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Accident Management Information Needs for a BWR with a MARK I Containment

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Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

In support of the U.S. Nuclear Regulatory Commission Accident Management Research Program, information needs during severe accidents have been evaluated for Boiling Water Reactors (BWRs) with MARK I containments. This evaluation was performed using a methodology that identifies plant information needs necessary for personnel to: (a) diagnose that an accident is in progress, (b) select and implement strategies to prevent or mitigate the accident, and (c) monitor the effectiveness of these strategies. The information needs and capabilities identified are intended to form a basis for more comprehensive information needs assessments. These assessments will be performed during the analysis and development of specific strategies, which will be used in accident management prevention and mitigation.

FIN No. B5723—Accident Management Framework

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ACCIDENT MANAGEMENT INFORMATION NEEDS FOR A BWR WITH A MARK I CONTAINMENT

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 be used to consolidate results from other key activities under this plan to further enhance safety programs for nuclear power plants. Implementation of accident management will ensure that planned actions and preparatory measures are developed that will enhance the capability of nuclear power plant personnel to effectively manage severe accidents.

The NRC identified *Instrumentation* as one of the five areas where risks associated with severe accidents can be further reduced. This conclusion was based on a review of reliable plant status information. Without adequate plant status information and guidance to ensure its proper use, plant operating personnel cannot reliably diagnose the occurrence of an accident, determine the extent and nature of the challenge to plant safety, monitor the performance of automatic systems, select and implement corrective strategies to prevent or mitigate the safety challenges, and monitor their effectiveness.

To support the NRC accident management work relating to instrumentation, a test program for boiling water reactors (BWRs) with MARK I containments is underway. The objectives of this program are to identify the following:

- Information needed to determine the status of BWRs during a broad range of severe accident conditions, including selection and implementation of corrective actions
- Existing plant measurements that could be used to directly or indirectly supply these information needs
- Situations where information from the measurement systems could mislead plant personnel.

Evaluation of the potential limitations of the plant instruments to function properly when exposed to varied environmental conditions that may occur during a wide range of postulated severe accidents is the subject of a separate NRC research program scheduled for completion in fiscal year 1991.

To satisfy the stated objectives, a four–step methodology was established to identify the BWR information needs during severe accidents and to determine the extent to which these needs could be met by currently used instrumentation. These steps are as follows:

- Identify the relationships between plant safety objectives, challenges to the safety objectives, mechanisms that cause the challenges, and strategies that would mitigate or prevent the mechanisms using a hierarchical tree structure.

- Identify what information is needed to determine whether the plant is at or approaching a state that would correspond to each branch point in the safety objective trees, developed in Step 1. Possible sources of this information (for example, reactor pressure, containment atmosphere temperature, etc.) would then be identified and assessed to see how well the information at the plant represents that which is needed to understand the conditions at that branch point.

- Determine whether current plant instrumentation is capable of providing the needed information.

- Identify any absence of information that is needed to distinguish individual branch points on the safety objective trees or other events that may mislead personnel involved in accident management.

Results from this methodology application can be summarized as follows:

- The safety objective trees developed for a BWR with a MARK I containment display plant severe accident information in a manner that clearly identifies the important safety functions for severe accidents and promotes understanding of the important challenges to these safety functions. Although the severe accident conditions presented on the tree are not new or unique, the structure of the trees allows easy visualization of how challenges to plant safety can be identified and what alternate means may be available to plant personnel for prevention or mitigation of a severe accident.

- The assessment of information needs for a BWR with MARK I containment indicates that, during a severe accident, there is insufficient instrumentation to determine whether the containment remains inerted. Lack of information on nitrogen concentration would make decisions on the use of strategies, such as containment venting, less certain because it would be unclear whether there was sufficient nitrogen to prevent hydrogen deflagration or detonation. There is also insufficient information to determine whether the containment boundary is being challenged once molten core material has penetrated the reactor vessel. Challenges to the containment boundary could result from a direct contact of molten material with the drywell shell and/or the ablation of concrete in the basemat.

- Currently, there are eleven information needs not supplied directly from existing instrumentation that might mislead accident management personnel. Three of these were judged to be most important: (a) the core relocation/damage status, (b) an imbalance in energy addition and removal, and (c) the Interfacing Systems pipe rupture status.

The lack of instrumentation to provide direct information on the core relocation/damage status would be most important during the early stages of core degradation. Liquid level measurements would provide precursor information to alert plant personnel of an impending core damage event. However, the lack of core exit thermocouples and temperature measurements in the steam lines would make the initiation of core heatup and the severity of core damage difficult to determine if adequate cooling is lost. Indirect measurements that would assist in detecting core damage are fission product monitors and isotopic analysis, which could indicate fuel pin rupture; and hydrogen concentration, which could indicate zircaloy oxidation if there is a path for the hydrogen to escape into the containment.

Thermocouples that measure the temperature of the metal in the reactor vessel lower head have the potential to indicate when molten core material relocates and the approach to failure of the lower head. This information would be very important in making decisions related to the management of resources during a severe accident. For example, decisions regarding continued use of resources to preserve vessel integrity as opposed to the use of these same resources to preserve containment integrity. The effectiveness of this measurement for accident management would be plant specific because the location and number of the vessel metal thermocouples varies from plant to plant.

The methods developed previously[2] and applied to BWRs in this evaluation were effective in identifying the information needed by plant personnel for management of severe accidents. Nuclear utilities are now addressing the severe accident issue for their plants, which will include (a) completion of individual plant examination (IPEs) and (b) eventual development and implementation of a severe accident management plan. Use of the methodology described and demonstrated in this document together with the results from the information needs assessment could be used in the development, implementation, and evaluation of effective accident management programs.

1. INTRODUCTION

Accident management is an essential element of the NRC Integration Plan for the closure of severe accident issues. This element will consolidate the results from other key elements such as Individual Plant Examination (IPE), Containment Performance Improvement (CPI), and Severe Accident Research Programs (SARP) in a form that can be used to enhance the safety programs for nuclear power plants. Accident management will ensure that planned actions and preparatory measures are developed that will enhance the capability of nuclear power plant personnel to effectively manage severe accidents. The NRC has identified five general areas in which the risks associated with severe accidents can be further reduced through accident management.[1] These five areas are as follows:

- Accident management strategies
- Training
- Guidance
- Instrumentation
- Decision–making responsibility.

Instrumentation was included as one of the five areas because of its important contribution to the performance of personnel involved in severe accident management. Plant personnel (reactor operators, shift technical advisors, technical support center personnel, etc.) are responsible for diagnosing the occurrence of an accident, determining the extent of the challenge to plant safety, monitoring the performance of automatic systems, selecting strategies to prevent or mitigate the safety challenge, and implementing the strategies and monitoring their effectiveness. Without adequate plant status information and guidance to ensure its proper use, these operating personnel cannot reliably identify and accomplish the actions necessary for accident management.

The safety–related instrumentation installed in nuclear power plants is primarily designed and qualified for preventing and mitigating accidents with a severity that is less or equal to a design basis accident. The capability of the instrumentation to supply the information needed for management of a broad range of severe accidents, has not been adequately demonstrated. Therefore, the objective of the work presented in this report is to determine the extent to which current plant instrumentation in BWRs with MARK I containments is capable of supplying the information needed to manage severe accidents. This objective is accomplished through application of a previously developed methodology,[2] which identifies the following: (a) the information needed to understand the status of the plant during a broad range of severe accident conditions including recovery actions, (b) the existing plant measurements that could be used to directly or indirectly supply these information needs, and (c) the conditions where information from the measurement systems could mislead plant personnel.

The remainder of this report describes the results, and the approach used in developing them. Section 2 describes the methodology used to identify the information needs for management of severe accidents. Section 3 describes the results from the application of the methodology to a BWR with a MARK I containment. The summary and conclusions are presented in Section 4, and references are listed in Section 5. Appendices are used for documenting the information developed during the application of the methodology.

2. METHODOLOGY AND APPROACH

The approach used in identifying the information needed to manage severe accidents for a BWR with a MARK I containment and to determine the ability of existing instrumentation systems to supply these needs is described in this section. This approach is based on a methodology that was developed during a previous NRC program.[2] A brief description of this methodology follows.

A four–step approach was developed for identifying nuclear power plant information needs during severe accidents and for determining the extent to which these needs will be met by information currently in use at the plants. These steps and their relationship are described in the Executive Summary and illustrated in Figure 1. A brief description of the purpose and products for each step is presented, followed by a more detailed description of the methodology for the individual steps.

The purpose of the first step is to identify the high–level safety objectives for the reference plant and to provide a means to relate these safety objectives to accident management strategies that have been identified for accomplishing them. The relationships identified in this step can be displayed in the form of a hierarchical tree that provides insights on the types of information that would be necessary to ensure that the plant safety objectives for severe accidents are met. The product of the first step is a set of safety objective trees that identify the relationships between safety objectives, challenges to these safety objectives, and strategies that would mitigate or prevent these challenges.

The purpose of the second step is to consider each branch point in the trees developed in Step 1 and determine what information would be needed to decide whether the plant is at a state that would correspond to each branch point. Once the information needed to identify the positions on the tree have been determined, the possible sources of this information (reactor pressure, containment atmosphere temperature, etc.) would be identified and assessed to see how well the information at the plant represents the information needed. The product of this step is the identified information needs and an assessment of the availability of this information at the plant.

The purpose of the third step is to identify whether the instrumentation that exists at the

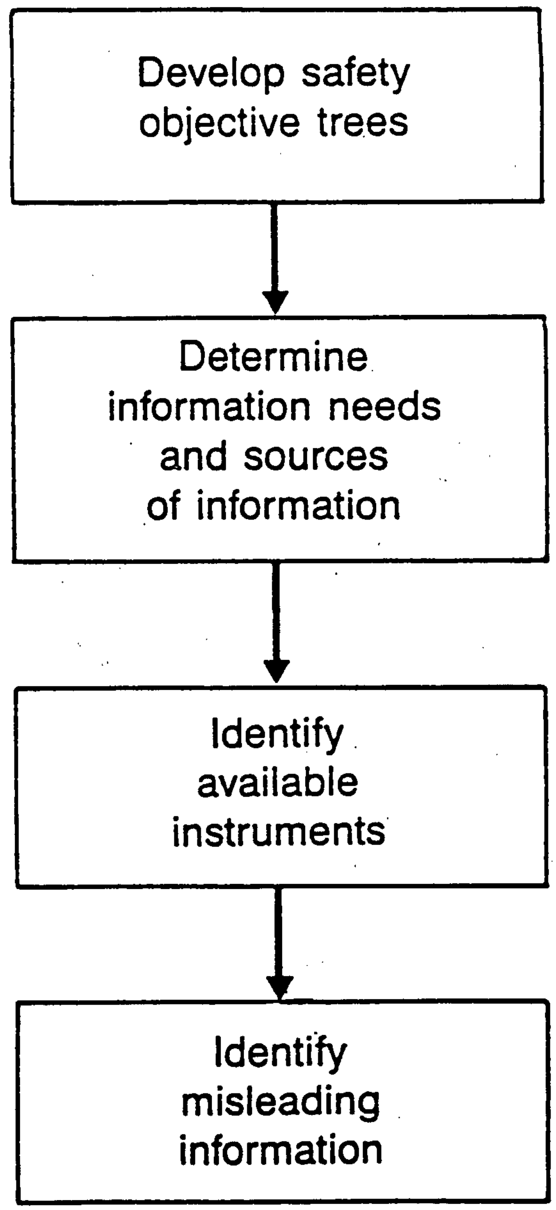

Figure 1. Steps in Methodology Development.

plant will supply the needed information identified in step 2. The product of this step is a means of relating existing plant instrumentation to information needs and an identification of information needs that are not supplied by existing instrumentation.

The purpose of the final step is to identify situations where the operator may be misled because the available information does not clearly distinguish individual branch points on the tree. The discussion below provides a more complete description of each of these steps.

2.1 Develop Safety Objective Trees

The first step in the development of the methodology utilizes a "top down" evaluation that requires an identification of the top–level objectives of severe accident management. These objectives were based on the NRC definition of accident management (see Reference 1):

> "Accident Management encompasses those actions taken during the course of an accident by the plant operating and technical staff to: (a) prevent core damage, (b) terminate the progress of core damage if it begins and retain the core within the reactor vessel, (c) maintain containment integrity as long as possible, and (d) minimize offsite releases."

The four items listed in this definition are appropriate as statements of the safety objectives for accident management. Use of the first objective in the development of a methodology for *severe* accidents was not considered to be appropriate because core damage would have already occurred in order for the accident to progress to the stage where it would be considered to be severe. The remaining items were selected as the safety objectives for severe accident management and were restated as: (a) prevent core dispersal from the vessel, (b) maintain containment integrity, and (c) mitigate fission product release.

These three top–level objectives for severe accident management can be related to actions (generally called strategies), that can be used to ensure that the objectives are met if an accident occurs. In order to ensure that these *safety objectives* are met, certain critical plant conditions, or *safety functions*, must be maintained within acceptable limits. An accident will present *challenges* to the safety functions that have the potential to cause the safety functions to exceed the acceptable limits. These challenges are caused by different *mechanisms* that occur in the plant. Finally, various *strategies* can be identified and implemented for preventing or mitigating the mechanisms that cause the safety function challenges.

The categories described above—safety objectives, safety functions, challenges, mechanisms, and strategies—form a natural hierarchy that defines the roles of personnel and equipment involved in accident management. Identification of the various levels in the trees is a logic–driven iterative process that requires input from experts in severe accident behavior and personnel with plant operations experience. Figure 2 presents an example that shows one branch of a safety objective tree for the first safety objective, Prevent Core Dispersal from Vessel.

The completed safety objective trees are used in the second step of the methodology as a tool to systematically determine the operating staff's information and measurement needs. It is also possible to evaluate the tree structure for specific severe accident scenarios to determine the effects of the scenario on the safety objectives, to identify challenges to the safety functions, to assess those strategies that are disabled by the event, and to chose those remaining strategies that are appropriate for use to mitigate safety function challenges.

2.2 Determine Information Needs

The types of information needed for severe accident management can be identified by

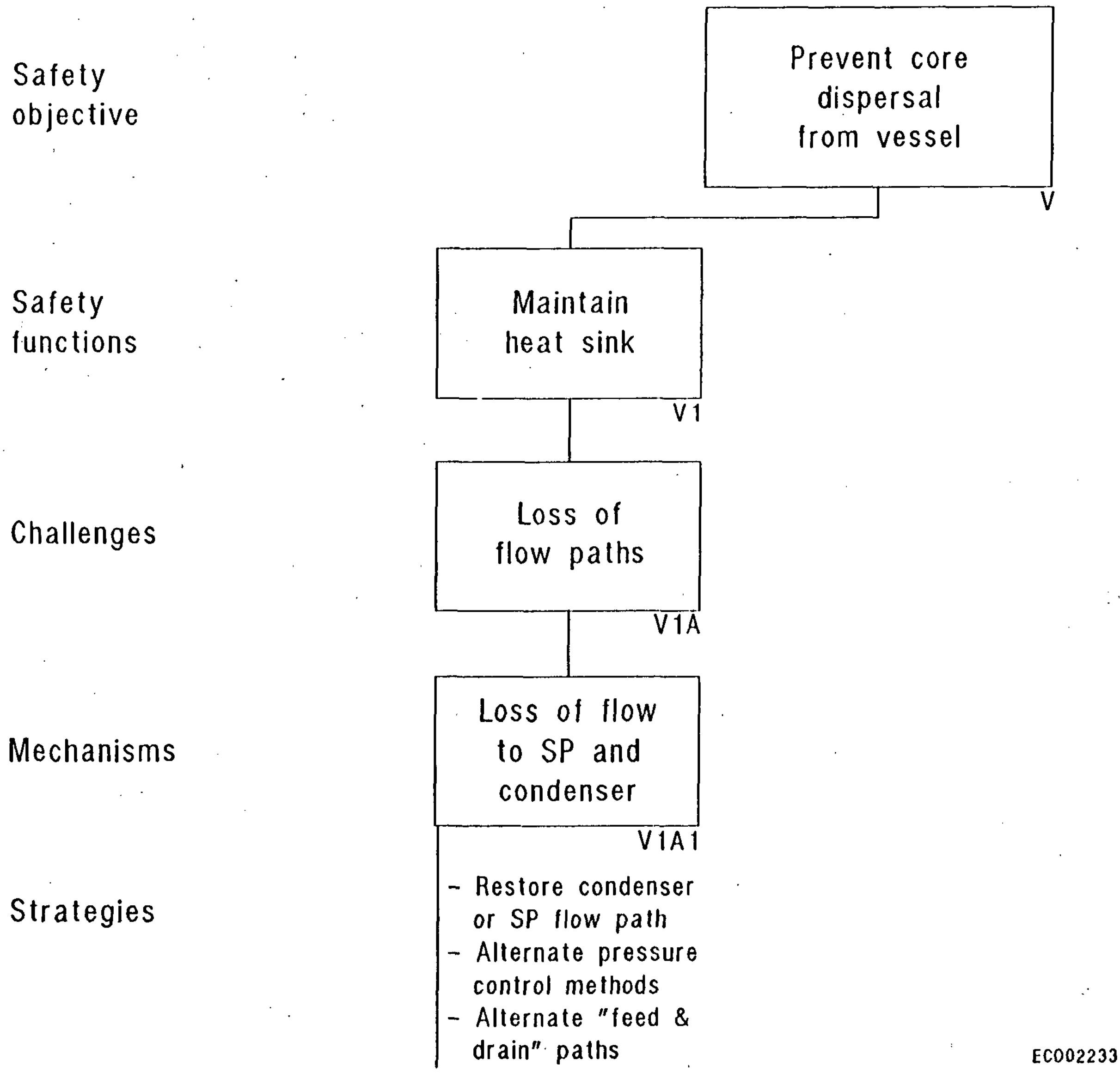

Figure 2. Example of one branch of a Safety Objective Tree.

considering the tasks that must be accomplished to support the severe accident management safety objectives. These tasks or activities include the following:

- Monitoring the status of the safety functions
- Detecting challenges to the safety functions
- Identifying, if possible, the specific mechanisms that could be causing the safety function challenges
- Selecting and implementing strategies for maintaining or restoring challenged safety functions
- Monitoring the performance of the strategies to determine their effectiveness.

Each of these activities can be related to a branch point on the safety objective trees discussed in Section 2.1.

