Handbook for

Phase 3 Fire Protection (FP)

Significance Determination Process (SDP) Analysis

December 30, 2005

ABSTRACT

This handbook was developed with two purposes in mind. First, it provides documentation of Phase 3 fire review activities such that interested staff or individuals can use this handbook to review and understand the analytical methods typically being used to process a Phase 3 fire protection significance determination process (SDP) review. Secondly, this document is intended to be a starting point or developmental step towards a longer range goal of generating the ability for more Phase 3 fire protection SDP activities to be accomplished within the NRC staff.

This handbook, while voluntary in its use, provides a structured framework for conduct of the Phase 3 fire protection SDP, based on state-of-the-art methods and practices developed under the Fire Risk Requantification Study. The Fire Risk Requantification Study was conducted as a joint activity between the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission (NRC) Office of Nuclear Reactor Research (RES), under terms of an NRC/EPRI Memorandum of Understanding.

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1.0 INTRODUCTION

1.1 Objectives and Scope of this Document

This document is intended to provide a framework for performing Significance Determination Process (SDP) Phase 3 analyses of fire protection issues, using established risk analysis tools methods and data, and to present issues encountered and lessons learned from previously completed Phase 3 SDP analyses, and the techniques used to address them.

The step-by-step process for conducting a limited-focus Phase 3 risk analysis is covered and the tools and recommended techniques that have successfully been applied in prior Phase 3 analyses are described. This document is not intended to supplement or replace existing fire probabilistic risk assessments (fire PRAs) nor are the methods presented here to be applied in performing broader (e.g., plant-wide) risk assessments.

This document is written for PRA practitioners with general familiarity of fire protection issues.

1.2 Background Information

The Fire Protection Significance Determination Process involves a series of qualitative and quantitative analysis steps for estimating the risk significance of inspection findings related to licensee performance in meeting the objectives of the fire protection defense-in-depth (DID) elements:

- Prevention of fires from starting,
- Rapid detection and suppression of fires that occur, and
- Protection of structures, systems, and components (SSCs) important to safety so that a fire that is not promptly extinguished by fire suppression activities will not prevent the safe shutdown (SSD) of the plant.

The Fire Protection SDP is based on simplified methods and approaches of a typical Fire PRA. The general philosophy of the Fire Protection SDP is to minimize the potential for false-negative findings, while avoiding undue conservatism. The Fire Protection SDP process is applied in a three-phase manner.

Phase 1 is a preliminary screening check intended for use by the Resident or Regional Office inspector(s) to identify fire protection findings with potential risk significance. If the screening criteria are met, the finding is assigned a preliminary risk significance ranking of Green and no further analysis is required. If the Phase 1 screening criteria are not met, the analysis continues to Phase 2.

Phase 2 involves a quantitative assessment of the increase in core damage frequency (CDF) due to a finding. A simplified, step-wise, conservative approach is employed. Each time new or refined analysis results are developed, a screening check is made to determine if a sufficient basis has been developed to justify assignment of a preliminary significance ranking of Green. If at any time the quantitative screening criterion is met, the analysis is considered complete, and subsequent steps need not be performed. Each step represents the introduction of new detail and/or the refinement of previous analysis results. Compensatory measures that might offset (in

part or in whole) the observed degradation are considered in Phase 2. If the determination of the Phase 2 assessment remains potentially safety significant, the finding may be turned over for a Phase 3 analysis.

The main objective of the Phase 3 assessment, as in the Phase 2 assessment, is to estimate the increase in CDF, associated with the finding. Phase 3 analysis is a focused PRA assessment of those fire protection findings that do not screen during the Phase 2 analysis. If determined necessary, this phase is intended to refine or modify the earlier screening results from Phases 1 and 2. Phase 3 analyses utilize current PRA techniques and rely on the expertise of knowledgeable risk analysts. The Phase 3 review is not mandatory and is only intended to confirm or refine the results of significant (i.e., White or above) findings from the Phase 2 assessment.

