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Assessment of Candidate Accident Management Strategies

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ABSTRACT

A set of candidate accident management strategies, whose purpose is to prevent or mitigate in-vessel core damage, were identified from various NRC and industry reports. These strategies have been grouped in this report by the challenges they are intended to meet, and assessed to provide information which may be useful to individual licensees for consideration when they perform their Individual Plant Examinations. Each assessment focused on describing and explaining the strategy, considering its relationship to existing requirements and practices as well as identifying possible associated adverse effects.

EXECUTIVE SUMMARY

Recognizing the risk reduction potential associated with accident management, the NRC has initiated an accident management program aimed at promoting the most effective use of available utility resources to prevent and mitigate severe accidents. This report contains an assessment of selected candidate accident management strategies developed from information obtained from the NUREG-1150 analysis, NUREG/CR-4920, NUREG/CR-5132, other PRAs, and industry reports and articles pertinent to accident management. The strategies were grouped according to the challenges they are intended to meet. Some of the strategies reported on apply to BWRs or PWRs only, others apply to both types of plants. The strategies described herein focus primarily on preventing or mitigating in-vessel core damage. Strategies aimed at preventing containment failure and/or mitigating the release of fission products to the environment are the subject of ongoing research and will be reported on in the future.

The assessment focused on describing and explaining each strategy, determining its relationship to existing requirements and practices as well as identifying possible associated adverse effects. The reactor vendor developed generic emergency procedure guidelines and the emergency operating procedures of several plants were examined to determine the extent to which these strategies may already be implemented in light of existing regulation and NRC/industry activities.

This report provides licensees with a more complete description of selected accident management strategies as well as information that might be useful to the licensees in assessing the feasibility of the strategies for their plants. The set of strategies discussed in this report is not meant to be complete or exhaustive. It is anticipated that other strategies important to the prevention or mitigation of core damage may be identified by the licensees through the conduct of their Individual Plant Examinations.

While all of the candidate strategies assessed in this report are believed to offer some benefit in terms of either prevention or mitigation of core damage accidents, some go beyond the traditional thinking which established the licensing design basis, and fall into the category of "last resort" measures. It should be kept in mind that there is no recommendation made herein for changes to the current safety practices.

It is intended that the implementation of the strategies discussed herein serve to strengthen the defense-in-depth against severe accidents by possibly extending the existing emergency operating procedures beyond design basis situations without compromising plant safety. Hence, in reviewing these strategies for applicability to their plants, licensees should give careful consideration to the possible adverse affects.

TABLE OF CONTENTS

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1. INTRODUCTION

1.1 Background

The concept of defense-in-depth, the high standards used for the design and construction of nuclear power plants, and the training of the operating staff all contribute to the low risk associated with nuclear power plants. Nevertheless, experience obtained from the NUREG-1150[1] analysis, as well as other PRA analyses, has shown that changes in plant operating procedures and/or relatively minor hardware modifications can reduce severe accident risk even further. This can often be accomplished by innovative use of existing plant equipment and has the added advantage of being cost effective when compared to risk reduction achieved as a result of major hardware addition to or modification of plant systems. Accident management measures in the form of incremental improvements which extend existing Emergency Operating Procedures (EOPs) somewhat further into severe accident regimes and make the most effective use of available utility resources can offer the potential for such a risk reduction.

The set of generic accident management strategies listed in Table 1 was identified and grouped from information obtained from the NUREG-1150 analysis, NUREG/CR-4920,[2] NUREG/CR-5132[3] and other PRAs.

NUREG-1150, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants" (Second Draft), documents a current assessment of the severe accident risks of different plant designs. The report provides summaries of the risk analysis results of the studied plants and perspectives on these results.

NUREG/CR-4920, Volumes 1 through 5, "Assessment of Severe Accident Prevention and Mitigation Features," identifies plant features and operator actions which were found to be important in either preventing or mitigating severe accidents. These features and actions were developed from insights derived from reviews of risk assessments performed on particular reference plants illustrative of the five different containment designs used in U.S. plants.

NUREG/CR-5132, "Severe Accident Insights Report," describes the conditions and events that nuclear power plant personnel may encounter during the latter stages of a severe core damage accident and what the effects and consequences might be due to actions they may take during these latter stages. The report also describes what can be expected of the performance of the key barriers to fission product release (primarily containment systems), what decisions the operating staff may face during the course of a severe accident, and what could result from these decisions based on the current state of knowledge of severe accident phenomena.

1.2 Objective/Scope

This report is intended to provide licensees with an assessment of a set of candidate accident management strategies as well as information that might be useful to the licensees in evaluating the feasibility of the implementation of one or more strategies for their plants. The relationship with existing requirements and practices as well as possible adverse effects associated with the strategy use are also identified. While the applicability of each strategy is likely to be plant specific, these strategies could be useful to utilities in their consideration of developing a capability to respond to accidents.

Appropriate sections of the reactor vendor developed generic emergency procedure guidelines[4-7] and EOPs from a number of plants were used to examine the extent to which these strategies may already be in place as a result of existing regulation and NRC/industry activities. These plants are Calvert Cliffs, Grand Gulf, LaSalle, Limerick, Oconee, Peach Bottom, Seabrook, Sequoyah, Surry, Susquehanna, Trojan and Zion. While many of these strategies are implemented in existing EOPs and other plant-specific operating procedures and instructions, the degree to which this is done varies widely across the industry. Therefore, this report provides generic information that may be useful for enhancing some procedures in order to take advantage of existing backup systems and components which could be made available during certain accidents.

This document does not include information on the risk reduction that might be achieved with implementation of individual strategies assessed herein since the actual risk reduction potential of a given strategy is highly plant specific. Examples of quantitative plant specific risk reductions can be found in such references as NUREG/CR-5263,[8] "The Risk Management Implications of NUREG-1150 Methods and Results," and Supplement No. 4 to NUREG-0979,[9] the GESSAR II Safety Evaluation Report. This information may be helpful in evaluating the potential implementation of one or more of these strategies.

An essential part of each strategy considered by the licensee should be an evaluation of how a strategy may affect plant equipment and operators during both normal and accident conditions. Included in this evaluation process, may be the following examples of operational implementation considerations across various accident conditions:

- Hardware considerations:
  - anticipated accident conditions which would influence equipment operability:
    - pressure,
    - temperature, and
    - radioactivity levels.
  - actual capabilities of existing hardware which might be used to backup failed safety systems:
    - water supply, (e.g., available tank, sump, pool inventory),
    - flow rates of alternate piping configurations to supply coolant, and
    - water quality (e.g., borated versus unborated, raw versus treated).
- Operator considerations (human factors):
  - added burden placed on operators and other plant staff,
  - adequacy of existing instrumentation,
  - need to bypass or change trip setpoints, and
  - habitability of areas which need to be accessed.

While all of the candidate strategies assessed in this report are believed to offer some benefit in terms of either prevention or mitigation of severe core damage accidents, some go beyond the traditional thinking which established the licensing design basis, and fall into the category of "last resort" measures.

It must be kept in mind that there is no recommendation made here for changes to the current safety practices. It is the intent that the implementation of the strategies discussed herein should serve to strengthen the defense-in-depth against severe accidents by possibly extending the existing EOPs beyond design basis situations without compromising plant safety.

It should also be noted in considering these strategies that there are some possible adverse effects associated with most, if not all, of them. Examples are the additional burden on operators and the possible drawbacks arising from the use of non-safety grade equipment on safety-related systems. Some of these adverse effects may be minimized by taking sufficient preparatory measures for certain strategies in the form of preparing cables, adaptors, jumpers, spool pieces, developing procedures for their use and training using the procedures. Some licensees may even want to train selected operating personnel and/or shift supervisors to deal with severe accident situations. The most successful accident management program would be one which makes maximum use of the existing human and hardware resources at the plant to maximize the effectiveness of accident prevention and mitigation while at the same time keeping costs and adverse effects to a minimum.

The strategies listed in Table 1 were rearranged and combined into twenty candidate strategies grouped by safety objectives and challenges they are intended to meet such as insufficient coolant, loss of power and loss of heat sink as shown in Figure 1. This arrangement is helpful for recognizing possible relationships among the strategies. Some strategies apply to Boiling Water Reactors (BWRs) or Pressurized Water Reactors (PWRs) only, others apply to both types of plants. The strategies described focus primarily on preventing or mitigating in-vessel core damage. Strategies aimed at preventing containment failure and/or mitigating the release of fission products to the environment will be addressed as part of ongoing NRC research and completed assessments of such strategies will be documented as appropriate.

The logic of Figure 1 should be helpful to utilities undertaking a systematic assessment of their accident management capabilities. An attempt has been made in each section to group the strategies in the order in which it is felt that the plant staff would most likely implement them, starting with conservation or improvement of normally used supplies or systems and ending with attempts to use alternate sources or systems. This is only a general grouping and the actual order of implementation would be accident scenario and plant dependent. Many of the strategies will be more effective when used together with one or more of the other strategies, and under certain conditions might only be applied when another strategy is also implemented. All of the strategies are meant to preserve the two safety objectives of maintaining core cooling, and reactivity control. Threats to these safety objectives are grouped into challenges, and these challenges are addressed by the accident management strategies. The safety objective of maintaining core cooling can be challenged by insufficient cooling, unavailable injection systems, power loss, and/or heat sink loss. The other safety objective of reactivity control can be challenged by the failure of the reactor to shut down or by a core damage accident that results in recriticality.

It is also important to realize that the set of strategies discussed in this report is not meant to be complete or exhaustive. Other strategies important to the prevention or mitigation of core damage may be identified by licensees through the conduct of their Individual Plant Examinations (IPEs) or during the course of their own accident management assessment.