To identify information needs, branch points are examined to ascertain the following: (a) determine the status of the safety functions in the plant, i.e., whether the safety functions are being adequately maintained within predetermined limits, (b) identify plant behavior (mechanisms) or precursors to this behavior that indicate that a challenge to plant safety is occurring or is imminent, and (c) select strategies that will prevent or mitigate this plant behavior and monitor the implementation and effectiveness of these strategies. The information needs for the challenges to the safety functions are not examined because the summation of the information needs for all mechanisms associated with a challenge comprise the information needs for the challenge itself.

To aid in the systematic identification and display of the accident management information needs, a table–based format was developed. Table 1 shows an example of the structure of this table. The rows on the table correspond to the levels of information listed previously, which were derived from the levels of the safety objective trees. The first section (row) of the table contains the information needs that relate to the safety function. This section is used to describe the information needed to determine whether the safety function is being maintained within the accepted safety limits. The second section (row) of the table displays information to identify a specific mechanism that may be a challenge to a safety function. Two different categories of information are important for identifying mechanisms: indicators and precursors. The indicators include information that identifies when a mechanism is actually occurring and challenging a safety function. The precursor information identifies whether a mechanism would be expected to occur in the future based on currently available information.

The final three categories (rows) relate to strategy selection and evaluation. The Selection Criteria category identifies the information needed to determine which strategies should be selected for a given situation, including consideration of the plant conditions under which the strategy can operate and be effective. The Strategy Initiation category gives the information needed for the operating staff to determine whether a strategy has been implemented as intended. The Strategy Effectiveness category describes the information needed to determine whether the strategy is having its intended effect; that is, whether implementation of the strategy is having a beneficial effect on the status of the safety function that is being challenged.

The respective columns in the table format include the identified information needs, the sources of the information categorized as to how well they represent the information needs, and the existing measurements that could supply the needed information. The information sources are subdivided into those that are considered to be either direct or indirect. A direct information source is one that can be used to provide information that will positively determine the presence or absence of a specific condition on the safety objective tree. For example, if the safety function addresses pressure control, a pressure measurement is a direct information source for understanding challenges to the safety function. An indirect information source can be used to infer the needed information, but there may be conditions where the information source may give ambiguous results. For example, an indication of radiation in the containment would be an indirect indication that the Maintain Core Heat Removal safety function was being challenged. This indication would be expected to lag the challenge and may not be easily interpreted because leakage of fluid containing fission products could also produce radiation levels in the containment.

Development of the input to the rows and columns requires the expertise of personnel with diverse backgrounds. A team of personnel with operations, instrumentation, and severe accident experience are needed to produce the needed information.

Table 1. Example structure of the information needs table

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Safety Function					
Mechanism	Indicator				
	Precursor				
Strategy	Selection Criteria				
	Strategy Initiation				
	Strategy Effectiveness				

2.3 Identify Available Information

Instruments that have the potential to supply information needs can be identified from the many instruments available at the plant by using various specific sources, such as piping and instrumentation diagrams, system instrument lists, and documentation showing compliance with Regulatory Guide 1.97.[3]

For the severe accident conditions represented by the information needs, there may be some information needs that existing instrumentation will not have the capability to supply. In addition, there may be existing instrumentation that does not have the needed range or is not qualified for conditions typical of those that will occur for some severe accidents. To assess these plant instrument limitations for severe accidents, a compilation of plant conditions that correspond to the identified information needs for a wide range of severe accidents would be required. This compilation would have to rely on the results of analyses performed with one or more severe accident computer codes. Ranges for existing measurements and results from their environmental qualifications could then be compared to parameters calculated during the analysis of severe accidents and then judgements could be made regarding the capability of existing measurement equipment to survive the harsh environments and supply accurate, unambiguous information. This report identifies what instrumentation is installed and capable of supplying needed information and also cites instances where *no* information is available. An evaluation of ranges and qualification conditions will be performed for a wide range of severe accident sequences during a follow–on project scheduled for completion in fiscal year 1991.

2.4 Identify Misleading Information

There are several ways in which the information supplied by the instrumentation could mislead personnel involved in accident management. Examples include as follows:

- Using information from instruments that include large error components because they are operating outside of their specified operating conditions
- Using information that is in error because the instruments are either damaged or failed
- Inferring information from an indirect source without consideration of implicit limitations.

Alerting the personnel involved in accident management that instrumentation is outside its specified range of qualification conditions could be easily accomplished if the environmental conditions for the instruments were measured or could be estimated based on the characteristics of the accident. A determination of the amount of error in the information would be much more difficult, but could be based on the type of instrument and the known or expected conditions. For the second example, identification of measurements that are failed or damaged could be determined through cross comparisons with similar or supporting instruments, which is a practice that could be used during the response to an accident.

The use of information from indirect sources could be misinterpreted in a way that would mislead accident management personnel. Misinterpretation of information may occur from a lack of understanding of the limitations of the instruments. For example, use of core liquid level to infer core cooling could mislead the operators if the core level drops below the top of the core. The level of water in the core that is adequate to prevent damage is dependent on several factors including the amount of water in the core region, the amount of power being generated in the fuel rods, and the pressure. For some conditions, a measured water level at the midplane of the core would provide adequate cooling, but for other conditions, there would not be sufficient water at the top of the core to cool the fuel rods and the temperature at the top of the core would begin to rise. In this situation, the information supplied by an instrument appears to fulfill the information need for verification of core cooling, however core heatup and degradation could occur if an indirect source of information is misinterpreted.

Results from the table–based format on information needs described in Section 2.2 can be used to identify the situations that present the greatest threat for misleading the operator. This identification is accomplished by determining which information needs do not have direct information sources and must rely only on indirect sources. Direct information sources would be difficult to misinterpret, if properly displayed, because they correspond one–for–one with the information need. As an example, if the safety function of interest is containment pressure, then the information need is the containment pressure history; and the direct information source is the containment pressure measurement. However, if the information need does not have a direct information source, then assessment of the situation and determination of what action should be taken must rely on indirect information sources.

The potential for misinterpreting the accident conditions and misleading the operator increases with the use of indirect sources of information because they can provide ambiguous information. Therefore, if the number of information needs that are being supplied by indirect sources is large, the potential to mislead the operator is even greater.

3. APPLICATION OF INFORMATION NEEDS METHODOLOGY TO A BWR WITH A MARK I CONTAINMENT

The methodology described in Section 2.1 has been applied to a BWR with a MARK I containment. This application was based on studies of plant features and instrumentation that are typical of some BWR plants but not necessarily representative of one particular plant. The objective of this application is to provide an evaluation of the status of information needs for this general class of plants. Section 3.1 describes the development of safety objective trees for a BWR with a MARK I containment. Section 3.2 provides the information needs that are needed for a BWR with a MARK I containment. Section 3.3 provides an identification of existing instruments that have the potential to fulfill the information needs, and Section 3.4 presents results that assess the potential to mislead accident management personnel, based on the results from the previous sections.

3.1 Safety Objective Tree Development

Three safety objectives, based on NRC information concerning accident management, were identified for a BWR with a MARK I containment in Section 2.1. Because this assessment and evaluation is being performed for severe accidents, inclusion of the Prevent Core Damage[a] safety objective is not appropriate. The current emergency operating procedures are intended to address this objective. The remaining safety objectives that are used in this development include as follows: (a) Prevent Core Dispersal from Vessel, (b) Maintain Containment Integrity, and (c) Mitigate Fission Product Release. The development was not based on a specific plant, but on information that is generally typical of some General Electric BWRs.

a. Core damage is considered to have occurred when the fuel rod cladding has ruptured and fission products have been released into the reactor system (RS).

Personnel with expertise in severe accidents and BWR operations were used to develop and review the trees.

It should be noted that the strategies shown on each safety objective tree are only examples and do not represent a complete set for the mechanisms and safety functions. Some strategies may not be practical under certain circumstances but are included to illustrate that there may be conflicting requirements for some plant safety functions. Most strategies presented are generic and require further evaluation to determine whether they would adequately maintain the appropriate safety functions for a specific plant construction. A brief description of the safety objective trees developed for the three safety objectives is discussed below.

3.1.1 Safety Objective Tree: Prevent Core Dispersal from Vessel. The safety objective for preventing core dispersal from the vessel into the containment is important for both short– and long–term accident management because the consequences of the accident are less serious when the core material is retained within the boundary of the reactor vessel. In addition, the strategies and actions associated with mitigating the effects of a degraded core are less complicated when molten core material does not interact with the containment structures.

The structure of the Prevent Core Dispersal from Vessel safety objective tree is shown in Figure 3. Four safety functions were identified that would support this safety objective. These safety functions were selected based on an understanding of the types of safety functions that are important for the previous phase of accident management (prevent core damage), together with the recognition that the complexity of system behavior and the extent of system failures during a severe accident limits the range of available actions. For the initial phase, Prevent Core Damage, the safety functions traditionally used for Reactor Pressure Vessel (RPV)–related accidents

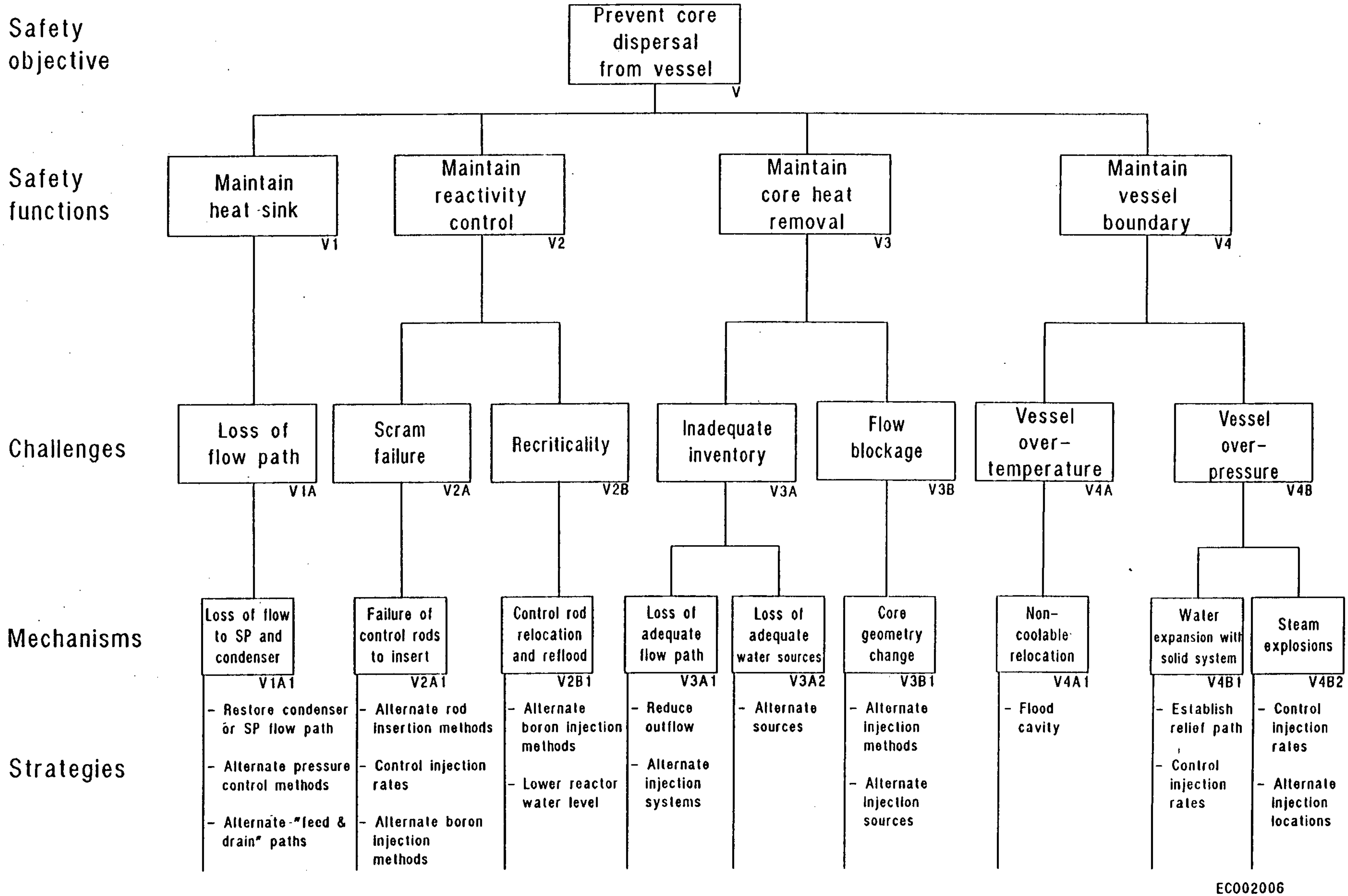

Figure 3. Safety Objective Tree: Prevent Core Dispersal from Vessel.

are: (a) Control RPV Water Level, (b) Control RPV Pressure, and (c) Control Reactor Power. Once core damage has occurred, the focus of accident management shifts to emphasize the prevention of further core degradation and to ultimately maintain the core within the vessel. In this situation, maintaining core heat removal would be the highest priority. The safety functions designated in Figure 3 as Maintain Heat Sink, Maintain Reactivity Control, and Maintain Core Heat Removal are necessary to support short– and long–term core temperature control. The fourth safety function, Maintain Vessel Boundary, is intended to maintain a damaged core within the reactor vessel.

For ease in relating the discussion to the various levels of the tree, each level has been assigned a unique identifier that is descriptive of its position on the tree. Thus, the Maintain Heat Sink safety function has an identifier called "V1." One of the mechanisms causing a challenge to this safety function is identified as "V1A1." The letter "V" identifies this safety function as relating to the Prevent Core Dispersal from Vessel safety objective tree. Each of the safety functions, challenges, mechanisms, and strategies in this tree are explained below.

3.1.1.1 Safety Function: Maintain Heat Sink. The availability of a heat sink is necessary to maintain long–term cooling of the core. The challenge to this safety function, Loss of Flow Path (V1A), would occur if both the condenser and the suppression pool were not available.

Challenge: Loss of Flow Path. The mechanism that would contribute to this challenge is Loss of Flow to Suppression Pool (SP) and Condenser (V1A1). The condenser would be unavailable if it had been isolated from the reactor or had lost its vacuum. The suppression pool would be unavailable when it had a high water temperature or an abnormal water level. The potential strategies that have been identified to control or prevent this mechanism are Restore Condenser or SP Flow Path, Alternate Pressure Control Methods, and Alternate "Feed and Drain" Paths. The effectiveness of any of these strategies would be strongly dependent on the condition of the plant and would have to be examined carefully prior to implementation.

3.1.1.2 Safety Function: Maintain Reactivity Control. Reactivity control is essential in minimizing energy generated in the core. There are two challenges that influence the capability to reduce reactivity in the core. The first challenge, Scram Failure (V2A), would occur if insufficient negative reactivity is inserted into the core to shutdown prompt power generation. The second challenge, Recriticality, results if core temperatures were sufficiently high to allow the control rod material to melt and relocate followed by an addition of water that is insufficiently borated.

Challenge: Scram Failure. The mechanism that would contribute to the Scram Failure challenge is Failure of Control Rods to Insert (V2A1). The control rods would fail to shutdown the reactor if they did not insert sufficient negative reactivity into the core to enable shutdown to decay heat levels. The strategies are Alternate Rod Insertion Methods, Control Injection Rates, and Alternate Boron Injection Methods. The unavailability of electrical power or other plant resources such as plant air or service water would need be considered when the alternate methods of inserting the control rods or alternate methods of injecting and developing additional borated water sources were being evaluated.

Control of injection rates would require that accurate core water level measurements were available as well as means of detecting high core temperature.

Challenge: Recriticality. The Control Rod Relocation and Reflood (V2B1) mechanism may cause recriticality during a severe accident. Because water must be present to cause recriticality and increase the power levels, cooling may also take place, and this mechanism may not result in significant relocation of additional core material. However, recriticality is not considered to be an acceptable core condition because adequate cooling for extended periods of time could be difficult to ensure for some severe accidents where the power is greater than decay heat levels. The strategies are Alternate Boron Injection Methods similar to those described for the Failure of Control Rods to Insert (V2A1) mechanism, and Lower Reactor Water Level. Strategies that would inject highly borated water for long periods of time would require an evaluation of the potential for boric acid precipitation to disrupt long–term cooling. The Lower Reactor Water Level strategy has the potential to cause additional core damage if there is not good information available.

3.1.1.3 Safety Function: Maintain Core Heat Removal. Energy removal from the core must be restored and maintained during a severe accident to halt the progression of core damage. There are two challenges that influence the capability to maintain adequate core heat removal. The first challenge, Inadequate Inventory (V3A), will occur when adequate cooling water is not available. The second challenge, Flow Blockage (V3B), is a special case where the coolant is restricted from entering the core, or portions of the core, as a result of changes in the geometry of the core material. Examples of this challenge include the formation of rubble beds upon collapse of core material or the formation of fuel bundle or subchannel blockages resulting from a melt/relocation process.

Challenge: Inadequate Inventory. The Loss of Adequate Flow Path (V3A1) mechanism and Loss of Adequate Water Sources (V3A2) mechanism would result in a challenge to core heat removal if there was not sufficient flow to keep the core very nearly immersed in water. Strategies for these mechanisms that could provide the necessary inventory include Reduce Outflow, Alternate Injection Methods, and Alternate Injection Sources.

Challenge: Flow Blockage. If there is insufficient cooling and if extensive core degradation and relocation begins, blockage could occur either in subchannels or on a broader scale that would restrict cooling of some portions of the core and challenge the capability to maintain core heat removal. The mechanism causing this challenge has been designated Core Geometry Change (V3B1). If a geometry change occurs, the core could transition into one or more configurations depending on the specific conditions of the material and the availability of cooling. The geometry could range from a rubble bed to a widespread crust of melted and refrozen core material that supports molten material. The capability to cool the various geometries could require different types of strategies. Unfortunately, there is no accurate means of determining the geometric configuration of the core as an accident progresses, therefore selection of geometry specific strategies would be impossible. Two general strategies that have the potential to provide cooling include Alternate Injection Methods and Alternate Injection Sources.

3.1.1.4 Safety Function: Maintain Vessel Boundary. If cooling of the core cannot be established early in the accident, relocation of portions of the core to the vessel lower plenum may occur. At this stage of the accident, the safety function related to maintaining core heat removal has been ineffective, and accident management efforts should be directed toward preserving the integrity of the vessel lower head. The challenges are Vessel Over–Temperature (V4A), and Vessel Over–Pressure (V4B).