The Phase 3 process focuses on those specific items that can impact the principal elements of the defense in depth for fire protection. For example, preventing fires from starting depends on such issues as ignition frequencies and proximity of fuel sources. Rapid detection and suppression of fires is affected by such issues as the reliability and effectiveness of automatic detection and suppression systems, the ability of the fire brigade to respond once called into action, fire propagation and growth characteristics, and severity of the fire at the time suppression is attempted. The impact that severe fires may have on SSD capability depends on specific systems and equipment directly challenged by the fire. The impact may also depend on the time to equipment damage given exposure to the fire and possible mitigating influences resulting from feasible manual actions. When considering the possibility of core damage from a fire event, often it is necessary to include potential consequences in terms of conditional core damage probability (CCDP) given the loss of one or more safety functions.

In support of these evaluations, general areas of a Phase 3 analysis include development of fire scenarios, conducting detailed analysis of installed fire barriers and fire detection/suppression systems, the impact on SSD components (including the effects of fire damage to cables), human factors (including operations and fire brigade personnel), modeling of fire propagation and timing estimates, and development of a plant model (event tree) to evaluate the possible impacts/responses resulting from a fire in a particular room.

1.3 Document Structure and Organization

This guide provides detailed discussions of the recommended methods, tools and techniques to apply during the conduct of an SDP Phase 3 analysis of fire protection issues. Chapter 1 provides-the overall objectives and scope of this document along with some general background material. Chapter 2 provides a brief overview of the complete process, including general descriptions of the required expertise and roles of the analysis team. Chapter 3 discusses the technical approach for conducting a Phase 3 analysis, presented in the form of specific activity steps. Chapter 4 provides detailed discussions of specific technical elements that comprise the Phase 3 analysis process. References cited within the guide are provided in Chapter 5. An example case illustrating the use of this procedure is provided in the appendix.

2.0 SDP PHASE 3 PROCESS OVERVIEW

2.1 The Overall Approach

Phase 3 analysis starts with a problem statement developed in Phase 2. Typically the problem statement addresses a specific performance deficiency in the plant that combined with a set of events or failures that potentially yield a core damage frequency greater than 10^{-6} per reactor year (i.e., other than Green risk color). Two examples are provided below:

> Example 1 – A review of the fire protection program had revealed that the licensee had not properly identified the routing of certain safe shutdown related cables. These cables were associated with one Charging System valve and two Component Cooling System valves. Spurious closure of these valves was assumed to cause loss of charging and component cooling supply to the RCP seals. The Phase 2 SDP Analysis had concluded that, because these cables were not protected, the fire risk of certain compartments was found to be other than Green.
>
> Example 2 - A review of the fire protection program revealed that the licensee has not conducted an adequate analysis of the effectiveness of the fire protection system for a segment of the cable tunnel from the hazards posed by the main transformer. Ejected burning oil from a catastrophic, energetic failure of the main transformer may potentially enter the cable tunnel through the gaps in a non-rated barrier hatch cover, causing damage to an important set of safety-related cables.

As it is demonstrated with these examples, a Phase 3 analysis is generally focused on a few specific areas of the plant. These two examples also point out that there could be wide differences among Phase 3 problem statements. In one case, the focus is on incorrect cable routing information and in the other case the focus is on fire propagation and damage. The approach employed should be tailored to the specifics of the problem. The analysis team should devise a strategy for analyzing each specific case. Various possible strategies are discussed in Section 2.3 below. However, in all cases, the overall approach can be divided into the following steps:

Step 1 - Preparation

The informational needs in terms of engineering drawings, analysis reports and calculation sheets for preparing the Phase 3 analysis is identified in this step. The on-site activities of the team are planned and coordinated with the licensee, the NRC Region representative(s) and NRC-NRR headquarters.

Step 2 - Site Visit

A site visit is necessary to ensure that all relevant areas of the plant are directly inspected and to facilitate meetings with licensee personnel that are most knowledgeable of the various aspects of the wide range of issues that may arise. The site visit should be regarded as the main opportunity to gather and verify the needed information and identify key issues necessary to conduct the Phase 3 analysis.

Step 3 - Post Visit Analysis
The Phase 3 analysis entails postulation of fire scenarios and related analyses leading to scenario occurrence frequency estimation. It also includes core damage frequency analyses based on the failures and conditions resulting from the postulated fire scenarios and failure analyses of various system elements and operator actions. A simplified plant response model (e.g., an event tree) is developed and used to facilitate core damage analyses and computations.