1.3 Relationship to Individual Plant Examinations

Generic Letter (GL) 88-20 issued by the NRC staff for the IPEs emphasized the importance of accident management. The strategies discussed in this report are presented as information which may be useful to individual licensees when they perform their IPEs. These strategies may aid the nuclear industry in taking cost effective, useful steps to further reduce risk from severe accidents by maximizing the use of existing resources. The strategies can be considered as an adjunct to the ones which may be identified through the IPE.

1.4 Organization of Report

Figure 1 shows the logic structure of the strategies and gives an overview of the organization of the rest of the report. The remaining sections describe the strategies in the order as indicated in the figure. Section 2 discusses strategies that deal with the challenge of insufficient coolant, Section 3 contains strategies which are concerned with the unavailability of injection systems, Section 4 addresses power loss strategies, and Section 5 assesses one strategy related to heat sink loss. The strategies contained in Section 6 are meant to meet the challenge of reactor shutdown failure.

Table 1 Generic Accident Management Strategies

I. Conserving and Replenishing Limited Resources

- Refill refueling water storage tank (RWST) with borated water, or condensate storage tank (CST) with condensate. Assure adequate supply of boron on site.
- Maintain emergency core cooling system (ECCS) suction to condensate systems to avoid pump failure due to high suppression pool temperature.
- Throttling containment sprays to conserve water for core injection.
- Conserve battery capacity by shedding non-essential loads.
- Use of portable battery chargers or other power sources to recharge batteries.
- Enable emergency replenishment of gas supply, or otherwise ensure operability of air operated components.
- Enable early detection, isolation, or otherwise mitigate the effects of an interfacing systems loss of coolant accident (LOCA).

II. Use of Systems/Components In Innovative Applications

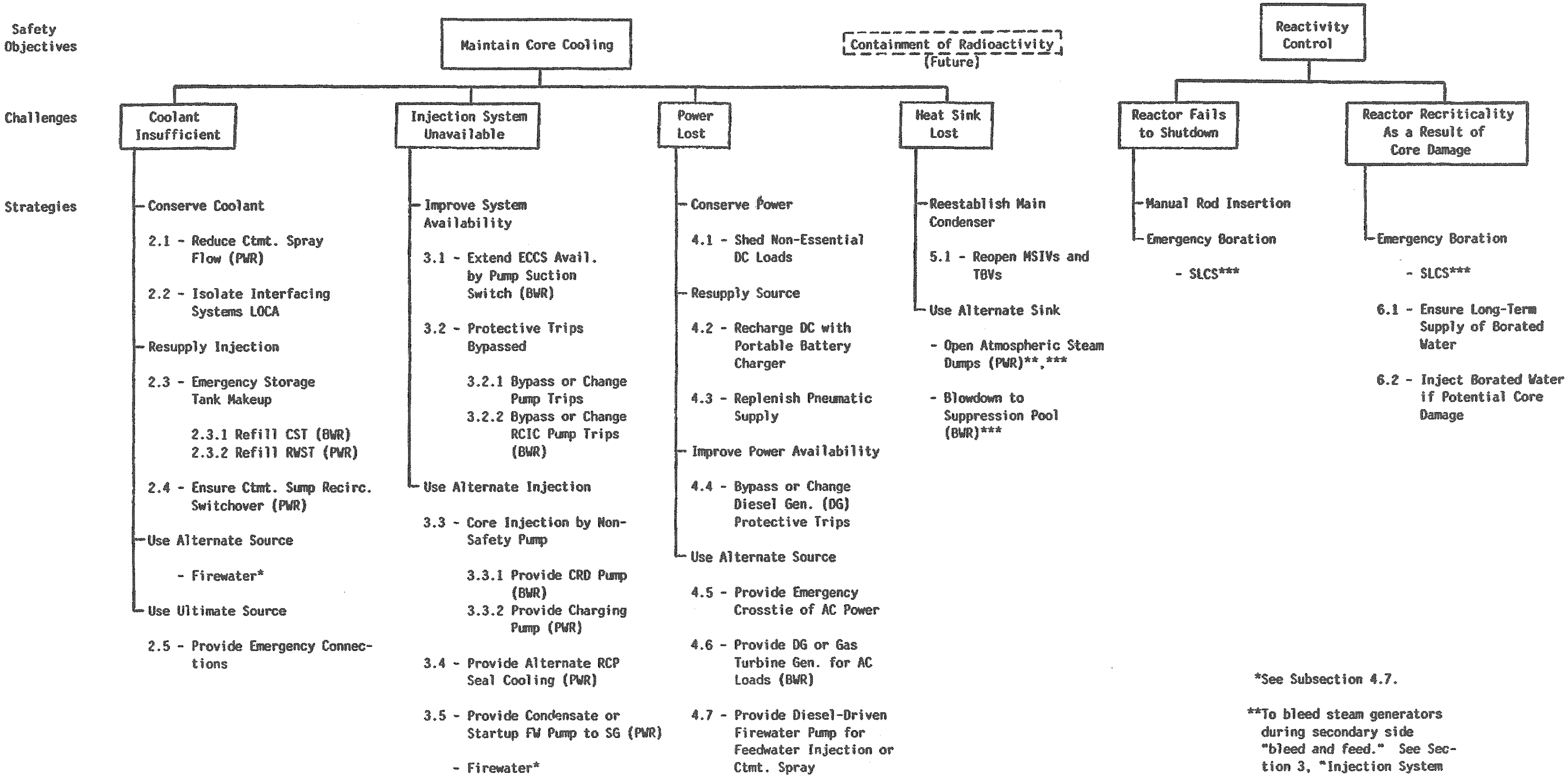
- Strategies to enable emergency use of available pumps to accomplish safety functions.
    - Use of diesel fire systems for injection to the containment sprays, a BWR core, or the PWR steam generators (SGs).
    - Use of control rod drive (CRD) pumps in BWRs or charging pumps in PWRs for core injection.
    - Use of alternate injection (e.g., hydro test pump) when reactor coolant pump (RCP) seal cooling is lost (seal failure concern).
    - Enable emergency crosstie of service water and closed (component) cooling water (CCW) to residual heat removal (RHR) in BWRs or feedwater in PWRs.
    - Use of condensate, or startup pumps for feedwater injection.

Table 1 (Cont'd)

- Strategies (and hardware) to enable emergency connection of available AC power sources to meet critical safety needs.
  - Use of diesel generator or gas turbine generator to drive CRD pumps for core injection.
  - Enable emergency crosstie of AC power between two units or to onsite gas turbine generator.
- Strategies to enable emergency connection of injection systems to alternate water sources.
  - Ensure appropriate recirculation switchover and cope with the failure to switch over in LOCA.
  - Enable emergency connection of service water or feedwater systems to rivers, reservoirs or municipal water systems.
- Strategies for Reactivity Control.
  - Initiate standby liquid control system (SLCS) in case of potential core damage and guard against boron dilution when core injection is restored.
  - Ensure abundant supply of borated makeup for long-term accident control.

III. Defeating Interlocks and Component Protective Trips in Emergencies.

- Reopen main steam isolation valves (MSIVs) and turbine bypass valves to regain the condenser as a heat sink.
- Extend reactor core isolation cooling (RCIC) availability by either raising the turbine exhaust pressure trip set point, or overriding the trip function.
- Enable emergency bypass of protective trips for diesel generators and injection pumps.



*See Subsection 4.7.

**To bleed steam generators during secondary side "bleed and feed." See Section 3, "Injection System Unavailable" for various feed alternatives.

***Not an Assessed Strategy.

Figure 1 Logic structure of accident management strategies.

2. STRATEGIES RELATED TO INSUFFICIENT COOLANT

2.1 Strategy to Reduce Containment Spray Flow Rate to Conserve Water for Core Injection (PWR)

Strategy Description

The aim of this strategy is to conserve refueling water storage tank (RWST) inventory to extend core injection, if emergency coolant sump recirculation is not available, by reducing containment spray (CS) flow rates. This strategy can be accomplished by one or more of the following: throttling the CS discharge valves, securing one or more totally redundant spray trains, and/or recirculating a portion of the discharge flow back to the RWST (via a test line). Another strategy which might be considered to be used as a means to conserve RWST inventory is included in Subsection 2.3.2, "Strategy to Refill Refueling Water Storage Tank With Borated Water."

The purpose of the CS system is to maintain containment pressure and temperature below their design values during accidents. In most PWRs, this is done with several redundant spray trains, each with its own pump, valves and headers. Upon automatic initiation on high containment pressure, the CS pumps take suction from the RWST and pump on the order of several thousand gallons per minute into the spray headers. If a low RWST level is reached (together with high containment sump level in a few plants), emergency coolant recirculation is initiated. In several plants examined if long-term CS is required the residual heat removal (RHR) pumps can be used to divert a portion of the coolant being recirculated to supply several spray headers with suction from the containment sump through the RHR heat exchangers. A CS pump test line is available in most plants allowing a CS pump to take suction from and discharge back to the RWST.

The large RWST drawdown rates associated with full flow CS operation may make a reduction of CS flow desirable in certain accidents. In particular, this strategy applies to those LOCA sequences where containment pressure is high enough to initiate CS but not sufficient to require the operation of all redundant CS trains.

Other related strategies include Subsections 2.2, "Strategy to Enable Early Detection, Isolation or Otherwise Mitigate the Effects of an Interfacing Systems LOCA," 2.4, "Strategy to Ensure Appropriate Recirculation Switchover and Manual Intervention Upon Failure of Automatic Switchover," and 6.1, "Strategy to Provide Additional Supply of Borated Makeup for Long-Term Accident Control."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic PWR vendors and the Emergency Operating Procedures (EOPs) of many PWRs were examined to determine the extent to which this strategy has been implemented. The use of a strategy to limit CS flow rates was found in many of the plant EOPs examined. In most cases this was accomplished by manually starting and stopping one or more CS pumps while using containment pressure as a guide. In some EOPs the maximum use of available containment fan coolers was also specified to reduce CS requirements. In one plant examined, the ability to achieve multiple flow rates in the CS trains was indicated. The actual procedural steps for accomplishing this were not given.