Challenge: Vessel Over–Temperature. The mechanism that would contribute to the Vessel Over–Temperature challenge is Non–Coolable Relocation (V4A1). The core material may be difficult to cool, upon relocation, if the core material breaks into very fine particles and forms a mass that is relatively impermeable to water, or if pieces are formed that are too large to transfer all the energy generated within, or if the material forms a pool in which molten material is in contact with the vessel head. Unfortunately, there are no existing measurements that have the capability to determine whether the core is, or is not, in a coolable geometry. Therefore, although different strategies are identified for this mechanism, it is doubtful that there is sufficient information available to determine which strategies are needed. Fortunately, many of the strategies are identical to those used in maintaining core heat removal, so they would likely be in the process of being implemented if the accident had progressed to the point of core relocation. If the core relocates in a non-coolable geometry, the only identified strategy that has the potential to prevent vessel failure would be to flood the cavity surrounding the vessel.

Challenge: Vessel Over-Pressure. The mechanisms that could cause vessel over-pressure are Water Expansion with Solid System (V4B1), and Steam Explosions (V4B2)

The Water Expansion with Solid System mechanism is a highly unlikely event when all safety relief valves fail to relieve sufficient fluid to reduce the pressure in the vessel. The strategies are Establish Relief Path, and Control Injection Rates.

The Steam Explosions mechanism could occur as a result of the very rapid generation of steam when molten core material mixes rapidly with water in the core region or lower plenum. The system must be at low to moderate pressure (less than about 700 psi) when this mixing occurs. There are no effective strategies to mitigate steam explosion. The general preventative strategies are Control Injection Rates, and Alternate Injection Locations.

3.1.2 Safety Objective Tree: Maintain Containment Integrity. The second accident management safety objective is designated as Maintain Containment Integrity. The tree for the Maintain Containment Integrity safety objective is shown in Figure 4. Three safety functions were identified for this safety objective that would contribute to preventing containment failure and assuring containment integrity: (a) maintain over-pressure and under-pressure control to prevent structural damage and eventual rupture of the containment, (b) maintain over-temperature control to prevent failure of the containment structures from the effects of excessive temperature, and (c) maintain containment integrity from leakage, bypass, or penetration by internally generated missiles. These safety functions are respectively designated Maintain Pressure Control (C1), Maintain Temperature Control (C2), and Maintain Integrity (C3). Each of these safety functions, along with their challenges, mechanisms, and strategies are explained below.

3.1.2.1 Safety Function: Maintain Pressure Control. There are two challenges that influence the capability to maintain control of the pressure in the containment. The Under-Pressure (C1A) challenge could be caused by rapid steam condensation inside the containment. The Over-Pressure (C1B) challenge would require a significant amount of information to diagnose the underlying causes of the mechanism and, in most cases, would need preventive strategies to be implemented prior to the occurrence of the challenge.

Challenge: Under-Pressure. Two mechanisms were identified as contributing to the Under-Pressure challenge: (a) Spray with Insufficient Non-Condensables (C1A1), which would occur if there is an insufficient quantity of nitrogen in the drywell, or nitrogen in combination with other noncondensables, and the drywell sprays are activated at a relatively high flow rate, and (b) Spray with Vacuum Breaker Failure (C1A2), which could create a sub-atmospheric pressure in the drywell and exceed shell failure capabilities.

Three strategies have been identified for the Spray with Insufficient Non-Condensables (C1A1) mechanism: (a) Add Nitrogen or Air, (b) Terminate Sprays, and (c) Limit Vent. Because venting would remove noncondensables from the drywell atmosphere, this strategy would need to be monitored to ensure that low levels of noncondensables were not reached in the containment.

Two strategies have been identified for the Spray with Vacuum Breaker Failure mechanism: Terminate Sprays, and Open Vent. In this strategy the vent could provide a flow path from the atmosphere to raise the pressure in the containment.

Challenge: Over-Pressure. Prevention of primary containment failure during an Over-Pressure challenge (C1B) could, in some cases,

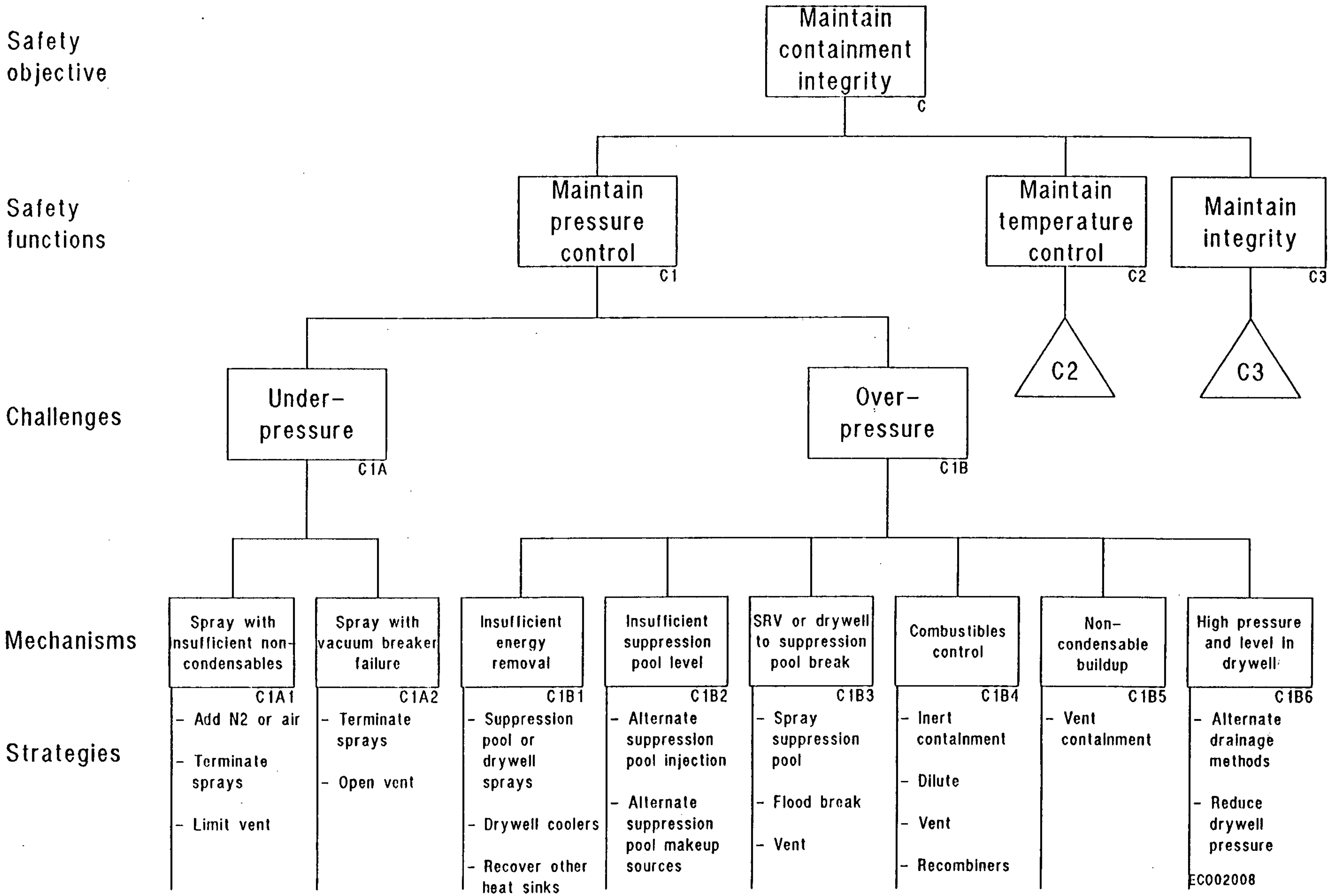

Figure 4. Safety Objective Tree: Prevent Containment Failure.

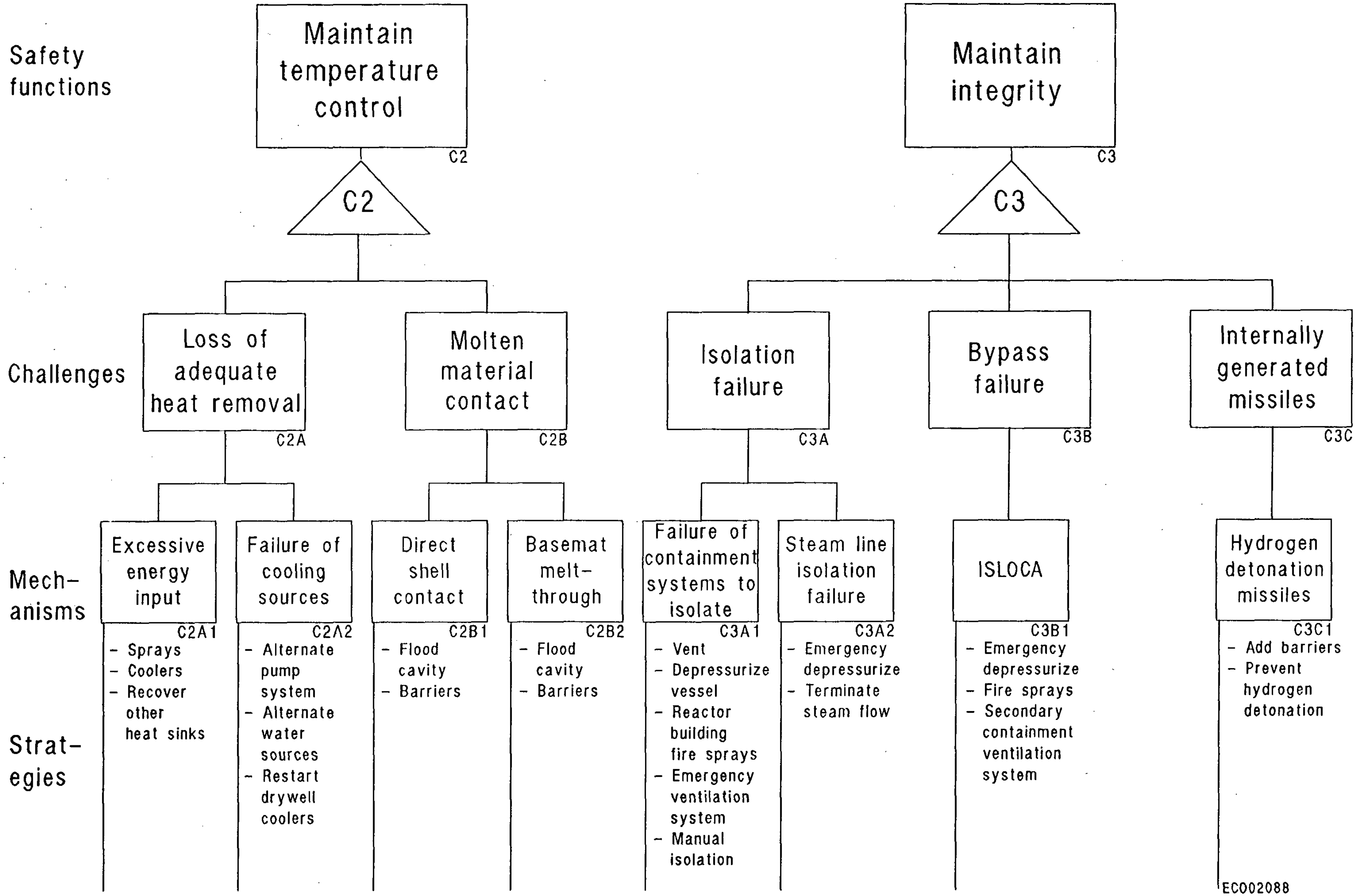

Figure 4. (continued).

be difficult because of the insufficient time for plant personnel to implement mitigating strategies. Six potential mechanisms have been identified that could cause containment pressurization: (a) Insufficient Energy Removal (C1B1), (b) Insufficient Suppression Pool Level (C1B2), (c) Safety Relief Valve (SRV) or Drywell to Suppression Pool Break (C1B3), (d) Combustibles Control (C1B4), (e) Noncondensable Buildup (C1B5), and (e) High–Pressure and Level in Drywell (C1B6).

The Insufficient Energy Removal mechanism would occur when heat removal systems fail to operate, or will not operate at their required capacity. Strategies to remove energy from the containment are Suppression Pool or Drywell Sprays, Drywell Coolers, and Recover Other Heat Sinks. For severe accident management, each of these strategies would need to rely on the use of alternate equipment or water sources to provide or enhance energy removal. In general, directions for use of the needed equipment and sources can be found in the emergency operating procedures.

The Insufficient Suppression Pool Level mechanism is not likely to occur unless there is a leak in the suppression pool boundary and failure of water addition systems or sources. Strategies include: Alternate Suppression Pool Injection, and Alternate Suppression Pool Makeup Sources.

The SRV or Drywell to Suppression Pool Break mechanism poses a serious safety challenge because it would require the SRV tailpipe or suppression pool to drywell vents to fail. The capability to condense some or all of the steam pressurizing the drywell would be lost at this stage of accident. The available strategies are Spray Suppression Pool, Flood Break, and Vent. Flooding the break could be effective if there is the capability for continued removal of energy and if there is sufficient water for flooding. Flooding may be difficult because there will not be good information on the location of the break.

The Combustibles Control mechanism can result in the burning or detonation of hydrogen or other combustible gases. Four strategies for mitigating this mechanism have been identified: (a) Inert Containment, (b) Dilute, (c) Vent, and (d) Recombiners. Determining whether the containment is in an inert condition during a severe accident may be difficult because of the complex phenomena that are occurring.

The Noncondensable Buildup mechanism could occur if large amounts of nitrogen, oxygen, hydrogen, air, or other gases accumulate in the containment. Venting the containment would be the primary strategy to reduce the concentration of noncondensables in the containment.

The High–Pressure and Level in Drywell mechanism could occur when both the pressure is at an elevated value and the water level in the drywell is high. This combination could cause the failure pressure of the drywell shell to be exceeded. A high water level in the drywell could be an outcome of continued injection to establish long–term cooling of a degraded core. Possible strategies are Alternate Drainage Methods, and strategies to Reduce Drywell Pressure.

3.1.2.2 Safety Function: Maintain Temperature Control. There are two challenges that have been identified as contributing to the Maintain Temperature Control (C2) safety function: Loss of Adequate Heat Removal (C2A) challenge, and Molten Material Contact (C2B). The Molten Material Contact challenge could occur if the molten material leaves the reactor vessel and contacts either the drywell shell or the containment basemat.

Challenge: Loss of Adequate Heat Removal. There are two mechanisms that would cause the inadequate heat removal in the containment: Excessive Energy Input (C2A1) mechanism, and Failure of Cooling Sources (C2A2). The release of excessive energy into the containment as a result of a direct energy release from the reactor vessel during a severe accident could challenge the containment temperature limits. Potential strategies include the use of Sprays, Coolers, and Recover Other Heat Sinks. These strategies are identical to strategies described previously for Insufficient Energy Removal (C1B1).

Three strategies have been identified for the Failure of Cooling Sources mechanism: (a) Alternate Pump Systems, (b) Alternate Water Sources, and (c) Restart Drywell Coolers. Each of these strategies would rely on equipment that is not normally used to supply cooling water. Many, if not all, of these systems are considered in the emergency operating procedures.

Challenge: Molten Material Contact. There are two possible mechanisms where molten core material could contact the containment and result in failure of the pressure and fission product boundary: (a) Direct Shell Contact (C2B2), and (b) Basemat Melt–Through (C2B2).

The Direct Shell Contact mechanism could occur if sufficient molten material has accumulated on the drywell floor and has spread across the floor and made contact with the drywell shell. Because the drywell shell is not cooled directly, the high–temperature core material may raise the shell temperature to the point that a failure occurs. The strategies identified for this mechanism are: Flood cavity and Barriers. Flooding of the cavity could inhibit the spread of the molten core and would provide some cooling of the wall if direct contact is made. The effectiveness of this strategy is currently being evaluated. The addition of barriers would require that a material capable of withstanding the high temperatures be identified and that barriers be fabricated and installed to protect the drywell shell. The practicality of this strategy has not been thoroughly reviewed.

The Basemat Melt–Through mechanism could occur if sufficient molten core material exited the vessel and was in contact with the concrete containment basemat. The strategies addressing the mitigation of the core–concrete interaction are Flood Cavity and Barriers. Water has been shown to be beneficial in slowing the ablation of the concrete if it is in place when the core relocates, or shortly thereafter.

3.1.2.3 Safety Function: Maintain Integrity. The third safety function for the Maintain Containment Integrity safety objective is Maintain Integrity (C3). This safety function would be challenged if piping, components, or equipment failed, which would prevent initiation of containment isolation or prevent its continuation. Three challenges have been identified: (a) Isolation Failure (C3A), (b) Bypass Failure (C3B), and (c) Internally Generated Missiles (C3C).

Challenge: Isolation Failure. Failure of the equipment to initially isolate the containment or failure to maintain isolation over the full period of the accident would comprise the mechanism for this challenge. The Failure of Containment Systems to Isolate (C3A1) mechanism refers to the failure of Nuclear Steam Supply Shutoff System actuated isolation valves and balance of plant (BOP) containment isolation valves except the main steam isolation valve (MSIV). The Steam Line Isolation Failure (C3A2) mechanism refers to the failure of MSIV isolation only. Failure of isolation would initially utilize strategies to establish reisolation, and would rely on hardware specific to the containment penetration lines. Availability of valves that could isolate, divert, or diminish the flow would depend on the configuration of the system and the capabilities of the valves and their actuators. If isolation fails, other strategies have been identified for mitigating fission product dispersal effect by reducing the driving force causing flow from the containment, or by controlling the inventory on fission products in the containment atmosphere. These strategies are part of the Mitigate Fission Product Release from containment safety objective.

Challenge: Bypass Failure. One mechanism has been identified that could lead to fission products bypassing the containment, the Interfacing System Loss–of–Coolant Accident (C3B1) mechanism. This mechanism could occur if there is a non–detectable pipe break or component failure outside the containment boundary. The strategies identified to mitigate this mechanism are Emergency Depressurize, Fire Sprays, and Secondary Containment Ventilation System. Emergency depressurization would be intended to reduce break flow by reducing the pressure differential from the containment to the atmosphere. The use of fire sprays in both the primary and secondary containment would reduce the fission product inventory available for dispersion. Use of the secondary containment ventilation system may aid in preventing secondary containment failure and remove fission products from the secondary containment atmosphere.