Step 4 - Report
The results are presented in a letter report format. The report should include a discussion of the problem, a summary description of the analysis and the results.

These steps are further discussed in Section 3 below.

2.2 Required Expertise

Fire risk analysis is a multi-disciplined endeavor requiring an understanding of:

- Probabilistic analysis of fire events (i.e., ignition, propagation, detection and suppression)
- Effects of fire environment on plant equipment and cables
- Possible circuit failure modes and their effect on system components
- Plant response to postulated equipment failures
- Probabilistic modeling of operator actions in response to equipment failure

Therefore, the Phase 3 analysis team should be composed of personnel who have working knowledge of the above listed disciplines.

Fire scenarios are often found as risk significant in nuclear power plant risk analysis. The main reason lies with the potential for multiple equipment or multiple system impact through cable fire damage. The principal cables of concern are generally associated with control and instrumentation circuits. Expertise in circuit analysis is often needed to establish the possibility of occurrence of the postulated failure modes of the equipment. It may be noted that the various failure modes of power cables may need to be considered as well to identify possible loss of equipment function.

Probabilistic analysis of postulated fire events requires experience in several areas. It requires experience in probabilistic modeling of fire ignition (fire ignition frequency analysis). A collection of methods and models are available for fire growth and propagation analysis that range from very simple spreadsheet based estimates (e.g., fire dynamics tools, as described in NUREG-1805 [Reference 1]) to very complex computer programs. Experience in properly selecting the computational method and required input data is needed to establish the thermal and temporal behavior of the postulated fire scenario. Fire detection and suppression analysis may require knowledge of fire protection systems features and fire fighting strategies and experience in probabilistic modeling of the detection and suppression failure scenarios.

The core damage frequency is often estimated from an elaborate model of plant response to postulated equipment failures. Such models are generally based on event trees and fault trees. Use of these models requires a thorough knowledge of the plant systems used for core cooling, core cooling strategies, equipment capabilities, and limitations of the plant.

Operator actions or failure in carrying out certain tasks are often an integral part of core damage scenarios. Human error probability analysis may require expertise in plant operations and probabilistic modeling of operator actions.

It must be added that not all Phase 3 cases may require all the various expertise typically used in a complete fire risk analysis. Each Phase 3 case is expected to have its unique characteristics and conditions.

2.3 Analysis Strategies

The objective of Phase 3 analysis is to arrive at a best risk estimate (i.e., color) for the finding using realistic methods and data deemed appropriate. One way the Phase 3 objective may be achieved is if it can be verified that the color of the finding is Green at any step of the analysis. For example, if the finding is about the location of certain cables, one may just focus on the circuits associated with those cables to verify that the postulated equipment failure modes are or are not possible to occur. If the circuit analysis yields that none of the postulated failure modes are possible, no further analysis would be needed. In the case of a burning oil spill on the hatch of the cable tunnel, the initial focus of the analysis should be a verification of the possibility of burning oil entering the cable tunnel. These two examples illustrate that the Phase 3 level of effort can be significantly minimized if the proper analysis strategy is employed.

The analysis strategy will depend on the specifics of the finding. The overall approach should be to focus on those parts of the problem that will yield a reduction in conservatism and uncertainty. The analysis process of arriving at a core damage frequency associated with a finding can be divided into the following segments:

- Fire scenario postulation
- Identification of combinations of equipment (target[1] sets) that may be affected by each postulated fire scenario
- Circuit analysis
- Ignition frequency estimation
- Fire propagation analysis
- Non-suppression probability estimation
- Human error probability estimation
- Conditional core damage probability estimation

The analyst should examine every one of these elements and identify those that will yield the largest reduction in conservatism and uncertainty.

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1 Per Reference 2, the term target may refer to fire damage targets and/or to an ignition target. A fire damage target is any item that could be adversely affected by the modeled fire. Typically a fire damage target is a cable or equipment item that belongs to the Fire PRA Component list. An ignition target would be any flammable or combustible material to which fire might spread.