While none of the EOPs were found which addressed the recirculation of a portion of the CS pump discharge back to the RWST, the ability to accomplish this may exist in some plants, via an existing pump flow test line. The ability and desirability to run reduced flows through the CS test line is plant and accident specific and would need to be examined individually for each plant.

Possible Adverse Effects

Reduced CS flow rates could result in higher containment pressures and temperatures due to reduced spray coverage and spray droplet atomization at lower spray header pressures. If the accident has reached the fuel damage stage there would also be less scrubbing of fission product aerosols from the containment atmosphere with reduced sprays. The operators would have to monitor the pressure and increase CS flow, if necessary.

The ability to reduce CS flow rates effectively by valve throttling appears limited in most plants that have gate valves rather than globe valves. Also, the ability to reduce CS flow rates by pump stoppage may introduce the possibility of restart failure.

2.2 Strategy to Enable Early Detection, Isolation, or Otherwise Mitigate the Effects of an Interfacing Systems LOCA (BWR and PWR)

Strategy Description

The aim of this strategy is to limit the effects of an interfacing systems LOCA (ISL) by early detection and isolation or if isolation is unsuccessful, with additional actions to mitigate the consequences. An ISL involves the loss of isolation between high and low pressure interfacing systems, and overpressurization of the low pressure system. The resultant breach of the low pressure system outside of containment results in a LOCA which bypasses the containment. Early detection and recognition of such an event is an important first step for achieving possible mitigation, if not isolation, of the ISL. Isolation of the failure may be possible and would halt the progress of this kind of accident. If isolation cannot be achieved, various other actions may be of use in mitigating the effects of an ISL.

The primary indicators of an ISL would be abnormal pressure, temperature and radiation measurements in different areas outside of containment. Where available, the correlation of information from valve position indicators and line flow rates, pressures, and temperatures could also aid in the identification of an ISL. Decreasing inventory levels of the reactor coolant system or the refueling water storage tank (RWST) along with a lack of corresponding increase in containment sump level are other possible indicators of an ISL in a PWR. In a BWR, the reactor coolant inventory and pressure along with condensate storage tank (CST) and suppression pool levels would be important indicators.

The isolation of some ISLs may be possible because a number of valves exist in many lines which can be closed to compensate for the break. However, in order to isolate an ISL, the operators must be able to pinpoint its location.

Therefore, isolation will depend in some measure on plant instrumentation, e.g., pressure indication and alarms in key lines, and on the operator's ability to accurately detect the break location. Additional training may improve the operator's ability to detect and isolate an ISL.

In some cases where isolation has failed, mitigation of the effects of an ISL may be possible by manual actions which might be proceduralized or described in guidance called out by the EOPs, e.g., flooding the location of the break in the low pressure system. The submergence of the break will provide some scrubbing of fission products and mitigate releases to the environment. The use of sprays can also help reduce the concentration of fission product aerosols; existing spray systems in the auxiliary building (i.e., fire sprays) are possibilities. The depressurization of the reactor vessel may also mitigate the effects of an ISL by reducing the mass flow rates out of the break. In some cases, the judicious use of available pumps to manage the drawdown rate from the RWST or CST could be appropriate in delaying the onset of core uncovery and damage. See the related strategies listed below.

The NRC has a related ongoing program that will investigate in detail the issue of ISL. More insight on this issue should result from the completion of this program.

Other related strategies include Subsections 2.1, "Strategy to Reduce Containment Spray Flow Rate to Conserve Water for Core Injection," 2.3.1, "Strategy to Refill Condensate Storage Tank," 2.3.2, "Strategy to Refill Refueling Water Storage Tank With Borated Water," 3.3.1, "Strategy to Use Control Rod Drive Pumps for Core Injection," 3.3.2, "Strategy to Use Non-Safety Related Charging Pumps for Core Injection," and 4.7, "Strategy to Use Diesel-Driven Firewater Pump for BWR Core Injection, PWR Steam Generator Injection or Containment Sprays."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors and Emergency Operating Procedures (EOPs) of several plants were found to have some procedures which addressed ISLs. These procedures include steps which typically check the major containment isolation valves in a systematic manner by opening and closing (cycling) each valve individually while monitoring for a reactor coolant system pressure increase. All of the EOPs reviewed for PWR plants were found to address accidents involving steam generator tube rupture (SGTR), a specific ISL that is often addressed as a separate issue.

Possible Adverse Effects

Attempts to isolate an ISL can lead to an aggravation of the accident if the wrong valves are operated/cycled or vital systems shutdown in an attempt to contain the leakage. In particular, the cycling of valves to diagnose and locate an ISL which then fail to close (or reclose) may add to the leakage.

Mitigative actions such as flooding the break location or using auxiliary building sprays may impact the performance of other systems located in that environment, e.g., shorting of electrical systems, etc.

2.3 Makeup to Emergency Storage Tank

2.3.1 Strategy to Refill Condensate Storage Tank (BWR)

Strategy Description

The aim of this strategy is to supply additional water to the condensate storage tank (CST) to help avoid or at least delay depletion of the tank. This strategy would augment the CST water capacity and therefore reduce the risk of core damage in events such as extended station blackouts or LOCAs involving failures which render the suppression pool (SP) unavailable as a supply for reactor injection. This strategy is accomplished by refilling the tank with treated water from other onsite sources. In the event that sources of treated water are not available, other sources could be considered. Replenishing CST water may be accomplished by normal plant operating pumping systems, by gravity drain, by manual operation, or by using pumping systems independent of station AC or DC power supplies. Possible treated water sources might be: the demineralized water storage tank, main condenser hotwell, or the fuel pool. In plants with multiple units where cross connections exist, treated water could be drawn from storage tanks maintained for the second unit. Possible untreated sources might be: the plant firewater system, a community fire pumper truck, or a municipal water supply.

By design, turbine-driven high pressure core injection/spray (HPCI/HPCS) or reactor core isolation cooling (RCIC) pumps supply CST water to the reactor vessel injection systems in the event of loss of normal high pressure cooling water sources (e.g., main feedwater). In a station blackout or certain LOCAs, high pressure injection into the core could be maintained for long periods of time by replenishing the water in the CST. In some plants, the HPCI and RCIC systems might be manually operated under acceptable radiation levels thus allowing high pressure injection to be maintained in those cases after the loss of station AC power. These turbine-driven pumps can maintain rated flow at very low vessel operating pressures.

Other related strategies include Subsections 3.3.1, "Strategy to Use Control Rod Drive Pumps for Core Injection," and 4.7, "Strategy to Use Diesel-Driven Firewater Pump for BWR Core Injection, PWR Steam Generator Injection or Containment Sprays."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR vendor and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. The ability to provide CST makeup during an accident was found in the EOPs of several plants. In several of these instances, makeup is provided via a cross-connect to another unit on site.

Possible Adverse Effects

Using any firewater pumping system could impact the ability of the firewater system to respond to a fire. The use of a plant firewater system may also limit its capability to be used to control radionuclides that may be released into reactor buildings during the late stages of a severe accident.

The use of any untreated water source has a certain potential for plugging the injection pathways to the reactor core and may inhibit complete closure of related valves when the injection is terminated.

If CST refill rates were significantly greater than emergency depletion rates, the possibility of tank overpressure may exist. Likewise, overfill of the SP may occur if other source(s) of injection are used in addition to the CST. This increased SP level may adversely effect containment venting.

Drawing water from a cross-connected unit could adversely impact the unaffected unit.

Refilling the CST from a municipal water system raises a possibility of backflow of contaminated water to the municipal water supply.

2.3.2 Strategy to Refill Refueling Water Storage Tank With Borated Water (PWR)

Strategy Description

The aim of this strategy is to supply additional borated water to the refueling water storage tank (RWST) to help avoid or at least delay the depletion of the water in the tank. The water may be required to respond to certain sizes and types of loss of coolant accidents (LOCAs), if emergency coolant sump recirculation is not available, where other sources of water are unavailable or less desirable to supply the requirements of core injection and possibly containment spray. The possible sources of water having sufficient boron concentration to maintain an appropriate reactor safe shutdown margin might be: normal RWST makeup (limited capacity), borated water holdup tank (possibly limited capacity), spent fuel pool (above fuel assemblies), unaffected unit's RWST (for multi-unit plants) via cross-connect (assuming appropriate measures being taken with the unaffected unit to compensate). Most, if not all, of these existing sources require AC power to pump the water.

The RWST (alternately called the refueling water tank or borated water storage tank) was designed as the initial source of borated water for the emergency core cooling system (ECCS) and containment spray system during a LOCA. The RWST will supply all of these emergency flow requirements until the tank is almost empty. If there is sufficient coolant discharged into the containment sump by that time, then there can be either an automatic or manual transfer of ECCS and containment spray pump suctions to the sump. This ECCS mode is called either containment sump recirculation or emergency coolant recirculation. Depletion of the RWST is of concern when the design capability of the ECCS and containment spray pumps to take and maintain suction from the containment recirculation sump may not be achieved. For example, sump recirculation would not be available if equipment malfunctions or sump blockage were to render all redundant recirculation trains inoperable, or if the water inventory accumulated in the sump were insufficient.

This refill strategy taken by itself addresses those LOCA situations where both, (i) the break is large enough that the RWST is in jeopardy of being emptied while still needed for emergency injection, and (ii) there is concern that sump recirculation will not work (e.g., interfacing systems LOCA to outside containment). This strategy would be ineffective for large break LOCAs in which the emergency flow requirements may be much greater than the refill capability.

In addition, it may not be necessary for small breaks where the RWST is not anticipated to be emptied.