Challenge: Internally Generated Missiles. The mechanism identified for this challenge is Hydrogen Detonation Missiles (C3C1). Hydrogen detonation was identified as having the potential to generate missiles with an energy sufficient to penetrate the containment shell. It would be expected that there would be a limited number of missiles that could be generated through hydrogen detonation. Strategies would include Add Barriers, if the location of potential missiles can be identified, and Prevent Hydrogen Detonation by using such strategies as providing additional nitrogen to ensure that the containment is inerted.

3.1.3 Safety Objective Tree: Mitigate Fission Product Release from Containment. The third accident management safety objective is Mitigate Fission Product Release (F). This safety objective is important because it is intended to minimize the quantity of fission products released and delay their release as long as possible if there is a failure of the containment boundary. The strategies associated with this safety objective would generally be implemented in conjunction with the strategies for the other two safety objectives and, in most situations, would enhance the effectiveness of these other strategies. The tree for the Mitigate Fission Product Release from Containment safety objective, shown in Figure 5, details the safety functions that must be maintained, the challenges to the safety functions, the mechanisms causing these challenges, and the strategies that could potentially be employed to respond to these mechanisms.

Three safety functions were identified that would contribute to mitigating the release of fission products: (a) Control Fission Products in Primary Containment (F1), (b) Control Fission Products in Secondary Containment (F2), and (c) Control Fission Products in Water (F3). A brief description of each of the safety functions follows.

3.1.3.1 Safety Function: Control Fission Products in Primary Containment. This safety function is concerned with controlling the concentration of fission products in the primary containment atmosphere. By reducing the quantity of fission products in the containment atmosphere, the amount available for release as a result of containment leakage or failure is also reduced. The challenge to this safety function is the presence of fission products in the atmosphere within the primary containment. Two mechanisms were identified that represent the types of fission products that could be dispersed within the primary containment during a severe accident. These mechanisms are Aerosol Dispersion (F1A1), and Gaseous Dispersion (F1A2).

The quantity of fission products suspended in the containment atmosphere in an aerosol form can be reduced through two potential strategies: (a) Sprays, and (b) Suppression Pool Vent. The sprays strategy would be preferred because the fission products would remain in the containment. The vent strategy would deposit most fission products in the suppression pool but the noble gases, as well as a small fraction of other fission products, would not be scrubbed out.

The second mechanism that influences the availability of fission products for release is Gaseous Dispersion in the primary containment atmosphere. These gaseous fission products behave differently than aerosols and, therefore, require a different set of strategies. Potential strategies that could be used to reduce the concentration of gaseous fission products in the atmosphere are Chemical Reactions, Cryogenic Systems, and Sprays. These strategies are not well established and would need further evaluation to assess their effectiveness.

3.1.3.2 Safety Function: Control Fission Products in Secondary Containment. This safety function is concerned with controlling the concentration of fission products in the secondary containment (Reactor Building) atmosphere. The

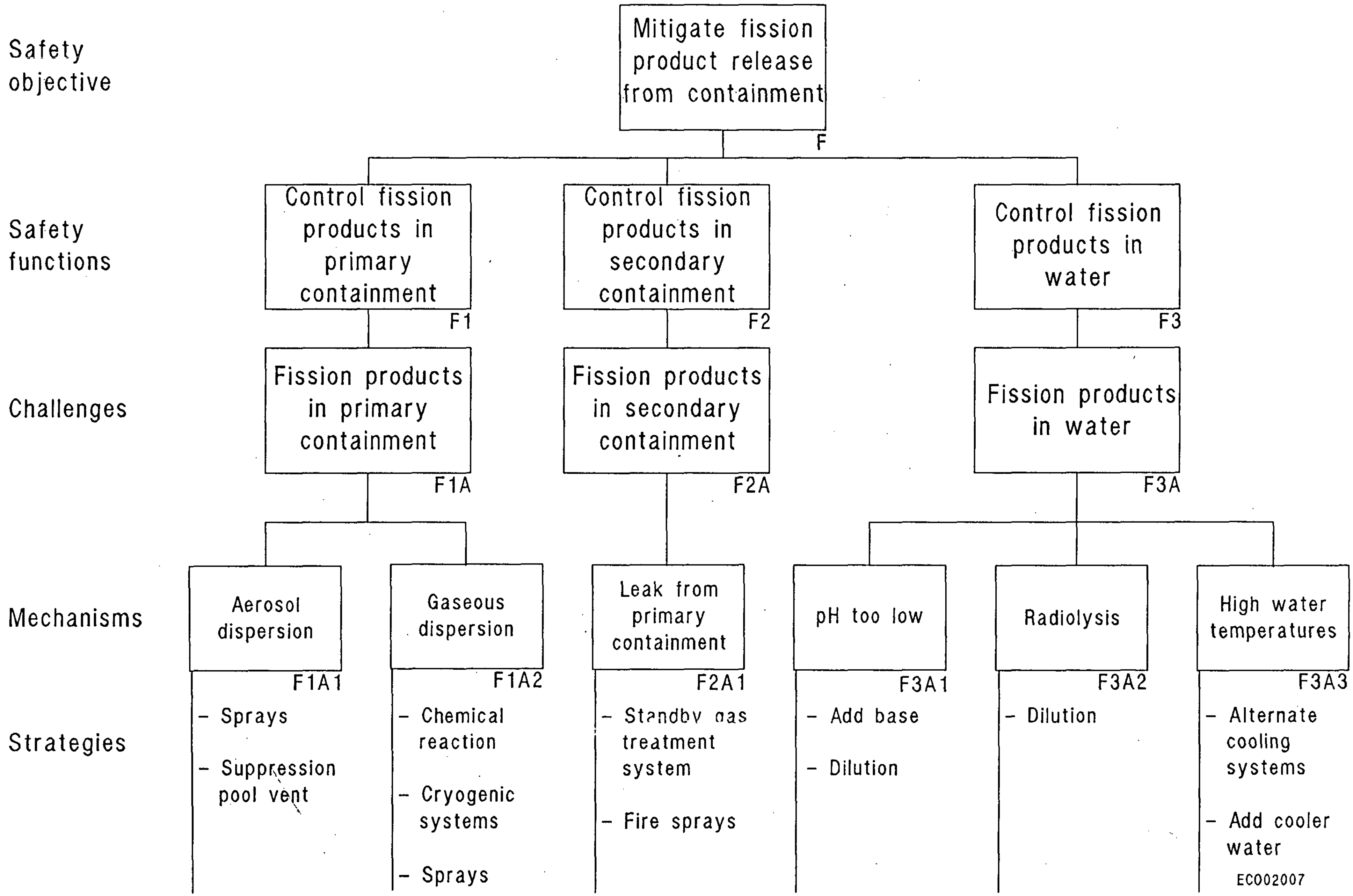

Figure 5. Safety Objective Tree: Mitigate Fission Product Release from Containment.

Secondary Containment is the final barrier that can prevent the release of fission products to the environment in the event of a severe accident. The challenge to this safety function is the presence of fission products in the atmosphere within the secondary containment. The mechanism that would contribute this event is the Leak from Primary Containment (F2A1). The strategies that could be used to reduce the concentration of fission products in the atmosphere are Standby Gas Treatment System, and Fire Sprays. However, not all BWRs with MARK I containments have fire sprays in their secondary containment.

3.1.3.3 Safety Function: Control Fission Products in Water. This safety function deals with preventing the release of fission products dispersed in the water inside the containment. If the fission products are held within the water, they would not be released through the containment atmosphere and would be less of a threat than if the water was inadvertently diverted to a location outside of the containment. The challenge to this safety function is the presence of Fission Products in Water (F3A).

The following three mechanisms can cause the release of fission products from the containment water: (a) when the pH of the water is too low, the capability to retain fission products is reduced, (b) radiolysis can cause the release of fission products from water, and (c) excessive water temperature will reduce the retention capability of the fission products in the water. These mechanisms are shown in the Prevent Fission Product Release from Containment safety objective tree as follows: pH Too Low (F3A1), Radiolysis (F3A2), and High Water Temperature (F3A3).

The strategies that can be used to address the first mechanism, a low pH in the containment water, are Add Base, and Dilution. The availability of systems to add water could affect the capability to dilute using more basic water.

The second mechanism that could result in the release of fission products from the containment water is radiolysis of the water in a high radiation field. The strategy identified as being capable of inhibiting radiolysis of the containment water is Dilution.

The third mechanism that could result in the release of fission products from the containment water is excessive water temperature. Excessive water temperature can result in the vaporization of fission products. For example, excessive water temperature could have a large influence on the effect of the containment spray if the containment atmosphere or structures were at a sufficiently high temperature to cause some or all of the spray droplets to evaporate. Strategies that could be used to reduce the effects of excessive water temperature on this mechanism are Alternate Cooling Systems, and Add Cooler Water.

3.2 Information Needs for a BWR With a MARK I Containment

The methodology for identifying information needs, described in Section 2.2, was applied to a BWR with a MARK I containment. The safety objective trees described in the previous section were used as the basis for development of the table–based format. This development was accomplished by personnel with both severe accident and operations experience, while the information was checked by personnel who conduct operator examinations for BWRs with MARK I containments. Information needs on plant hardware status were generally not listed because it is recognized that such needs as switch positions, valve alignments, etc. would be required prior to the use of plant systems.

The information needs tables that were developed for the BWR are presented in Appendix A. The first four pages are from the Prevent Core Dispersal from Vessel (V) safety objective tree and are displayed for discussion purposes in Table 2. Included are the information needs for the Maintain Heat Sink (V1) safety function, the Loss of Flow to SP (suppression pool) and Condenser (V1A1) mechanism, and the Restore Condenser Flow Path strategy. The format of the

Table 2. Example information needs table

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain heat sink safety function (V1)	Energy removal rate	None		None	None
			Suppression pool water level	Suppression pool water level	
			Suppression pool water temperature	Suppression pool water RTD	
			Main steam isolation valve open/close position	MSIV position indicator	
			Bypass valve position	Bypass valve position	
			Condenser pressure	Condenser pressure	
			Main steam line steam flow rate	Main steam line steam flow rate	
			Reactor vessel pressure history	Reactor pressure	
			Suppression pool & drywell pressure	Suppression pool & drywell pressure	

Table 2. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicator				
Loss of flow to suppression pool and condenser mechanisms (V1A1)	Flow rate to suppression pool	None		None	None
			Relief valve actuation signal	Valve switch	
			Relief valve tail pipe	Tail pipe thermocouple	
			Acoustic monitor	Acoustic monitor	
			Suppression pool water temperature	Suppression pool water RTD	
Loss of flow to suppression pool and condenser mechanisms (V1A1)	Flow rate to condenser	None		None	None
			Main steam line steam flow rate	Main steam line steam flow rate	

Table 2. (continued)

Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
		Main steam isolation valve open/close position	MSIV open/close position	
		Bypass valve position	Bypass valve position	
Precursor				
Condenser vacuum	Condenser pressure		Condenser pressure	
Loss of circulation water	Circulating water flow rate		Circulating water flow rate	
Steam jet air ejector status	Steam pressure to STAE		Steam pressure	
	Valve position		Valve position	
Mechanical vacuum pumps	Power (480 VAC)		Power indication	
	Valve position		Valve position	

Table 2. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Restore Condenser Flow Path Strategies	Selection Criteria				None
	Condenser availability	Condenser vacuum		Condenser vacuum pressure	
		Electro hydraulic control system		Electro hydraulic control system	
		Circulating water system status		Circulating water flow rate	
	Main steam line break status outside containment		Auxiliary building & turbine building radiation	Area radiation monitors	
			Auxiliary building & turbine building temperature	Leak detection system	
	Fuel failure status		Fission product release	OFG radiation	

table enables the reader to quickly scan the columns to determine information needs, identify the sources of information, and ascertain availability of existing instruments. The information need for the Maintain Heat Sink safety function is the energy removal rate from the reactor system. Because there are many ways that energy can be removed from the reactor system and many of these are not measured with sufficient accuracy to derive an energy removal rate, it was concluded that a direct information source for energy removal rate does not exist. There are, however, numerous indirect information sources. Some of these, such as main steam line steam flow rate, could provide a reasonable measurement of energy removal rate, but others, such as suppression pool water temperature, would require an indication of the distribution of temperatures in the pool as well as an indication of the amount of water in the suppression pool to provide an accurate determination of the energy removal rate.

An indicator supplying an information need for the Loss of Flow to SP and Condenser mechanism (V1A1) would be the flow rate of the steam to the condenser. This is considered to be an indicator for the information need because there is an information source (flow rate to the condenser) that could be used to determine whether a loss of flow to the condenser had occurred. There is a direct information source for this information need, main steam line steam flow rate, and there is an instrument available to provide this information. An example of a precursor information need would be Loss of Condenser Vacuum. A sharp reduction in condenser vacuum, would provide early information that would alert the operator to the potential for a loss flow to the condenser, but could also occur for certain other plant conditions.

The fourth page of the example table provides the information needs for the Restore Condenser Flow Path strategy. These information needs are relatively clear because they all have direct information sources and available instruments.

The results presented in Table 2 and in the extensive information needs tables contained in Appendix A show the redundancy and diversity of the plant instruments in supplying the information needs. Redundancy can be determined by evaluating the number of direct and indirect information sources that are available for each information need. Diversity can be obtained by comparing the number of different types of information sources. These comparisons would not account for such considerations as common cause failures (which could reduce the redundancy), or the ability of some diverse instruments to supply the needed information.

Because the information needs tables are lengthy and contain large quantities of data on information needs and available instruments, several methods of extracting and summarizing the important findings were considered. There are two major types of findings that are important:

- Information needs for which neither direct nor indirect information sources exist

- Information needs with only indirect sources of information.

These two types of findings are discussed in Sections 3.3 and 3.4, respectively.

3.3 Capability of Existing Instrumentation

An evaluation was made to determine whether the existing instrumentation has the capability to supply all of the identified information needs. This evaluation was accomplished by using the results from the information needs tables to search for those needs that do not have instrumentation capable of supplying either direct or indirect sources of information. A total of five information needs were identified during the evaluation that cannot currently be satisfied by existing measurements in a BWR with a MARK I containment.

Strategies were generally not considered in the evaluation because they are intended as an example and may not represent a complete listing of information needs. Each of the five information needs is discussed as follows:

1. *Non–Condensables Concentration*—There is insufficient instrumentation to provide complete information on the concentration of non–condensables inside the drywell. The concentration of nitrogen is most important because containment inerting is accomplished by maintaining a positive nitrogen pressure within the primary containment. Not knowing the nitrogen concentration would make it difficult to determine whether the drywell remained in an inerted condition during some strategies, such as venting. The absence of an inerted condition could lead to hydrogen deflagration or detonation, or if combined with sufficient drywell sprays, could result in a low–pressure condition requiring open vacuum breakers to prevent damage to the containment.

2. *Direct Shell Contact*—There are no instruments currently installed that would provide reliable information on the integrity of the drywell shell. If molten core material makes contact with the drywell shell during a severe accident, the drywell may fail. Knowledge of the approach to drywell failure would be important to plant personnel for understanding plant status, and for selecting and implementing actions, such as flooding of the drywell.

3. *Basemat Melt–Through*—The escape of fission products into the soil and ground water beneath the basemat could have serious long–term consequences. However, there are no apparent accident management strategies that would utilize this information even if it was available. The information would, therefore, only be useful in the emergency response process, and the information is not considered necessary for accident management.

4. *SRV Tailpipe Integrity*—The integrity of the safety relief valve (SRV) tailpipe is not measured directly or indirectly in a BWR plant. If the tailpipe fails and is open to the containment atmosphere, the condensation feature of the suppression pool is lost and elevated pressures may occur. Although the SRV tailpipe is not anticipated to fail during a severe accident, information on tailpipe integrity would help personnel involved in accident management to ensure that the integrity of the containment is maintained. However, there are a significant number of other plant measurements, such as containment pressure, that would aid in mitigating the effects of a tail pipe failure.

5. *Containment Leak Location*—Placement of instruments to detect leaks in the containment would be very difficult owing to the relatively large number and types of containment penetrations. Although a knowledge of the leak location would be useful in devising strategies to deal with containment failure, installation of detection equipment is not considered to be practical.

For those information needs that are considered to be important, means of obtaining the information should be considered. These means could take several forms, such as strategy consideration, using computational aids, or hardware changes. Determination of the optimum means for obtaining the information was beyond the scope of this project.

3.4 Potential to Mislead Accident Management Personnel

The potential for information needs with only indirect sources of information to mislead accident management personnel were discussed in Section 2.4. To determine the extent of this potential for a BWR with MARK I containment, the tables in Appendix A were searched to identify those information needs whose direct sources of information were not measured and could only be inferred from measurements of indirect information sources.

For discussion purposes, information needs have been categorized into those that could be important in misleading personnel, identified as Category 1, and those that would be much less important, listed as Category 2. The following list summarizes the findings of this search:

Category 1–More Important

- Core relocation/damage status
- Imbalance in energy addition and removal
- Interfacing System (IS) pipe rupture status.

Category 2–Less Important

- Energy removal rate
- Flow rate to suppression pool
- Flow rate to condenser
- Control rod material location
- Vessel release rate
- Energy addition rate into containment
- Presence of fission products in primary containment
- Inadequate heat removal from suppression pool water.

The categorization process considered the type and diversity of indirect information available and the degree of ambiguity that would be expected from these sources. In addition, consideration was given to the importance of the information in making decisions on the progress of an accident or on the selection or monitoring of corrective strategies. The following discussion presents a brief description of the Category 1 information needs and the rational for why Category 2 information needs were less important.

1. *Core Relocation/Damage Status*—There are no direct measurements to provide an unambiguous indication of the status of the core during the timeframe when core damage is occurring. Liquid level measurements would provide precursor information to alert the plant personnel that core damage was approaching. However, the lack of core exit thermocouples would make a determination of the timing and severity of core damage difficult if the liquid level fell below the top of the core for a substantial period of time. The most reliable instrumentation would be the fission product monitors and isotopic analysis to indicate rupture of the fuel pins, and hydrogen concentration, which could provide an indication of zircaloy oxidation if there is a path for the hydrogen to escape into the containment. If portions of the core relocated to the lower plenum, the reactor vessel wall thermocouples could provide an indication of this occurrence, however, very late in the core degradation sequence of events. Delays in obtaining information, such as hydrogen measurements, and the lack of temperature information, would limit the capability of plant personnel to understand the timing and extent of core damage.

