identifying the severe accident safety functions starts with the overall objectives of accident management and relates these objectives to the various strategies using a hierarchical tree structure. The role of personnel in the management of a severe accident is to ensure that certain safety objectives are met. In order to meet these safety objectives, certain critical plant safety functions must be maintained within acceptable limits. An accident will present challenges to the safety functions, which are caused by different mechanisms. Although not necessary for the categorization process, the strategies for preventing or mitigating the mechanisms that cause safety function challenges can also be listed. The safety objectives, safety functions, challenges, mechanisms, and strategies form a natural hierarchy that, for convenience of analysis, can be arranged in a tree structure.

For this example, assume that the plant safety functions associated with prevention of the accident have not been successfully employed and, as a consequence, core damage has occurred and a severe accident is underway. (Core damage is considered to have occurred when there is significant oxidization of the cladding and fission products have been released into the reactor coolant system.) The severe accident management objectives and their supporting safety functions can be separated into two categories, those associated with in-vessel accident management and those associated with containment and release management. These categories correspond with the barriers to fission products that remain once the fuel has been damaged and encompass strategies that can be implemented to reduce the inventory of fission products available for dispersion to the environment. Based on this categorization, the plant safety objectives can be defined as prevent core dispersal from vessel, prevent containment failure, and mitigate fission product release from containment.

Safety objective trees have been developed during NRC-sponsored accident management research for a pressurized water reactor (PWR) with a large dry containment (Hanson et al. 1990) and for a boiling water reactor (BWR) with a Mark I containment (Chien and Hanson 1991). Both of these sets of safety objective trees are applicable to plants with similar design characteristics. Examples of the three trees for the PWR are shown in Figures 4, 5, and 6.

Categorization of severe accident sequences can be accomplished based on the mechanisms shown on the safety objective trees. These mechanisms represent unique identifiers of challenges to plant safety functions and strategies with the potential to prevent or mitigate challenges to safety functions related directly to these mechanisms. Examples of assessment categories for this method are Inadequate Secondary Inventory, Inadequate RCS Inventory, Direct Containment Heating, Failure to Isolate, and Steam Generator Tube Rupture.

The third method combines the characteristics of the first two methods to define assessment categories. It was developed to reduce the number of categories by correlating the events from the event trees with the mechanisms from the safety objective trees. Correlation can be accomplished by charting the events associated with each sequence from the event trees onto the mechanisms represented on the safety objective trees. An example sequence that begins with a loss of steam generator feedwater and progresses through a steam generator tube rupture and eventual core relocation and containment failure is charted onto safety objective trees in Figures 7 and 8. The diagonal lines through the mechanism boxes indicate that the mechanism corresponds to an event in a particular sequence. In the charting process, several events may be correlated under a single mechanism, and this mechanism is then used as an assessment category. For example, High-Pressure Safety Injection Failure and Low-Pressure Safety Injection Failure both fall under the Inadequate RCS Inventory mechanism. By compiling results from the charting of all sequences, mechanisms that are not important challenges to safety functions for that plant-specific categorization are identified. Based on the Phase 3 results, we estimate that about twenty percent of the mechanisms could be eliminated from consideration as assessment categories if the correspondence between all events and mechanisms were charted. In addition, if the events from each sequence were charted, relationships between individual assessment categories could be identified. An understanding of the relationship among assessment categories may be important, because strategies that may be beneficial for one assessment category must be examined to ensure that they do not cause negative effects for related assessment categories.

We concluded that any of the three methods of defining severe accident assessment categories could be used in the remaining steps of the process. However, we prefer using assessment categories defined by the third method, a combination of events and safety objective tree mechanisms, because the number of categories is reduced and the trees show the relationship between the plant safety objectives, the remaining assessment categories (mechanisms), and potential and final strategies. Understanding these relationships should assist in identifying plant accident management capabilities and assessing potential accident

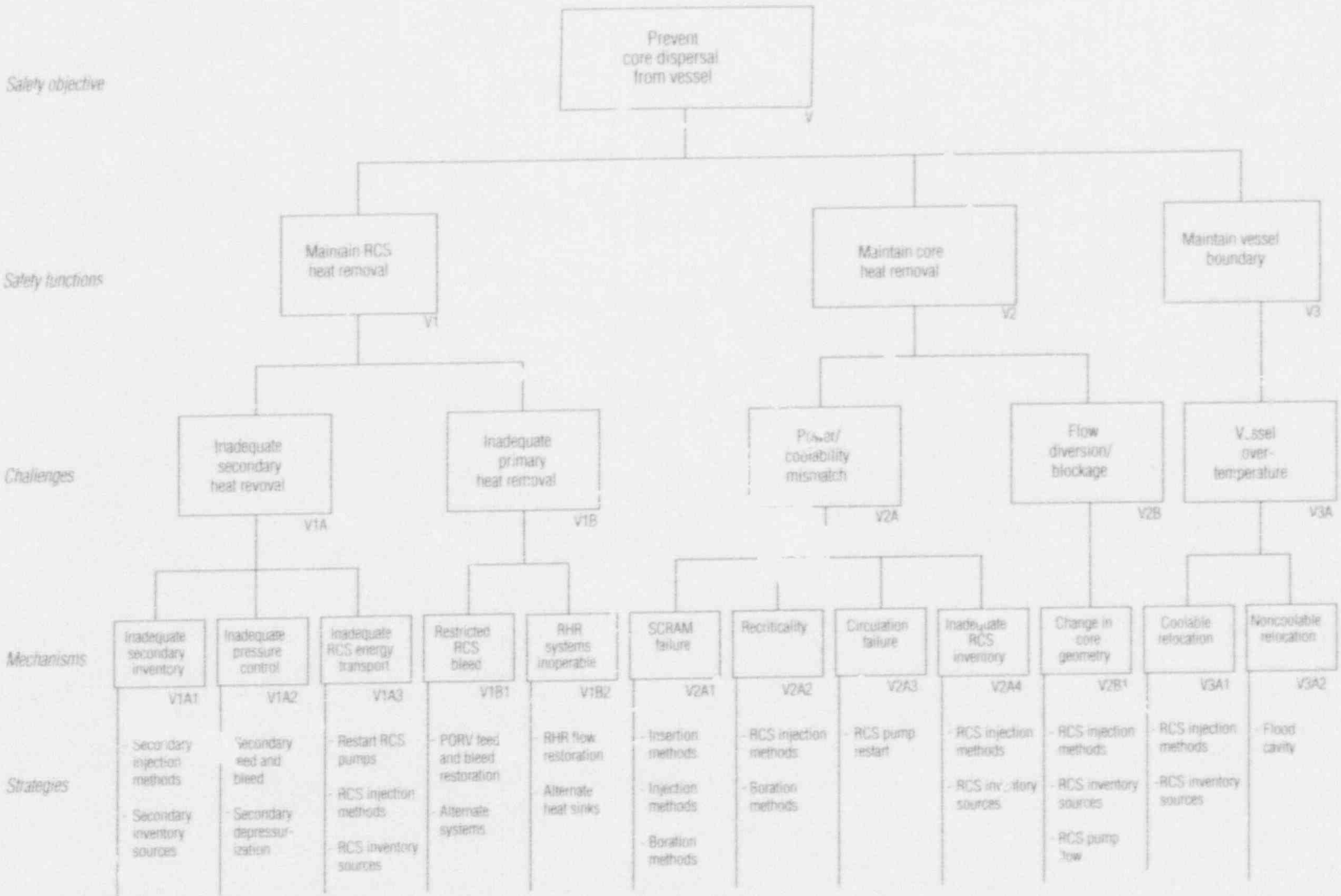


Figure 4. Safety objective tree: prevent core dispersal form vessel.

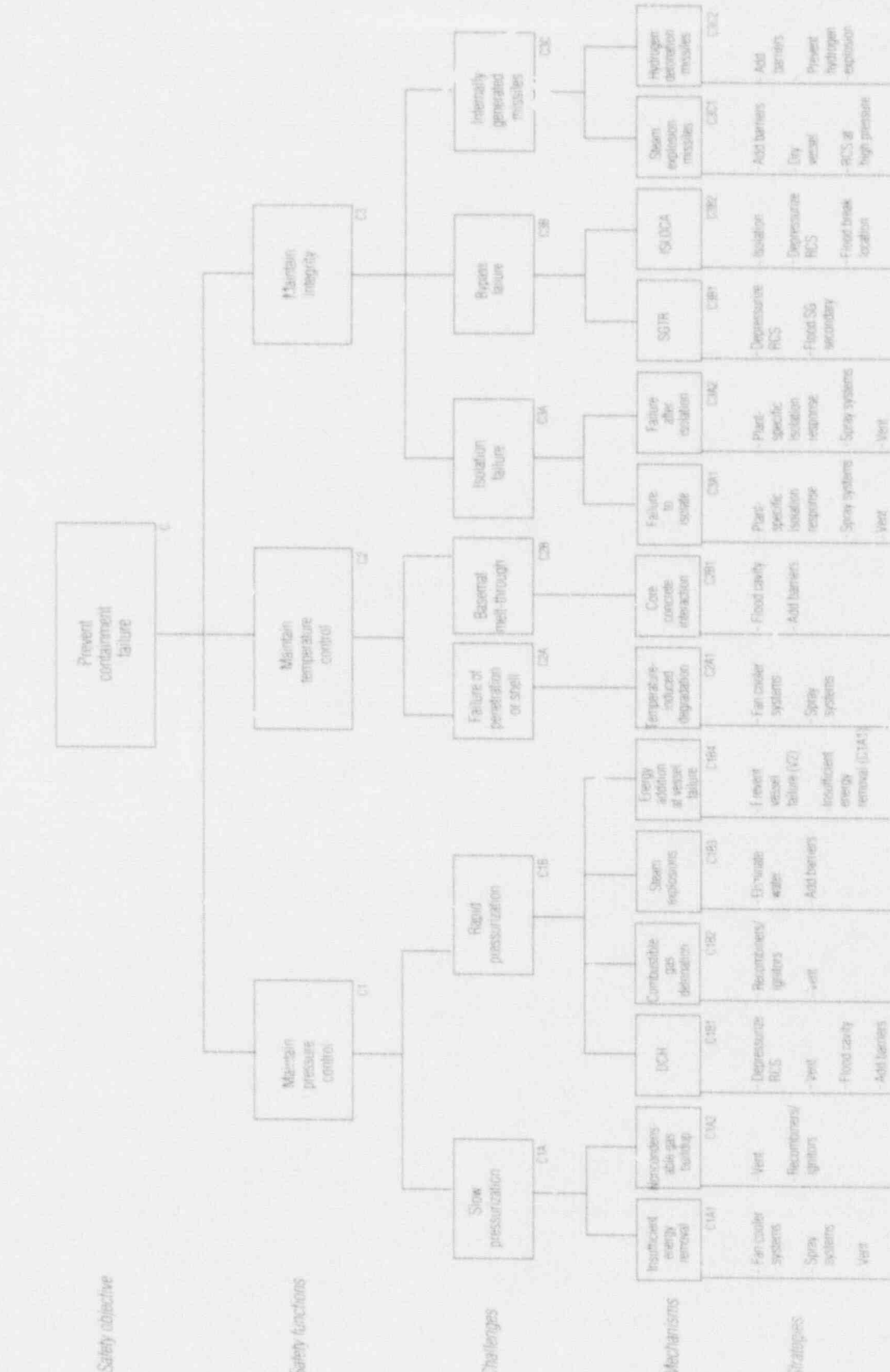


Figure 5. Safety objective tree: prevent containment failure.

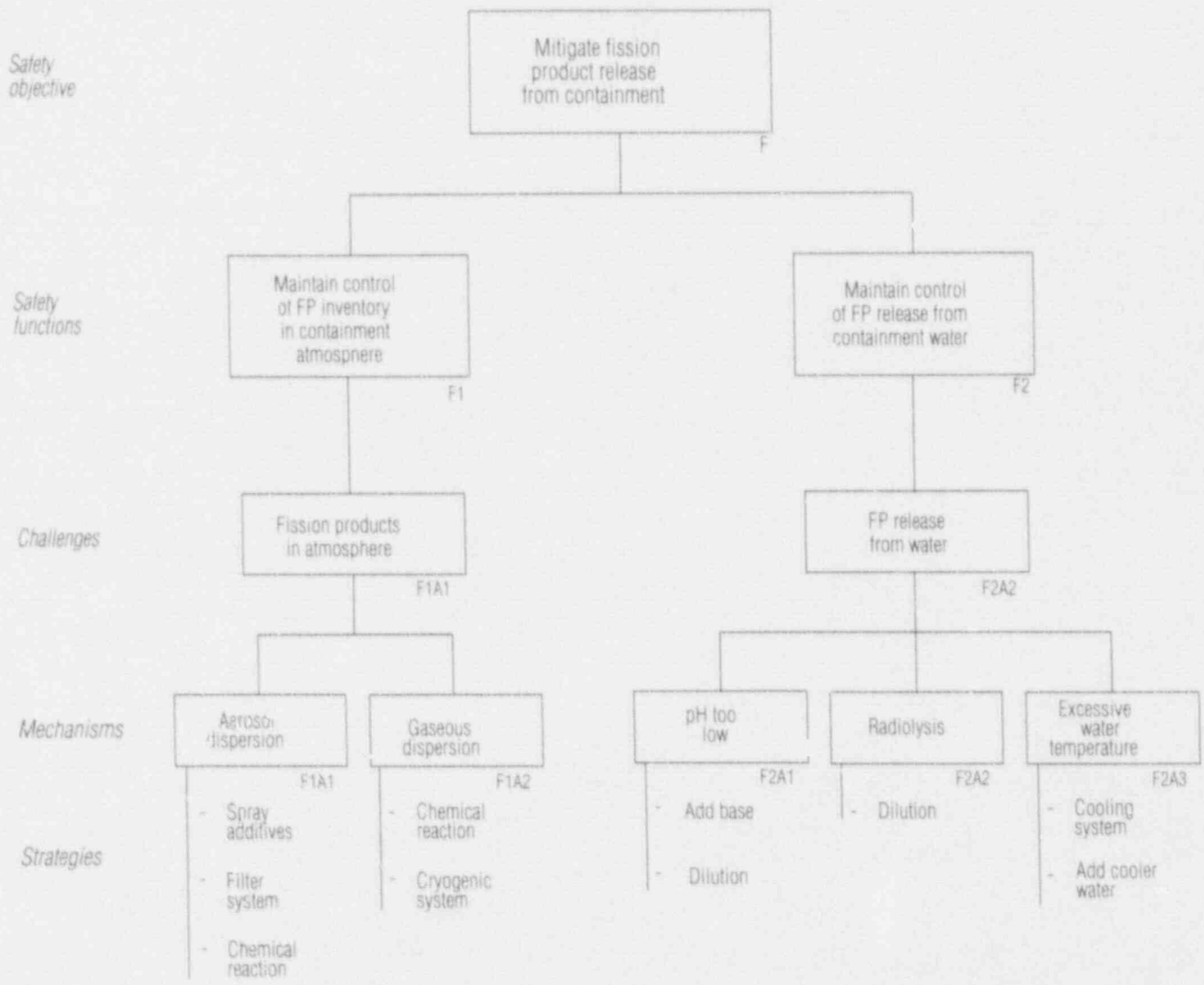


Figure 6. Safety objective tree: mitigate fission product release from containment.