Other related strategies include Subsections 2.1, "Strategy to Reduce Containment Spray Flow Rate to Conserve Water for Core Injection," 2.2, "Strategy to Enable Early Detection, Isolation or Otherwise Mitigate the Effects of an Interfacing Systems LOCA," 2.4, "Strategy to Ensure Appropriate Recirculation Switchover and Manual Intervention Upon Failure of Automatic Switchover," and 6.1, "Strategy to Provide Additional Supply of Borated Makeup for Long-Term Accident Control."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. Procedural steps directing the operator(s) to initiate RWST makeup during a LOCA were found in the EOPs of all plants examined. However, the EOPs most often refer back to a normal operating procedure (or instruction) which is only able to provide very limited amounts of RWST refill. In some multi-unit plants, cross connections do exist between each unit's RWST and their EOPs take advantage of this by calling for either limited gravity feed or pump transfer between the tanks. The use of the spent fuel pool as another source of makeup was also addressed in some EOPs.

In the EOPs of at least one plant, the use of unborated water (e.g., fire water) was mentioned as a possibility, although no formal step-by-step procedure was given. In this case, the procedural step directed the operator to consider the use of unborated water, but only after consulting the Technical Support Center (TSC).

Possible Adverse Effects

Depleting the inventory of the spent fuel storage pool could possibly reduce decay heat removal capability in the spent fuel. In addition, if the level drops low enough, this might possibly result in spent fuel damage and/or increased radiation levels in the fuel storage building.

If RWST refill rates were significantly greater than emergency depletion rates, the possibility of borated water loss due to tank overfill/overpressure may exist.

Drawing borated water from a cross-connected unit could adversely impact the unaffected unit.

As noted above, this strategy advocates the use of RWST refill sources having sufficient boron concentration to maintain an appropriate reactor safe reactivity shutdown margin. The use of unborated refill water can potentially raise concern over recriticality if its use results in sufficiently diluted water being injected into the reactor. This is especially true at the beginning of a fuel cycle when the required operating boron concentrations are relatively high.

2.4 Strategy to Ensure Appropriate Recirculation Switchover and Manual Intervention Upon Failure of Automatic Switchover (PWR)

Strategy Description

The aim of this strategy is to assure that a recirculation flow path exists for the emergency core cooling system (ECCS) and the containment spray (CS) when the refueling water storage tank (RWST) supply reaches its required switchover point during a LOCA event, and/or the water level in the containment recirculation sump reaches a specified level. This strategy is accomplished by assuring automatic or manual recirculation switchover and to cope with an automatic switchover failure when required by manual intervention.

During a LOCA inside containment, the water lost from the reactor coolant system (RCS) will flow into the containment sump. During the initial phase of the accident, water for core injection is supplied from the RWST. When the water level in the containment sump and/or RWST reach(es) a specified level, the ECCS pump suction may be switched over either remotely or locally from the RWST to the containment water sump. When sump water is recirculated (emergency coolant sump recirculation), the remaining water inventory in the RWST is conserved. In addition, sump recirculation allows for long-term heat removal via the residual heat removal (RHR) heat exchangers.

Other related strategies include Subsections 2.1, "Strategy to Reduce Containment Spray Flow Rate to Conserve Water for Core Injection" and 2.3.2, "Strategy to Refill Refueling Water Storage Tank With Borated Water."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. Procedural steps directing the operator(s) to assure the switchover were found in the EOPs of most plants examined including manual backup to automatic failure.

Possible Adverse Effects

Local switchover (outside the control room) to emergency coolant sump recirculation may present problems associated with valve locations being in possible high radiation areas.

2.5 Strategy to Ensure Adequate Plant Heat Removal Capability by Emergency Connection(s) of Existing or Alternate Water Sources (BWR and PWR)

Strategy Description

The aim of this strategy is to ensure an adequate long-term supply of water to maintain coolant inventory and remove heat from the reactor and other plant loads. This strategy could be implemented during an accident in which all higher priority water supplies and systems are unavailable or inadequate. This strategy is accomplished by providing backup emergency connections such as: water supply to service water (SW) from existing or alternate sources including rivers, lakes, reservoirs, municipal water systems, ocean, etc.; SW supply directly to the feedwater (or condensate) system. Actual hard-piped crossties between systems needed to implement this strategy are unlikely to exist in most plants. The alternative would be to utilize a temporary hose connection arrangement. Although such an arrangement would depend on specific plant configuration, it is likely that some plants have a penetration or blank flange that could be adapted by a hose connection. The proposed connected systems most probably will require AC power and sufficient pumping capability to deliver adequate supplies of cool water. Therefore this strategy may be affected by a station blackout.

The SW system takes suction from an adequate source of water such as a river, lake, ocean or cooling tower basin and provides cooling to all plant loads during reactor shutdown. During normal reactor operation, most heat loads are handled by the main turbine generator, feedwater heaters and the main condenser via the circulating water system. The SW system handles other loads such as pump cooling and spent pool cooling.

Other related strategies include Subsections 3.5, "Strategy to Use Condensate Pumps or Startup Feedwater Pumps for Steam Generator Injection," and 4.7, "Strategy to Use Diesel-Driven Firewater Pump for BWR Core Injection, PWR Steam Generator Injection or Containment Sprays."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. Procedural steps for parts of this strategy exist in a number of plants.

Possible Adverse Effects

The alternate water supply selected by this strategy may not be adequately filtered, therefore, in cases where this water is used for reactor core or steam generator injection, the injection path may become partially obstructed with debris especially in the feedwater spargers.

The impurities in untreated water pumped into a reactor core or steam generator could potentially lead to somewhat higher radiation levels in the system. Connecting the plant systems to rivers, reservoirs or municipal water systems could open these latter systems to possible contamination.

Service water supply directly to the feedwater (or condensate) system may reduce cooling water supply to normal SW loads.

3. STRATEGIES RELATED TO UNAVAILABLE INJECTION SYSTEMS

3.1 Strategy to Extend Emergency Core Cooling System Availability by Switching Pump Suction (BWR)

Strategy Description

The aim of this strategy is to extend the availability of the emergency core cooling system (ECCS) function by switching the suction of the associated pumps from the suppression pool (SP) to an alternate condensate inventory. The transfer of the suction from the SP to a cool alternate source of ECCS water may be appropriate in response to some types of events, such as loss of coolant accident (LOCA), long-term station blackout and anticipated transient without scram (ATWS). In these events, the SP temperature may become high enough to risk loss of emergency pumps due to accelerated wear or inadequate net positive suction head. To accomplish this strategy, possible sources of cool water to the suction of the ECCS pumps might be: the condensate storage tank (CST), the main condenser hotwell via the main condensate or condensate transfer system, spent fuel pool or any other large quantity of cool water which can be accessed by either permanent connections or temporary hookups including hose connections. Most of these sources require AC power to pump the water to the ECCS pump suction. To accomplish this switchover, valve interlocks may have to be bypassed or changed.

In most BWRs, the high pressure ECCS pumps, namely, high pressure coolant injection or core spray (HPCI or HPCS) and reactor core isolation cooling (RCIC) initially take suction from the CST (preferred source) and later switch to the SP. The low pressure ECCS pumps, namely low pressure coolant injection (residual heat removal) and low pressure core spray (LPCI and LPCS) normally take their suction from the SP with limited (or no) ability to readily use the CST as an alternate. The condensate transfer system, usually in conjunction with the condensate system, link the main condenser hotwell with the CST thus providing the ability to transfer water both ways between the hotwell and the tank. In addition, in at least one plant, there is piping which allows the condensate transfer system to provide a limited supply of hotwell water to the suction of the low pressure ECCS systems.

Other related strategies include Subsections 2.3.1, "Strategy to Refill Condensate Storage Tank," 3.3.1, "Strategy to Use Control Rod Drive Pumps for Core Injection," and 4.7, "Strategy to Use Diesel-Driven Firewater Pump for BWR Core Injection, PWR Steam Generator Injection or Containment Sprays."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR vendor and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. In the EOPs examined, there were no procedural steps found that directed the switch back of any high pressure ECCS pump suction from the SP to the CST.

Possible Adverse Effects

The rising SP water level associated with the suction transfer back to the CST could be of concern as long-term containment performance might be diminished if it is not corrected.

3.2 Emergency Bypass or Change of Pump Protective Trips

3.2.1 Strategy to Enable Emergency Bypass or Change of Protective Trips for Injection Pumps (BWR and PWR)

Strategy Description

The aim of this strategy is to enable continued injection pump operation beyond the point where they would normally trip, with the intention of preventing or mitigating an accident before the pumps fail. This strategy is accomplished by bypassing certain protective trips or changing trip setpoints on injection pumps unless this could result in early failure of the pumps.

The following identifies those injection pumps by their plant system and possibly related trips which might be considered to be of some benefit if bypassed or changed during an accident condition:

In BWR plants, the pumps are associated with the following systems, namely, reactor feedwater, high-pressure core injection (HPCI), high-pressure core spray (HPCS), low-pressure coolant injection (LPCI) mode of RHR, low-pressure core spray (LPCS) and control rod drive (CRD). Examples of trips are high turbine exhaust pressure, high reactor water level, low steam supply pressure, low pump suction pressure, low lube oil pressure, low control oil pressure, thrust bearing wear, low oil tank level, high bearing vibration, electrical trips, in-line valves not full open and high steam line flow.

In PWR plants, the pumps are associated with the following systems, namely, charging and high and low pressure safety injection, main feedwater, auxiliary feedwater and condensate (plus condensate booster or heater drain). A few examples of associated trips are high turbine exhaust pressure, low pump suction pressure, high steam generator level, low steam supply pressure and high steam line flow.

The trips mentioned above for BWRs and PWRs may not be all inclusive, however, they are representative of those at most plants. One or more of these trips may be considered for potential bypassing under emergency conditions. An assessment of each trip considered for bypass should be performed as part of the strategy evaluation process. This assessment should include detailed information on the original design requirements for each trip and analysis of potential accidents in which these trips might be bypassed. The assessment should include beneficial attributes as well as detrimental aspects of bypassing individual trips.