Scenario postulation, target set identification, ignition frequency estimation, and fire propagation analysis are interrelated. This set can generally be addressed by the same strategy. For example, often it can be easily shown that a specific ignition source cannot damage a specific target set above or near the source. This allows the analyst to screen ignition sources using simplistic and conservative data and methods. Screening ignition sources is one method of screening postulated scenarios and the final effect is reduction in ignition frequency estimation, which should yield a more realistic final CDF estimate. Thus, if the analyst would suspect that a significant reduction in fire occurrence frequency can be demonstrated by screening the ignition sources, the first step of the analysis may then be focused on this part. Also, based on this exercise, the analyst would select those ignition sources that will be subjected to a detailed analysis.

A circuit analysis may yield that the postulated equipment failure mode cannot occur from the specific cable that has been identified at the specific location of the postulated fire scenario. If this conclusion can be reached, the entire analysis has to be revisited to ensure that other scenarios do not exist that may be relevant to the finding. A circuit analysis may also yield that the probability of the failure mode (given cable damage) is relatively small.

A review of the operator actions may provide the basis to determine the focus of the detailed analyses. If the licensee's mitigation strategy for the Phase 3 problem statement includes operator actions, an initial, somewhat detailed review of relevant procedures and chain of events may yield useful information. For example, if it can be demonstrated that the human error probability is relatively small, which would also result in a small CCDP, no detailed fire analysis may be needed. Using a conservative estimate for fire occurrence frequency, the analyst may be able to conclude that the final risk level is Green.

The analyst has to use judgment and personal experience with past fire risk analyses to determine areas of analysis concentration. Since it is not possible to anticipate all the different conditions that may necessitate a Phase 3 analysis, a comprehensive treatise of potential strategies does not seem to be possible. Review strategies that were followed in past Phase 3 analyses are discussed below as further illustrations on this matter.

Case 1 – New Cables Identified

The licensee had not properly identified the routing of certain safe shutdown related cables. The Phase 3 problem definition established the need to assess the fire risk of five plant compartments where those cables were present. The compartments were large spaces in the plant with a large number of cable trays below the ceiling. However, failure of the majority of the cables was found to have little adverse effect on safe shutdown. Based on a conservative fire propagation analysis it was concluded that a severe fire affecting all the cables and equipment in each compartment was extremely unlikely. From a review of the location of various cables and the function and failure modes of the affected components, a set of localized sub-areas within the compartments were identified that had a unique combination of cables. Only those sub-areas that contained the newly discovered cables were retained for further analysis. Ignition sources were identified for each sub-area, which included transient combustibles. Based on the ignition sources the fire ignition frequencies were estimated. The CCDPs associated with the sub-areas

were calculated assuming all the cables of the sub-area are lost. Based on the CDF (derived from multiplying the CCDP and ignition frequency) a small group of sub-areas with the highest CDF value were selected for fire propagation, detection and suppression analyses.

Case 2 – Procedure Deficiency
The licensee's procedures did not provide sufficient guidance to ensure, once Reactor Coolant Pump (RCP) seal injection is lost, that it is restored quickly enough to preclude the possibility of severe drop in pressurizer level. Additionally, given the delay in aligning the charging system cross-connect line from the other unit, existing procedural guidance to restore seal package cooling immediately following system cross-connect could have aggravated the severity of seal package damage. This increased the likelihood of, and consequences from, an RCP seal LOCA. In this case, the RCP seal injection failure possibility was studied. Specific plant functions were identified that if failed, would result in the RCP seal injection failure. For those functions, the circuits and associated cables and buses were identified that if failed, would result in function failure. The collection of rooms where the two redundant safety-related 4kV switchgears were located was identified as the only area within the plant where complete loss of RCP seal injection would be experienced. A fire propagation analysis verified that there are no fire scenarios that may damage cables in the adjacent rooms. The focus of the analysis was then shifted towards specific cables and combination of electrical cabinets (e.g., 4kV switchgear) that would cause the postulated damage. Several localized areas (sub-areas) within one switchgear room were identified. The remainder of the analysis focused on the ignition sources and fire propagation scenarios based on the equipment and cables within each sub-area.