2. *Imbalance in Energy Addition and Removal*—Information on energy imbalance conditions could play an important role in the selection of strategies to mitigate severe accidents.

Indirect information sources exist; for example, coolant temperature, pressure, etc., but these sources may not be properly placed to provide sufficient information for selecting the most effective strategies. Because direct measurements are not considered to be practical, the placement and interpretation of the indirect measurements of energy addition and removal should be carefully examined.

3. *Interfacing System (IS) Pipe Rupture Status*—The capability to terminate an interfacing system pipe rupture by closing valves or to mitigate the effect of the rupture by flooding break locations depends on the capability to determine where the break has occurred. A leak detection system is installed to detect leaks only to systems that normally are exposed have high–temperature water or steam. This leak detection system may not be effective for a wide range of conditions and changing environments because it is not easy to determine a suitable actuation setpoint for detecting small leaks without triggering a false alarm.

The information needs in Category 2 were considered to be less important for several reasons; for example, the lack of direct information on energy removal rate from the core would not alter the accident management approach to removing it. While some of the indirect measurements provide a good indication of reactor cooldown rate, a difficult situation would arise if the reactor *couldn't* cool down, and the overall heat balance would become important (see Category 1, Item 2). Another example would be the presence of fission products in primary containment. Current strategies for mitigating the effects of fission products in the containment are not sufficiently sophisticated to motivate the need for different strategies for aerosols and other gases. In these cases, a direct measurement would provide better information than an indirect measurement, but it would not make accident management more effective.

The results of the evaluation of the potential to mislead personnel involved in accident management has identified information needs for which direct or improved indirect measurements would be beneficial. These needs should be evaluated further to determine the acceptable means of providing the needed information or to provide a clearer understanding of the limitations on accident management.

Other conditions that could mislead the operators include instrument failures as a result of severe environmental conditions and instrument range limitations. These additional instrument failure modes are important but are pertinent to a specific plant.

4. CONCLUSIONS AND RECOMMENDATIONS

An evaluation has been completed that provides important insights on the information needs for a BWR with a MARK I containment during severe accidents, and the capability of existing plant instrumentation to supply this information. Based on this evaluation the following conclusions were made:

- The safety objective trees developed for a BWR with a MARK I containment display plant severe accident information in a manner that promotes understanding of safety functions that are important for severe accidents and the challenges to these safety functions. Although the severe accident conditions presented on the tree are not new or unique, the structure of the trees allows easy visualization of how challenges to plant safety can be identified and what alternate means may be available to plant personnel for prevention or mitigation of a severe accident.

- The assessment of information needs for a BWR with MARK I containment indicates that there is not sufficient instrumentation to determine whether the containment remains inerted with nitrogen throughout a severe accident. Lack of information on nitrogen concentration would make decisions on the use of strategies such as venting more difficult because it would be unclear whether there was sufficient nitrogen to maintain an inerted condition in the containment. There is also insufficient information to determine whether the containment boundary is being challenged once molten core material has penetrated the reactor vessel. This challenge could result from a direct contact of molten material with the drywell shell and/or the ablation of concrete in the basemat.

- There are about 11 information needs in which personnel involved in accident management have the potential to be mislead because they must rely on interpretation of instruments that do not directly supply the needed information. Three of these were judged to be most important: (a) the core relocation/damage status, (b) an imbalance in energy addition and removal, and (c) the Interfacing Systems pipe rupture status.

The lack of instrumentation to provide direct information on the core relocation/damage status would be most important during the early stages of core degradation. Liquid level measurements would provide precursor information to alert the plant personnel that core damage was approaching. However, the lack of core exit thermocouples and measurements of steam line temperature would make the initiation of core heatup and the severity of core damage difficult to identify if cooling is lost. Indirect measurements that would assist in detecting core damage are fission product monitors and isotopic analysis, which could indicate fuel pin rupture; and hydrogen concentration, which could provide an indication of zircaloy oxidation if there is a path for the hydrogen to escape into the containment.

Thermocouples that measure the temperature of the metal in the reactor vessel lower head have the potential to indicate when molten core material relocates and the approach to possible failure of the lower head. This information would be very important in determining the management of resources during a severe accident. For example, decisions regarding continued use of resources to preserve vessel integrity as opposed to the use of these same resources to preserve containment integrity. The effectiveness of this measurement for accident management would be plant specific because the location and number of the vessel metal thermocouples varies from plant to plant.

The methods developed previously[2] and applied to BWRs in this evaluation were effective in identifying the information needed by plant personnel for management of severe accidents. Nuclear utilities are now addressing the severe accident issue for their plants and are concentrated in the following areas: (a) completion of individual plant examination (IPEs) and (b) eventual development and implementation of a severe accident management plan. Use of the methodology described and demonstrated in this document could be used to assist in the development, implementation, and evaluation of effective accident management programs.

5. REFERENCES

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3. Regulatory Guide 1.97, *Instrumentation for Light Water Cooled Nuclear Power Plants to Assess Plant and Environmental Conditions During and Following an Accident*, Rev. 3, May 1983.

APPENDIX A

INFORMATION NEEDS TABLES FOR A BWR WITH A MARK I CONTAINMENT

APPENDIX A
INFORMATION NEEDS TABLES FOR A BWR WITH A MARK I CONTAINMENT

The tables in this Appendix describe the information needs for a Boiling Water Reactor with a MARK I containment. To identify these information needs, the branch points in the safety objective trees were examined to decide what information is necessary to (a) determine the status of the safety functions in the plant, i.e., whether the safety functions are being adequately maintained within predetermined limits, (b) identify plant behavior (mechanisms) or precursors to this behavior that indicate that a challenge to plant safety is occurring or is imminent, and (c) select strategies that will prevent or mitigate this plant behavior and monitor the implementation and effectiveness of these strategies. The information needs for the challenges to the safety functions are not examined because the summation of the information needs for all mechanisms associated with a challenge comprise the information needs for the challenge itself.

In the tables, the rows correspond to five levels of information that were derived form the levels of the safety objective trees. The first section (row) of the table contains the information needs that relate to the safety function. This section is used to describe the information needed to determine whether the safety function is being maintained within the accepted safety limits. The second section (row) of the table displays information to identify a specific mechanism that may be a challenge to a safety function. Two different categories of information are important for identifying mechanisms: indicators and precursors. The indicators include information that identifies when a mechanism is actually occurring and challenging a safety function. The precursor information identifies whether a mechanism would be expected to occur in the future based on currently available information.

The final three categories (rows) relate to strategy selection and evaluation. The Selection Criteria category identifies the information needed to determine strategies that should be selected for a given situation, including consideration of the plant conditions under which the strategy can operate and be effective. The Strategy Initiation category gives the information needed for the operating staff to determine whether a strategy has been implemented as intended. The Strategy Effectiveness row describes the information needed to determine whether the strategy is having its intended effect; that is, whether implementation of the strategy is having a beneficial effect on the status of the safety function that is being challenged.

The respective columns in the table format include the identified information needs, the sources of the information categorized as to how well they represent the information needs, and the existing measurements that could supply the needed information. The information sources are subdivided into those that are considered to be either direct or indirect. A direct information source is one that can be used to provide information that will positively determine the presence or absence of a specific condition on the safety objective tree. For example, if the safety function addresses pressure control, a pressure measurement is a direct information source for understanding challenges to the safety function. An indirect information source can be used to infer the needed information, but there may be conditions in which the information source may provide ambiguous results. For example, core exit temperature readings may provide reasonable information for fuel cladding temperatures for some system conditions, but would not provide an accurate indication for other combinations of system flow and fluid conditions.

Development of the input to the rows and columns required the expertise of personnel with diverse backgrounds. A team of personnel with operations, instrumentation, and severe accident experience were used to produce the tables.

Table A-1. Prevent Core Dispersal from Vessel (V) - Loss of Flow to Suppression Pool or Condenser Mechanism (V1A1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Heat Sink Safety Function (V1)	Energy Removal Rate	None		None	
			Suppression Pool Water Level	Suppression Pool Water Level	
			Suppression Pool Water Temperature	Suppression Pool Water RTD	
			Main Steam Isolation Valve Open/ Close Position	MSIV Position Indicator	
			Bypass Valve Position	Bypass Valve Position	
			Condenser Pressure	Condenser Pressure	
			Main Steam Line Steam Flow Rate	Main Steam Line Steam Flow Rate	
			Reactor Vessel Pressure History	Reactor Pressure	
			Suppression Pool & Drywell Pressure	Suppression Pool & Drywell Pressure	

Table A-1. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicator				
Loss of Flow to Suppression Pool and Condenser Mechanisms (V1A1)	Flow rate to Suppression Pool	None		None	
			Relief Valve Actuation Signal	Valve Switch	
			Relief Valve Tail Pipe	Tail Pipe Thermocouple	
			Acoustic Monitor	Acoustic Monitor	
			Suppression Pool Water Temperature	Suppression Pool Water RTD	

Table A-1. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Loss of Flow to Suppression Pool and Condenser Mechanisms (V1A1)	Flow Rate to Condenser	None		None	
			Main Steam Line Steam Flow Rate	Main Steam Line Steam Flow Rate	
			Main Steam Isolation Valve Open/Close Position	MSIV Open/Close Position	
			Bypass Valve Position	Bypass Valve Position	
	<u>Precursor</u>				
	Condenser Vacuum	Condenser Pressure		Condenser Pressure	
	Loss of Circulation Water	Circulating Water Flow Rate		Circulating Water Flow Rate	
	Steam Jet Air Ejector Status	Steam Pressure to STAE		Steam Pressure	
		Valve Position		Valve Position	

Table A-1. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Mechanical Vacuum Pumps	Power (480 VAC)		Power Indication	
		Valve Position		Valve Position	
Restore Condenser Flow Path Strategies	<u>Selection Criteria</u>				
	Condenser Availability	Condenser Vacuum		Condenser Vacuum Pressure	
		Electro Hydraulic Control System		Electro Hydraulic Control System	
		Circulating Water System Status		Circulating Water Flow Rate	
	Main Steam Line Break Status Outside Containment		Aux. Building & Turbine Building Radiation	Area Radiation Monitors	
			Aux. Building & Turbine Building Temperature	Leak Detection System	
	Fuel Failure Status		Fission Product Release	OFG Radiation	

Table A-1. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Selection Criteria (Cont.)</u>				
				Post Accident Monitoring System	
	<u>Strategy Initiation</u>				
	Main Steam Line Steam Flow	Main Steam Line Steam Flow		Main Steam Line Steam Flow	
	<u>Strategy Effectiveness</u>				
	Reactor Pressure	Reactor Steam Pressure		Steam Dome Pressure	
	Reactor Temperature	Reactor Water Temperature		Reactor Water Temperature Monitor	
Restore Suppression Pool Flow Path Strategies	<u>Selection Criteria</u>				
	Suppression Pool Water Level	Suppression Pool Water Level		Suppression Pool Water Level	
	Suppression Pool Water Temperature	Suppression Pool Water Temperature		Suppression Pool Water Temperature	

Table A-1. (continued)

Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
<u>Selection Criteria</u>				
Reactor Power	Reactor Power		Nuclear Instrumentation	
			Process Computer	
Reactor Pressure	Reactor Steam Pressure		Steam Dome Pressure	
Reactor Water Inventory	Reactor Water Level		Reactor Water Level	
<u>Strategy Initiation</u>				
Safety Relief Valve Flow	Steam Flow		Acoustic Monitor	
		Tail Pipe Temperature	Tail Pipe Thermocouple	
		Relief Valve Actuation Signal	Valve Switch	
		Tail Pipe Pressure	Tail Pipe Pressure Indicators	

Table A-1. (continued)

Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
<u>Strategy Effectiveness</u>				
Reactor Pressure	Reactor Pressure		Steam Dome Pressure	
Reactor Coolant Temperature	Reactor Coolant Temperature		Reactor Coolant Temperature	
<u>Selection Criteria</u>				
Reactor Pressure Trend	Reactor Pressure		Steam Dome Pressure	
HPCI (CST to CST) Availability	HPCI Status		HPCI Status	
RCIC				
Feed Water System (Steam Driven Pump) Availability	FWS Status Condenser Vacuum		FWS Status Condenser Pressure	
RWCU (Recirculation) Availability	RWCU Status		RWCU Status	
Head Vent Availability	Head Vent Valve Status		Head Vent Valve Status Lights	
RHR Steam Condensing	RHR Status		RHR System Status	

Table A-1. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Strategy Initiation</u>				
	Steam Flow Rate to Systems		System Flow Rate	Flow Rate of Various Systems	
	<u>Strategy Effectiveness</u>				
	Reactor Pressure	Reactor Steam Pressure		Steam Dome Pressure	
	Reactor Temperature	Reactor Water Temperature		Reactor Coolant Temperature Monitor	
Alternate "Feed & Drain" Paths Strategies	<u>Selection Criteria</u>				
	Reactor Pressure Trend	Reactor Steam Pressure		Steam Dome Pressure	
	Feed Water System Status	Feed Water System Status		Feed Water System Status	
	Main Steam Line Drains Availability	Main Steam Line or chain Valves Status		Valves Status	
	RWCU (Blowdown Mode) Availability	RWCU Status		RWCU Status	
	HPCI (CST to Vessel) Availability	HPCI Status		HPCI Status	

Table A-1. (continued)

Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
RCIC (CST to Vessel) Availability	RCIC Status		RCIC Status	
<u>Strategy Initiation</u>				
Injection Flow Rate	Flow Rate		Flow Rate of Various Systems	
Drain Flow Rate		Steam Line Valve Position	Valve Position Indicators	
<u>Strategy Effectiveness</u>				
Reactor Pressure	Reactor Steam Pressure		Steam Dome Pressure	
Reactor Temperature	Reactor Water Temperature		Reactor Coolant Temperature	
Reactor Water Inventory	Reactor Water Level		Reactor Water Level	

Table A-2. Prevent Core Dispersal From Vessel (V) - Failure of Control Rods to Insert Mechanism (V2A1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Reactivity Control Safety Function (V2)	Core Reactivity	Reactor Period		Source Range Monitor	
		Neutron Flux Trend		Source, Intermediate, Local, and Power Range Monitors	
			Control Rod Position Indicators	Rod Position Information System	
			Coolant Pressure	Reactor Pressure	
			Steam Line Steam Flow Rate	Main Steam Line Steam Flow Rate	
			SRV Actuation History	Acoustic Monitors	

Table A-2. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicator				
Failure of Control Rods to Insert Mechanism (V2A1)	Control Rod Position	Individual Rod Positions		Individual Rod Position Limit Switches	
			Rod Drive System Operation	Scram Air Header Pressure Scram Inlet and Outlet Valve Position Switches	
			Reactor Protection System Operation	RPS Scram Group Lights (White Lights)	

Table A-2. (continued)

Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Precursor				
Scram Discharge Volume Water Inventory	Scram Discharge Volume Level		SDIV Level Switches	
		SDIV Drain and Vent Path Open	SDIV Drain and Vent Path Valve Position	

Table A-2. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Rod Insertion Methods Strategies	<u>Selection Criteria</u>				
	Control Rod Position	Control Rod Position		Rod Position Information System	
	Reactor Power	Reactor Power		Nuclear Instrumentation	
	Reactor Protection System (RPS) Status	RPS Status		Scram Lights / Scram Status	
	Control Rod Drive Status	CRD System Status		CRD System Status	
	Reactor Manual Control Status	RMCS Status		RMCS Status	
	<u>Strategy Initiation</u>				
	Control Rod Position	Control Rod Position		Rod Position Information System	
	<u>Strategy Effectiveness</u>				
	Reactor Power	Reactor Power		Nuclear Instrumentation	

Table A-2. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Control Injection Rates Strategies (Power/Level Control)	<u>Selection Criteria</u>				
	Reactor power	Reactor Power		Nuclear Instrumentation	
	Reactor Water Inventory Level	Reactor Water Level		Reactor Water Level	
	Control Rod Position	CRD Position		RPIS	
	Suppression Pool Temperature	Suppression Pool Temperature		Suppression Pool Temperature	
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	ADS Status	Control Circuit		Inhibite Switch	
	SRV Status			**See Table A-1 "Restore Suppression Flow Path Strategies, SRV Flow"**	
	<u>Strategy Initiation</u>				
	Injection Flow Rate	System Flow Rate		Flow Rate Meter	

Table A-2. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Strategy Effectiveness</u>				
	Reactor Power	Reactor Power		Nuclear Instrumentation	
Alternate Boron Injection Methods Strategies	<u>Selection Criteria</u>				
	SLC Status CRD Status RWCU Status Feedwater System Status HPCI Status RCIC Status	Status of Various Systems		Status of Various Systems	
	<u>Strategy Initiation</u>				
	Boron Injection Rate		System Flow Rate	Flow Rate Meter	
			Boron Storage Tank Level	Standby Liquid Control System Tank Level	
	<u>Strategy Effectiveness</u>				
	Boron Concentration	Coolant Sampling		Post Accident Sampling System	

Table A-3. Prevent Core Dispersal From Vessel (V) - Control Rod Relocation and Reflood Mechanism (V2B1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Reactivity Control Safety Function (V2)	Core Reactivity	Reactor Period		Source Range Monitor	
		Neutron Flux Trend		Source, Intermediate, Local and Power Range Monitors	
			Control Rod Position Indicators	Rod Position Information System	
			Coolant Pressure	Reactor Pressure	
			Steam Line Steam Flow Rate	Main Steam Line Steam Flow Rate	
			Safety Relief Valve Actuation History	Acoustic Monitors	

Table A-3. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicators				
Control Rod Relocation and Reflood Mechanism (V2B1)	Control Rod Material Location	None		None	
			Reactivity	Nuclear Instrumentation	
			System Pressure	Reactor Vessel Pressure	
			Steam Flow	Main Steam Line Steam Flow	
				Relief Valve Acoustic Monitor	
				Relief Value Tail Pipe Temperature and Pressure	
	Indicator				
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	
	Reflood Water Boron Concentration	Coolant Sampling		Post Accident Sampling System	