Other related strategies include Subsections 3.2.2, "Strategy to Extend Reactor Core Isolation Cooling System Availability by Pump Trip Function Bypass or Change," and 4.4, "Strategy to Enable Emergency Bypass or Change of Protective Trips for Emergency Diesel Generators."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. For the plants reviewed, no procedural steps utilizing this strategy were found.

Possible Adverse Effects

Bypassing protective trips or changing the setting of trip values could be detrimental and would possibly result in the need for constant operator vigilance and dependence on the adequacy of existing instrumentation. This is expected to provide needed short-term pump availability, but ultimately could lead to extended loss in the longer term and risk substantial pump damage.

3.2.2 Strategy to Extend Reactor Core Isolation Cooling System Availability by Pump Trip Function Bypass or Change (BWR)

Strategy Description

The aim of this strategy is to enable the continued reactor core isolation cooling (RCIC) system operation beyond which the pump would trip with the intention of preventing or mitigating an accident. This strategy is accomplished by bypassing certain RCIC pump protective trips or changing one or more trip setpoints, (e.g., turbine exhaust pressure) unless this could result in early failure of the pump or its steam turbine. The strategy of bypassing/changing RCIC pump trip setpoint(s) is treated separately from the broader strategy of pump trip bypass (Subsection 3.2.1) because the associated risk reduction potential is perceived to be greater.

The RCIC system is designed to maintain sufficient water in the reactor vessel to cool the core should the vessel be isolated. Its turbine-driven pump normally takes suction from the condensate storage tank and discharges into a main feedwater line for injection into the vessel. Reactor steam drives the turbine to maintain pump flow and the exhausts to the suppression pool (SP). The turbine is designed to trip automatically on various off normal conditions such as high turbine exhaust pressure, RCIC system isolation (e.g., low steam pressure, high steam flow, high temperature in various locations, etc.), low pump suction pressure and turbine overspeed.

During an anticipated transient without scram (ATWS) or a station blackout (SBO) situation where continued RCIC operation is needed to maintain vessel water level, thereby preventing core uncovery and possible core damage, it may be beneficial to bypass or change one or more present turbine trip setpoints. For example, the high SP temperatures associated with an ATWS or SBO will eventually require controlled reactor pressure reduction as the SP temperature rises to satisfy the SP heat capacity limit. These elevated SP temperatures and reduced reactor pressure may cause a RCIC turbine trip from either high turbine exhaust pressure or low steam pressure before appropriate RCIC operability limits are reached. This is true, especially if the turbine exhaust pressure is significantly above SP pressure. These operability limits should take into account the accident conditions and the associated need to prevent core damage.

Another related strategy includes Subsection 3.2.1, "Strategy to Enable Emergency Bypass or Change of Protective Trips for Injection Pumps" which addresses pumps in other systems other than the RCIC system.

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR vendor and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. For the EOPs examined, no procedural steps were found which used this strategy.

Possible Adverse Effects

Bypassing protective trips or changing the setting of trip values could be detrimental and would possibly result in the need for constant operator vigilance and dependence on the adequacy of existing instrumentation. This is expected to provide needed short-term pump availability, but ultimately could lead to extended loss in the longer term and risk substantial RCIC pump or turbine damage.

3.3 Core Injection by Non-Safety Related Pump

3.3.1 Strategy to Use Control Rod Drive Pumps for Core Injection (BWR)

Strategy Description

The aim of this strategy is to inject water into the reactor vessel to prevent or mitigate reactor core damage. This strategy is accomplished by the use of the control rod drive (CRD) pumps for core injection of unborated water when other methods are not available and during an anticipated transient without scram (ATWS), when control of reactor vessel water level is required to minimize reactor power, e.g., reactor water level/power control.

The CRD pump sub-system consists of two AC operated pumps that while supplying motive force for control rod movement during normal operation also inject water into the vessel lower head via the CRD mechanisms to cool the mechanism drive piston seals. At least one of these pumps is operating at all times during normal operation and is aligned to draw water from the main condenser hotwell reject line or the condensate storage tank. The flow of water into the vessel from the CRD system through the seals is regulated from the control room by throttling system control valves. After a scram, the seal flow is increased substantially by the increased pressure directed to each mechanism by the opening of scram inlet valve. This is true unless there is a CRD system failure such as loss of the pumps during a station blackout. Therefore, until the scram is reset, the CRD pump(s) provide a source of core injection (above normal seal cooling flow) when other methods (e.g., Condensate/Feedwater, Reactor Core Isolation Cooling and High Pressure Injection or Spray) are not available. This CRD flow can be maximized by using a pump test bypass line[10] or opening up the CRD pressure control valves for a total injection flow of no more than several hundred gallons per minute.

In addition to using the CRD pumps as a backup to other methods of core injection there are two special cases when their use might be considered, namely, for reactor water level/power control during an ATWS when boron is not available, and then again when core uncovery is suspected.

During an ATWS event in which boron is not available, reactor water level/power control may be a viable means of preventing or mitigating core damage. In this situation, CRD pump(s) in combination with another injection pump may be useful as a source of controlled core injection to minimize reactor power.

In the event of an accident involving suspected core uncovery and possible core damage, the possible use of CRD pumps is covered in Subsection 6.2, "Strategy to Inject Borated Water in Case of Potential Core Damage and to Guard Against Boron Dilution in the Core."

Other related strategies include Subsections 4.7, "Strategy to Use Diesel-Driven Firewater Pump for BWR Core Injection, PWR Steam Generator Injection or Containment Sprays," and 6.1, "Strategy to Provide Additional Supply of Borated Makeup Water for Long-Term Accident Control."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR vendor and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. Procedural steps to use the CRD pumps to restore and maintain reactor vessel water level were found in the EOPs of the plants examined. In addition, under extreme low water level conditions without an ATWS, several EOPs reviewed include step(s) to maximize CRD flow.

Possible Adverse Effects

Controlling water level correctly during an ATWS may prove to be difficult even when using the CRD pumps in combination with another injection pump. This level control concern may be compounded by misleading or conflicting indication(s) of vessel level and reactor power.

3.3.2 Strategy to Use Non-Safety Related Charging Pumps for Core Injection (PWR)

Strategy Description

The aim of this strategy is to supply water to the reactor vessel by using non-safety related charging pumps when other sources of borated water are unavailable for high pressure emergency core injection requirements. Note that a non-safety related charging pump as used in this strategy refers to any installed high head charging pump whose electrical power does not come from an emergency bus and which has not been qualified to safety-related standards. To accomplish this strategy, electrical power to the motor-driver(s) of the pump(s) should be assured via the normal non-emergency bus or possibly by provisions for connecting to a more reliable alternate AC source.

During normal operations, a redundant charging pump supplies borated water to the reactor vessel at the proper high pressure flow and boron concentration for volume and chemical control. In most PWRs, the charging pump discharge flow splits before reaching the reactor vessel, with some flow going to each reactor coolant pump (RCP) gland seal assembly (seal injection) while the majority goes into the reactor coolant system (RCS) cold leg(s). Most Combustion Engineering PWRs do not use seal injection to provide seal cooling; in these plants, all charging flow goes to the cold leg(s).

It is important to note that in many PWRs the design and implementation of the high head charging pumps is such that they operate as part of the chemical and volume control system (CVCS). In an emergency, these safety related pumps switch their function to provide high pressure emergency injection. Given a safety signal, these pumps will automatically start or continue to run (with automatic restart upon restoration of power). The signal also switches the charging pump suction from the normal source (the volume control tank) to their emergency source, the refueling water storage tank (RWST). In contrast, there are a few plants whose charging pumps were not designed as emergency pumps and are only operated as normal CVCS components. These non-safety charging pumps (including positive displacement reciprocating type pumps) could still be used, if available, for emergency core injection.

This strategy addresses emergency situations where the reactor coolant system (RCS) remains at high pressure as for instance due to loss of feedwater in the steam generators (SG), anticipated transient without scram (ATWS) or small break LOCA. During these situations with RCS pressure above the shutoff head of most high head safety injection pumps, only the charging pumps can provide injection to the RCS.

Other related strategies include Subsections 3.5, "Strategy to Use Condensate or Startup Feedwater Pumps for Steam Generator Injection," and 4.7, "Strategy to Use Diesel-Driven Firewater Pump for BWR Core Injection, PWR Steam Generator Injection or Containment Sprays."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic PWR vendors and the Emergency Operating Procedures (EOPs) of many plants were examined to determine the extent to which this strategy has been implemented. Procedural steps directing the operator(s) to initiate core injection with a non-safety related charging pump were not identified in the EOPs of any of the plants examined. Of course, most of these plants have safety related charging pumps so that this strategy would not apply to them.

Possible Adverse Effects

Other than generic concerns discussed in the Introduction of this report, there were no specific concerns identified for this strategy.

3.4 Strategy to Use Alternate Seal Injection (e.g., Hydrotest Pump) When Reactor Coolant Pump Seal Cooling is Lost (PWR)

Strategy Description

The aim of this strategy is to regain reactor coolant pump (RCP) shaft seal cooling by an alternate means of seal injection. To accomplish this strategy, a suitable alternative for normal seal injection should be considered. One alternative might be an installed hydrotest pump. This strategy only applies to those PWRs which normally use seal injection.

During normal operation, one of (at least) two redundant charging pumps supply borated water to the reactor vessel at the proper high pressure flow and boron concentration. In those PWRs using seal injection, the charging pump discharge flow splits before reaching the reactor vessel with some flow going to each RCP shaft seal assembly (seal injection) while the majority goes into the RCS cold leg(s). The seal injection flow in turn splits in the seal assembly with some of the flow going down into the RCP pushing relatively cool water past the RCP thermal barrier, thus preventing RCS water from entering the seal assembly. The remainder of the seal injection flow passes through the pressure breakdown seal stages and exits to the volume control tank and other leakoff paths. If seal injection flow is lost (or does not exist as part of the RCP seal assembly design like in most Combustion Engineering plants), the seals are cooled by low temperature RCS water flowing up through the seal assembly. This RCS water is cooled by a heat exchanger in the RCP thermal barrier supplied by component cooling water (CCW). Alternate seal injection cannot be used in plants which do not normally use seal injection. Plants which have seal injection, would have to use an alternate when the normal seal injection and thermal barrier seal cooling are not effectively cooling the RCP seals.