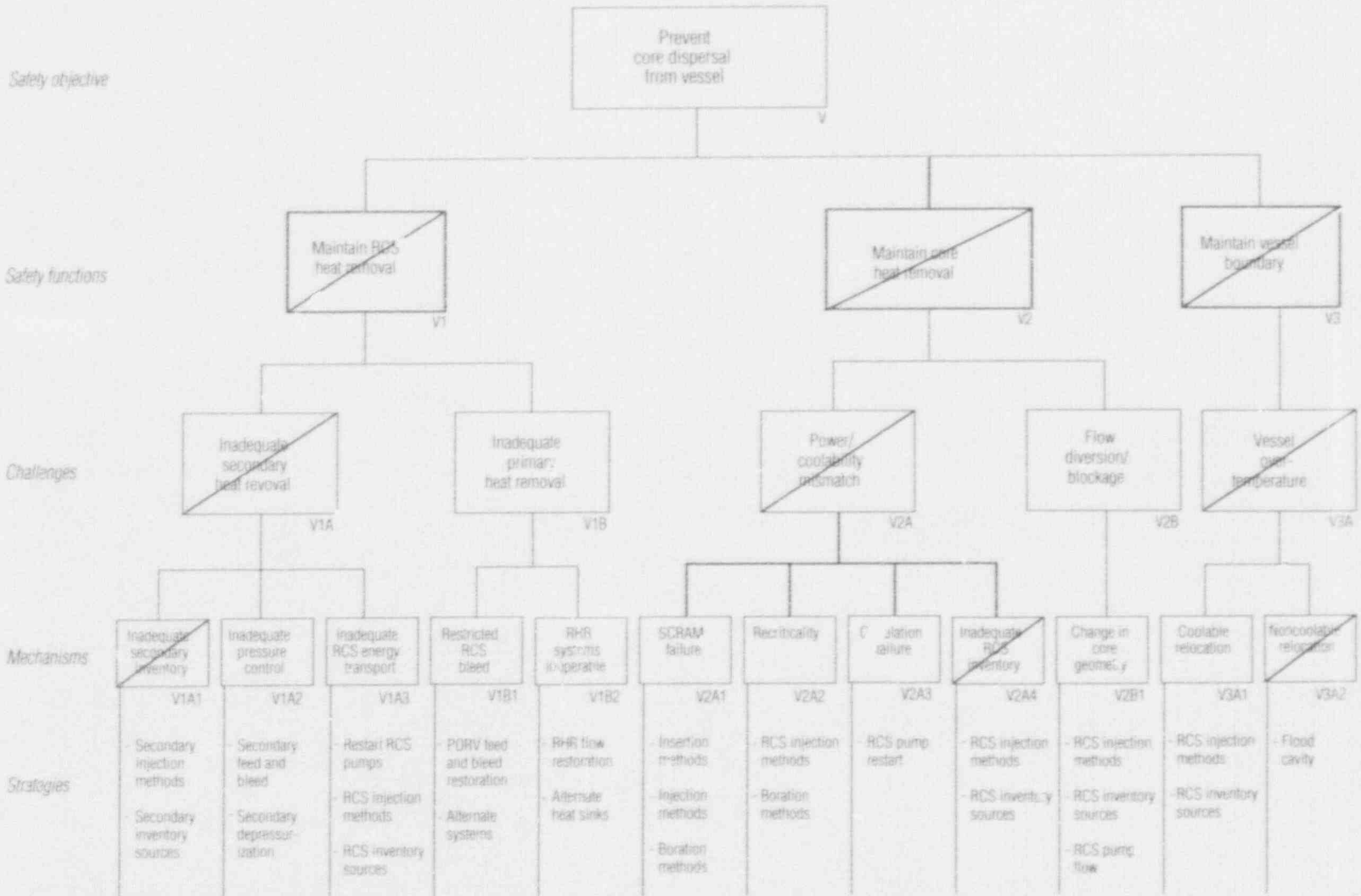


Figure 7. Sequence markings on Prevent Core Dispersal from vessel safety ojbective tree.

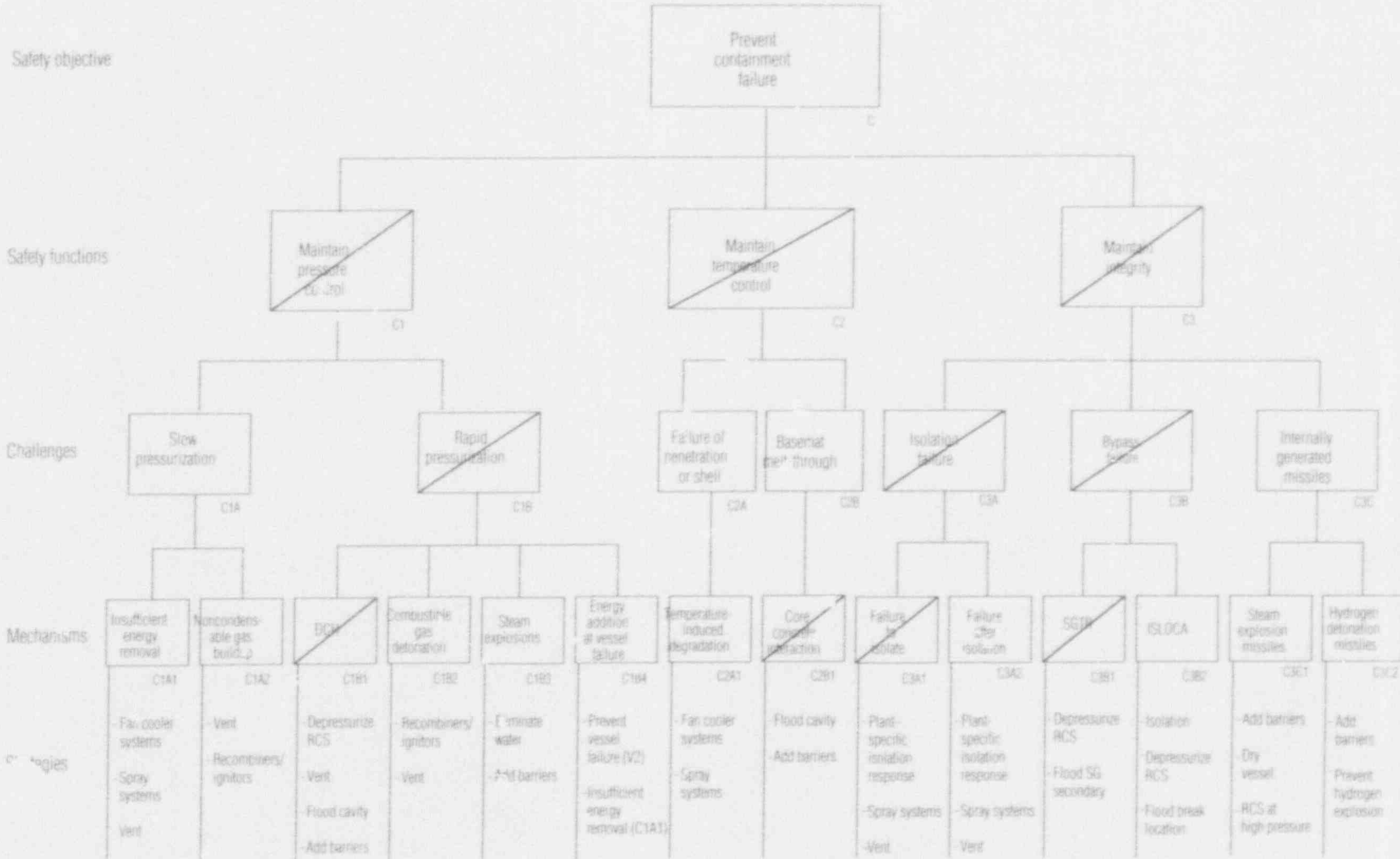
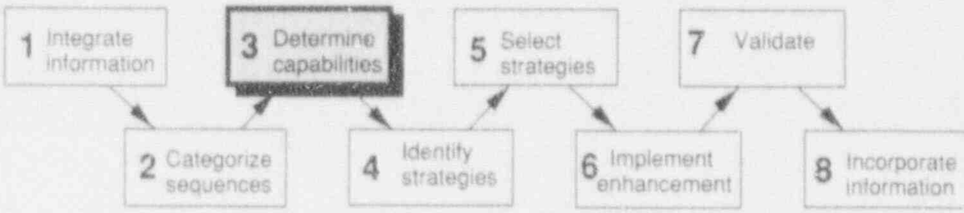
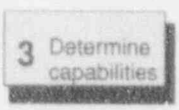


Figure 8. Sequence markings on prevent containment failure safety objective tree.

Step 3. Identify Accident Management Capabilities for Categories



The objective of this step is to identify the plant hardware and personnel capabilities that could supplement the response or replace the function of the current safety and support systems during severe accidents. A table format was proposed in the prototype process to organize the identification and assessment of capabilities. However, the Phase 3 validation results showed that the table format was not effective in providing information with sufficient detail to determine what changes in capabilities would improve accident management. To supply the necessary detail, a more structured approach was developed using a question-answer format for each of five areas known to be important for accident management. The following substeps describe how to carry out this approach.



Substep 3.1. Develop Capability Questions

Develop a set of questions that can be used to identify the accident management capabilities of plant hardware and personnel for each of the assessment categories described in Step 2. The questions should be stated in terms sufficiently general to apply to all assessment categories yet contain enough specific information to stimulate the proposal of alternate accident management strategies during the next step. Both short-term and long-term needs for accident management should be considered. To ensure a broad examination of the capabilities, questions should be included for the following major areas.

- **Procedures and Guidance.** Initially, develop questions to identify the procedures and guidance currently in place for use by the station operations staff and emergency response teams. Be sure to consider the EOPs for the operations staff and the documented guidance for the staff at the emergency response facilities to assist plant operations in managing the accident. Determine whether there are procedures and guidance for the use of alternative systems and equipment, long-term recovery actions, and assessment of multiple instrument readings to support accident management. Next, include questions to determine whether extensions of existing procedures and guidance could improve accident management. Also, include questions to determine whether additional procedures would enhance accident management for the assessment category.

- **Delineation of decision-making authority or responsibilities.** Develop questions to identify the decision making responsibilities and authority for the station and corporate technical support activities and the procedures and guidance that define them. Determine whether decision-making responsibility and authority is defined for situations where alternative procedures, equipment, or instrumentation could be used. Questions should be included to determine what changes in responsibility and authority would enhance accident management. For example, should the control room personnel have the primary responsibility during severe accidents, and the emergency response center personnel act in a supporting role, or should the emergency response facility personnel have the primary responsibility during a severe accident. Identifying responsibility and authority in this area could strongly influence other areas, such as procedures and guidance.

- **Equipment.** Develop questions to identify existing equipment that could be used to supplement or replace the function of plant safety systems. The systems considered should not be limited to safety grade systems. The questions should also identify resources, for example, borated water, unborated water, compressed air, cooling water, etc., that are necessary for accident management. They should also identify design or environmental limitations for the existing equipment to aid in determining potential restrictions in operation under severe accident conditions. Additional questions should determine whether (a) repair or replacement of failed equipment is possible in the available time, (b) alternate equipment at the plant has the capability to prevent or mitigate the severe accident conditions, (c) mobile equipment with the necessary capabilities can be transported to the site and interface with the plant equipment within existing time constraints, (d) conservation of resources, such as battery power, could be beneficial, and (e) alternate means of supplying resources, for example boration of unborated water sources, are possible. Also, include questions to determine whether the addition of equipment or resources would enhance accident management for the sequence category.

- **Instrumentation.** Develop questions to identify the key instrumentation in the plant needed to recognize the initiation of severe accident conditions and follow the progression of events for each assessment category. Questions should also identify either the range or the environmental limitations of the instrumentation and any means to integrate or extend the usefulness of instrumentation included in the existing instrument systems, for example, specially designed cabinets to protect from harsh environments, or analysis aids. Additional questions should determine whether means (hardware or software) are available to qualify the data and identify unreliable information. Questions should be included to identify alternate instrumentation that could supply similar or identical accident management information or additional instrumentation that would enhance accident management capabilities.

- **Training.** Develop questions to identify the training programs given to the station operations and technical support teams for understanding accident behavior and their roles and functions during an emergency and to identify the type and purpose of the training. Questions should also identify training using simulators or drills and determine if there are limitations in their use, and whether the personnel are aware of these limitations. Additional questions should determine whether provisions have been made to ensure that the training is effective for severe accident situations. Questions should be included to identify what changes could be made to improve existing training and whether the addition of training would enhance the effectiveness of severe accident management.

All questions should be stated such that they can be applied to each of the assessment categories. Structure the questions so that the answers cannot be given as a simple yes or no, but contain specific, detailed information on plant and personnel capabilities. Table 5 presents a sample set of questions similar to those developed and used during Phase 3. These questions are general and can be used as a basis for developing plant-specific sets of questions for a wide range of reactor plant types.

3 Determine capabilities

Substep 3.2 Identify Plant Capabilities

Assign individual team members to answer the questions developed in the previous substep for each of the assessment categories identified in Step 2. Detailed answers should be documented and reviewed by all team members in order to acquire additional information in each area of the team's expertise. Compile the answers to the questions for each sequence category so they can be used as input to Steps 4 and 5 to aid in identifying and evaluating strategies for preventing or mitigating the consequences of severe accidents.

Table 5. Questions for assessing general accident management capabilities.

Procedures

These questions should be applied to each assessment category. Precede each question by the phrase, "For this assessment category, . . . "

1. Which of the current procedures are applicable for preventing or mitigating the severe accident conditions?

2. If alternate systems and equipment are important, what procedures and guidance exist to facilitate their use?

3. What procedures consider long-term recovery actions (actions that are necessary weeks or months after the initiation of a severe accident)? How do the procedures address the following long-term needs?

   - The need to manage the long-term effects of radiation on habitability, access to plant areas, personnel exposure, equipment degradation, and instrument degradation

   - The need to provide long-term cooling for the core material in the RCS and the containment

   - The need to manage combustible gases that accumulate in the containment as a result of radiolysis or chemical reaction

   - The need to manage the chemistry of the water in the containment to minimize degradation of equipment

   - The need to control the leakage of water and gases from the containment

   - The need to manage the waste material generated during and following a severe accident

4. What procedures and guidance provide instructions on how to evaluate information that is apparently conflicting, either from instrumentation or from other sources?

5. What changes could be made to the current procedures and guidance to enhance the capability to prevent or mitigate the severe accident conditions?

6. What additional procedures could be added to enhance the capability to prevent or mitigate plant damage?

Decision Making

These questions should be applied to each assessment category. Precede each question by the phrase, "For this assessment category, . . . "

1. What are the current assignments of responsibility and authority for decision-making and where are they documented?

Table 5. (continued)

2. To what extent is long-term accident management considered in the decision-making process, including the basis for determining when the recovery phase is complete?

3. What decision making is defined in the current procedures and guidance? How should the authority and responsibility roles for severe accident management be allocated: the control room procedures and personnel having the primary role or the emergency response facility guidance and personnel having the primary role.