Table A-3. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Boron Injection Methods Strategies	**See Table A-2.**				
	<u>Selection Criteria</u>				
Lower Reactor Water Level Strategies	Reactor Power	Reactor power		Nuclear Instrumentation	
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Suppression Pool Temperature	Suppression Pool Temperature		Suppression Pool Temperature	
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	
	<u>Strategy Initiation</u>				
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	
	<u>Strategy Effectiveness</u>				
	Reactor Power	Reactor Power		Nuclear Instrumentation	

Table A-4. Prevent Core Dispersal from Vessel (V) - Loss of Adequate Flow Path Mechanism(V3A1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Core Heat Removal Safety Function (V3)	Core Heat Removal	Core Water Inventory History		Reactor Vessel Water Level	
			Fuel Rod Temperature	None	
			Reactor Pressure History	Reactor Pressure	
			Vessel Coolant Activity	Post Accident Sampling System	
			Containment Radiation Levels	Containment Atmosphere Radiation Monitor	
			Containment Hydrogen Concentration	Containment Atmosphere Hydrogen Monitor	

Table A-4. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicators				
Loss of Adequate Flow Path Mechanism (V3A1)	Injection Flow Rate	Cooling Water Injection Rate and Valve Lineup		System Status (Flow Rate, Pump Head, Valve Position, etc) of FWS/CNM, HPCI, LPCS, LPCI, RCIC	
			Reactor Water Inventory	Reactor Water Level Indications	
			Safety Relief Valve Flow	Reactor Steam Dome Pressure	

Table A-4. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Reduce Outflow Strategies	<u>Selection Criteria</u>				
	Location of Leak		Area Temperature	Leak Detection System RTD	
			Sump Level	Sump Level	
			Area Radiation	Radiation Monitoring System	
			System Flow Rate	System Flow Rate/Leak Detection System Flow Measurement	
	<u>Strategy Initiation</u>				
	Reduced Outflow		Reactor Water Inventory	Reactor Water Level	
	<u>Strategy Effectiveness</u>				
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	

Table A-4. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Injection Systems Strategies	<u>Selection Criteria</u>				
	Reactor Water Level Trend	Reactor Water Level		Reactor Water Level	
	Status of Alternate Injection System, e.g., RHR Service Water/Fire System/ECCS Keep Full Systems/ Interconnections with other Units/SLC (Test Tank)/SLC (Boron Tank)	Status of Alternate Injection Systems		System Instrumentation	

Table A-4. (continued)

Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
<u>Strategy Initiation</u>				
Coolant Injection Rate	System Injection Rate		System Flow Meter	
		Reactor Water Inventory	Reactor Water Level	
<u>Strategy Effectiveness</u>				
Reactor Water Inventory	Reactor Water Level		Reactor Water Level	

Table A-5. Prevent Vessel Failure (V) - Loss of Adequate Water Sources Mechanism (V3A2)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Core Heat Removal Safety Function (V3)	Core Heat Removal	Reactor Water Inventory History		Reactor Water Level	
			Fuel Rod Temperature	None	
			Reactor Pressure History	Reactor Pressure	
			Vessel Coolant Activity	Post Accident Sampling System	
			Containment Radiation Levels	Containment Atmosphere Radiation Monitor	
			Containment Hydrogen Concentration	Containment Atmosphere Hydrogen Monitor	

Table A-5. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicators				
Loss of Adequate Water Sources Mechanisms (V3A2)	Suppression Pool Inventory	Suppression Pool Water Level		Suppression Pool Water Level	
		Suppression Pool Water Temperature		Suppression Pool Water Temperature	
	Condensate Storage Tank Inventory	CST Water Level		CST Water Level	
	Alternate Water Source Inventory	Water Level		Water Level Measurements In Alternate Sources	

Table A-5. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Sources Strategies	<u>Selection Criteria</u>				
	Reactor Water Level Inventory History	Reactor Water Level		Reactor Water Level	
	Availability of Alternate Water Sources	Level Indication		Level Indication	
		Valve Status		Valve Status	
	<u>Strategy Initiation</u>				
	Coolant Injection Rate	System Injection Rate		System Flow Meter	
	<u>Strategy Effectiveness</u>				
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	

Table A-6. Prevent Core Dispersal from Vessel (V) - Core Geometry Change Mechanism (V3B1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Core Heat Removal Safety Function (V3)	Core Heat Removal	Reactor Water Inventory History		Reactor Water Level	
			Fuel Rod Temperature	None	
			Reactor Pressure History	Reactor Vessel Pressure	
			Vessel Coolant Activity	Post Accident Sampling System	
			Containment Radiation Concentration	Containment Atmosphere Radiation Monitor	
			Containment Hydrogen Concentration	Containment Atmosphere Hydrogen Monitor	

Table A-6. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicators				
Core Geometry Change Mechanism (V3B1)	Core Material Temperature and Geometry	Cladding and Fuel (Location and Temperature)		None	
			Reactor Water Activity	Post Accident Sampling System	
			Reactor Vessel Temperature	Reactor Vessel Temperature Recorders	
			Drywell Hydrogen Content	Drywell Hydrogen Monitors	
	Precursors				
	CPR, LHRG, APLHGR	Plant Process Computer		Plant Process Computer	
			Reactor Neutron Flux	Nuclear Instrumentation	
	Reactor Vessel Inventory	Reactor Water Level		Reactor Water Level	
	Off Gas System Activity	OFG Activity		OFG Reactivity Meters	

Table A-6. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Injection Methods Strategies	See Table A-4. "Alternate Injection Systems Strategies"				
Alternate Injection Sources Strategies	See Table A-5. "Alternate Sources Strategies"				

Table A-7. Prevent Core Dispersal from Vessel (V) - Non-Coolable Relocation Mechanism (V4A1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Vessel Boundary Safety Function (V4)	Vessel Integrity	Vessel Visual Observation		None	
			Reactor Vessel Metal Temperature	Reactor Vessel Temperature Recorder	
			Reactor Pressure	Reactor Steam Dome Pressure	
			Drywell Leakage Rate	Drywell Sumps Level Trend	
	Indicators				
Non-Coolable Relocation Mechanism (V4A1)	Vessel Integrity	Vessel Visual Observation		None	
		Reactor Vessel Metal Temperature		Reactor Vessel Temperature Recorder	
			Reactor Pressure	Reactor Steam Dome Pressure	

Table A-7. (continued)

Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
<u>Precursors</u>				
Core Relocation Status	None		None	
		Radiation Outside Core Region	SRM	
		Reactor Pressure	Reactor Steam Dome Pressure	
Drywell Radiation	Drywell Radiation		Drywell Radiation Monitor	
Core Damage Status	None		None	
		Fission Product Release	OFG Reactivity Meters	
		Isotopic Analysis	Reactor Water Sampling	
		Hydrogen Production	Drywell Hydrogen Monitors	
		Reactor Water Inventory	Reactor Water Level	

Table A-7. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Flood Cavity Strategy	<u>Selection Criteria</u>				
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	
	Reactor Vessel Temperature	Reactor Vessel Metal Temperature		Reactor Vessel Thermocouples	
	<u>Strategy Initiation</u>				
	Containment Flooding Flow Rate	System Flow Rates		System Flow Rates	
	<u>Strategy Effectiveness</u>				
	Containment Water Level		Suppression Pool Level	Suppression Pool Level	
			Suppression Pool Pressure	Suppression Pool Pressure	

Table A-8. Prevent Core Dispersal from Vessel (V) - Water Expansion with Solid System Mechanism (V4B1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Vessel Boundary Safety Function (V4)	Vessel Integrity	Vessel Visual Observation		None	
			Reactor Vessel Metal Temperature	Reactor Vessel Thermocouple	
			Reactor Pressure	Reactor Steam Dome Pressure	
			Drywell Leakage Rate	Drywell Sumps Level Trend	
	Indicators				
Water Expansion with Solid System Mechanism (V4B1)	Reactor Pressure	Reactor Pressure		Reactor Steam Dome Pressure	
			Reactor Vessel Flange Leak	Leak Detection System	
			Water Temperature	Reactor Water RTDs	
			Injection Flow Rate	Injection Flow Rate	

Table A-8. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Precursors</u>				
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	
Establish Relief Path Strategies	<u>Selection Criteria</u>				
	Reactor Pressure	Reactor Pressure		Reactor Steam Dome Pressure	
	Reactor Water Level	Reactor Water Level		Reactor Water Level	
	Status of Steam Line Drain	Steam Drain Valve Positions		HPCI/RCIC/ Main Steam Line Drain Valve Positions	
	Status of Head Vent	Head Vent Positions		Head Vent Positions	
	Status of Isolation Condensor	IC Vent Positions		IC Tube Vent Valve Positions	
	<u>Strategy Initiation</u>				
	Reactor Vessel Release Rate		Reactor Water Inventory	Reactor Water Level	

Table A-8. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Strategy Effectiveness</u>				
	Reactor Pressure	Reactor Pressure		Reactor Pressure	
Control Injection Rates Strategies	<u>Selection Criteria</u>				
	Reactor Pressure	Reactor Pressure		Reactor Steam Dome Pressure	
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	
	Injection System Status	Injection System Status		Injection System Flow & Pressure	
	<u>Strategy Initiation</u>				
	Reactor Vessel Injection Rate	System Injection Rate		System Flow Rate Meter	
	<u>Strategy Effectiveness</u>				
	Reactor Pressure	Reactor Pressure		Reactor Steam Dome Pressure	

Table A-9. Prevent Core Dispersal from Vessel (V) - Steam Explosions Mechanism (V4B2)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Vessel Boundary Safety Function (V4)	Vessel Integrity	Vessel Visual Observation		None	
			Reactor Vessel Metal Temperature	Reactor Vessel Thermocouple	
			Reactor Pressure	Reactor Steam Dome Pressure	
			Drywell Leakage Rate	Drywell Sumps Level Trend	
	Indicators				
Steam Explosions Mechanism (V4B2)	Reactor Pressure	Reactor Pressure		Reactor Steam Dome Pressure	
	Precursors				
	Reactor Vessel Inventory History	Reactor Vessel Water Level		Reactor Vessel Water Level	
	Core Damage Status	None		None	
			Coolant Activity	Post Accident Sampling System	

Table A-9. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
			Containment Hydrogen Concentration	Hydrogen Monitors	
Control Injection Rates Strategies	<u>Selection Criteria</u>				
	Status of Core Damage	None		None	
			Drywell Hydrogen Concentration	Drywell Hydrogen Monitors	
	Reactor Vessel Metal Temperature	Reactor Vessel Metal Temperature		Vessel Temperature	
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	
	<u>Strategy Initiation</u>				
	Reactor Vessel Injection Rate	System Injection Rates		System Injection Flow Rate	
	<u>Strategy Effectiveness</u>				
	Vessel Integrity	None			
			Reactor Vessel Pressure History	Reactor Steam Dome Pressure	

Table A-9. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Injection Locations Strategies	<u>Selection Criteria</u>				
	Status of Core Damage	None		None	
			Drywell Hydrogen Concentration	Drywell Hydrogen Monitors	
	Reactor Water Inventory	Reactor Water Level		Reactor Water Level	
	Reactor Vessel Pressure	Reactor Vessel Pressure		Reactor Steam Dome Pressure	
	<u>Strategy Initiation</u>				
	Injection Rate	System Injection Rate		System Injection Flow Rate	
	<u>Strategy Effectiveness</u>			None	
	Vessel Integrity	None	Reactor Pressure History	Reactor Steam Dome Pressure	

Table A-10. Maintain Containment Integrity (C) - Spray with Insufficient Non-Condensables Mechanism (C1A1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Pressure Control Safety Function (C1)	Containment Pressure History	Drywell Pressure		Drywell Pressure	
		Suppression Chamber Pressure		Suppression Chamber Pressure	
	Indicators				
Spray with Insufficient Non-Condensables Mechanism (C1A1)	Spray Flow Rate	Spray Flow Rate		Spray Flow Rate	
	Nitrogen Concentration	None		None	

Table A-10. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Add Nitrogen or Air Strategies	<u>Selection Criteria</u>				
	O_2 Content in Drywell	Oxygen Content		Oxygen Monitor	
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Containment Vent & Purge System Status	Containment Vent & Purge System Status		System Flow Meter	
	Nitrogen Inerting System Status	Nitrogen Inerting System Status		System Flow Meter	
	<u>Strategy Initiation</u>				
	Nitrogen or Air Flow Rate	Flow Rate		Flow Meter	
	<u>Strategy Effectiveness</u>				
	Non-Condensables in Drywell	None		None	

Table A-10. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Terminate Sprays Strategies	<u>Selection Criteria</u>				
	Drywall Pressure	Drywell Pressure		Drywell Pressure	
	Drywell Temperature	Drywell Temperature		Drywell Temperature	
	<u>Strategy Initiation</u>				
	Containment Spray Flow Rate	Spray Flow Rate		System Flow Meter	
	<u>Strategy Effectiveness</u>				
	Drywell Temperature	Drywell Temperature		Drywell RTD	
	Drywell Pressure	Drywell Pressure		Drywell Pressure	

Table A-10. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Limit Vent Strategies	<u>Selection Criteria</u>				
	Containment Pressure	Drywell Pressure		Drywell Pressure	
	Containment Vent & Purge System Status	Containment Vent & Purge System Status		System Flow Meter	
	Drywell Temperature	Drywell Temperature		Drywell RTD	
	Non-condensable Concentration in Drywell	None		None	
	<u>Strategy Initiation</u>				
	Containment Vent Flow Rate	Vent Flow Rate		Vent Flow Rate Meter	
			Drywell Pressure	Drywell Pressure	

Table A-10. (continued)

Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
<u>Strategy Effectiveness</u>				
Containment Pressure	Drywell Pressure		Drywell Pressure	

Table A-11. Maintain Containment Integrity (C) - Spray with Vacuum Breaker Failure Mechanism (C1A2)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Pressure Control Safety Function (C1)	Containment Pressure	Drywell Pressure		Drywell Pressure	
		Suppression Chamber Pressure		Suppression Chamber Pressure	
	Indicators				
Spray with Vacuum Breaker Failure Mechanism (C1A2)	Vacuum Breaker Operability and Spray Flowrate	Status of Vacuum Breaker		Vent Header Vacuum Breaker Limit Switches	
		Drywell Pressure		Drywell Pressure	
		Spray Flow Rate		Spray Flow Meter	
			Containment Temperature	Drywell RTD	

Table A-11. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Terminate Sprays Strategies	<u>Selection Criteria</u>				
	Drywell to Suppression Chamber Differential Pressure	Drywell to Suppression Chamber Differential Pressure		Drywell to Suppression Chamber Differential Pressure	
				Drywell Pressure Suppression Chamber Pressure	
	Vacuum Breaker Status	Vacuum Breaker Status		Vacuum Breaker Limit Switches	
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Suppression Chamber Pressure	Suppression Chamber Pressure		Suppression Chamber Pressure	
	<u>Strategy Initiation</u>				
	Containment Spray Flow Rate	Spray Flow Rate		Drywell Spray Flow Meter	
				Suppression Pool Spray Flow Meter	
			Spray Valve Positions	Spray Valve Positions	

Table A-11. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Strategy Effectiveness</u>				
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Suppression Chamber Pressure	Suppression Chamber Pressure		Suppression Chamber Pressure	
Open Vent Strategies	<u>Selection Criteria</u>				
	Containment Pressure	Containment Pressure		Drywell Pressure Suppression Chamber Pressure	
	Purge & Vent System Status	System Status		System Status	
	<u>Strategy Initiation</u>				
	Vent Flow Rate	Vent Flow Rate		System Flow Meter	
			Damper Positions	Damper Positions	
	<u>Strategy Effectiveness</u>				
	Containment Pressure	Containment Pressure		Drywell Pressure Suppression Chamber Pressure	

Table A-12. Maintain Containment Integrity (C) - Insufficient Energy Removal Mechanism (C1B1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Pressure Control Safety Function (C1)	Containment Pressure History	Drywell Pressure		Drywell Pressure	
		Suppression Chamber Pressure		Suppression Chamber Pressure	
	Indicators				
Insufficient Energy Removal Mechanism (C1B1)	Imbalance in Energy Addition and Removal	None		None	
			Drywell Temperature	Drywell Temperature	
			Drywell Pressure	Drywell Pressure	
			Containment Spray Flow Rate	Containment Spray Flow Meter	
			Drywell Cooler Status	Drywell Cooler Air Thermocouple	
			Condenser Status	Condenser Vacuum	
				Circulating Water Status	
				MSIV Positions	

Table A-12. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Suppression Pool or Drywell Sprays Strategies	<u>Selection Criteria</u>				
	Containment Pressure	Containment Pressure		Drywell Pressure Suppression Chamber Pressure	
	Containment Temperature	Containment Temperature		Drywell RTD Suppression Chamber RTD	
			Suppression Pool Water Temperature	Suppression Pool Water RTD	
	Suppression Pool Water	Suppression Pool Water		Suppression Pool Water	
	<u>Strategy Initiation</u>				
	Spray Flow Rate	Spray Flow Rate		Suppression Pool Spray Flow Meter Drywell Spray Flow Meter	
	<u>Strategy Effectiveness</u>				
	Containment Pressure	Containment Pressure		Drywell Pressure Suppression Chamber Pressure	

Table A-12. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Drywell Coolers Strategies	<u>Selection Criteria</u>				
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Drywell Temperature	Drywell Temperature		Drywell RTD	
	Drywell Coolers Status	Drywell Cooler Fans Status		Fan Indicating Light	
		Drywell Cooling Water Status		Drywell Cooling Water Status	
	<u>Strategy Initiation</u>				
	Drywell Cooler Air Differential Temperature	Drywell Cooler Air Differential Temperature		Cooler Air Thermocouples	
	<u>Strategy Initiation</u>				
	Drywell Temperature	Drywell Temperature		Drywell RTD	

Table A-12. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Recover Other Heat Sinks Strategies	<u>Selection Criteria</u>				
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Suppression Pool Status (SRV, HPCI, RCIC)	Suppression Pool Status/System Status of SRV/ HPCI/RCIC/ Reactor Pressure		Suppression Pool Temperature/ Suppression Pool Level/SRV/ Acoustic Monitor/ Status of HPCI/ RCIC/Reactor Pressure	
	Condenser (Steam Line, Steam Line Drain)	Condenser Vacuum/ MSIV Status/ Electro Hydraulic Control System (EHC) Status		Condenser Vacuum/ MSIV Positions/ EHC Pressure	
	<u>Strategy Initiation</u>				
	Heat Removal Rate	None		None	
			System Flow Rate	System Flow Meter	
	<u>Strategy Effectiveness</u>				
	Drywall Pressure	Drywell Pressure		Drywell Pressure	