This alternate RCP seal injection strategy specifically addresses those situations where the safety related charging pumps and the CCW flow to the RCP thermal barrier heat exchangers are not adequately cooling the RCP seals in PWR plants with RCP seal injection.

A related strategy is included in Subsection 3.3.2, "Strategy to Use Non-Safety Related Charging Pumps for Core Injection."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic PWR vendors and the Emergency Operating Procedures (EOPs) of several plants utilizing seal injection were examined to determine the extent to which this strategy has already been implemented. Procedural steps directing the operator(s) to lineup and initiate alternate seal injection were not identified in the EOPs of the plants examined. These domestic plant EOPs, direct the operator(s) to trip the RCPs on loss of seal cooling. However, the reactor safety literature revealed at least two foreign plants (in different countries) which have made provisions to use a hydrotest pump for alternate seal injection.

Possible Adverse Effects

Other than generic concerns discussed in the Introduction of this report, there were no specific concerns identified for this strategy.

3.5 Strategy to Use Condensate Pumps or Startup Feedwater Pumps for Steam Generator Injection (PWR)

Strategy Description

The aim of this strategy is to provide steam generator (SG) feedwater injection when normal station AC power is available, and main feedwater (MFW) and auxiliary (emergency) feedwater (AFW) pumps are unavailable. To accomplish this strategy, a suitable alternate for MFW and AFW should be used. Suitable alternates might be the main condensate pumps, the heater drain pumps or a startup feedwater pump. For whichever alternate is used, the SG pressure must be reduced below the shutoff head of the pump and any interlock preventing the use of these pumps in this strategy would have be bypassed or overridden. This strategy cannot be implemented in a station blackout because the pumps require AC power for their operation.

The condensate pumps normally pump water from the main condenser hotwell to the suction side of the MFW pumps via booster pumps (or heater drain pumps, if appropriate). Where startup feedwater pumps exist in PWRs, they are of various capacities. Generally they take suction from the condensate storage tank (CST) and inject into the SG.

During an accident where the MFW pumps and the AFW pumps are unavailable, the SG pressure can be reduced and the MFW isolation valves could be reopened to permit the condensate pumps to inject directly into the SGs bypassing the MFW pumps. The flow of these pumps at low pressures may be sufficient to provide cooling to the reactor coolant system in certain accident situations. Similarly, other pumps could be used. Specific plant analysis would be required to determine when these pumps could provide sufficient cooling to handle decay heat loads.

Other related strategies include Subsections 2.5, "Strategy to Ensure Adequate Plant Heat Removal Capability by Emergency Connection(s) of Existing or Alternate Water Sources," and 4.7, "Strategy to Use Diesel-Driven Firewater Pump for BWR Core Injection, PWR Steam Generator Injection or Containment Sprays."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. Procedural steps to use condensate pumps for low pressure SG injection were found in the procedures of several plants examined.

Possible Adverse Effects

During restoration of a secondary heat sink, it may become necessary to inject relatively cool water into a hot dry SG even after core damage. This injection from the main condenser hotwell or the CST may result in excessive thermal stresses in the SG, possibly leading to SG tube failure. Reestablishing injection will result in SG repressurization and may lead to SG pressure greater than the shutoff head of one or more of the lower head pumps considered for this strategy (e.g., main condensate pumps, heater drain pumps).

4. STRATEGIES RELATED TO LOSS OF POWER

4.1 Strategy to Conserve Battery Capacity by Shedding Non-Essential Loads (BWR and PWR)

Strategy Description

The aim of this strategy is to conserve station battery power for essential loads as long as possible in the event of a station blackout (SBO). The essential loads are those related to maintaining control of the systems needed to bring the plant to a safe shutdown and maintain it. To accomplish this strategy, non-essential DC loads should be shed.

During an emergency, the plant's DC power system provides a reliable supply of power to DC and vital AC bus loads required by the emergency equipment. Its design is plant specific and may be influenced more by the architect/engineering firm involved in the plant design and construction than by the plant or containment type. For redundancy at least two divisions are used and newer plants typically have four divisions. Each division has its own battery and one or more battery chargers. Normally the DC loads are supplied by the installed battery chargers which keep the batteries up to full charge. During an SBO, the installed chargers stop charging and the DC and vital AC bus loads start to discharge the batteries.

Other related strategies include Subsections 4.2, "Strategy to Use Portable Battery Chargers or Other Power Sources to Recharge Station Batteries," and 4.5, "Strategy to Enable Emergency Crosstie of AC Power Between Two Units or to an Onsite Gas Turbine Generator."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. All plants were found to have some provisions for load shedding in their EOPs.

The NRC's 1988 SBO Final Rule required that all plants be capable of withstanding a total loss of AC electrical power for a specified duration while maintaining both reactor core cooling and containment integrity. According to the rule, the capability for coping with an SBO of specified duration may be determined by an appropriate analysis in lieu of providing an additional onsite emergency AC power source. The analysis should include a description of the procedures and a list of equipment modifications that will be implemented. It is likely that most plants will implement procedures for load shedding to help respond to the rule.

Possible Adverse Effects

Implementing this strategy allows for the possibility of inadvertently shedding the wrong loads and/or delayed shedding of correct loads, hence prematurely depleting the station batteries during an SBO.

4.2 Strategy to Use Portable Battery Chargers or Other Power Sources to Recharge Station Batteries (BWR and PWR)

Strategy Description

The aim of this strategy is to recharge the station batteries during a station blackout (SBO) thereby providing prolonged DC power supply for vital safety functions in the plant. To accomplish this strategy, a power source such as a suitably sized portable gasoline engine driven battery charger might be used to recharge a station battery. The chargers would be placed into operation during an SBO when the return of AC power does not seem imminent and time to accomplish the portable hook up task is available. This strategy should reflect consideration of the need and priorities for power to vital ECCS related functions and a minimum set of plant sensors which adequately monitor plant status.

The DC power system provides a reliable supply of power to DC and vital AC bus loads required by the emergency equipment. Its design is plant specific and may be influenced more by the architect/engineering firm involved in the plant design and construction than by the plant or containment type. For redundancy at least two divisions are used and newer plants typically have four divisions. Each division has its own battery and one or more battery chargers. Normally the DC loads are supplied by the installed battery chargers which keep the batteries up to full charge. During an SBO, the installed chargers cease charging and the DC and vital AC bus loads start to discharge the batteries.

Other related strategies include Subsections 4.1, "Strategy to Conserve Battery Capacity by Shedding Non-Essential Loads," and 4.5, "Strategy to Enable Emergency Crosstie of AC Power Between Two Units or to an Onsite Gas Turbine Generator."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors along with the EOPs of several plants were reviewed to determine the extent to which this strategy has been implemented. In one instance, the use of portable battery chargers was found.

The NRC's 1988 SBO Final Rule required that all plants be capable of withstanding a total loss of AC electrical power for a specified duration while maintaining both reactor core cooling and containment integrity. According to the rule, the capability for coping with an SBO of specified duration may be determined by an appropriate analysis in lieu of providing an additional onsite emergency AC power source. The analysis should include a description of the procedures and a list of equipment modifications that will be implemented. It is possible that some plants may propose to add portable battery chargers to help respond to the rule.

Possible Adverse Effects

Implementing this strategy involves the use of non-safety grade equipment on a safety related system which could jeopardize the remaining battery capacity if the portable charger is not properly isolated or properly used.

4.3 Strategy to Enable Emergency Replenishment of the Pneumatic Supply for Safety Related Air Operated Components (BWR and PWR)

Strategy Description

The aim of this strategy is to mitigate an accident by preventing the premature functional loss of critical equipment requiring instrument air (IA). This strategy is accomplished by replenishing the air supply with an appropriately filtered and dried alternate supply to ensure that safety related air-operated valves and instruments will be able to operate as necessary during an extended severe accident. Options for additional air supplies include: service air (SA) systems (which is typically non-safety related), diesel air compressors (typically used as a backup to the SA system), and additional onsite storage of bottled air systems.

The accumulators of safety-related air-operated valves at plants considered in this study provide air pressure for a certain number of valve cycles after loss of supply-air pressure. However, during an extended accident, more valve actuation cycles may be needed to ensure shutdown of the plant and to provide long term cooling. Valves not normally considered in design basis accidents may be considered if they can help prevent or mitigate an extended accident.

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented.

Modifications of systems or additional equipment currently in place at plants reviewed include: a crossover connection between the SA and IA systems to backup IA, a portable diesel compressor available for connection to an SA connection, nitrogen gas bottle banks as needed to provide long term actuation of safety-related air operated valves, and backup such as a liquid nitrogen truck. Some modifications to the air supply systems at many plants have occurred in compliance with Generic Issue 43 (Instrument Air), Generic Issue A-44 (Station Blackout) and Generic Issue B-56 (Diesel Reliability).

In the plants reviewed, the modifications to provide backup bottled nitrogen for critical safety-related valves and crossover lines were found in most EOPs. To a lesser extent, the remainder of the proposed modifications were also referenced in the EOPs.

Possible Adverse Effects

The use of SA in components normally supplied by IA without a filter/dryer system may result in malfunction and even failure of these components.

Cross-connections of nitrogen systems in BWR plants with inerted containments with the air systems may compromise containment inerting requirements.