4. How were the currently used lines of communication between the control room and the technical support center and other emergency response and planning facilities evaluated and validated?

5. What decision points are identified for expediting administrative controls to facilitate the repair or recovery of equipment?

6. What guidance is given to decision makers for prioritizing alternate actions, identifying and avoiding potential negative effects, and evaluating long-term plant recovery?

7. What changes in the assignments of responsibility and authority could be made to increase the capability to prevent or mitigate plant damage?

8. What additional assignments of responsibility and authority could be made to increase the capability to prevent or mitigant plant damage?

Equipment

These questions should be applied to each assessment category. Precede each question by the phrase, "For this assessment category, . . ."

1. What existing plant equipment could be used to perform the function of failed safety systems, for example, non-safety-grade equipment that could supply water, or jumpering to make available alternate sources of power?

   a. What are the maximum and minimum operating limits for the existing equipment that could be used as alternates to safety-grade equipment?

2. What provisions could be made to facilitate repair or replacement of failed equipment for this assessment category? Consider both the availability of parts and the capability to gain access to failed equipment exposed to severe accident environments.

   a. What onsite replacement equipment and spare parts have been identified, including their location and means of transport and installation within the time available?

   b. What advance preparation of hardware, for example, spool pieces, pre-positioning of equipment, etc., would facilitate the use of existing alternate equipment to provide a significant increase in equipment capability?

Table 5. (continued)

c. What offsite equipment is there that could be identified and adequately prepared for transport to the site under accident conditions? What amount of time would be required to assemble, transport, and use this equipment? Is this time adequate?

3. What resources can be managed and conserved, such as battery power or borated water, to prevent or delay severe accident consequences, and what is the technical basis for determining the effect of their management and conservation? How have long-term needs been considered?

   a. Is equipment available that has the capability to replenish exhausted resources within the time frame available for recovery. Are suppliers of essential resources identified?

   b. What offsite resources are there that could be identified and adequately prepared for transport to the site under accident conditions? What amount of time would be required to assemble, transport, and use these resources? Is this time adequate?

4. What potential options for use of equipment from another unit have been considered and optimized?

5. What additional equipment would enhance the capability to prevent or mitigate severe accidents.

Instrumentation

These questions should be applied to each assessment category. Precede each question by the phrase, "For this assessment category, . . ."

1. What instruments are necessary to identify the symptoms and applicable strategies that will enable accident management personnel to prevent or mitigate severe accident conditions?

2. What are the limitations on the instrumentation to provide needed information on plant severe accident behavior and how are they communicated to accident management personnel? Consider limitations resulting from failures in the long term (weeks or months after initiation of the severe accident).

3. What means (protection from harsh environments, operator aids, etc.) have been developed to ensure existing instruments can be used under the expected severe accident conditions?

4. What methodologies have been established to identify unreliable data from instruments under severe accident conditions?

5. What changes could be made to the current instrument systems to enhance the capability to prevent or mitigate severe accident conditions?

6. What additional instruments would enhance the capability to prevent or mitigate severe accident conditions?

Table 5. (continued)

Training

These questions should be applied to each assessment category. Precede each question by the phrase, "For this assessment category, . . . "

1. How does the training provide personnel involved in accident management with an understanding of the possible severe accident plant behavior, and how is it determined that this training is being given at the proper levels and in the detail required for all personnel involved in accident management?

2. How are all personnel involved with the training simulator made aware of its limitations in representing severe accident conditions, and how is it made clear when the simulation is no longer valid?

3. How does the training for all personnel involved in accident management ensure that all important actions or decisions for severe accident management are included?

4. What training is provided for all accident management personnel on the possible limitations of equipment, instrumentation, and plant information? How are limitations that may occur in the long term (weeks or months after a severe accident) considered?

5. How are personnel trained to proceed if instruments give what appears to be conflicting readings?

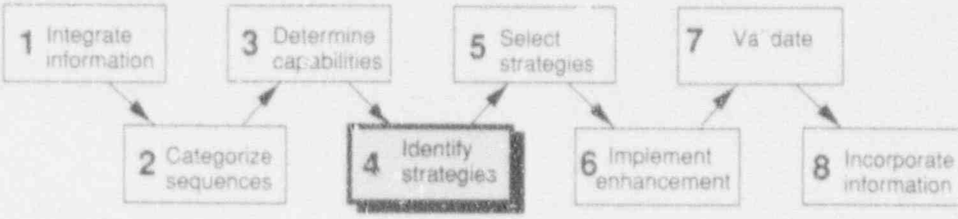
6. What additional training is provided to implement the use of alternative systems and equipment?

7. How do drills and simulator exercises consider the following potential restrictions: instrument error and failure, inhibited access to equipment as a result of high temperature or radiation levels, limited lighting or loss of resources such as electricity, and constraints on the availability of personnel with the proper skills?

8. What changes could be made to the current training program to enhance the capability to prevent or mitigate plant damage?

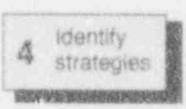
9. What additional training could be provided to enhance the capability to prevent or mitigate plant damage?

Step 4. Identify Potential Strategies



The objective of Step 4 is to identify accident management strategies having the potential to prevent or mitigate conditions that affect the events or mechanisms that compose the assessment categories from Step 2. This is a key step in the process because the identified potential strategies form the base from which final strategies are selected for implementation (Step 5). The product of this step is a description of each potential strategy with sufficient information that one can perform a detailed evaluation of its effectiveness.

We have developed a process with three substeps to identify potential strategies. We base the process on a functional approach to ensure that protection is provided over a wide range of potential severe accident conditions and to enhance your ability to integrate the severe accident strategies and actions with current emergency operating procedures (EOPs). You identify potential strategies in two ways. First, evaluate the capabilities of the plant hardware and personnel developed in Step 3 to identify potential preventative or mitigative actions for each assessment category. Second, review results from sources outside the plant (for example, potential strategies identified by the NRC, PRA studies, or experience at similar plants) to determine their applicability. Potential strategies can then be integrated and documented in sufficient detail that detailed evaluations can be performed. Following is a brief description of each process substep.



Substep 4.1. Develop Proposed Strategies From Plant Capabilities

A severe accident at a nuclear power plant can occur only as a result of multiple equipment failures or human errors. As a severe accident progresses, there will be opportunities to intervene in the sequence of events and prevent or mitigate further negative consequences. The plant hardware and personnel capabilities described in the answers to the questions in Step 3 are used as a resource to identify potential means of intervention.

Two areas where potential severe accident management strategies could be developed are (a) improving existing strategies to enhance their effectiveness or extend their range of application for severe accident conditions and (b) adding capabilities in the form of additional procedures, equipment, instrumentation, or training for each of the assessment categories. The team should meet together and review the answers to all questions for each of the assessment categories. Answers for each assessment category should be reviewed individually and as a whole to gain insights on where changes or additions could improve accident management. Be sure to consider the need for both defense in depth and diversity when identifying potential strategies. Do not unduly limit the discussions among team members or constrain or criticize ideas. An evaluation of the feasibility and effectiveness of proposed strategies is performed later in the process. Following are examples of changes or additions that could be helpful in stimulating ideas for potential strategies. They may or may not apply to a particular plant, depending on the conditions at the plant, which are reflected in the answers to the questions given in the previous step. These examples are not intended to cover all possible potential strategies but are offered to assist in the identification process.

Procedure Changes or Additions.

a. Modify or add procedures to incorporate cautions for conditions that may have a large impact on the plant or personnel. An example strategy is to add cautions at appropriate locations to indicate the symptoms leading up to Direct Containment Heating and the potential consequences.

b. Modify or add procedures to improve diagnosis of accident conditions. An example strategy is to add procedure steps to identify the symptoms of an ISLOCA and describe what plant instrumentation would aid in understanding these symptoms.

c. Modify or add procedures to use existing systems in different ways. An example strategy is to add steps to a procedure that would use existing piping and equipment to cross connect the safety injection system of one unit with a similar system from another unit at the same site.

d. Modify or add procedures to use existing resources in different ways. An example strategy is to add steps to a procedure to use existing piping and equipment to route water from a storage tank, not normally used for safety purposes, to a safety injection or auxiliary feedwater system.

e. Modify or add procedures to improve the timing of intervention during an accident. An example strategy is to add steps to change the initiation criteria for strategies to improve strategy performance by providing additional time for complex tasks to be performed or additional time for the strategy to be effective.

f. Modify or add procedures and guidance in the emergency response facilities, for example the technical support center, to better define their activities and interfaces during severe accidents. An example strategy is to add guidance in the technical support center that describes what instrumentation to evaluate to estimate the time of reactor vessel lower head failure and how to best determine whether the lower head has failed.

g. Modify or add procedures and guidance that consider long-term accident management (necessary actions that occur weeks or months after accident initiation).

Decision Making Changes or Additions.

a. Modify the plant documentation (for example, the administrative procedures, the emergency plan implementation procedures, etc.) to improve the definition of who has the authority and responsibility for decisions and actions during a severe accident. An example strategy is to improve the definition of the responsibilities and authority of personnel that would increase the effectiveness of existing or new strategy by reducing the time necessary for a decision to be made.

b. Modify the organizational structure for the management of the plant during a severe accident.

Equipment Changes or Additions.

a. Implement critical repairs that could be accomplished in a reasonable time period. Consider the availability of parts at the location of the repairs, time needed to complete the repairs in comparison to the expected time available, personnel required, types and duration of adverse conditions, etc. An example strategy is to identify repairs that could be accomplished for a safety injection pump and determine any limiting factors that could hinder completing these repairs, such as the long-term effects of radiation on plant access, personnel exposure, and equipment degradation.

b. Replace failed equipment, either physically or in function, with equipment that resides at the plant location. Develop the plans necessary to replace this equipment. An example strategy is to replace a valve that is failed in a critical location with an equivalent valve from an onsite stock. A second example would be the use of a portable battery charger to extend the life of plant batteries during a station blackout.

c. Replace failed equipment, either physically or in function, with equipment that could be transported to the site within a reasonable period of time and under possible adverse conditions. Develop the plans necessary to replace this equipment. An example strategy is to transport a portable diesel generator to the site to supply emergency power.

d. Use existing equipment in new or different ways. An example strategy is to use the firewater system to reduce the release of fission products from the plant site by spraying water on release locations, like the steam generator relief valves, from prearranged positions.

e. Add modest amounts of equipment to enhance the capability to manage severe accidents. An example strategy is the addition of a spool piece that would allow the connection of a non-safety grade pump to a safety injection system.

f. Conserve resources that are in short supply (for example, electrical power, borated water, diesel fuel, etc.) to prevent challenges to safety functions. An example strategy is the conservation of borated water during an ISLOCA, by reducing the injection rate to the reactor coolant system, so that the period of core cooling can be extended to provide time needed to accomplish system isolation.

g. Replenish resources that are in short supply. An example strategy is to provide the equipment and the supplies of chemicals needed to make borated water with the proper concentrations from unborated water sources and to direct this supply to the borated water storage tank.

h. Replace resources using either onsite or offsite sources. Example strategies are the connection of the condensate storage tank to the borated water storage tank to provide additional coolant inventory, and bringing in fire trucks to supply needed inventory. (Note that for either strategy it will be necessary to determine whether the water needs to be borated.)

Instrumentation.

a. Modify existing instrument systems to protect the instruments and cabling from harsh environments that exist during severe accidents. An example strategy is the addition of a cabinet or shield to protect a transducer from high temperatures that could occur during hydrogen burns.

b. Replace instrument system components with components that extend the range and are qualified to more stringent conditions. An example strategy is to replace the hot leg temperature detectors with a model that will measure higher temperatures and be environmentally qualified to higher temperatures and pressures.

c. Use analysis aids to supplement or replace information from the instrumentation. Consider using analysis aids to validate and integrate information from instruments, interpret instrument output to obtain additional information, and estimate plant parameters that are not measured. An example strategy is the development of a simple analysis aid to use information from the pressurizer pressure, core exit thermocouples, reactor vessel level monitoring system, and source range nuclear instrumentation to estimate the water level in the reactor vessel and core during a severe accident.

Training.

a. Modify the existing training to aid personnel in understanding their role in the management of severe accidents. An example is the modification of training materials to include detailed training for the technical support personnel to aid them in interfacing with personnel in the control room during a severe accident.

b. Modify existing training to eliminate identified shortcomings in the capability of personnel to manage severe accidents. An example strategy is the modification of training materials to include estimating the time of failure of the reactor vessel lower head and its consequences.

c. Provide additional training to enhance the capabilities of personnel to manage severe accidents. An example strategy is to add a training module to help personnel understand the nature and consequences for a broad range of severe accidents identified in the IPE or PRA.

4 Identify strategies — Substep 4.2. Consider Strategies From Outside Sources

Potential strategies can also be identified by reviewing information on strategies that have been proposed for general severe accident applications or specifically considered for other plants with similar designs. Consider strategies developed by sources outside of your specific plant and judge their applicability based on your answers to the questions developed in Step 3. Examples of information sources on potential strategies that should be considered include the following:

- Both the A and the B strategies that have been identified and evaluated by the NRC (Lucan, Vandenkieboom, and Lehner 1990)
- Strategies that are contained in emergency procedure guidelines but may not be implemented in the plant specific EOPs
- Strategies identified for similar plants either from actual operating experience or from the IPE/PRA process
- Strategies developed as a result of research on severe accidents (Dukelow et al. 1992, Kelley et al. 1990, Neogy and Lehner 1991, Williams and Gregory 1990; Lin and Lehner 1991, Lin et al. 1992.

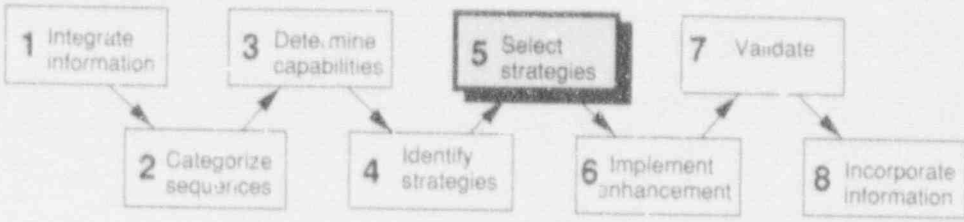
4 Identify strategies — Substep 4.3. Identify Proposed Strategy Characteristics

The final task should be to review the proposed strategies to ensure that all sequence categories identified in Step 2 have been reviewed and that a minimum of one potential strategy has been identified for each sequence category.

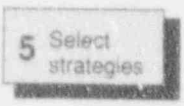
Once potential strategies are identified, describe each with sufficient information to perform a detailed assessment. Document the following information for each potential strategy:

- Assessment categories (from Step 2) for which the proposed strategy is expected to be used.
- Changes or additions in the use of plant hardware or operations that would be needed to accomplish the strategy. For example, identify and document special equipment needs such as the use of mobile battery chargers to provide long-term battery power in the event of a station blackout.
- Information needed and instrumentation available to supply it in order to determine whether the challenged safety functions are being maintained within safe bounds.
- The resources needed in terms of the personnel and equipment having the capability to restore the safety function and the water, power, air, and other resources necessary based on the severe accident conditions. Examples include details on personnel needed in terms of both the personnel involved and operations staff, the technical support center personnel, etc., and as much information as is available at this point on the levels of effort required.
- The expected timing of the key phenomena and the influence of this timing on the capability to use the accident management resources of the plant. This information could be in the form of plots or tables of the key phenomena developed from calculations.