Case 3 – Cable Tunnel Fire Due to Large Transformer Failure
The Cable Tunnel hatch was located near the main transformer. The hatch cover was a non-rated barrier that separated the Cable Tunnel, a safety-related area, from a non-safety related area (main transformer yard). A catastrophic, energetic failure of the main transformer could eject burning oil on top of the hatch. The oil could potentially enter the tunnel through the gaps in the hatch and ignite the cables of important safety equipment. The analysis, therefore, focused on the ignition source frequency evaluation and the possibility of burning oil passing through the gaps between the hatch and its frame. It was concluded that the flames would not be quenched while passing through the narrow gaps around the hatch cover and there was a possibility of a fire inside the cable tunnel if burning oil dropped on the hatch. An analysis of the fire detection and suppression systems and fire brigade response was also conducted at the initial stages of Phase 3 effort. It was concluded that no credit could be given to the fire brigade putting the fire out before cable damage occurred. However, the water deluge system was credited. It was concluded that it could put the fire out before significant damage would occur.

3.0 OVERALL ANALYSIS PROCESS STEPS

This chapter provides a discussion of the overall analysis process steps that were introduced in the preceding chapter.

3.1 Step 1: Preparation

The main purpose of this step is to prepare for the site visit and anticipate analysis needs during and after the visit. This step includes the following:

- Identification of informational needs
- Planning of on-site activities
- Communication and coordination with licensee and other members of site visit team

3.1.1 Informational Needs

The informational needs, in very general terms, can be categorized as those specifically defining the problem and those that provide information about the plant, its PRA and fire PRA.

The following informational items should be obtained and reviewed prior to the site visit:

- Phase 2 analysis report and supporting calculation sheets
- Engineering drawings (preferably piping and instrumentation diagrams) of relevant systems
- Layout drawings of areas that may be analyzed
- Fire protection documents and fire response plans for those areas
- Relevant operating and other procedures

The following informational items may also be beneficial to be reviewed prior to the site visit:

- Appendix R analysis report
- Fire hazard analysis report
- IPEEE submittal to the NRC
- IPE report

Since most plant documents are updated as changes take place in the plant, it is important to obtain those document versions that were in effect during the performance period associated with the finding. In practice this may pose some difficulties because current conditions of the plant may not match that observed by the inspectors at the time the finding was identified. Despite this difficulty, the SDP protocol dictates that Phase 3 analysis be conducted assuming plant conditions identical to that existing during the performance period associated with the finding.

3.1.2 Planning

The Phase 2 analysis report and related available documents should be reviewed and a site visit planned to address the specific issues raised in that analysis. The plan would streamline the expected activities at the plant and facilitate licensee's assistance. The following issues may be considered and planned for prior to the site visit:

- Schedule and duration of site visit
- Contact persons for the plant, licensee, NRC Region and NRC-NRR
- Plant areas to be visited
- Need to take a camera into the plant
- Plant documents that will be requested for review
- Plant or licensee experts that will be needed for an interview
- Analysis team members who will be participating in the site visit

It is not necessary to prepare a written plan. However, it will be beneficial for the person responsible for orchestrating the visit to maintain notes on the above listed topics. It is important to schedule the visit at a time when the plant areas of concern would be in the condition postulated by the Phase 2 analysis. For example, if the analysis is focused on power operation, a site visit during an outage is not recommended. Plant conditions during an outage are markedly different from normal power operation conditions. This is especially important to the fire risk analysis because often equipment is moved into or out of plant areas and transient items are often brought into an area during an outage that are normally stored at a different location.

Plant areas may be selected liberally before the visit. During the visit, after an initial review of the findings, the list can easily be shortened. It is often more difficult to add new areas because of time constraints or operational conditions.

Some of the documents, because of their size, are more conveniently reviewed on site. The analysis team may then request copies of specific sections or pages for a more detailed post-visit review. For example, the information supporting circuit analysis is generally found in a very large stack of oversize drawings and computerized data reports. The analyst responsible for circuit analysis generally needs a small subset of those drawings.

Plant personnel who are familiar with the following aspects of the identified issue should be available during the site visit to be interviewed or participate in discussions with the analysis team:

- Plant operations: control room and plant operators, who would be familiar with the normal and emergency operating procedures, level of personnel training, etc.
- System functions: often members of the engineering staff, who would be familiar the specific design features of the system(s) of interest and related equipment items, control strategies and plant response to various upset conditions.
- Existing PRA models: licensee staff who are responsible for developing and running the PRA model and have a clear understanding of the various assumptions underlying the model.