4.4 Strategy to Enable Emergency Bypass or Change of Protective Trips for Emergency Diesel Generators (BWR and PWR)

Strategy Description

The aim of this strategy is to enable continued emergency diesel generator (EDG) operation beyond the point where they would normally trip, with the intention of preventing and mitigating an accident before the EDGs fail. This strategy is accomplished by bypassing certain protective trips or changing their trip setpoints unless this selective bypassing or changing could result in early failure of the EDGs.

The EDGs in most plants have been designed with an automatic bypass of some protective trips during an emergency start. Examples of the types of trips typically bypassed during emergency starts are: high jacket water temperature, high vibration, low turbocharger lube oil pressure, main bearing high temperature, and connecting rod bearing high temperature. Other trips which are found to be automatically bypassed in some plants are low lube oil pressure, high crankcase pressure, and generator-differential.

If automatic bypass of any of the above trips is not presently part of the system design in a particular plant, i.e., within its design basis, they may still be candidates for manual bypass. The current regulatory guidance allows for bypassing an EDG trip under accident conditions provided that the operator has sufficient time to react appropriately to an abnormal EDG unit condition.

An assessment of each trip considered for bypass should be performed. This assessment should include detailed information on the original design requirements for each trip and analysis of potential accidents in which the trip might be bypassed. If trips are bypassed in an accident condition, the need for continuous or frequent monitoring of parameter readings should be assessed.

Other related strategies include Subsections 3.2.1, "Strategy to Enable Emergency Bypass or Change of Protective Trips for Injection Pumps," 3.2.2, "Strategy to Extend Reactor Core Isolation Cooling System Availability by Pump Trip Function Bypass or Change," and 4.5, "Strategy to Enable Emergency Crosstie of AC Power Between Two Units or to an Onsite Gas Turbine Generator."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. For the plants reviewed, no procedural steps utilizing this strategy were found.

The NRC's 1988 SBO Final Rule required that all plants be capable of withstanding a total loss of AC electrical power for a specified duration while maintaining both reactor core cooling and containment integrity. According to the rule, the capability for coping with an SBO of specified duration may be determined by an appropriate analysis in lieu of providing an additional onsite emergency AC power source. The analysis should include a description of the procedures and a list of equipment modifications that will be implemented. This strategy could be part of such a response to the rule.

Possible Adverse Effects

Bypassing EDG protective trips or changing their trip setpoints could be detrimental and would possibly result in the need for constant operator vigilance and dependence on the adequacy of existing instrumentation. This action is expected to provide needed short-term EDG availability, but ultimately could lead to extended loss in the longer term and risk substantial EDG damage.

4.5 Strategy to Enable Emergency Crosstie of AC Power Between Two Units or to an Onsite Gas Turbine Generator (BWR and PWR)

Strategy Description

The aim of this strategy is to provide an alternate source of AC electrical power to the unit's emergency buses to help recover from a station blackout (SBO) when the unit's normal and emergency AC power sources are lost. This permits continued operation of safety-related equipment. This strategy is accomplished by establishing an emergency crosstie capability (AC switchyards and/or diesel generators) between equivalent AC power systems of two units at a multi-unit site, or by connecting an available onsite gas turbine generator to the AC power system to provide an alternate AC power source. Plant electrical systems are usually compatible and only require minor design and planning to accomplish crosstying of electrical equipment at multi-unit facilities, through the use of switchgear and controls, but this would need to be addressed as part of strategy assessment.

Implementation of this strategy may not be possible at single unit locations unless another source of independent offsite AC power exists, e.g., a gas turbine generator. Several plants examined were found to have large gas turbine generators onsite.

For this strategy, a gas turbine generator or other AC power source, must be capable of developing plant emergency bus voltage. If a gas turbine generator is considered, black start capability is desirable.

Another related strategy includes Subsection 4.6, "Strategy to Use a Diesel Generator or Gas Turbine Generator to Power a Control Rod Drive or Other Appropriate Pump for Core Injection."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. Procedural steps to implement this strategy were not found.

The NRC's 1988 SBO Final Rule required that all plants be capable of withstanding a total loss of AC electrical power for a specified duration while maintaining both reactor core cooling and containment integrity. According to the rule, the capability for coping with an SBO of specified duration may be determined by an appropriate analysis in lieu of providing an additional onsite emergency AC power source. The analysis should include a description of the procedures and list of equipment modifications that will be implemented. This strategy could be part of such a response to the rule.

Possible Adverse Effects

Electrical system crossties at multi-unit sites may compromise the emergency AC power reliability of the unit sharing its power, e.g., fault propagation.

4.6 Strategy to Use a Diesel Generator or Gas Turbine Generator to Power a Control Rod Drive or Other Appropriate Pump for Core Injection (BWR)

Strategy Description

The aim of this strategy is to supply alternate electrical AC power to drive a control rod drive (CRD) or another appropriate pump for core injection and/or emergency boration. This strategy is accomplished by supplying emergency power from a mobile diesel generator or a gas turbine generator to provide the appropriate AC power source to drive the pump(s). Other appropriate pumps might be residual heat removal (RHR) pumps and condensate/motor-driven feedwater pumps assuming the generator has sufficient capacity.

The use of this generator could prevent or mitigate a station blackout (SBO) accident. An alternate AC generating unit used for driving the CRD pumps may be beneficial in other selected accident scenarios as well. Several plants examined were found to have large gas turbine generators onsite.

For this strategy, a gas turbine generator or other AC power source, must be capable of developing the required pump bus voltage and adequate capacity. If a gas turbine generator is considered, black start capability is desirable.

Other related strategies include Subsections 3.3.1, "Strategy to Use Control Rod Drive Pumps for Core Injection," 4.5, "Strategy to Enable Emergency Crosstie of AC power Between Two Units or to an Onsite Gas Turbine Generator," and 6.1, "Strategy to Provide Additional Supply of Borated Makeup Water for Long-Term Accident Control."

Relationship with Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR vendor and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. Procedural steps to perform this strategy have not been found.

The NRC's 1988 SBO Final Rule required that all plants be capable of withstanding a total loss of AC electrical power for a specified duration while maintaining both reactor core cooling and containment integrity. According to the rule, the capability for coping with an SBO of specified duration may be determined by an appropriate analysis in lieu of providing an additional onsite emergency AC power source. The analysis should include a description of the procedures and a list of equipment modifications that will be implemented. This strategy could be part of such a response to the rule.

Possible Adverse Effects

Providing a mobile AC generator, connecting it to the appropriate bus and operating the injection pump may increase the need for operator vigilance.

4.7 Strategy to Use Diesel-Driven Firewater Pump for BWR Core Injection, PWR Steam Generator Injection or Containment Sprays (BWR and PWR)

Strategy Description

The aim of this strategy is to provide an alternate source of BWR core injection, PWR steam generator (SG) injection, or containment spray (CS) in both BWRs and PWRs. To accomplish this strategy, a diesel-driven firewater pump will be used as a source of the water. Actual hard-piped crossties from the firewater system to provide these functions do not exist in many U.S. plants. The alternative would be a temporary hose connection arrangement with the necessary connectors (e.g., spool piece). Although such an arrangement would depend on specific plant configuration, it is likely that most plants have a penetration or blank flange that could be adapted to a hose connection from the firewater system. Injection to a BWR core or to a PWR SG is more important than spraying the drywell of a BWR or the containment of a PWR.

The firewater supply system typically consists of one or more electrically driven pump(s) and a backup pump driven by a dedicated diesel engine. These pumps feed a firewater main which is tapped at various locations around the plant site. For plants located near fresh water rivers or lakes, suction to the fire pumps is usually taken directly from these sources and therefore has an unlimited supply. For other plants, the firewater pumps are supplied by one or more storage tanks with capacities of several hundred thousand gallons each.

This strategy addresses accident sequences involving a loss of all feedwater (both main and auxiliary) or a loss of CS. Since the diesel-driven fire pump is independent of station AC power, this strategy may also be used in station blackout scenarios. Also the use of the diesel firewater system to supply the spray headers could possibly prevent or delay containment overpressure failure during accidents such as LOCAs involving a loss of containment heat removal.

A related strategy is Subsection 3.5, "Strategy to Use Condensate Pumps or Startup Feedwater Pumps for Steam Generator Injection."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. In some plants the EOPs call for the use of the diesel-driven fire pumps as an alternate source of injection into either a BWR core or the PWR SGs. However, its use for either BWR or PWR containment sprays was not found.

The NRC's 1988 SBO Final Rule required that all plants be capable of withstanding a total loss of AC electrical power for a specified duration while maintaining both reactor core cooling and containment integrity. According to the rule, the capability for coping with an SBO of specified duration may be determined by an appropriate analysis in lieu of providing an additional onsite emergency AC power source. The analysis should include a description of the procedures and a list of equipment modifications that will be implemented. This strategy could be part of such a response to the rule.

Possible Adverse Effects

The use of the diesel-driven firewater pumps for BWR core injection, PWR SG injection or containment spray is a reduction in the flow available for the actual fire suppression systems in the unlikely event these are needed in the same time frame.

The use of non-filtered firewater for CS may result in clogged nozzles in the spray headers. If appreciable flow can be achieved through the CS headers in a PWR, the addition of this unborated water into the containment sump may pose possible reactivity problems due to boron dilution when the sump is used for core cooling during emergency sump recirculation.

The use of CS in the later stages of an extended accident when the containment atmosphere may contain significant amounts of steam, air and hydrogen, would condense steam and could result in more readily combustible mixtures.