Step 5. Evaluate and Select Strategies and Identify Enhancements



The objective of this step is to evaluate the potential strategies for each assessment category, to select those that should be implemented, and to identify the accident management enhancements that must be implemented at the plant for the selected strategies. Figure 2 presents the process with seven substeps to accomplish the objective. Recognize that the results from one substep may influence substeps both below and above it. Hence, iterations may be necessary between substeps to accomplish strategy selection. The product of Step 5 is a description of the enhancements that should be implemented at the plant.



Substep 5.1. Develop Preliminary Procedures and Guidance

Develop preliminary procedures and guidance to form a basis for assessing the viability and effectiveness of each strategy. These preliminary procedures and guidance will define the tasks needed to implement the strategy and will identify the organizational units within the accident management staff to which the tasks are assigned. This information will permit assessing the tasks to determine the demands on personnel and equipment, the estimated likelihood of success of the strategy, and the relative value or impact and priority of the strategy. Preliminary procedures need to be developed only in the detail sufficient to make them useful for the above purposes. We distinguish in this document between *procedures* and *guidance*. Procedures are characterized by detailed, specific steps; guidance by more generalized instructions. The difference is not absolute.

The preliminary procedures permit selecting the types of final procedures that would be used to implement the strategy. Examples of these final procedures may include the following:

- An additional EOP that implements a particular strategy
- Modifications to existing EOPs to permit use of a particular strategy, coordinate TSC support of the control room operators, clarify the decision making for certain actions, etc.
- Procedures and guidance for activities by personnel outside the control room to implement a strategy, for example, to establish temporary configurations of equipment alignments
- Guidance that aids the implementation of a strategy through activities of the TSC staff
- Procedures and guidance that provide for disciplined, preplanned activities by the accident management organizational units during the course of an accident (these units include the TSC, the EOF, operations support, engineering, maintenance, and document control)
- Guidance for the on-going tasks of situational assessment, response planning, and decision making.

For each preliminary procedure, develop a timeline and task analysis in the level of detail needed to assess the strategy. The timeline and task analysis lists the key phenomenological events and operator tasks in a time sequence with estimated time intervals. A range of possible time intervals may be needed for strategies that can be applied over a wide range of possible plant conditions. (A simple format for the timeline and task analysis at this stage of definition of the procedures is a tabular, sequential listing of key events and actions with estimated time intervals. There may be strategies where time is not a restriction and a simple ordering of key events will suffice.) Also, identify on the timeline the information interface between the operators and the plant hardware, that is, the information available to signal the need for initiation of an action and to signal the effect of the action.

Continue this timeline and task analysis in order to develop and tabulate the information necessary to permit assessing the strategy as to

- Expected plant response
- Needed performance of personnel, including the available time
- Estimated performance of the equipment used in the strategies
- Availability of instruments and information.

The product of this substep of the process will be a tabular sequence of the key events, operator actions, major assignments of responsibilities, equipment used, expected response of the plant, and needed instruments and information.

5 Select strategies

Substep 5.2. Assess Phenomenological Behavior

The objective of this effort is to judge the effectiveness of the proposed strategies by evaluating the thermal, hydraulic, radiological, and chemical phenomenological behaviors. To accomplish this objective, you must understand the phenomenological behavior for the identified plant sequences. Obtaining this understanding requires the use of either applicable existing severe accident plant analyses or use of a severe accident analysis code package. While there may be a number of best-estimate analyses that exist to address the use of some strategies, there may be a need to perform additional studies for some strategies, because existing analyses may be unable to identify both the conditions and actions for success *and* failure. Since instrument, operator, and equipment/system behavior is also important to assessing strategy effectiveness, existing best-estimate analyses may be inadequate in some cases to provide a comprehensive knowledge of all the needed phenomenological behaviors. Therefore, you might need to supplement the existing analysis base with additional computations or analyses to cover all needed information. Since the variation in instrument, equipment, and system physical and chemical behaviors can be extensive, you should also identify the range in variation or uncertainty in the phenomenological behaviors.

The process of evaluating the effectiveness of the proposed strategy as it relates to the sequence in question is as follows:

- List the key events/phenomena that characterize the accident sequence for which the strategy is to be applied. Examples of the key events include core melt and relocation into the lower plenum, lower head failure, containment pressurization and heatup caused by accumulation of hydrogen or high-energy melt ejection, and containment failure.
- For these key events, identify existing analyses that could be used to evaluate effectiveness of the strategy. These analyses should be directly applicable to the strategy and phenomena in question or bound the expected behavior.
- When existing analyses are unavailable or are limited in application, best-estimate analyses may be used to perform sensitivity studies to assess both the positive and negative aspects of the strategy. Multiple analyses may be required to determine the most beneficial sequence of actions, use of equipment, and human performance.
- These analyses should provide the parameters to envelope the plant instrument responses for the accident sequence in addition to giving the timing of phenomenological events, trending and magnitude of the event consequences, and radiological release consequences. The operator

actions and equipment performance could then be evaluated so that their associated impact on the accident consequences could then be obtained. In order to perform these evaluations, the existing analyses or analytical methods to be used in generating new analyses should have the capability to predict the following:

- Thermal/hydraulic behavior during blowdown
- Severe core damage and core melt progression
- RCS pressure boundary failure
- Severe accident containment behavior
- Containment failure and radiological release and dispersion.

The above capabilities are consistent with the five phases of Table 5. The codes and models with these capabilities should contain the physical, chemical, and fission product/radiological behaviors necessary to predict or bound the consequences of a severe accident sequence for both the in-vessel and ex-vessel phenomena. The methods and results of the IPE should provide the majority of the needed information and capabilities to evaluate the phenomenological behaviors pertinent to the strategies. Also, assessments of many of the strategies such as those for prevention may not require analyses of all of the above phenomena.

In the process of assessing the effectiveness of the proposed strategy, you may need to develop computational aids, which can be an integral part of many of the proposed strategies. These computational aids would be used by the technical support teams during the accident and would be developed as needed to ensure timely initiation and effective implementation of the proposed strategy. The computational aids needed to ensure effectiveness of the strategies might include the following:

- Methods to determine that a strategy is performing properly, or that the strategy is effective
- Methods to assess development of new or proposed changes to a given strategy/procedure to determine effectiveness and feasibility
- Methods to assess equipment behavior given the severe accident environment. These methods should include the ability to project time to core uncovery, time to vessel lower head failure, and time to containment failure. Where the uncertainty is high or the phenomenological behaviors have wide variation in response, alternate strategies could be devised as backup to better deal with the unknown. Where specific strategies are not appropriate, guidelines could be provided that use computational aids in the decision making.
- Methods to assess the impact of a strategy or procedure on plant risk.

These methods could also be nomographs or graphics covering the full range of expected conditions for a given phenomena. The form and extent of the methods will be dictated by the informational needs required to ensure the proposed strategy and resultant procedure are effectively and timely implemented. The results of this task are therefore a list of needed computational aids or methods needed to ensure successful implementation of the proposed strategy/procedure. We discuss in detail the process for developing the computational aids identified in this step in Step 6.4, Implement Computational Methods and Aids.

The products of this step include the following:

- Justification for the proposed strategy where effectiveness of the strategy is based on the results of previous analyses, or the performance of additional analyses
- A list of computational aids required to determine strategy effectiveness during an accident. These aids would be used by the technical support teams, for example, during an actual event.

5 Select strategies

Substep 5.3. Evaluate Human Performance

The objective of this step is to determine (a) whether it is possible for the personnel to perform their tasks, (b) what can be done to increase the likelihood of success in terms of plant equipment, procedures, engineered methods and computational aids, and (c) the type and extent of training necessary.

Each proposed strategy should be evaluated. The activities that are used to deal with accident conditions for which there are no predetermined strategies should also be evaluated. These evaluations should be carried out by a multidisciplinary team of professionals, including operations, systems engineering, human factors engineering, TSC staff members, and maintenance engineers. The process includes the following tasks, which may need to be iterated based on the availability of information from other tasks.

- Based on the analyses of the prior tasks, review the timing (Substep 5.2), the procedural guidelines (Substep 5.1) for the strategies, as well as the thermal-hydraulic analyses (Substep 5.2) to determine if situations exist where insufficient time, insufficient information, or hostile environments adversely impact successful completion of the required task.

- Model the strategies using state-of-the-art human reliability analysis techniques to facilitate the estimation of the overall success probability that the human will accomplish the task at hand. This quantitative approach should result in the capability to assess the likelihood of successful implementation as being high, medium, or low. Modeling will include entry into the procedure, as well as exit from the procedure, and will include all procedures to ensure that no conflicts exist among procedural packages.

- Identify the criteria that will enable the operating crew to recognize success or failure.

- Determine the relative workload that the operator has and how it effects overall probability of success. This analysis will be conducted such that the success rate will be reported as high, medium, or low.

- Examine the strategy to determine how changes in (a) equipment, (b) modifying the procedure or training, (c) automating a task, or (d) designing engineered aids to assist the human might be made to improve the overall success probability. Give special attention to identifying guidelines for members of the accident management team outside the control room.

- If changes are identified, the sequence might then be reanalyzed to obtain new timings, environments, etc., and might be requantified to obtain the new probability of success.

The products of this substep will be as follows:

- Verified procedural guidelines

- A list of necessary equipment

- Estimated likelihood of successful completion of strategy by plant personnel

- Preliminary training requirements

- Engineered methods necessary for accomplishing procedures

- Computational aids to increase the likelihood of successful human performance.

5 Select strategies

Substep 5.4. Evaluate Equipment Performance

The objective of this task is to determine whether the equipment involved in the potential strategies will perform the actions necessary for the strategies to be successful. The equipment evaluated is restricted to that needed to successfully carry out the strategies.

The analyses associated with evaluating the equipment performance will highly depend on the type of equipment and the severe accident conditions it is exposed to. All types of equipment might need to be evaluated, including communication equipment. Evaluating equipment performance will include the following tasks:

- Use the results of Substep 5.3 to develop a list of equipment involved in the potential strategies and to determine what access personnel would have to this equipment under specific severe accident conditions.

- Compare the design conditions of the equipment identified with those determined for the sequences for which the plant vulnerabilities were defined, in order to identify equipment that would be operating outside of its design range.

- Perform evaluations of equipment identified as operating outside its range to determine

  - The likelihood that the equipment will perform its required functions with the expected accident conditions imposed upon it. For example, can valves be opened or reclosed based on the pressure conditions; will equipment survive the loads imposed by pressure or flows, etc.

  - Whether the equipment will operate if exposed to the harsh environment associated with the severe accident. For example, will cables that bring electrical power or control signals to the equipment survive the severe accident environment.

- Evaluate potential failure modes of the equipment to ensure the equipment will operate over the required period of operation. Consider the effect of supporting equipment whose failure could result in the failure of the needed equipment. For example, overheating a power-operated relief valve could cause the solenoid to fail on the air operator, which would shut off the air supply and allow the valve to close from its desired open position.

The product of this substep would include

- A list of equipment required to successfully accomplish each proposed strategy.

- Documentation of any limitations or restrictions that must be placed on the equipment based on its inability to perform its required function or its inability to operate under existing environmental conditions.

- Identification of potential failure modes.

This information will be used to assess the likelihood of success for the strategies.

5 Select strategies

Substep 5.5. Evaluate Instrument Performance

Instrumentation currently installed in nuclear power plants for use in accident management situations was primarily designed to measure parameters that would be used to prevent or mitigate design-basis accidents. Since severe accident behavior is complex compared to the design-basis accident, and since the plant parameters of interest can vary over wider ranges, the objective of this substep is to

- Determine the information needed by personnel involved in severe accident management to (a) identify the need to take action during severe accidents, (b) provide sufficient information to select appropriate strategies to prevent or mitigate the consequences of these severe accidents, and (c) monitor the effectiveness of the strategies

- Identify the existing plant measurements capable of supplying these information needs

- Identify known limitations on the capability of these measurements to function properly under the conditions that will be present during a wide range of postulated severe accidents

- Determine whether there is need for improvement in existing measurements, and, if needed, changes or minor additions to instrument and display systems.

To accomplish these objectives, we have developed a process with four tasks, where the tasks correspond to each of the objectives.

The first task in the process is designed to identify the information needed to ensure that personnel can successfully manage the important plant sequences as identified by the sequence categories. An example process for identifying the needed information would use the safety objective trees discussed in Step 2 (Figures 4 through 6). These trees would form the foundation for this process since they show how the proposed strategies and the plant safety functions are related. For each sequence category affected by a proposed strategy, the branch points of the safety objective trees should be examined to determine

- What information is necessary to identify the status of the safety functions being challenged, that is, what information is needed to determine whether the challenged safety functions are being adequately maintained
- What information is necessary to identify the plant behavior (mechanisms), or precursors to this behavior, that are causing, or have the potential to cause, the challenges to plant safety
- What information is necessary to select strategies that will prevent or mitigate this plant behavior and monitor the implementation and effectiveness of these strategies.

Once you have identified the information needs for the proposed strategies and affected sequence categories, determine what measurements have the potential to supply the identified information and compare these potential measurements with the existing plant measurements. At this stage, concentrate on whether the types of measurements installed can supply the information, not on the specific details of transducer, cabling, etc.

For those measurements having potential to supply the information, the third task is to identify possible limitations on their performance during severe accidents:

- Examine the measurement capabilities based on the status of support, auxiliary, and plant safety systems (for example, off-site power, emergency power, service water, etc.) during the identified plant-specific severe accidents to determine which measurements would be operational. This examination could be accomplished using the classifications of instruments from Regulatory Guide 1.97 or dependencies developed during the IPE or PRA. If Regulatory Guide 1.97 classifications are used, they could be compared to the information based on the analysis performed during the IPE and other relevant analysis that would indicate when equipment failed.
- Examine measurement capabilities based on the possible measurement ranges associated with the identified plant-specific severe accidents to determine what measurements would provide accurate information. This examination could be accomplished by comparing the actual measurement ranges with the information gathered from the IPE and other sources, such as Regulatory Guide 1.97.
- Identify the capability of measurements to operate under the expected plant environmental conditions associated with the identified plant-specific severe accidents. An approach to assessing the environmental conditions could be to develop a severe accident envelope for each important measurement type and location based on the severe accident information available for the plant. An example would be an envelope for temperatures or radiation levels at the location of important instruments in the containment. The qualification conditions for the existing measurements could then be compared with the envelopes to identify which measurements would not be operational and which information needs could not be met. This approach would offer the advantage of looking at a

broader spectrum of the severe accidents that would effect the plant and would provide added assurance that low-probability events would have been considered when a determination of the adequacy of the instrumentation is made.

For the fourth task, ensure that all information needs for the sequence categories and for the potential strategies can be met. If information needs cannot be supplied, identify alternate means of providing the information. Examples of alternate means are modifying the existing equipment to expand the range or to harden it against harsh environmental conditions, developing computational aids that derive the needed information from measurements that will be operational, and installing new hardware.