- Fire protection analysis (e.g., Appendix R compliance): plant personnel who are familiar with equipment and cable locations, assumptions underlying the analysis done for maintaining compliance, information sources supporting the analyses, etc.

In addition, the fire protection system experts and fire brigade coordinators may need to be available for the interviews. It is extremely important for plant personnel who are intimately familiar with the specific areas of concern to accompany the analysis team during plant walk downs.

3.1.3 Communications with Licensee and the Team

As part of the planning process the licensee, the NRC Region representative(s) and NRC-NRR headquarters should be contacted about the site visit. The licensee needs to know who will be visiting the site, the length of the site visit, and which licensee staff members should be available for interviews or participation in meetings during the site visit. The licensee also needs to know the documents that will be requested and reviewed. It is also important to request from the licensee a room of sufficient size for use by the analysis team for the duration of the visit. The room should be large enough to accommodate the full analysis team and several members of licensee staff, and have sufficient table space for at least two teams to work simultaneously on large drawings.

3.2. Step 2: Site Visit

The site visit is the main opportunity for the analysis team to gather and verify the needed information and identify key issues necessary to conduct the Phase 3 analysis. The site visit may include the following activities approximately in the order listed below:

- An initial meeting with licensee staff about logistics, areas to be visited and schedule of key meetings
- Plant walk down and direct inspection of plant areas relevant to the finding
- Identification of focus areas (analysis strategy)
- Discussion sessions with licensee staff about walk down observations and the PRA model that can be used to estimate the CCDP and CDF
- Document review sessions
- Revisit relevant plant areas, if needed
- Exit meeting

It is important to emphasize to the licensee in the initial meeting that their participation in the discussion sessions would be welcome and their views would be taken into consideration. Plant walk downs should be conducted carefully and deliberately. In each area, sufficient notes and pictures (if necessary) should be taken to ensure that the exact setup of the area is fully understood by analysis team members. If manual actions are part of the finding, the route of the

operators and specific actions taken should be walked down and verbally demonstrated.
The focus of the discussion sessions should be on: 1) plant conditions as observed at the time of this walk down and the conditions as they existed during the performance period associated with the finding, 2) PRA models that will be built to provide the CCDP and CDF estimates for the conditions as they existed during the performance period associated with the finding, and 3) methods or data for estimating fire scenario occurrence frequencies. Often, many diverse and very specific questions arise during these sessions. The licensee's presence facilitates finding answers and locating relevant documents and facts. It is recommended that the analysis team obtain and review all relevant documents during the on-site visit to ensure that any additional issues generated from this review can be addressed before departing the site.

It is often necessary to revisit relevant plant areas and refocus some of the walk down observations. Additional plant areas may be visited as a result of discussion sessions.

The main purpose of the exit meeting should be to verify any additional informational needs to be provided after the site visit. The analysis team will not have any final conclusions to share with the licensee; however, based on direct site observations and information reviewed, the team may have a revised focus that could be shared with the licensee.

3.3 Step 3: Post Visit Analysis

The Phase 3 analysis process, as noted earlier in this guidance, is based on fire PRA methodology (see Reference 2 for the most recent description of a Fire PRA methodology and related data.) Unlike a fire PRA that addresses the entire plant, the methodology employed for a Phase 3 analysis is focused on a specific issue or plant area. This Phase 3 analysis process is performed based on the information obtained during the site visit (Step 2) and can be described in the following set of tasks listed in the approximate order of execution:

- PRA model development (generally an event tree)
- Identification of relevant systems and components
- Circuit analysis (if necessary)
- Component and cable locations (i.e., identification of plant areas of concern)
- Fire scenario development and target sets
- Fire ignition frequency estimation
- Fire propagation analysis
- Fire detection and suppression analysis
- Fire scenario occurrence frequency estimation
- Analysis of manual actions outside the control room
- CCDP estimation
- CDF estimation