Table A-13. Maintain Containment Integrity (C) - Insufficient Suppression Pool Level Mechanism (C1B2)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Pressure Control Safety Function (C1)	Containment Pressure History	Drywell Pressure		Drywell Pressure	
		Suppression Chamber Pressure		Suppression Chamber Pressure	
	Indicators				
Insufficient Suppression Pool Level Mechanism (C1B2)	Suppression Pool Level	Suppression Pool Level		Suppression pool Level	
			Suppression Pool Temperature	Suppression Pool Temperature	
			Reactor Pressure	Reactor Pressure	
			Drywell Pressure	Drywell Pressure	
	Precursors				
	Suppression Pool Water Level	Suppression Pool Water Level		Suppression Pool Level	
			Suppression Pool Temperature	Suppression Pool Temperature RTD	
			Reactor Pressure	Reactor Pressure	
			Drywell Pressure	Drywell Pressure	

Table A-13. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Suppression Pool Injection Strategies	<u>Selection Criteria</u>				
	Suppression Pool Water Level	Suppression Pool Water Level		Suppression Pool Water Level	
	HPCI (CST to Suppression Pool) Status	None		None	
			System Flow	System Flow Meter	
			CST Level	CST Level	
	RCIC (CST to Suppression Pool) Status		System Flow	System Flow Meter	
			CST Level	CST Level	
	RHR (Service Water to Suppression Pool Status	System Flow		System Flow Meter	
	<u>Strategy Initiation</u>				
	Suppression Pool Makeup Flow	Makeup Flow		System Flow Meter	
	<u>Strategy Effectiveness</u>				
	Suppression Pool Water Level	Suppression Pool Water Level		Suppression Pool Water Level	

Table A-13. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Suppression Pool Makeup Sources Strategies	<u>Selection Criteria</u>				
	Fire Water Tank Level	Tank Water Level		Tank Water Level	
	Suppression Chamber Pressure	Suppression Chamber Pressure		Suppression Chamber Pressure	
	<u>Strategy Initiation</u>				
	System Flow Rate	System Flow Rate		System Flow Rate	
	<u>Strategy Effectiveness</u>				
	Suppression Pool Water Level	Suppression Pool Water Level		Suppression Pool Water Level	

Table A-14. Maintain Containment Integrity (C) - SRV or Drywell to Suppression Pool Break Mechanism (C1B3)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Pressure Control Safety Function (C1)	Containment Pressure History	Drywell Pressure		Drywell Pressure	
		Suppression Chamber Pressure		Suppression Chamber Pressure	
	Indicators				
SRV or Drywell to Suppression Pool Break Mechanism (C1B3)	Drywell to Wetwell Interface Integrity	None		None	
			Drywell to Suppression Pool DP System Operability	DP Indicator	
	SRV Tailpipe Integrity	None*		None	

a. Specific Plant Procedure or Methods Detect Tailpipe Break.

Table A-14. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Spray Suppression Pool Strategies	<u>Selection Criterial</u>				
	Suppression Chamber Pressure	Suppression Chamber Pressure		Suppression Chamber Pressure	
	Suppression Pool Water Level	Suppression Pool Water Level		Suppression Pool Water Level	
	<u>Strategy Initiation</u>				
	Suppression Pool Spray Flow Rate	Suppression Pool Spray Flow Rate		Suppression Pool Spray Flow Rate	
	<u>Strategy Effectiveness</u>				
	Suppression Chamber Pressure	Suppression Chamber Pressure		Suppression Chamber Pressure	
	Drywell Pressure	Drywell Pressure		Drywell Pressure	

Table A-14. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Flood Break Strategies	<u>Selection Criterial</u>				
	Location of Break	None		None	
	Suppression Pool Water Level	Suppression Pool Water Level		Suppression Pool Water Level	
	See Table A-13 "Alternate Suppression Pool Injection Strategies"				
	<u>Strategy Initiation</u>				
	Suppression Pool Water Makeup Flow Rate	Suppression Pool Make Up Flow Rate		System Flow Meter	
	<u>Strategy Effectiveness</u>				
	Suppression Chamber Pressure	Suppression Chamber Pressure		Suppression Chamber Pressure	

Table A-14. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Vent Strategies	Selection Criteria				
	Suppression Chamber Pressure	Suppression Chamber Pressure		Suppression Chamber Pressure	
	Suppression Pool Water Level	Suppression Pool Water Level		Suppression Pool Water Level	
	Status of Primary Containment Purge & Vent System	Status of Purge & Vent System		Status of Purge & Vent System	
	Containment Atmosphere Activity	Fission Product Concentration		Fission Product Monitors	
	Strategy Initiation				
	Suppression Chamber Vent Flow Rate	Suppression Chamber Vent Flow Rate		Vent Flow Meter	
			Damper Positions	Damper Positions	
	Strategy Effectiveness				
	Suppression Chamber Pressure	Suppression Chamber Pressure		Suppression Chamber Pressure	
	Drywell Pressure	Drywell Pressure		Drywell Pressure	

Table A-15. Maintain Containment Integrity (C) - Combustibles Control Mechanism (C1B4)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Pressure Control Safety Function (C1)	Containment Pressure History	Drywell Pressure		Drywell Pressure	
		Suppression Chamber Pressure		Suppression Chamber Pressure	
	Indicators				
Combustibles Control Mechanism (C1B4)	Drywell Hydrogen and Oxygen Concentration	Hydrogen and Oxygen Monitors		Hydrogen and Oxygen Monitors	
			Nitrogen Inerting System Status	Nitrogen Inerting System Status	
			Hydrogen Recombiners Status	Hydrogen Recombiners Status	
			Containment Purge & Vent Status	Containment Purge & Vent System Status	
			Drywell Unit Coolers Status	Drywell Unit Coolers Status	
	Precursors				
	Core Uncovered	Reactor Water Level		Reactor Water Level Recorders	

Table A-15. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Inert Containment Strategies	<u>Selection Criteria</u>				
	Oxygen and Hydrogen Concentration	Oxygen and Hydrogen Concentration		Oxygen and Hydrogen Monitors	
	Nitrogen Concentration	None		None	
	Nitrogen Inerting System Status	Nitrogen Inerting System Status		Nitrogen Inerting System Status	
	<u>Strategy Initiation</u>				
	Nitrogen Purge Flow Rate	Nitrogen Purge Flow Rate		Nitrogen Purge Flow Rate	
			Nitrogen Purge Pressure	Nitrogen Purge	
	<u>Strategy Effectiveness</u>				
	Oxygen and Hydrogen Concentration	Oxygen and Hydrogen Concentration		Oxygen and Hydrogen Monitors	

Table A-15. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Dilute Strategies & Vent Strategies	<u>Selection Criteria</u>				
	Oxygen and Hydrogen Concentration	Oxygen and Hydrogen Concentration		Oxygen and Hydrogen Monitors	
	Purge & Vent System Status	Purge & Vent System Status		Purge & Vent System Status	
	<u>Strategy Initiation</u>				
	Purge & Vent Flow Rate	Purge & Vent Flow Rates		Purge & Vent Flow Rates	
	<u>Strategy Effectiveness</u>				
	Drywell Hydrogen Concentration	Hydrogen Concentration		Hydrogen Concentration	

Table A-15. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Recombiners Strategies	<u>Selection Criteria</u>				
	Drywell Oxygen and Hydrogen Concentration	Oxygen and Hydrogen Concentration		Oxygen and Hydrogen Monitors	
	<u>Strategy Initiation</u>				
	Recombiners Turned On	Control Panel Indication		Control Switches, etc.	
	<u>Strategy Effectiveness</u>				
	Drywell Oxygen and Hydrogen Concentration	Oxygen and Hydrogen Concentration		Oxygen and Hydrogen Monitors	

Table A-16. Maintain Containment Integrity (C) - Non-Condensable Buildup Mechanism (C1B5)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Pressure Control Safety Function (C1)	Containment Pressure History	Drywell Pressure		Drywell Pressure	
		Suppression Chamber Pressure		Suppression Chamber Pressure	
	Indicators				
Non-Condensable Buildup Mechanism (C1B5)	Non-Condensable Concentration in Containment	Oxygen Concentration		Oxygen Monitor	
		Hydrogen Concentration		Hydrogen Monitor	
			Drywell Pressure	Drywell Pressure Measurement	
			Instrument Air Overpressure	Instrument Air System Pressure	

Table A-16. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Vent Containment Strategies	<u>Selection Criteria</u>				
	Non-Condensables in Containment	Oxygen and Hydrogen Concentration		Oxygen and Hydrogen Monitors	
	Nitrogen Concentration	None		None	
	Purge & Vent System Status	Purge & Vent System Status		Purge & Vent System Status	
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Suppression Pool Pressure	Suppression Pool Pressure		Suppression Pool Pressure	
	Containment Atmosphere Activity	Fission Product Concentration		Fission Product Monitors	
	<u>Strategy Initiation</u>				
	Containment HVAC Flow Rate	HVAC System Flow Rate		HVAC System Flow Rate	
	<u>Strategy Effectiveness</u>				
	Non-Condensables Concentration	Oxygen and Hydrogen Concentration		Oxygen and Hydrogen Monitors	

Table A-16. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Sprays Strategies	<u>Selection Criteria</u>				
	Non-Condensables in Containment	Oxygen and Hydrogen Concentration		Oxygen and Hydrogen Monitors	
	Drywell Spray System Status	Spray System Status		Spray System Status	
	Drywell Temperature	Drywell Temperature		Drywell Temperature	
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Suppression Pool Level	Suppression Pool Level		Suppression Pool Level	
	<u>Strategy Initiation</u>				
	Containment Spray Flow Rate	Spray System Flow Rate		Spray System Flow Meter	
	<u>Strategy Effectiveness</u>				
	Drywell Pressure	Drywell Pressure		Drywell Pressure	

Table A-17. Maintain Containment Integrity (C) - High Pressure & Level in Drywell Mechanism (C1B6)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Pressure Control Safety Function (C1)	Containment Pressure History	Drywell Pressure		Drywell Pressure	
		Suppression Chamber Pressure		Suppression Chamber Pressure	
	Indicators				
High Pressure & Level in Drywell Mechanism (C1B6)	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Drywell Level	Drywell Level		None	
			Suppression Pool Level	Suppression Pool Level	
			Suppression Chamber Pressure	Suppression Chamber Pressure	
			Drywell Pressure	Drywell Pressure	

Table A-17. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Drainage Methods Strategies	Selection Criteria				
	Containment Water Level	None		None	
			Suppression Pool Water Level	Suppression Pool Water Level	
			Suppression Chamber Pressure	Suppression Chamber Pressure	
			Drywell Pressure	Drywell Pressure	
	Status of Systems with Suction Source from containment	Status of Various Systems		Status of LPCI, HPCI, RCIC, Core Spray, Sump Pumps	
	Strategy Initiation				
	DW Drainage Flow Rate	Drainage Flow Rate		System Flow Rate	
	Strategy Effectiveness				
	Containment Water Level	None		None	

Table A-17. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
			Suppression Pool Water Level	Suppression Pool Water Level	
			Suppression Chamber Pressure	Suppression Chamber Pressure	
			Drywell Pressure	Drywell Pressure	
Reduce Drywell Pressure Strategies	<u>Selection Criteria</u>				
	Drywell Pressure	Drywell Pressure		Drywell Pressure	
	Containment Atmosphere Activity	Fission Product Concentration		Fission Product Monitors	
	Purge & Vent System Status	Purge & Vent System Status		Purge & Vent System Status	
	<u>Strategy Initiation</u>				
	Purge & Vent System Flow	Purge & Vent System Flow		System Flow Meter	
	<u>Strategy Effectiveness</u>				
	Drywell Pressure	Drywell Pressure		Drywell Pressure	

NOTE: Also See Table A-12.

Table A-18. Maintain Containment Integrity (C) - Excessive Energy Input Mechanism (C2A1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Temperature Control Safety Functions (C2)	Drywell Temperature	Drywell Temperature		Drywell RTD	
			Drywell Spray Flow Rate	Drywell Spray Flow Meter	
			Drywell Unit Coolers Status	Drywell Unit Coolers Status	
			Drywell Vent & Purge System	Vent & Purge Flow Meter	
	Suppression Pool Temperature	Suppression Pool Temperature		Suppression Pool RTD	
			Suppression Pool Spray Flow Rate	Suppression Pool Spray Flow Meter	

Table A-18. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicators				
Excessive Energy Input Mechanism (C2A1)	Energy Addition Rate into Containment	None		None	
			Drywell Temperature	Drywell RTD	
			Suppression Pool Temperature	Suppression Pool RTD	
			Drywell Pressure	Drywell Pressure	
			Suppression Chamber Pressure	Suppression Chamber Pressure	
			Safety Relieve Valve Status	SRV Position Indicators, Acoustic Monitors	
	Precursors				
	LPCCI Operability	LPCI Status		LPCI System Flow, Temperature, etc.	

Table A-18. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Sprays Strategies	See Table A-12.	"Suppression Pool or Drywell Sprays Strategies"			
Coolers Strategies	See Table A-12.	"Drywell Coolers Strategies"			
Recover Other Heat Sink Strategies	See Table A-12.	"Recover Other Heat Sinks Strategies"			

Table A-19. Maintain Containment Integrity (C) - Failure of Cooling Sources Mechanism (C2A2)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Temperature Control Safety Functions (C2)	Drywell Temperature	Drywell Temperature		Drywell RTD	
			Drywell Spray Flow Rate	Drywell Spray Flow Meter	
			Drywell Unit Coolers Status	Drywell Unit Coolers Status	
			Drywell Vent & Purge System	Vent & Purge Flow Meter	
	Suppression Pool Temperature	Suppression Pool Temperature		Suppression Pool RTD	
			Suppression Pool Spray Flow Rate	Suppression Pool Spray Flow Meter	
	Indicators				
Failure of Cooling Sources Mechanism (C2A2)	Drywell Temperature	Drywell Temperature		Drywell RTD	
	Drywell Coolers Operability	Drywell Coolers Status		Drywell Coolers Air Temperes	

Table A-19. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Pump System Strategies & Alternate Water Sources Strategies	<u>Selection Criteria</u>				
	Drywell Temperature	Drywell Temperature		Drywell RTD	
	Alternate Pump System & Water Sources Availability	Alternate Pump System & Water Source Status		Alternate Pump System & Water Source Status	
	<u>Strategy Initiation</u>				
	Cooling Water Flow Rate	Cooling Water Flow Rate		Cooling Water Flow Meter	
	<u>Strategy Effectiveness</u>				
	Drywell Temperature	Drywell Temperature		Drywell RTD	

Table A-19. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Restart Drywell Coolers Strategies	See Table A-12.	"Drywell Coolers Strategies"			

Table A-20. Maintain Containment Integrity (C) - Direct Shell Contact Mechanism (C2B1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Temperature Control Safety Functions (C2)	Drywell Temperature	Drywell Temperature		Drywell RTD	
			Drywell Spray Flow Rate	Drywell Spray Flow Meter	
			Drywell Unit Coolers Status	DW Unit Coolers Status	
			Drywell Vent & Purge System	Vent & Purge Flow Meter	
	Suppression Pool Temperature	Suppression Pool Temperature		Suppression Pool RTD	
			Suppression Pool Spray Flow Rate	Suppression Pool Spray Flow Meter	
	<u>Indicators</u>				
Direct Shell Contact Mechanism (C2B1)	Drywell Shell Temperature	None		None	
	Core Melt Location in Drywell	None		None	

Table A-20. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Precursors</u>				
	Reactor Vessel Integrity	Vessel Wall Temperature		Vessel Wall Thermocouples	
	Drywell Atmosphere	Fission Product Concentration	Reactor Water Inventory	Reactor Water Level	
				Fission Product Monitors	
Flood Cavity Strategies	See Table A-7. "Flood Cavity Strategies"				
Barriers Strategies	<u>Selection Criteria</u>				
	Core Melt Location	None		None	
			Vessel Wall Temperature	Reactor Vessel Thermocouples	
	<u>Strategy Initiation</u>				
	Barriers Installed	Barriers Installed		Visual	

Table A-20. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Strategy Effectiveness</u>				
	Drywell Temperature	Drywell Temperature		Drywell RTD	
Drywell Spray Strategies	See Table A-12. "Suppression Pool or Drywell Sprays Strategies"				

Table A-21. Maintain Containment Integrity (C) - Basemat Melt-Through Mechanism (C2B2)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Temperature Control Safety Functions (C2)	Drywell Temperature	Drywell Temperature		Drywell RTD	
			Drywell Spray Flow Rate	Drywell Spray Flow Meter	
			Drywell Unit Coolers Status	Drywell Unit Coolers Status	
			Drywell Vent & Purge System	Vent & Purge Flow Meter	
	Suppression Pool Temperature	Suppression Pool Temperature		Suppression Pool RTD	
			Suppression Pool Spray Flow Rate	Suppression Pool Spray Flow Meter	
	Indicators				
Basemat Melt-Through Mechanism (C2B2)	Core Melt Location in Drywell	None		None	
	Amount of Concrete Ablated	None		None	

Table A-21. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Precansors				
	Reactor Vessel Integrity	Vessel Wall Temperature		Vessel Wall Thermocouples	
	Drywell Atmosphere Activity	Fission Product Concentration	Reactor Water Inventory	Reactor Water Level Fission Product Monitors	
Flood Cavity Strategies	See Table A-7. "Flood Cavity Strategies"				
Barriers Strategies	See Table A-20. "Barriers Strategies"				

Table A-22. Maintain Containment Integrity (C) - Failure of Containment Systems to Isolate Mechanism (C3A1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Integrity Safety Function (C3)	Primary Containment Integrity	Containment Leak Location		None	
		Isolation Valves Status		Isolation Valves Status	
			Containment Pressure History	Drywell Pressure	
			Radiation Level Outside Containment	Radiation Monitoring System	
			Reactor Building Temperature	Reactor Building RTD	
			Reactor Building Water Level	Sump and Floor Water Levels	
			Drywell Oxygen Content	Drywell Oxygen Meter	

Table A-22. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicators				
Failure of Containment Systems to Isolate Mechanism (C3A1)	Containment Isolation System Failure Location	Containment Isolation System Status		Containment Isolation Valves Status	
			Reactor Building Radiation	Radiation Monitoring System	
	Precansors				
	Drywell Atmosphere Activity	Fission Product Concentration		Fission Product Monitors	
	Reactor Vessel Integrity	Reactor Vessel Wall Temperature		Reactor Vessel Wall Thermocouples	