5 Select strategies

Substep 5.6. Select Strategies

The objective of this substep is to rank the potential strategies and select those that should be implemented. To rank the strategies, use criteria based on the desired outcome of the strategies, for example the effectiveness of the strategy and the likelihood that it can be successfully employed during a severe accident. The results from the assessments performed during previous steps provide the input necessary to accomplish the ranking. You should then select the strategies to be implemented based on the rankings and on criteria that reflect established principles of nuclear power plant safety, such as defense in depth and diversity.

Rank each potential strategy for each sequence category for which it has been identified as being beneficial. In addition, evaluate the possibility that a potential strategy could have a negative effect on safety for the remainder of the sequence categories. The criteria with which to rank the potential strategies should include the following:

- Likelihood of successful implementation. The results of the previously conducted steps for strategy evaluation (Substeps 5.1 through 5.5) will have identified the likelihood (high, medium, or low) that the personnel involved in accident management could successfully implement the potential strategy for each applicable sequence category. Those potential strategies having a low likelihood of success should not be considered further.

- Effectiveness against severe accident sequences identified for the plant. The effectiveness of the potential strategies in preventing or mitigating the identified severe accidents should be ranked. Examples of criteria that could be used for ranking effectiveness are as follows:

  - Potential strategies that reduce fission product release and exposure of the public are ranked high

  - Potential strategies that reduce the probability of core damage are ranked high

  - Potential strategies that prevent severe accidents are ranked higher than potential strategies that mitigate only

  - Potential strategies that return the plant to a long-term stable state are ranked higher than potential strategies that only delay additional severe accident behavior

  - Potential strategies that are effective against a larger number of severe accident sequence categories are ranked high

  - Potential strategies that are effective for severe accident sequence categories for which few other strategies have been identified are ranked high

  - Potential strategies that have small uncertainties are ranked higher than potential strategies with large uncertainties.

- The potential for negative effects. Certain strategies may have the potential for causing adverse effects on plant or public safety, even though the strategy may be effective for a specific severe accident condition. An example is the potential for an unnecessary release of radiation to the environment or the release of increased quantities of radiation. Some strategies may also increase the potential for additional equipment failures, operator errors, or personnel exposure. Potential strategies that would result in negative effects either for the sequence categories for which they are developed or for other sequence categories are ranked lower.

- The availability of supporting information. Potential strategies that use readily available information from the existing measurement systems, from existing displays, or from other existing sources are ranked higher than strategies that require development of additional instrumentation, displays, or other equipment.

- Impact on existing procedures or plant equipment. Potential strategies that do not require extensive changes in the existing plant procedures or hardware are ranked higher.

Your final ranking of the potential strategies should be based on a weighting of the rankings of the individual criteria. The weighting factors could vary, depending on plant needs, but the first, second, and third criteria should be assigned the highest weighting factors.

Once you have ranked the strategies, determine which ones should be implemented at the plant. The process for making this determination should be based on the following criteria:

- If there are sequence categories for which there are no currently identified strategies, the top-ranked potential strategy for that category should be selected for implementation

- Those potential strategies that provide desired additional defense in depth for sequence categories should be implemented

- Those strategies that provide additional diversity for sequence categories should be implemented.

The product of this step is the strategies that should be implemented at the plant, together with the rational that justifies the selection of strategies.

5 Select strategies

Substep 5.7. Select Accident Management Enhancements for Implementation

The objective of this substep is to select the enhancements for accident management that will provide the mechanism for successful implementation of the selected strategies. These enhancements may be for procedures and guidance, decision making, equipment and engineered methods, computational aids, information needs, and training. We expect some strategies will be effective against several sequence categories. Therefore, the number of enhancements are expected to be a smaller number than the number of selected strategies. However, care must be taken to ensure that modifications affecting common systems or common administrative controls are consistent, and that they function as an integrated whole in the accident management plan.

The process to accomplish this substep includes three tasks. The first task is to identify the enhancements and subsequently categorize them. Each content area of procedures and guidelines, decision making, equipment and engineered methods, computational aids, information needs, and training will have to be evaluated to identify enhancements. The information needed for this evaluation will rely on the analysis results obtained from Substeps 3.1 and 3.2 and Substeps 5.1 through 5.6. For each of the above listed areas, compare what is currently available at the plant with what the evaluations indicate is needed to implement the selected strategies. In order to accomplish this comparison, you must examine the prior analyses from the perspective of the requirements placed on plant personnel by each strategy and what needs these personnel have to successfully respond to the accident. Document this analysis such that the following is known: the skills, knowledge, and abilities required of plant personnel; the requirements beyond their current capability; whether or not the necessary instrumentation is available; wh. a structure is in place to permit the required decisions to be made and subsequent actions to be taken; and whether appropriate procedures and guidelines exist for the plant personnel to carry out the strategy. This information will be directly available from the prior analyses and will only need to be put in a common form and format for selection of enhancements. This documentation of the prior analyses will then form the basis for identifying the necessary enhancements, as presented below.

- The procedural steps identified for each strategy (Substep 5.1) will form the basis for the enhancements for procedures. Special consideration should be given to form and format of the procedures and to where they will best fit within the util'ty's existing procedural structure.

- The decision making required by the strategy (Substep 6.2) must be compared to the existing decision making structure to ensure that appropriate plant personnel are empowered to take action as required by the strategy.

- The identification of equipment and engineered methods (Substeps 5.4, 6.3) will come directly from the formulated strategy, specifically what equipment and methods the strategy requires beyond the existing capabilities.

- The identification of needed computational aids (Substep 6.4) will come from an analysis of the strategy and the requirements that ,e strategy places on the operator. For example, owing to time constraints or the complexity of a calculation, an aid may be necessary for the operator to make needed calculations in the evolution of an accident.

- The identification of the enhancements for information needs (Substep 6.5) will come directly from a comparison of what instrumentation is required for the strategies versus what is available at the plant. Enhanced instrumentation may be required where existing instrumentation will fail because of environmental considerations or where new measurements, not needed for previously analyzed conditions, are needed.

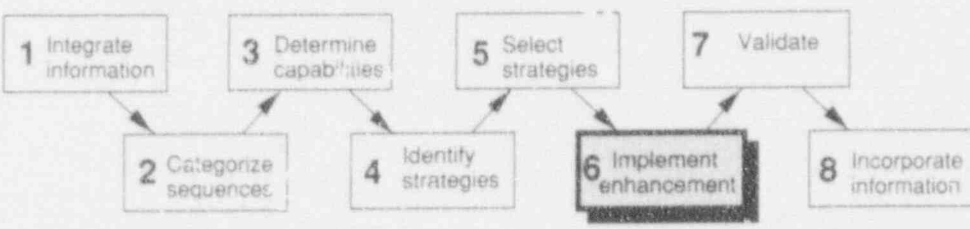
- The identification of enhancements for training (Substep 6.6) will come from the analysis of the skills, knowledge and abilities (SKAs) necessary for the operators to carry out the strategy. These SKAs can then be compared to those already present in the utility training program, and where deficiencies occur training developed.

Once the enhancements have been identified, the next task in the process is integration. Integration of the enhancements will group like enhancements, which will in turn help prevent duplication of effort and will allow for effective structuring of the enhancements. The integration will also make evident any inconsistencies across the strategies for all the identified enhancements. Accomplish this integration with a multi-disciplinary team to ensure consistency of the integration and treatment of the enhancements. The integration will also identify the common enhancements that effect all strategies, such as generalized training in severe accidents for the entire accident management team. The product of this step will be the list of selected enhancements.

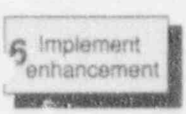
The third task of the process is to develop a structure to organize the strategies. The structure should be symptom-based and function-oriented. The structure will provide the means to determine further ambiguities or conflicts among the strategies or with established operating procedures. The structure will most likely need to cover not only procedures designed for the control room, but also for use in the TSC. It is possible that the level of detail contained in the procedures for the control and TSC will differ in detail. This step should be accomplished by a team of individuals similar to that used to construct the EOPs, as specified in NUREG-0899. After the structure is determined, checks should be made to determine if the entire accident management space, in terms of safety functions, has been covered so that there is confidence in the completeness and applicability of the strategies that make up the accident management program.

The product from this substep will be a complete set of enhancements that will help to ensure complete coverage of the accident space and optimization of successful implementation of the various strategies. The enhancements will cover procedures, decision making, equipment and engineered methods, computational aids, information needs, training, and enhancements for accident situations.

Step 6. Implement Enhancements and Strategies



The objective of this step is to implement the accident management enhancements and strategies identified in Step 5. They are implemented by developing modified or additional procedures and guidelines, computational aids, equipment, and training. This step also delineates decision-making responsibility and authority.



Substep 6.1 Implement Procedures and Guidelines

The objective of this substep is to develop the procedural and guideline documents that will permit selection and use of applicable accident management strategies in the event of a severe accident. Extensions and enhancements of existing procedures and guidelines may satisfy a major part of this objective. When an additional type of procedure is required, interface it constructively with existing procedures to ensure coordinated accident management activities. Three categories of tasks should be reviewed to determine the need for developing procedures and guidelines: (1) the preliminary tasks developed in Step 5.1 for each procedure enhancement identified in Substep 5.7, (2) the continuing tasks necessary in the event of an accident, irrespective of the strategies being applied, and (3) the tasks that might be necessary to manage the unique, and perhaps novel, developments of a specific accident. Figure 9 illustrates the relation of procedures and guidelines to the four major accident management centers [control room, technical support center (TSC), operational support center (OSC), emergency operations facility (EOF)] during the progression of a severe accident.

The analysis of the necessary tasks for applying a specific strategy provides the basis for determining the need for additional procedures or guidelines for that strategy. The need to add to an existing EOP, or to add a separate EOP, should be one of your first considerations. If the strategy requires tasks outside of the control room, select a method for interfacing that action with the EOPs. If the decisions for executing specific tasks are to be centered in the TSC or EOF, then this should be pre-specified to the control room. A similar provision should be made if decisions concerning repair, restoration, or modification of equipment or systems is expected to be made by a work party in the plant. In analyzing such tasks, specify the extent to which control room personnel will be expected to remain cognizant of plant conditions and the extent to which cognizance will be transferred to the TSC or the EOF.

Assess tasks intended or expected to be conducted outside the control room, especially those in the TSC or the EOF or those to be performed by work parties, to determine the need for pre-planned guidelines to supplement the training and experience of the personnel involved. Develop procedures or guidelines for these tasks with adequate

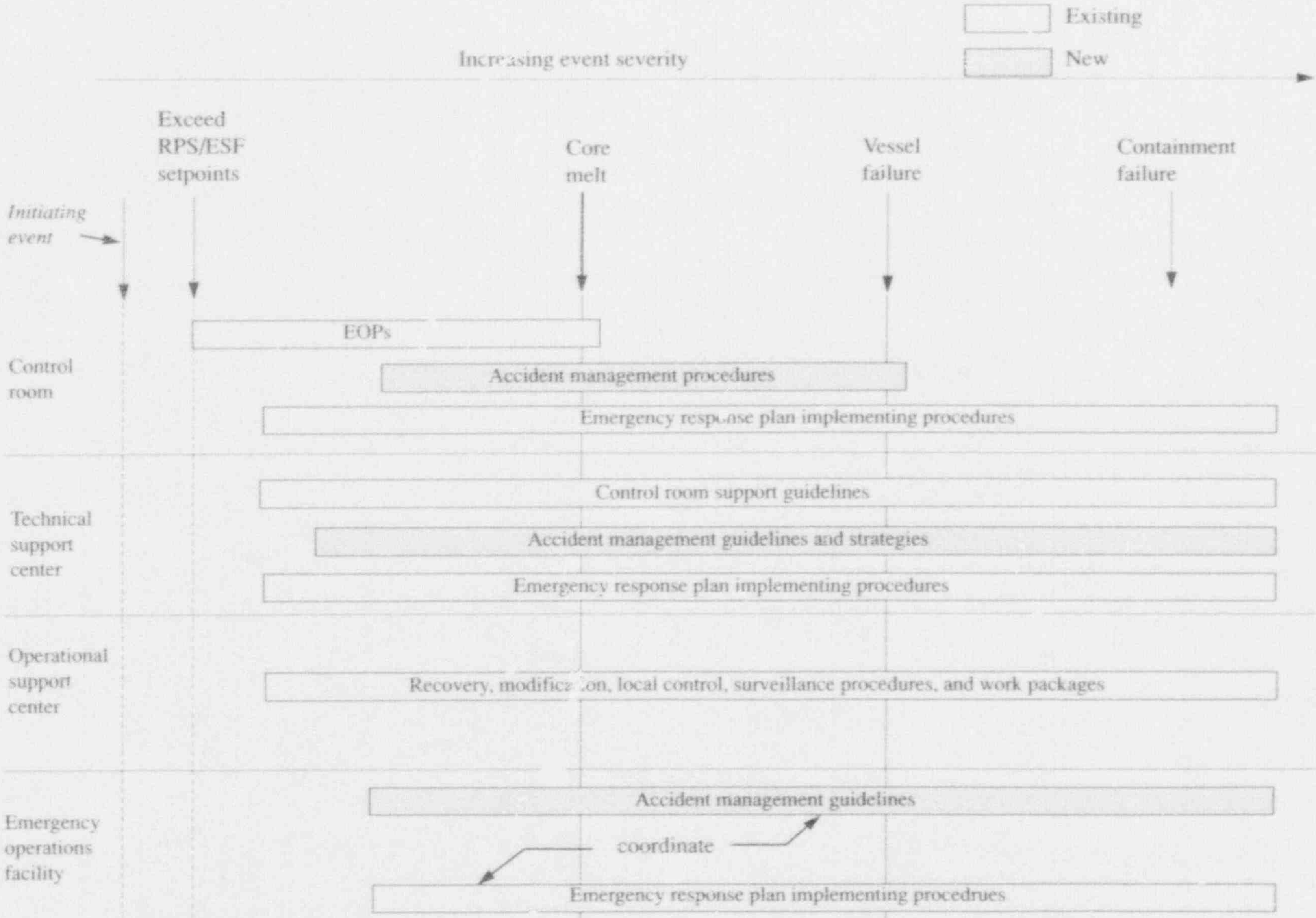


Figure 9. Formats for guidance during the progression of a hypothetically severe accident.

detail to ensure that the performance level of the personnel will be predictable and you have confidence that the task will be accomplished within the required time. Achieving this level of confidence may require supplementing the procedures with ready access to special information, for example, plant systems and equipment data, results of thermal-hydraulic analysis, and checklists. Use a consistent, unambiguous format in procedures for operational decisions intended to be made in the TSC or the EOF; we prefer the IF-THEN format recommended in NUREG-0899 for EOPs.

Confidence in the predictability of timely performance of repair, restoration, or realignment tasks specified in the strategy may also require preplanned work packages. The level of detail in the preplanned work packages could be minimized if the strategy allows sufficient lead time, and if support personnel are expected to be available during the event to provide appropriate detail. If staging of tools, material, or equipment is necessary to make the strategy feasible, appropriate reference would be necessary in the preplanned work package. The degree of staging, for example, storage in a dedicated location at the site versus identification of possible suppliers (two contrasting examples) would depend on the probable time expected to be available during the event.