5. STRATEGIES RELATED TO LOSS OF HEAT SINK

5.1 Strategy to Reopen Main Steam Isolation Valves and Turbine Bypass Valves to Regain the Main Condenser as a Heat Sink (BWR and PWR)

Strategy Description

The aim of this strategy is to regain the main condenser as a heat sink by reopening the main steam isolation valves (MSIVs) (or their drain bypass headers) and the turbine bypass valves (TBVs) after they have closed. To accomplish this strategy, condenser vacuum must be maintained or reestablished and circulating water must be available. Then main steam line (MSL) pressure on both sides of the MSIVs may be equalized while the MSLs are being drained and warmed. If the MSIVs are to be opened, the isolation signal input(s) which closed the MSIVs must be cleared and reset, or the isolation interlocks bypassed or defeated. This strategy addresses those valve isolation situations where the main condenser is available with its vacuum maintained or able to be reestablished easily. Therefore, circulating water, turbine gland sealing steam and the vacuum pumps must be available. Also, the circumstances which caused the isolation must be corrected or tolerated if the isolation is to be overridden. If overridden, the isolation function will probably be defeated thus eliminating any further automatic reisolation.

Note that this strategy does not include reopening BWR MSIVs based on closure caused by a MSL break or fuel damage associated with high radiation. Likewise, it does not include reopening PWR MSIVs based on closure caused by a MSL break located downstream of the MSIVs. Those PWR MSIV closures associated with isolating a steam generator tube rupture or MSL break from that steam generator (SG) may also be excluded.

In almost all BWRs, there are four MSLs each containing two redundant MSIVs, both near the primary containment, one inside and one outside. Each valve is designed to rapidly close on abnormal conditions. The closure of one MSIV in each MSL will prevent the release of extraordinary amounts of radioactive materials to the turbine building and/or the plant stack in the event of abnormal fuel failure. Further, the MSIV closure will limit reactor vessel inventory loss in the event of a MSL break outside primary containment. The closure is initiated by containment isolation logic to all valves simultaneously, or manually from the main control room.

In almost all PWRs, there is one MSIV (or equivalent set of check valves) on each of the MSLs near the containment on the outside. These MSIVs are designed also to rapidly close on abnormal conditions. The closure of all MSIVs will prevent the rapid cooldown of the reactor coolant system (RCS) in the event of a MSL break outside of containment. Also, the closure of all valves will reduce the containment pressure buildup due to a MSL break inside containment by preventing backflow through the intact MSLs. Further, it will limit loss of reactor coolant inventory and possible radioactive release in the event of a steam generator (SG) tube rupture. The closure is initiated automatically or manually from the main control room by isolation logic to all valves simultaneously.

On both BWRs and PWRs, drains are located on either side of the MSIVs. These sets of drains permit drainage to a drain system or the main condenser hotwell. The drain system is utilized to drain water out of, and warm up, the MSLs. It also equalizes pressure across the MSIVs. This may have to be done along with resetting or defeating the MSIV isolation signal prior to attempting the reopening of an isolated MSIV.

The TBVs on most BWRs and PWRs are designed and used to provide the normal means of controlled cooldown of the plant via MSL pressure control prior to the use of residual heat removal (RHR). The TBV isolation logic is normally based on the loss of condenser vacuum. This logic should not be defeated as part of this strategy since the integrity of the main condenser and its hotwell could be jeopardized if it were pressurized.

Using the main condenser as a heat sink avoids dumping steam to the suppression pool in a BWR or to the atmosphere by the steam generator atmospheric dump valves in a PWR, especially during an ATWS. If the reactor is shutdown, the use of the MSL drain headers without reopening MSIVs in some plants may be adequate.

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the BWR and PWR domestic vendors and the Emergency Operating Procedures (EOPs) of many plants were examined to determine the extent to which this strategy has been implemented. For several BWRs examined, there were detailed procedural steps for reopening the MSIVs and TBVs to regain the main condenser as a heat sink, if available, provided there is no indication of a MSL break or gross fuel failure. Among the PWRs, several have procedural steps to reopen the MSIVs and TBVs.

Possible Adverse Effects

Defeating the MSIV isolation function logic and reopening the MSIVs potentially can have a negative influence on the state of the plant, e.g., failure of the condenser due to overpressure is a possibility.

There is also the possibility of the operator(s) error when the action requires many relatively complicated and unfamiliar steps to be accomplished. Even if the defeated logic is performed correctly, the automatic isolation capability is most probably lost thus significantly increasing the need for operator vigilance and possible manual isolation.

6. STRATEGIES RELATED TO SHUTDOWN FAILURE (REACTIVITY CONTROL)

6.1 Strategy to Provide Additional Supply of Borated Makeup Water for Long-Term Accident Control (BWR and PWR)

Strategy Description

The aim of this strategy is to supply adequate borated makeup water for long-term accident control. Consideration must be given to the potential needs for borated water that may result from the wide range of plant specific accidents. To accomplish this strategy, a sufficient supply of boron must be accessible on site or readily available. The amount of borated water and its concentration needs to be identified and steps necessary to prepare it for supply to the reactor vessel specified.

In PWRs, borated water is used in the reactor coolant system (RCS) and maintained at proper concentration for long-term reactivity control. A loss of coolant accident (LOCA) could place a significant demand for borated makeup water that may exceed the refueling water storage tank (RWST) capacity and if containment sump recirculation fails or is unavailable, additional sources of borated water would be required. This source may be a large tank of concentrated boric acid, such as the boric acid storage tank, combined with a large source of water, such as the demineralized water storage tank, at the suction of the charging pumps.

In BWRs, boron is only used when control rods are not available for reactivity control, as in the case of an anticipated transient without scram (ATWS). Reactor water level/power control is used during an ATWS while arranging for boron injection to shutdown the reactor. Boron injection is normally accomplished by the standby liquid control system (SLCS). Other than the SLCS tank capacity, most BWRs only have a limited supply of borated water available and that quantity only exists in an unprepared form.

Other related strategies include Subsections 2.3.2, "Strategy to Refill Refueling Water Storage Tank With Borated Water," and 6.2, "Strategy to Inject Borated Water in Case of Potential Core Damage and to Guard Against Boron Dilution in the Core."

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR and PWR vendors and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. In the EOPs reviewed for PWRs, there exist methods and practices for mixing boron and water and then injecting the mixture into the RWST at a limited rate.

For BWRs, the EOPs examined provided for additional supplies of boron and alternate methods of injection in response to the ATWS rule. They may not be sufficient for accident conditions where core damage is anticipated.

Possible Adverse Effects

Other than generic concerns discussed in the Introduction of this report, there were no specific concerns identified for this strategy.

6.2 Strategy to Inject Borated Water in Case of Potential Core Damage and to Guard Against Boron Dilution in the Core (BWR)

Strategy Description

The aim of this strategy is to ensure that proper concentrations of boron can be injected and maintained in the reactor core when core uncovery and possible damage are suspected. This strategy is accomplished by the appropriate use of the standby liquid control system (SLCS) or an alternate injection method such as the control rod drive (CRD) system, the reactor water cleanup (RWCU) system, etc., using a limited capacity source of borated water (see Subsection 6.1, "Strategy to Provide Additional Supply of Borated Makeup Water for Long-Term Accident Control"). Borated water supply for an alternate injection method may be accomplished by temporary connections. Most plants require AC power for boron injection. A source of independent power for boron injection may be desirable in the case of a station blackout that results in core damage. The strategy for such a power source is covered in Subsection 4.6, "Strategy to Use a Diesel Generator or Gas Turbine Generator to Power a Control Rod Drive or Other Appropriate Pump for Core Injection."

In the event of an accident involving core uncovery, the control rods are predicted to begin to melt prior to the fuel rods, thus core reflood could result in possible recriticality. To avoid or reduce the chances of recriticality and possible associated rapid power generation, borated water could be injected using the systems mentioned above.

Once the boron has been injected into the vessel, adequate boron concentrations need to be maintained in the core. The reactor vessel refill rate should be controlled so that boron is not lost from the core. As long as water escapes the vessel in the form of steam above the water level, significant amounts of boron should not escape; boron dilution, therefore, should not be an important concern. If, however, it escapes below the water level boron may be lost from the core and dilution may provide a recriticality concern. Until a source of borated water is again available and injected to shut down the reactor, the potentially damaged core will have to be cooled by unborated water injection at controlled rates. A balance of reactor water level/power control will have to be achieved, which will have to be maintained until some method can be found to inject boron. This might be accomplished by CRD pump(s) possibly used in conjunction with another injection pump, the combination of which would be sufficient to control and maintain an appropriate water level.

The use of CRD pump(s) is covered in Subsection 3.3.1, "Strategy to Use Control Rod Drive Pumps for Core Injection." If power level can be controlled at a low level, by maintaining liquid at appropriate levels in the core, damage may be stopped and core cooling may be achieved, although it is not assured.

The unborated water injection part of this potential core damage related strategy is assessed as being beyond the design basis of a plant and requires further investigation including consideration of planning and training if such a situation is anticipated.

Other related strategies are mentioned above.

Relationship With Current Requirements and Practices

The generic emergency procedure guidelines of the domestic BWR vendor and the Emergency Operating Procedures (EOPs) of several plants were examined to determine the extent to which this strategy has been implemented. Procedural steps to inject borated water from SLCS and alternate injection paths were found in several plant EOPs. The initiation of borated water found in the EOPs was in response to an anticipated transient without scram (ATWS). No procedures were found that address boration in the event of core damage.

Possible Adverse Effects

During an accident involving core damage with a very low vessel water level, the injection of unborated water at a high flow rate may significantly increase reactor power with detrimental effects (including the possibility of increased fuel rod failure). Controlling water level and flow appropriately after the onset of core damage may be difficult even when using the CRD pumps. This is especially true when unborated water is injected and boron dilution is a reactivity concern.

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11. ABSTRACT *(200 words or less)*

A set of selected candidate accident management strategies, whose purpose is to prevent or mitigate in-vessel core damage, were developed from various NRC and industry reports. These strategies have been grouped in this report by the challenges they are intended to meet, and assessed to provide information which may be useful to individual licensees for consideration when they perform their Individual Plant Examinations. Each assessment focused on describing and explaining the strategy, considering its relationship to existing requirements and practices as well as identifying possible associated adverse effects.

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