Table A-22. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Selection Criteria</u>				
Accident Venting Strategies	Status of Primary Containment Purge & Vent System	Status of Primary Containment Purge & Vent System		Status of Primary Containment Purge & Vent System	
	Primary Containment Radioactivity	Containment Fission Product Concentration		Fission Product Monitors	
	<u>Strategy Initiation</u>				
	Containment Vent Flow Rate	Vent System Flow Rate		Vent System Flow Meter	
	<u>Strategy Effectiveness</u>				
	Containment Pressure	Drywell Pressure		Drywell Pressure	

Table A-22. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Selection Criteria</u>				
Depressurize Vessel Strategies	Status of SRV/ ADS/ Bypass Valves/ RHR (Steam Condensing)/ Main Steam Line Drain/ HPCI Steam Line/ RCIC Steam Line/ Head Vent/ IC Tube Side Vent	Status of SRV/ ADS/ Bypass Valves/ RHR (Steam Condensing)/ Main Steam Line Drain/ HPCI Steam Line/ RCIC Steam Line/ Head Vent/ IC Tube Side Vent		Status of SRVS/ ADS/ Bypass Valves/ RHR (Steam Condensing)/ Main Steam Line Drain/ HPCI Steam Line/ RCIC Steam Line/ Head Vent/ IC Tube Side Vent	
	<u>Strategy Initiation</u>				
	Flow Rate to Release Vessel Pressure	System Flow Rate		System Flow Rate	
			Safety Relief Valve Positions	Safety Relief Valve Status	

Table A-22. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Strategy Effectiveness</u>				
	Radioactivity Released Outside Containment	Radiation Level Outside Containment		Radiation Monitors	
Reactor Building Fire Sprays Strategies	<u>Selection Criteria</u>				
	Reactor Building Pressure	Reactor Building Pressure		Reactor Building Pressure	
	Reactor Building Temperature	Reactor Building Temperature		Reactor Building Temperature	
	Reactor Building Radiation Level	Reactor Building Radiation Level		Reactor Building Radiation Level	
	<u>Strategy Initiation</u>				
	Fire Spray Flow Rate	Fire Spray Flow Rate		Fire Spray Flow Meter	
	<u>Strategy Effectiveness</u>				
	Reactor Building Radiation Level	Reactor Building Radiation Level		Reactor Building Radiation Level	

Table A-22. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Emergency Ventilation Strategies	<u>Selection Criteria</u>				
	Containment Radiation Level	Drywell Radiation Level		Drywell Radiation Monitor	
	Status of Standby Gas Treatment System (SBGT)	Status of SBGT System		Status of SBGT System	
	<u>Strategy Initiation</u>				
	SBGT System Flow Rate	SBGT System Flow Rate		SBGT System Flow Rate	
	<u>Strategy Effectiveness</u>				
	Containment Radiation Level	Drywell Radiation Level		Drywell Atmosphere Radiation Monitor	

Table A-22. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Manual Isolation Strategies	Selection Criteria				
	Location of Failure	Valve Position Indication		Valve Position Indication	
		Flow Rates		Flow Rates	
	Strategy Initiation				
	Flow Rates	Flow Rates		Flow Rates	
	Strategy Effectiveness				
	Area Radiation	Radiation Monitor		Radiation Monitor	

Table A-23. Maintain Containment Integrity (C) - Steam Line Isolation Failure Mechanism (C3A2)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Integrity Safety Function (C3)	Primary Containment Integrity	Containment Leak Location		None	
		Isolation Valves Status		Isolation Valves Status	
			Containment Pressure History	Drywell Pressure History	
			Radiation Level Outside Containment	Radiation Monitoring System	
			Reactor Building Temperature	Reactor Building RTD	
			Reactor Building Water Level	Sump and Floor Water Levels	
			Drywell Oxygen Content	Drywell Oxygen Meter	

Table A-23. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Indicators</u>				
Steam Line Isolation Failure Mechanism (C3A2)	Steam Flow from Containment and Steam Line Identification	MSIV Position		MISIV Status	
			Radiation Level in Turbine Building	Radiation Monitor	
		Main Steam Line Steam Flow		Main Steam Line Steam Flow	
			RX Building Temperature (a)	Reactor Building RTD	
			Turbine Building Temperature (a)	Steam Tunnel Temperature	
		RICI Turbine Steam Line Flow (a)		Steam Line Flow Indication	
		HPCI Turbine Steam Line Flow (a)		Steam Line Flow Indication	
Emergency Depressurize Strategies	See Table 3.5 "Depressurize Vessel Strategies"				

a. Would require a Steam Line Break to cause a Radiation Problem.

Table A-23. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Selection Criteria				
Terminate Steam Flow Strategies	Status of Main Steam Stop Valves	Status of Main Steam Stop Valves		MSV Position Lights	
	Strategy Initiation				
	Main Steam Line Flow Rate	Main Steam Line Flow Rate		Main Steam Line Flow Meter	
	Strategy Effectiveness				
	Turbine Building Radioactivity	Turbine Building Atmosphere Radiation		Atmosphere Monitoring System	

Table A-24. Maintain Containment Integrity (C) - ISLOCA (C3B1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Integrity Safety Function	Primary Containment Integrity	Containment Leak Location		None	
		Isolation Valves Status		Isolation Valves Status	
			Containment Pressure History	Drywell Pressure History	
			Radiation Level Outside Containment	Radiation Monitoring System	
			Reactor Building Temperature	Reactor Building RTD	
			Reactor Building Water Level	Sump and Floor Water Levels	
			Drywell Oxygen Content	Drywell Oxygen Meter	

Table A-24. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Indicators</u>				
ISLOCA Mechanism (C3B1)	Interfacing Systems Pipe Rupture Location	None		None	
			Check Valve Status	Check Valve Indications	
			Local Area Temperature	Leak Detection System RTD	
			Interfacing System Pressure	Interfacing System Pressure	
			Local Radiation Levels	Radiation Monitoring System	
			Reactor Building Sump Level	Reactor Building Sump Levels	
Emergency Depressurize Strategies	See Table A-22.	"Depressurize Vessel Strategies"			
Fire Sprays Strategies	See Table A-22.	"Reactor Building Fire Sprays"			

Table A-24. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Selection Criteria				
Secondary Containment Ventilation System Strategies	Status of Reactor Building HVAC System	Status of Reactor Building HVAC System		Status of Reactor Building HVAC System	
	Strategy Initiation				
	Reactor Building HVAC System Flow	Reactor Building HVAC System Flow		Reactor Building HVAC System Flow	
	Strategy Effectiveness				
	Reactor Building Radioactivity	Reactor Building Air Borne Radiation		Atmosphere Monitoring System	

Table A-25. Maintain Containment Integrity (C) - Hydrogen Detonation Missiles Mechanism (C3C1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Maintain Integrity Safety Function (C3)	Primary Containment Integrity	Containment Leak Location		None	
		Isolation Valves Status		Isolation Valves Status	
			Containment Pressure History	Drywell Pressure History	
			Radiation Level Outside Containment	Radiation Monitoring System	
			Reactor Building Temperature	Reactor Building RTD	
			Reactor Building Water Level	Sump and Floor Water Levels	
			Drywell Oxygen Content	Drywell Oxygen Meter	

Table A-25. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	Indicators				
Hydrogen Detonation Missiles Mechanism (C3C1)	Penetration of Containment by a Missile	Containment Visual Obsevation		None (Visual)	
			Containment Pressure	Containment Pressure	
	Precursors				
	Increasing Hydrogen Concentration	Containment Hydrogen Containment		Hydrogen Monitoring System	
	Core Damage Status	None		None	
			RCS Coolant Activity	Post Accident Sampling System	

Table A-25. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Add Barriers Strategies	<u>Selection Criteria</u>				
	None- Passive System				
	<u>Strategy Initiation</u>				
	None- Passive System				
	<u>Strategy Effectiveness</u>				
	Primary Containment Integrity	None		None	
			Second Containment Area Radiation	Radiation Monitoring System	

Table A-25. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Selection Criteria</u>				
Prevent Hydrogen Detonation Strategies	Containment Hydrogen Concentration	Containment Hydrogen Concentration		Hydrogen Monitoring System	
	Status of Nitrogen Inerting System			Nitrogen Inerting System Status	
	<u>Strategy Initiation</u>				
	Nitrogen Injection Rate		Nitrogen System Pressure	Nitrogen System Pressure	
	<u>Strategy Effectiveness</u>				
	Containment Hydrogen Concentration	Containment Hydrogen Concentration		Hydrogen Monitoring System	

Table A-26. Mitigate Fission Product Release from Containment (F) - Aerosol Dispersion Mechanism (F1A)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instrument	Potential Instrument
Control Fission Products in Primary Containment Safety Function (F1)	Presence of Fission Products in Containment Atmosphere	None		None	
			Containment Radiation Level	Radiation Monitoring System	
				Noble Gas Monitor	
	Indicators				
Aerosol Dispersion Mechanism (F1A1)	Presence of Aerosols in Containment Atmosphere	Fission Product Particulate Monitor		Noble Gas Monitor	
			Containment Radiation Level	Radiation Monitoring System	
	Precursors				
	Core Damage Status	None		None	
			Coolant Activity	Reactor Sampling System	

Table A-26. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Sprays Strategies	See Table A-12.	"Suppression Pool or Drywell Sprays Strategies"			

Table A-26. (Continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Selection Criteria</u>				
Suppression Pool Vent Via Standby Gas Treatment System (SBGT)	Suppression Pool Atmosphere Radioactivity	Radiation Level		Radiation Monitor	
	Status of Purge & Vent System	Status of Purge & Vent System		Status of Standby Gas Treatment System (SBGT)	
	<u>Strategy Initiation</u>				
	SBGT from Suppression Pool Flow Rate	SBGT from Suppression Pool Flow Rate		SBGT from Suppression Pool Flow Meter	
	<u>Strategy Initiation</u>				
	Drywell Atmosphere Radioactivity	Radiation Level		Radiation Monitor	

Table A-27. Mitigate Fission Release From Containment (F) - Gaseous Dispersion Mechanism (F1A2)

	Information Needs	Direct Information Needs	Indirect Information Needs	Available Instruments	Potential Instruments
Control Fission Products in Primary Containment Safety Function (F1)	Presence of Fission Products in Containment Atmosphere	None		None	
			Containment Radiation Level	Radiation Monitoring System	
				Noble Gas Monitor	
	Indicators				
Gaseous Dispersion Mechanism (F1A2)	Presence of Fission Product Gases in Containment Atmosphere	None		None	
			Noble Gas Concentration	Noble Gas Monitor	
			Containment Radiation Level	Radiation Monitoring System	
	Precursors				
	Core Damage Status	None		None	
			RCS Coolant Activity	PASS Sampling System	

Table A-27. (continued)

	Information Needs	Direct Information Needs	Indirect Information Needs	Available Instruments	Potential Instruments
Chemical Reaction Strategies	Selection Criteria				
	Concentration of Gaseous Fission Products	None		None	
			Containment Radiation Level	Radiation Monitoring System	
	Strategy Initiation				
	Amount of Chemical Adding into Containment	Tank Level		Tank Level	
	Strategy Initiation				
	Fission Product Level in Containment	Fission Product Monitor		Nobel Gas Monitor	

Table A-27. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Cryogenic Systems Strategies	<u>Selection Criteria</u>				
	Nobel Gases in Containment	Noble Gas Concentration		Noble Gas Monitors	
	<u>Strategy Initiation</u>				
	Cryogenic System Status	Cryogenic System Status		Cryogenic System Status	
	<u>Strategy Effectiveness</u>				
	Reduction of Noble Gas Level	Noble Gas Contents		Noble Gas Monitors	
Sprays Strategies	See Table A-12. "Suppression Pool or Drywell Sprays Strategies"				

Table A-28. Mitigate Fission Product Release From Containment (F) - Leak from Primary Mechanism (F2A1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Control Fission Products in Secondary Containment Safety Function (F2)	Presence of Fission Products in Secondary Containment	RX Building Sump Water Chemistry		Sump Water Sampling	
		RX Building Radiation Level		Radiation Monitoring System	
	<u>Precursors</u>				
	Loss of Primary Containment Integrity	See Table A-10. "Maintain Pressure Control Safety Function"			
	<u>Indicators</u>				
Leak from Primary Mechanism (F2A1)	See Table A-29, A4.3 "Control Fission Products in Secondary Containment Safety Function"				

Table A-28. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Standby Gas Treatment System Strategies	<u>Selection Criteria</u>				
	Status of Standby Gas Treatment System (SBGT)	Status of SBGT System		Status of SBGT System	
	<u>Strategy Initiation</u>				
	SBGT Flow rate	SBGT Flow Rate		SBGT Flow Meter	
	<u>Strategy Effectiveness</u>				
	Secondary Containment Fission Product Level	Reactor Building Radiation Level		Radiation Monitoring System	

Table A-28. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Fire Sprays Strategies	See Table A-22. "Reactor Building Fire Sprays Strategies"				

Table A-29. Mitigate Fission Product Release From Containment (F) - PH Too Low Mechanism (F3A1)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Control Fission Products in Water Safety Function (F3)	Presence of Fission Products in Containment Water	Suppression Pool Water Fission Products Content		Suppression Pool Water Sampling	
	Indicators				
PH Too Low Mechanism (F3A1)	PH Level in Suppression Pool	Suppression Pool Water PH Level		Suppression Pool Water Sampling	
	Precursors				
	Core Damage	None		None	
			Reactor Coolant Activity	Sampling System	

Table A-29. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Add Base Strategies	<u>Selection Criteria</u>				
	Amount of Containment Water	Suppression Pool Water Level		Suppression Pool Water Indicator	
			Drywell vs. Suppression Pool Pressure	Drywell Pressure Indicator Suppression Chamber Pressure Indicator	
	<u>Strategy Initiation</u>				
	Flow of Basic Solution	Flow in system Adding Basic Solution		Flow Meter	
	<u>Strategy Effectiveness</u>				
	Containment Water PH Level	Suppression Pool Water PH Level		Suppression Pool Water Sampling	

Table A-29. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Dilution Strategies	<u>Selection Criteria</u>				
	Availability of Dilution Water	Dilution System Tank Level		Tank Level	
	Amount of Water Contaminated	Suppression Pool Water Level		Suppression Pool Water Level	
	<u>Strategy Initiation</u>				
	Flow of Water to Containment	Injection Pump Flow		Flow Meter	
	<u>Strategy Effectiveness</u>				
	Containment Water PH Level	Suppression Pool Water PH Level		Suppression Pool Water Sampling	

Table A-30. Prevent Fission Product Release From Containment (F) - Radiolysis Mechanism (F3A2)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Control Fission Products in Water Safety Function (F3)	Presence of Fission Products in Containment Water	Suppression Pool Water Fission Products Content		Suppression Pool Water Sampling	
	<u>Indicators</u>				
Radiolysis Mechanism (F3A2)	Presence of Radiolytic Products	None		None	
			Containment Atmosphere Radioacti-vity	Radiation Monitor	
	<u>Precursors</u>				
	Core Damage Status	None		None	
			Reactor Coolant Activity	Sampling System	

Table A-30. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Dilution Strategies	Selection Criteria				
	Amount of Radiolytic Products in Water	Suppression Pool Water Sampling		Suppression Pool Water Sampling	
	Availability of Dilution Water	Dilution System Tank Inventory		Tank Level Indicators	
	Strategy Initiation				
	Flow of Water to Damaged Core	Injection Pump Flow		Flow Indicator	
	Strategy Effectiveness				
	Amount of Radiolytic Products in Water	Suppression Pool Water Sampling		Suppression Pool Water Sampling	

Table A-31. Mitigate Fission Product Release From Containment (F) - High Water Temperatures Mechanism (F3A3)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Control Fission Products in Water Safety Function (F3)	Presence of Fission Products in Containment Water	Suppression Pool Water Fission Products Content		Suppression Pool Water Sampling	
	<u>Indicators</u>				
High Water Temperature Mechanism (F3A3)	Sump Water Temperature	Drywell Sump Water Temperature		Floor Drain Sump Water Temperature	
				Equipment Drain Sump Water Temperature	
		Suppression Pool Water Temperature		Suppression Pool Thermocouple	
	<u>Precursors</u>				
	Inadequate Heat Removal from Suppression Pool Water	None		None	
			Suppression Pool Water Temperature	Suppression Pool Water Temperature	

Table A-31. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
Alternate Cooling Systems Strategies	<u>Selection Criteria</u>				
	Status of Drywell Coolers	Status of Drywell Coolers		Drywell Cooler Air Temperature	
	Status of Drywell Sump Coolers	Drywell Sump Coolers Status		Drywell Sump Coolers Status	
	<u>Strategy Initiation</u>				
	System Flow Rate	System Flow Rate		System Flow Meter	
	<u>Strategy Effectiveness</u>				
	Containment Water Temperature	Drywell Sump Water Temperature		Sump Water RTD	
		Suppression Pool Water Temperature		Suppression Pool Water RTD	

Table A-31. (continued)

	Information Needs	Direct Information Source	Indirect Information Source	Available Instruments	Potential Instruments
	<u>Selection Criteria</u>				
Add Cooler Water Strategies	Status of Radwaste System	Status of Radwaste System		Status of Radwaste System	
	Available Water Sources Injecting to Containment	Tank Inventory		Tank Level	
	<u>Strategy Initiation</u>				
	Feed & Bleed Rate	System Flow Rate		System Flow Meters	
	<u>Strategy Effectiveness</u>				
	Containment Water Temperature	Drywell Sump Water Temperature		Drywell Sump Water RTD	
		Suppression Pool Water Temperature		Suppression Pool Water RTD	

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In support of the U. S. Nuclear Regulatory Commission Accident Management Research Program, information needs during severe accidents have been evaluated for Boiling Water Reactors (BWRs) with MARK I containments. This evaluation was performed using a methodology that identifies plant information needs necessary for personnel to: (a) diagnose that an accident is in progress, (b) select and implement strategies to prevent or mitigate the accident, and (c) monitor the effectiveness of these strategies. The information needs and capabilities identified are intended to form a basis for more comprehensive information needs assessments. These assessments will be performed during the analysis and development of specific strategies, which will be used in accident management prevention and mitigation.

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