The need for preestablished procedures or guidelines extends beyond the readiness to apply specific strategies. It also includes the continuing accident management tasks of assessment, supervision, and control. Most of these tasks would be performed by personnel other than control room operators, and the form of the procedure or guidelines should be appropriate for the job position and task. Personnel who will apply the procedural guidance should participate in selecting the format and level of detail. They may be the most appropriate individuals to write the procedure. The format could range from a detailed principles-of-operation flow sheet to a check list, for example. The criterion should be that the procedural guidance should be sufficient for any certified individual to complete the task satisfactorily within the time available. The continuing accident management tasks include the following:

- Determining the safety status of the plant and determining the emergency action levels (EALs)
- Transmitting information on the current and predicted plant safety status
- Controlling the configuration of plant systems
- Controlling activities and staging of onsite personnel
- Analyzing accident management, consisting of situational assessment, determination of need for action, and management of resources during execution of the actions. See Table 6 for examples of real-time analytical tasks that may require guidance for personnel in the TSC.
- Control of emergency exposures of personnel
- Maintaining records and logs.

The tasks expected to be needed in the event of unique or novel developments in the accident scenario would involve the generation of new, or revised, emergency operating procedures or work packages. (Determination of the existence of a possible unique accident situation and of the required response is a continuing task, as discussed above). Review existing policies, standards, and procedures for generating and revising operating procedures and work packages to determine what enhancements are advisable to make them useful during a severe accident situation. If not already provided for, make enhancement or specially provide to expedite the generation, review, and approval of emergency procedures and work packages. A special procedure for the assembly and conduct of operations of a multidisciplinary team for this purpose is appropriate. The need for oral direction through the accident management structure should be explicitly met by standing, preplanned procedures, policies, and guidelines. In addition to this explicit definition, review the accident management procedures, authorities, and responsibilities to ensure against contradictions or conflicts.

Table 6. Examples of real-time accident management analysis in the Technical Support Center

Diagnosis . essment/accident situation

Assess the status of core, contain.nent, and important safety systems

Perform basic calculations to assess state of plant and containment

RCS and containment leak rates and paths
Reactor power and fluid levels
Atmosphere flammability/detonability

Determine instrumentation performance and validity of indicators under severe accident conditions

Recognize the onset of core damage and infer state of core damage from temperature, pressure, coolant chemistry, and containment radiation conditions

Predict the probable timing of key events during the accident

Core damage
Major loss of core geometry
Containment venting/overpressure

Anticipate problems likely to further degrade the configuration of core and safety systems

Potential failure mechanisms, for example,

Failure of pumps caused by loss of component cooling water, high pool temperature, inadequate NPSH
Heatup of equipment caused by loss of room cooling
Loss of HPCI, RCIC caused by loss of control power
Temperature-induced failure of RCS and steam generator tubes

Challenges to core and containment resulting from severe accident phenomena

Hydrogen combustion
Reactor vessel failure and direct containment heating
Liner melt-through
Concrete attack/ablation
Gross containment leakage and leakage location

Estimate pressure and temperature rise from projected hydrogen combustion or reactor vessel failure

Table 6. (Continued)

Formulate Accident Response

- Identify and assess accident management strategies to prevent or arrest core damage, prevent containment failure, and reduce radiological releases
  - Identify alternate or nonsafety-grade equipment that can compensate for the loss of safety-grade equipment and systems (use list of candidate accident management strategies)
  - Identify system configurations that can provide adequate core cooling
  - Recognize limitations and restrictions on the use of plant systems to mitigate accident consequences (such as pressure rating of containment vent piping, design discharge head of condensate and service water pumps, and interlocks on operation of reactor coolant pumps or main steam isolation valves)
  - Understand possible measures to mitigate radioactive releases once the core, vessel, or containment has been damaged (such as use of reactor building fire sprinklers to reduce releases, and flooding containment prior to vessel failure to prevent liner attack)
- Use PRA/IPE insights to set priorities for corrective actions

Implement response actions

- Take positive action to reestablish the redundancy, diversity, and independence of the safety systems, and integrate effort with control room operators
- Implement accident management strategies to arrest core damage, prevent containment failure, and reduce radiological releases
  - Pre-plan to expedite implementation, for example, prepositioning stocks of materials, electrical jumper cables, hose adapters
  - Preapprove authority to override formal procedures and controls or implement ad hoc equipment modifications

Monitor and update

- Monitor the effectiveness of strategies implemented by the control room operators
- Anticipate problems likely to further degrade the configuration of core and safety systems

Finally, any procedures specifically intended for potential use in accident management should be reviewed to verify that they

- Are technically correct and complete
- Are integrated with other procedures or policies such that possible procedural contradictions are resolved and any necessary transfer between procedures is provided for
- Are consistent with the accident management organization and assignment of duties and responsibilities such that the performance assignment is clear
- Are considered usable by the departments or positions who may use them
- Include defenses against human error or methods to detect and recover from human error.

The products of this substep will be the procedures, guidelines, job descriptions, organizational charts, check lists, etc., that provide preplanned, documented direction to the utility staff for management of an accident.

6 Implement enhancement

Substep 6.2 Implement Delineation of Decision Making Responsibilities

Decisions may be required during the course of an accident to develop or revise emergency procedures; to develop, approve, and release emergency work packages; to determine the best estimate of the status of the plant and the progression of events; or to select a strategy for management of the plant. The objective of this part of the process is to develop and implement the structure for this decision making during the course of a severe accident. This structure should encompass

- Organization
- Responsibilities
- Decision-making authority
- Generation and review of proposed actions
- Communications.

The process for developing the accident management decision-making structure will focus on identification and assessment of the types of decision-making and decision-support tasks that could be needed during an actual severe accident. This assessment should determine the changes needed to the station's decision-making structure, that is, the emergency response organization, responsibilities, authorities, reviews, and communications.

Review the present structure for decision making during an emergency at the nuclear station (organization tables, position descriptions, procedures, etc.) to determine where enhancement is needed to fill the following needs:

- Incorporation of new strategies into the procedures for emergency operation where the strategies may involve a higher level of operational control than the present EOPs, that is, plant management instead of systems control
- Coordination between onsite accident management (plant response) and offsite emergency response for the purpose of minimizing the risk of radiation exposure of the public (for example, venting of the containment and management of response to a planned, smaller radiological release rather than risk a later, larger release)
- Mutual recognition of the divisions of functions and responsibilities between the control rooms, the TSC, and the EOF, and the ability to smoothly shift the centers of operational control as appropriate for the tasks performed during the accident
- Capability to decide on the best estimates of the accident status and progression, the major risks, and the options for response, and to use these decisions as the basis for management of the plant

- Capability to decide whether actions beyond the license restrictions are needed for reasons of safety and the capability for timely and appropriate action, as authorized by 10 CFR 50.54 paragraphs (x) and (y)

- Capability to make best use of onsite equipment, materials, and personnel resources.

The subject of decision-making responsibilities can be examined for three different regions of operation in the regime of severe accidents:

- Operation per present EOPs

- Operation per future EOPs extended by additional Technical Guidelines that implement new strategies for severe accidents

- Operation beyond the extended and previously approved EOPs that exist at the time of initiation of the accident.

Operation with Present EOPs

Review any operational experiences with the present EOPs during drills or actual operational events to determine where management of the plant response could be improved. Potential areas of improvement include operator aids, backup procedures or checklists, staging of tools or material, TSC guidelines, TSC personnel training, etc. Since these operational experiences are quite limited as to the event severity, supplement your reviews by walk-throughs of the EOPs for selected severe accident sequences. Finally, assess the results of the reviews to determine if the decision-making structure (as defined above) should be enhanced.

Operation with Approved, Extended EOPs

The decision-making structure should provide for onsite actions, for example, containment venting, which should be coordinated with offsite authorities. The decision-making structure should be supported by specific steps in the extended EOPs (see Figure 10), or in the guidelines for operations in the TSC or the EOF. In the containment venting example, the Technical Guidelines for the EOPs should define the decision-making structure and the symptoms used to arrive at the decision. The extended EOP, together with other utility procedures and policies, would implement the guideline to specify both *how* and *who* makes the decision.

The decision-making structure should provide guidelines for communication between the TSC and the control room. Certain information upon which to base a decision for control room actions may be derived from plant status analysis performed in the TSC. Determining the capability for needed equipment to operate under the conditions that may exist may be an example.

The focus for the formation of strategic decisions for operation during severe accidents should be in the TSC, with the authority for certain decisions residing with the EOF Director (the Director for Emergency Operations). This would permit the control room operators to concentrate on the control of plant systems, which could become very demanding if repairs, modifications, or interconnections are in progress. In general, severe accident management would not be needed until after the TSC and EOF are fully manned. Nevertheless, the possibility of early core damage remains (such as might result from an extremely unlikely external event), and the existing broad authorities of the senior reactor operator/shift supervisor (SRO) should stand. Procedures and training should be reviewed to ensure that the SRO is prepared to make the appropriate decisions.

Operation Beyond Extended and Previously Approved EOPs

The need for this mode of operation should be minimized by prior planning. However, the possibility does exist for a need arising during a severe accident for operation beyond extended and previously approved EOPs. The uncertainties in both deterministic and probabilistic analysis may be a major contributor to this situation, even where a Level III PRA has been completed and the results have been incorporated into the approved EOPs.

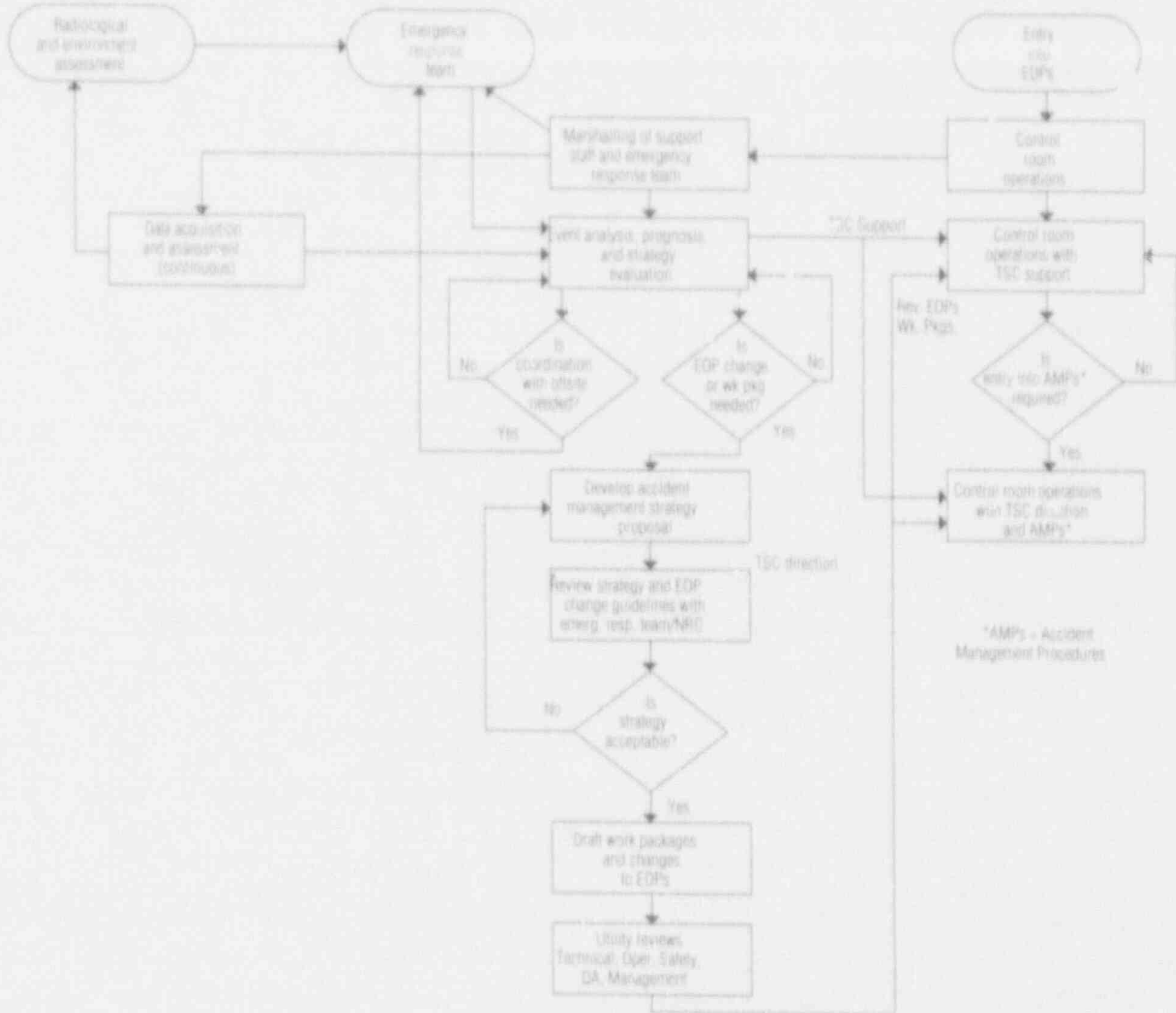


Figure 10. Decision-making flow for plant operations during accident management.

This possibility has serious implications because, by definition, this situation would be one with high, contingent risks and limited time for making a decision. The decision-making structures in the accident management plan should be prepared for this need by providing for the continued, but expedited, forms of decision support.

Typical management of decision making by a utility during an emergency at a nuclear station recognizes and promotes the principle of separation of the decision process into three distinct stages: (a) the original diagnosis or generation of options for action, (b) a distinct and somewhat independent review of the diagnostic results and the proposed actions, and (c) a managerial approval action. This principle should be reemphasized by the decision structure established in the accident management plan for the nuclear station.

The delineation of decision making in the accident management plans for operation beyond previously extended and approved EOPs should derive from the above-described proven principles and practices. Where time permits, use appointed personnel during the accident to provide the established reviews and approvals. Provision should be made to expedite the execution of the reviews and approvals. The staffing of the TSC and the corporate EOF should provide personnel with the skills, experience, and training for this express purpose. The concept is to provide alternate personnel, shorter turn-around, and, ultimately, to omit steps. For a rapidly progressing event, the senior manager would retain the authority to issue an on-the-spot change or an oral command to take action beyond the EOPs. However, in order for this to be effective, not disruptive, the authority must be predefined and disclosed to the staff.

The nuclear utilities in the decade since TMI-2 developed mechanisms for marshalling significant offsite resources within short enough time intervals to be of possible use during a severe accident. These resources can support decision making directly by providing analytical and technical capabilities. The offsite resources can provide indirect support for decision making by increasing the number and range of available options for corrective or mitigative actions. Existing planning at utilities for emergency response has identified specific offsite resources for augmenting the capabilities of the OSC staff for repairs, modifications, replacements, or installations.

There is considerable information available on the discipline of decision making and on the results of studies on actual decision making. This literature strongly suggests that the type of decision making required during the management of a severe accident be structured to be performed in two stages: situational assessment and resource management (see Figure 11). This is defense against a natural inclination to take what may be premature, ill-conceived action when the decision making structure is under the combined pressures of possible severe consequences and limited time for available action.

Table 7 illustrates application of this decision-making structural concept, which is a list of the tasks the accident management team would be expected to carry out during an actual significant event. A nuclear station's accident management plan should include procedures and guidelines for decision making that integrate the organization tables, statements of responsibilities and authorities, and lines of communications into an effective decision-making structure. This structure should be based on an assessment of the types of decision tasks that may be required during the management of a severe accident. This assessment can also identify where aids to the decision task flow could be helpful, such as procedures, communications, training, etc.

6 Implement enhancement

Substep 6.3. Implement Equipment and Engineered Methods

The objective of this substep is to implement the equipment and engineered systems determined to be needed for the selected strategies. This substep will only be necessary if the enhancements selected in Step 5 identify the need for equipment or engineered methods that cannot be met using existing hardware.

We consider equipment to be the hardware normally used in the plant. Examples include

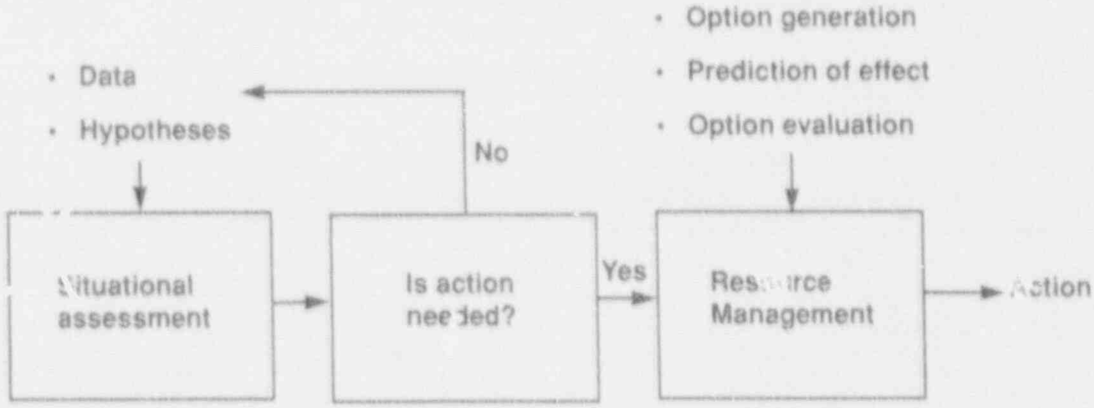


Figure 11. Decision flow.

Table 7. Decision-making tasks for accident management

The primary responsibility for these tasks should rest with the TSC staff, which should consist of qualified representatives from engineering analysis, systems engineering, operations, and maintenance. Until the TSC is staffed, the responsibilities for these tasks will need to be carried by the on-shift station staff, for example, the control room shift supervisor (SRO), the STA, and the maintenance supervisor. During this period, priority is given to tasks 1, a, b, and c.

1. Situational Assessment

a. Determine current values and immediate trends of safety-related parameters and safety functions. Give priority in this assessment to parameters and safety functions that are abnormal or trending toward safety limits

b. Determine which EOP(s) should be entered and what steps within the EOP(s) are immediately applicable

c. Develop a hypothesis for the event

1. Determine the apparent cause or driving force(s) for the progression of the event

2. Identify and prioritize the safety functions and systems that are of concern

3. Identify the path through the EOP(s) that will be applicable for placing the plant in a safe and stable state

4. Continue to test the hypothesis against instrument readings and other information. Update or discard hypothesis and develop alternate hypotheses

d. Determine if action should be taken to support the EOPs (staffing, maintenance and repair, materials, analysis, operator aids, communications and minor change to EOPs). If YES, refer the task of determining what actions are required to **Resource Management**

e. Develop a prediction of the accident progression based on the best available hypothesis (or upon alternate hypotheses that are of creditable probability)

f. Determine if action beyond the EOPs should be taken. If YES, refer the task of determining what actions are required to **Resource Management**

2. Resource Management

a. Refer to Task 1.d and f for definition of the need for action to support the EOPs or for action beyond the EOPs that resulted from situational assessment. Select action(s) based on the following:

1. Determining what options are available

2. Prediction of effects of each option giving consideration to relative uncertainties, onsite and offsite consequences, short-term and long-term considerations

Table 7. (continued)

3. Evaluation of the options based on positive and negative effects, resource consumption, and uncertainties

b. Implement selected option(s):

1. Development of work packages or procedures

2. Independent review

3. Management approval

4. Release

5. Execution and situational assessment (refers to need for return to Task 1)

The present capabilities for decision making during the application of accident management strategies should be reviewed using a job or task analysis method. The products of this analysis will be the station documentation that defines the decision-making structure:

Organization charts	The charts or tables that show the positions that begin to be manned at an Alert EAL and are fully manned at a Site Area Emergency
Position descriptions	The position or job descriptions that define the position title, duties, tasks, responsibilities, and authorities of the job positions in the above organization
Procedures	The procedures, guidelines, checklists, etc., that may be used by individuals in the above positions
Communications	The phones, radios, and other means used to communicate between individuals at different locations plus the typical complement of individuals at each center such as the control room, TSC, EOF, OSC, and others
Decisionmaking information	The kinds, origins, and flow of information to decision formation centers (for example, the plant computer data link to the TSC)
Methods of implementing decisions	The results or outputs from the decision making process and the administrative procedures concerning their generation a. Emergency Procedures b. Job orders/work packages c. Change notices to existing documents d. Other forms of issuing a decision, conclusion, declaration, command (an example is a declaration of an EAL) e. Information reports to offsite ERCs *and* to utility and station staff

pumps, valves, piping, etc. Engineered systems are a special class of equipment, which includes hardware or software especially designed for a specific strategy to assist in implementing or carrying it out. An example would be a spool piece that could be installed to allow a fire hose from the firewater system to be attached to the inlet of an injection pump. If the modification of existing or the addition of new hardware is needed, the results from Step 5 should provide a concise description of the changes or new hardware needs.

The tasks for the implementation process for equipment and engineered methods are described in general terms, since the process for modifying or adding hardware will differ from plant to plant:

- A requirements specification should be developed for each modification to provide the needed equipment or engineered method. This specification should describe the following:
  - The purpose and needed specific capabilities of the engineered system or method
  - The technical guideline for a procedure for using the engineered system or method
  - The environmental conditions under which the engineered system will be used.
- The documented requirements should be used as the basis for a development and implementation plan that provides the following information.
  - The procedure for using the engineered system/method
  - The applications and limitations
  - Identification of the personnel using the system/method
  - Documentation of the system or method in which the purpose, application or use, and basis for the procedures are described in sufficient detail to allow independent quality assurance to be performed.
- The proper modification or installation of the needed equipment or engineered methods should be verified using accepted plant test procedures for this process. Proper coordination and interfacing with existing or newly implemented operating procedures, training, etc. should also be verified using accepted plant procedures.

The equipment and engineered systems should be developed as necessary to facilitate effective implementation of the needed strategies and procedures. These engineered systems should be easily accessed and include documentation with a simple step-by-step means of achieving the desired outcome, along with the training for appropriate staff personnel to effect implementation. An up-to-date list of suppliers that are the primary source of key resources should also be maintained to ensure sufficient backup for obtaining needed parts, etc. This list of resource suppliers should be maintained by both the technical support and station operations personnel, with the appropriate amount of lead time for acquisition noted for all key backup resources. These resources should include, for example, condensate and borated water supplies, diesel generators, backup injection pumps, etc.

6 Implement enhancement

Substep 6.4. Implement Computational Methods and Aids

The objective of this substep is to ensure that appropriate computational aids are developed that will complement and assist in the implementation of severe accident management strategies to prevent or mitigate severe accident consequences. These computational aids include methods for monitoring the current status of the plant, and projecting the progression of key phenomenological events, timings, and consequences identified in Step 5 as necessary for strategy success.

Some examples of computational aids are as follows:

- Computational methods and aids to determine plant status and predict the progression of the accident sequence, and to determine timing of key phenomenological events (initiation of core melt, lower head failure, containment failure, etc.)

- Computational methods and aids to predict severe accident consequences (core damage assessments; combustion potential as determined by the containment hydrogen, steam, and air content that results in inertion, deflagration and detonation conditions; magnitude and distribution of radiological releases; etc.)

- Computational methods and aids to assess the impact on the accident consequences of modifications to, or creation of new, severe accident strategies or procedures that may be needed during the event.

The format of the aids used in the above examples might include the following:

- Nomographs (for example, containment hydrogen, air, steam profiles showing inertion, deflagration, and detonation regions; time to lower head failure based on core exit thermocouple time-at-temperature; containment failure probability as a function of RCS pressure at time of lower head failure; etc.)

- Simple calculational methods to be used in hand calculations

- More complex calculational methods to be implemented on a PC

- Simplified fast-executing system codes capable of estimating response, for example, transient thermal-hydraulic blowdown of the RCS or containment temperature and pressure response

- An integrated severe accident analysis code package that includes transient thermal hydraulic models, severe core damage and melt progression models, RCS pressure boundary failure models, containment phenomena models, and radiological release models. This package may be on a mainframe or special workstation environment and should be fast-executing.

The process of assembling the above computational aids includes the following:

- From the assessment of information needs that cannot be supplied by the existing measurements identified in Substep 5.5, Evaluate Instrument Performance, list the information needs of the operating staff for those items where information necessary to manage the accident is deficient (failed, unavailable, missing, or excessive error). If possible, computational aids should be developed and implemented to provide the missing information. These aids may provide information for diagnosis, sources of backup information for confirmation, or for decision making in accident management.

- As required by the final plant and station procedures and guidelines and the results from Substep 5.3, computational aids and methods may also be needed by the technical support center staff to alert the operators that a given procedure will be needed to control an impending accident consequence. These computational aids would be used to assess plant status and to project the overall accident progression. These aids would be used to understand progression of event and where and when the impending challenges to the plant safety functions will occur.

- As identified in the assessment of phenomenological behavior in Step 5.2, computational aids may be required to implement and monitor the status of some of the strategies.

- From the needs identified above, prepare a requirements specification and a development and implementation plan for each of the computational aids needed.

Use of the above computational methods and aids is particularly important when information is unavailable to the operating staff because either the severe accident environment has failed the plant instrumentation, or the instrumentation needed to provide the information does not exist. In this context, computational methods and aids can serve to fill those information deficiencies where plant instrumentation has failed or does not exist. Use of the last available plant instrument information could serve as input to the computational methods and aids to predict those severe accident phenomena and parameters not available but necessary for effective accident management.

6 Implement enhancement

Substep 6.5. Implement Information Needs

The objective of this substep is to develop and implement the enhancements associated with the instrumentation. This substep will only be necessary if the enhancements selected in Step 5 identify the need for information that cannot be met by the instruments in their present configuration or by other means such as computational aids. If the modification of existing, or the addition of new, instrumentation is needed, the results from Step 5 should provide a concise description of the changes or new instrumentation needs. The tasks involved in this substep are as follows:

- Identify the requirements for modifying or installing any needed instrumentation based on the integrated set of instrumentation needs developed during Step 5. Use these requirements to develop a requirements specification that can be used to develop implementation plans. The information in the specification document should include, for example, the following:
  - Specification of the general type of measurement, for example, pressure, temperature, etc.
  - The needed range and accuracy
  - The location of the transducer
  - Environmental conditions to which the transducer, cabling, signal conditioning, or other equipment will be subjected
  - Special support system and signal conditioning needs, including the need for emergency electrical power and for processing the data to provide additional information
  - Special display needs, including the location and type of displays needed.
- Use the identified requirements to develop a plan for implementing the instruments. The plan should provide the details on the modification or development of instrumentation using the established plant procedures and practices and should include a description of what coordination is needed with other implementation efforts. For example, describe the interfaces with procedures development and training to ensure that the information from the instrumentation is being used properly and that the personnel involved in accident management will be trained on its use. Close coordination with training on computational aids may also be required for some instrumentation.
- Using accepted plant procedures, verify proper modification or installation of the needed instrumentation. Also, using accepted plant procedures, verify proper coordination and interfacing with existing or newly implemented procedures, training, etc.

6 Implement enhancement

Substep 6.6. Implement Training

The objective of this substep is to provide information on the development of training requirements for successful execution of each enhancement. Base the training requirements on the data obtained from the procedure development task, the phenomenological analyses, the equipment performance, the human performance evaluation elements of the framework, the instrumentation, the computational aids, etc. This will ensure that the training adequately addresses all aspects of the job within the system. Develop requirements for all participants in the process of accident management for a given strategy. This includes not only the reactor operators but also members of the TSC and others as defined by the individual utilities. These requirements will differ substantially as a function of the position, and will be composed, for example, of different combinations and levels of academic knowledge versus practical working-level knowledge of various phenomena and systems. Also consider general training in the areas of teamwork and decision making, as these areas may greatly impact overall performance of the utility. The process for development of this training should follow acceptable, industry standard practices (Bloom), and will be based on all prior analyses conducted in Steps 3 and 5.

- Perform a detailed analysis to determine the role that training will play for all individuals involved in the management of accidents for each strategy and its man-machine system. This should include training for control room personnel, members of the TSC, and others involved in the accident management process as defined by the individual utilities. This analysis should be based on task analysis data, which includes all the necessary information regarding skills, knowledge, abilities, tools, information, and required operator aids to enable complete development.

- Define the goals and objectives of the training. Formally state goals and objectives, using behavioral, enabling, and terminal learning objectives.

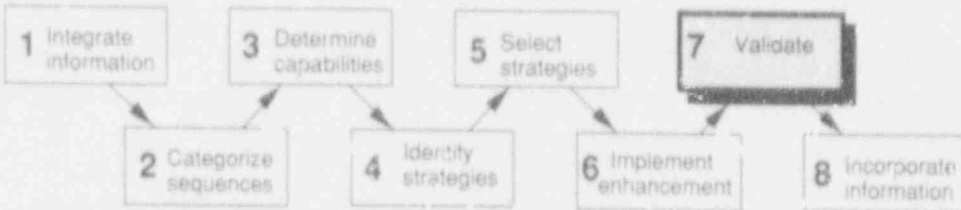
- Select instructional methods and media. Give special attention to ensure the highest transfer of training is possible, by using state-of-the-art simulation techniques, and by involving all accident management team members.

- Select and develop evaluation criteria that directly test the mastery of the instruction objectives and successful completion of the goals, as well as all materials and facilities.

- Develop a plan for drills and follow-up, to maintain utility readiness.

The product of this element will be a complete training module that will ensure mastery of the tasks necessary for the successful implementation of the selected strategy.

Step 7. Perform Program Validation



The objective of this element is to a provide a process for the validation of the strategies and enhancements, including the engineered methods, procedures, and training.

To provide a comprehensive validation of the implemented plan, conduct a complete operational test or drill of each strategy. We recognize that many of the scenarios for the proposed strategies might include plant states that cannot be interactively modeled by commercially available simulators at present. However, a part task/part scope simulation can be engineered to accomplish the required testing environment. It may be appropriate to use recorded scenarios that are simply played back on the simulator (developed for the specific purpose), or to use a severe accident code package on a work station. Such determinations will need to be made on a strategy-by-strategy basis by individual utilities. This will include evaluating all strategies, and evaluating the utility's mechanism for coping with accidents for which no strategy presently exists. Conduct a two-phase approach to this test.

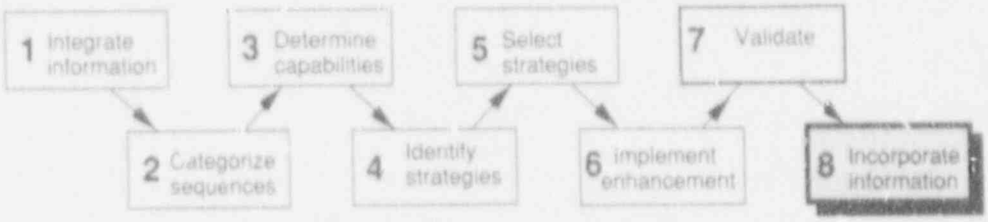
Phase 1 should be a simple walkthrough consisting of a step-by-step check of the engineered methods, procedures, and training to determine if they support each strategy. For example, do procedures support execution of the strategy? Do engineered methods work and are they available when required by the strategy? Does the training provided facilitate effective implementation of each strategy? Such questions should be asked for each strategy to ensure probable execution. Any deficiencies should be corrected prior to the full operational testing.

Phase 2 should be a full operational test of the strategy, which includes all parts of the organization involved in the accident:

- The test should require personnel to diagnose what strategy is appropriate and how to implement the strategy given the scenario presented to them
- The test should include all personnel involved in the strategy
- The test should include performance measures that relate to successful termination of the scenario by the strategy
- These measures should be identified in advance and should be keyed to improving overall performance of the staff while implementing that strategy
- Minimally, these performance measures should cover the plant equipment and status, procedures and guidelines, engineered aids, and training material
- The measures should be taken, evaluated, and the results documented, indicating relative success of the implementation and identifying any needed improvements.

The product of this step is a documented test and evaluation of the implementation of the strategy, including the identification of any necessary modifications.

Step 8. Incorporation of New Information



Since severe accident research will continue during the development of the accident management programs, new information will become available after the accident management programs have been put in place. As new information becomes available, the means of incorporating this new information into the accident management programs will be necessary. The new information might identify new severe accident phenomena or quantify the effects of some severe accident behaviors, which could create the need for new strategies or invalidate existing procedures or strategies. To evaluate new information as it becomes available, develop an evaluation process and implementation plan as part of your accident management program. This evaluation and implementation plan should include

- A means of acquiring the new information, including information developed by the operating staff from drills, walkthroughs, training, plant operating experience, results of new research, etc.
- An assessment of the impact of the new information on the plant and accident management program
- The means of incorporating the new information into the accident management process to improve accident management
- Means to validate and verify the changes
- Means to update the training program
- Means to document the changes, including appropriate engineering discipline reviews and signoff.

The process for incorporating new information into the program includes the following steps:

- A means of maintaining cognizance of new research results and developments in accident management should be put in place. This may include a formal procedure where a designated engineering discipline summarizes the results of a brief review of a list of potential new developments with application to accident management. The documentation of this review could occur at least once each year or at the time an important research development or new information becomes available. The review would either state that the list of new developments is not worthy of inclusion or give recommendation to formally investigate a change for possible incorporation into the accident management program.
- If new information has been recommended for possible inclusion into the program, a formal evaluation is then performed.
- A change to the existing accident management program should be documented for evaluation. All appropriate disciplines should then be used in the evaluation process to determine that
  - The change does not increase the probability of occurrence or consequences of an

accident or malfunction of equipment important to safety previously evaluated.

- The change does not create the possibility of an accident or malfunction of a different type than previously evaluated.

- The change does not reduce the margin of safety defined previously in the basis for the technical specifications.

- The change does not adversely affect achievement of a long term stable state of core cooling.

Procedures should already exist for making plant procedural, technical specification, or design changes. These same procedures should be used in evaluating changes to the accident management program. It is important to ensure that all major engineering disciplines be involved in a formal, documented review to ensure completeness and awareness to the change. The engineering disciplines engaged in the evaluation should include

Mechanical Engineering

Civil Engineering
Nuclear or Reactor Engineering
(Reactor Physics)

Nuclear Safety Engineering
(Design Basis Accidents and PRA)

Electrical Engineering

Licensing
Station Operations

Training and Emergency Response.

- Once each discipline has approved the change, perform Steps 2 through 7 to ensure completeness in incorporating the change into the accident management plan.

The product of this step will be a formal procedure for identifying, approving, and incorporating new research results or developments into the accident management program.

4. Criteria for Assessing Accident Management Plans

We have developed a set of general assessment criteria that can be used to assess the adequacy of methods suggested for developing severe accident management plans or to examine the capability of plans that are completed. These criteria are based on the preliminary criteria documented in NUREG/CR-5543, and revisions to these criteria presented in Volume 2 of this NUREG/CR, but they have been generalized so that they are not specific to a particular development or implementation process.

The assessment criteria are organized using the nine general attributes of accident management discussed in Section 2. They are presented in three groups that follow the sequence for preparation and implementation of an accident management plan: (1) criteria for attributes that relate to the preparation of information necessary to develop accident management plans, (2) criteria for attributes that are important during the preparation and implementation of accident management plans, and (3) criteria for attributes that are necessary to ensure that an established accident management plan is validated and properly maintained.

4.1 Prepare Necessary Information

Criteria for the attribute relating to gathering and preparing information necessary for developing an accident management plan are presented in this section. The attribute is stated first, followed by the criteria.

1. *Adequate information should be assembled to understand the capabilities and potential limitations of the plant, including both equipment and personnel.*

   a. Information should be compiled that clearly identifies those severe accident sequences to which the plant could be vulnerable, including high-consequence low-probability sequences and sequences with a high probability of core damage. For each accident sequence, the information should be sufficiently detailed to describe important failures of equipment, human errors, important events and their timing, and current and potential prevention or mitigation actions. Detailed IPE or PRA results will generally satisfy this criterion.

   b. Accident sequences should be grouped or categorized such that they can aid in identifying plant accident management capabilities and assessing the support of plant safety functions by accident management strategies. These assessment categories should encompass the plant IPE or PRA results to ensure that all severe accident behavior that might challenge the plant safety functions are included. Separate groups or categories should be established if significant differences are noted in the timing of key events, system conditions, support system availability, or system environmental conditions.

   c. Detailed descriptions of the plant equipment, instrumentation, operations, resources (borated water, electrical power, etc.), and training should be compiled. These descriptions must include design and operational limitations.

   d. A review should be performed to identify how existing plant hardware and personnel can be used to provide the capability to manage severe accidents. The review should use structured and formal methods that apply to all groups or categories, for example, a structured set of questions designed to determine how current procedures, safety and nonsafety equipment, instrumentation, decision making responsibility and authority, and training relate to severe accident prevention and mitigation.

4.2 Accident Plan Development and Implementation

Criteria for the attributes relating to developing and implementing an accident management plan are presented in this section. The attributes include the five NRC accident management framework elements. Each attribute is listed, followed by the criteria.

1. *A clearly identified set of accident management strategies should be available to effectively prevent or mitigate undesirable accident consequences.*

   a. Strategies should be identified that could enhance the capability to prevent or mitigate the challenges to plant severe accident safety functions in each of the following areas: (a) prevent core dispersal from the vessel, (b) prevent containment failure, and (c) mitigate fission product release. Strategies for preventing core damage should be included if appropriate.

   b. Severe accident management strategies should consider, but not be limited to

   - Repair and restoration of failed equipment
   - Use of alternate equipment
   - Use of alternate resources
   - Conservation of resources
   - Timing for increased effectiveness
   - Existing strategies proposed for general severe accident applications or specifically developed for similar plants.

   c. The use of special tools; special purpose hardware, for example, spool pieces; analysis aids; and special purpose procedures and guidance should be considered for strategies where implementation times are short.

   d. Strategies should consider the long-term needs for accident management in terms of

   - The long-term effects of radiation on habitability, access to plant areas, personnel exposure, equipment degradation, and instrument degradation
   - The need to provide long-term cooling for the core material in the RCS and the containment
   - The need to manage combustible gases that accumulate in the containment as a result of radiolysis or chemical reaction
   - The need to manage the chemistry of the water in the containment to minimize degradation of equipment
   - The need to control the leakage of water and gases from the containment
   - The need to manage the waste material generated during and following a severe accident

   e. All strategies should be evaluated using techniques that include phenomenological analyses, human factors analyses, plant systems and equipment performance analyses, and analysis of instrument capabilities to determine

   - The likelihood of successful implementation
   - The effectiveness for preventing or mitigating the consequences of severe accidents
   - The potential for the strategy to result in negative effects for the public, plant personnel, or the plant systems and equipment
   - The availability of information from plant instrumentation necessary for

strategy selection, implementation, and evaluation

f. The severe accident management strategies should be organized into a symptom-based, function-oriented structure, and should be reviewed to ensure coverage of all plant safety functions. A minimum of one strategy should be identified for each group or category of severe accidents identified. Whenever possible, strive for redundancy and diversity in the strategies identified.

g. Results from the strategy evaluations should be used to prioritize the order of strategy use if two or more strategies are identified for implementation.

2. *Procedures and guidance should be implemented at all appropriate levels in the organization for executing the strategies.*

a. Procedures for the management of severe accidents, including severe accident management strategy selection, implementation, and monitoring should be available for the plant operating crew. They should be based on results from task analysis and be integrated with existing plant EOPs and emergency response facility guidance. They should clearly establish lines of authority and responsibility and identify the coordination that is necessary with personnel in the emergency response facilities.

b. Guidance for the management of severe accidents, including severe accident management strategy selection, implementation, and monitoring, should be available for all personnel in the emergency response facilities. The guidance should be integrated with the procedures used by the operating crew. They should clearly establish lines of authority and responsibility and specify necessary coordination.

c. Procedures and guidance should exist during a severe accident for the continuing tasks of communications among the personnel and organizations involved in accident management, control of plant configuration and personnel, and control of personnel exposure.

d. Special needs of personnel involved in implementing strategies should be recognized, that is, specialized tools, analysis aids, etc.

3. *Engineered methods (necessary systems and equipment) should be identified for the proper implementation of strategies.*

a. The need for supporting systems, equipment, services, and operator action should be described for each severe accident strategy.

b. The likelihood of failure, impact of failure, estimated failure time, and failure mode of systems and equipment necessary for severe accident management should be determined.

c. The following information should be available for each new piece of equipment or each new engineered system identified:

- The purpose and needed specific capabilities for the equipment, engineered system, or method
- A guidel for creating a procedure for using the system, if needed
- The environmental conditions under which the engineered system will be used
- Limitations on the use of the equipment, engineered system, or method

4. *Adequate plant status information should be available to monitor all plant safety functions and to select and assess the effectiveness of all strategies.*

a. The existing plant instrumentation should be reviewed to ensure that the severe accident information needs are being met in terms of the capability to

- Provide information needed to monitor plant status

- Identify challenges to plant severe accident safety functions

- Provide the information necessary to select strategies that will prevent or mitigate the effects of challenges

- Determine the effectiveness of selected strategies

Consideration should be given to whether instrument ranges are adequate; the hardware will operate in the severe accident plant environments, for example, high temperature, pressure, humidity, and radiation fields; and the necessary plant support systems are available when the information is needed.

b. Where existing instrumentation is not adequate for severe accidents, alternate means of supplying the needed information should be identified. Examples are modifying existing instrument systems, adding new instrumentation, or using computational aids or analysis aids.

c. The requirements for display of plant information should be assessed based on the types of information that will be needed by personnel involved in accident management.

d. Validated computational aids or analysis aids may be used to supplement plant instrumentation if the existing instruments are not adequate.

5. *Lines of decision-making authority and responsibility should be clearly delineated.*

a. The decisions and related activities that might be required to support strategies for each assessment category should be defined, and the individual responsibilities for their execution should be specified in the procedures and guidance documents.

b. Decision making applicable to accident management should be visible in the accident management structure, including decisions on (a) whether accident management actions are needed, and (b) which actions to select and how to manage resources

c. The communications necessary to support accident management decisions, including face-to-face communication needed for coordinating activities, should be defined

d. Analysis aids should be developed and validated to support decisions when the time available for making the decisions is short. These analysis aids should also support decisions to use strategies that may be devised during the progression of a severe accident

6. *Adequate training should be provided for all personnel involved in accident management.*

a. All personnel involved in accident management should be generally trained for severe accident situations. Included should be a discussion of severe accident phenomena, plant-specific accident progression results from the IPE or PRA, expected response of important instrumentation, information on the expected response of the plant to severe accident strategies, and possible actions that personnel could take to improve this response.

b. Training should include procedures and guidance associated with strategies identified for severe accidents.

c. Training should be provided in such specialized areas as decision making, use of special tools, special purpose hardware, analysis aids, and special purpose procedures and guidance.

d. Care should be taken to avoid incorrect use of simulators during training for severe accident situations; inadequate models may produce severe accident results that are misleading to the trainees.

e. Training should consider accident management actions that are necessary in the long term to ensure that the plant remains in a safe, stable state. Consideration should be given to the types of instrumentation expected to be operating, areas of the plant that are accessible, equipment that is likely to fail, and plans for its replacement, etc.

4.3 Plan Validation and Maintenance

Criteria for the attributes related to the validation and long-term maintenance of the accident management plan are presented in this section.

1. *Performance of the implemented accident management plan should be validated.*

   a. The accident management plan, together with all supporting documentation, should be compiled and cross-referenced in a form that can be reviewed and the results validated.

   b. A complete walkdown of each severe accident management strategy and its associated procedures and analysis aids should be conducted.

   c. A complete operational test or drill of each severe accident management strategy should be conducted. These drills should use accident sequences that will challenge all aspects of the strategies.

   d. Drills should realistically represent low-probability events. There should be adequate feedback so that actions taken by accident management personnel during a drill will have a realistic effect on the progression of the drill scenario.

   e. Validation should be performed for analysis aid software or other software used in accident management.

2. *A formal mechanism should be in place to identify and incorporate new information into the implemented accident management plan as it becomes available.*

   a. Cognizance should be maintained of new research results and developments in accident management and severe accident behavior.

   b. New information should be assessed as it becomes available to determine if the effectiveness of the accident management plan can be improved.

   c. If new information is determined to have a significant impact on accident management, potential changes to the implemented accident management plan should be identified and evaluated to ensure that they do not compromise the capability of safety systems to prevent or mitigate design-basis accident, or severe accident management. Those found to be beneficial should be documented and added to the existing accident management plan.

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11. ABSTRACT (200 words or less)

This document is the first volume of a two-volume NUREG/CR. It describes a four-phase approach for developing criteria that can be used for assessing the adequacy of severe accident management plans for nuclear power plants. The general attributes of accident management plans (Phase 1) are identified, and a process for developing and implementing severe accident management plans (Phase 2) is described. This process is based on a prototype process described in NUREG/CR-5543. The prototype process was revised using results from an evaluation of this process (Phase 3), which is documented in Volume 2. General criteria for assessing the adequacy of accident management plans are also presented (Phase 4). These criteria were based on process specific criteria presented in Volume 2 and NUREG/CR-5543.

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