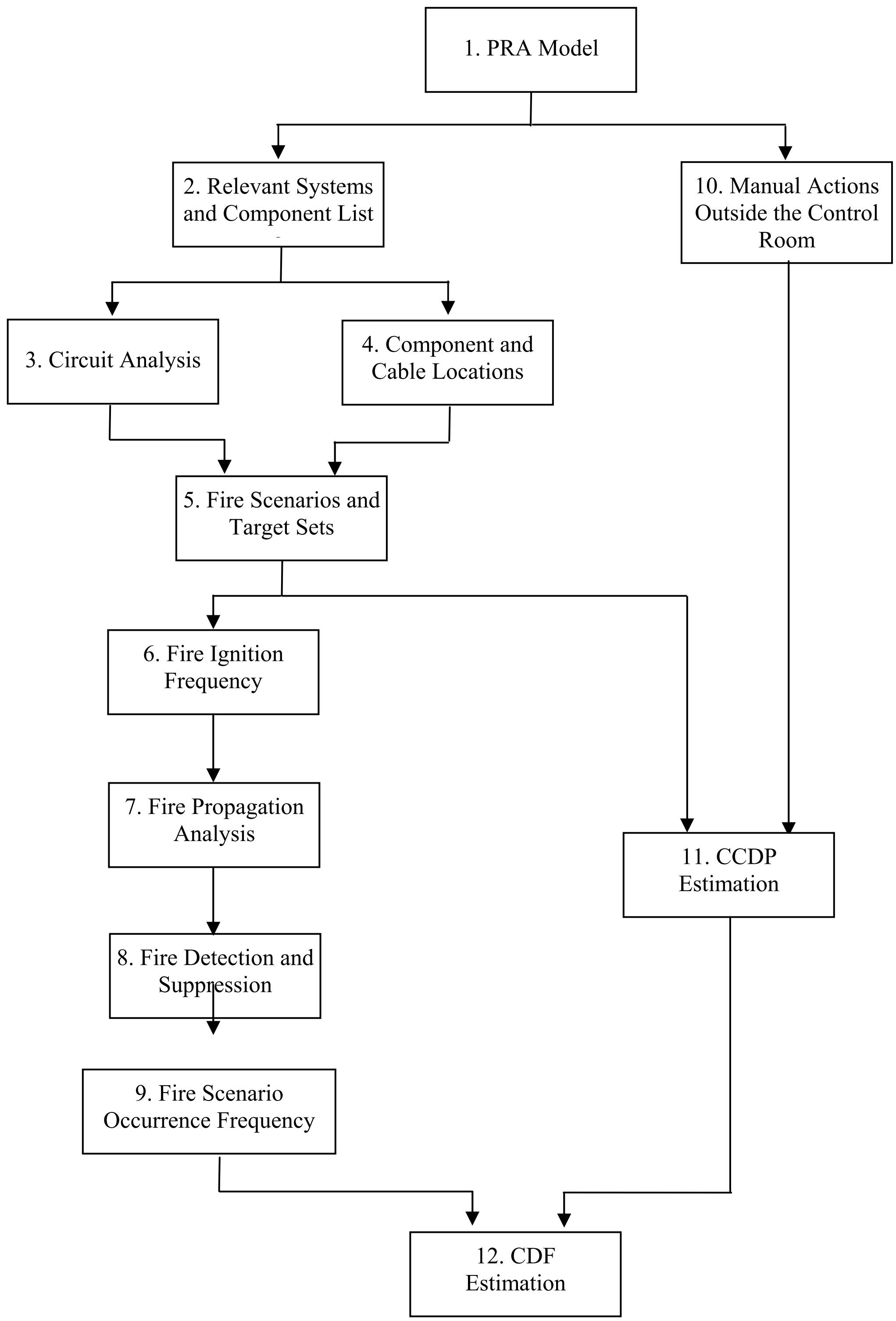
Figure 1 provides a flow chart of these tasks. A discussion of each task is provided in Section 4. The sequence presented in this chart should be regarded as approximate. Adjustments are often necessary based on the specific needs of a Phase 3 SDP problem. For example, circuit analysis may not be necessary if control cables are not a part of the problem. Also, the analyst may have to revisit some of the tasks after other tasks are attempted. For example, the event tree in the first task may need to be readjusted based on new information gained during the manual actions analysis task.

It may be necessary to develop a new event tree model or modify those in the existing PRA to address the Phase 3 issues (block 1 in Figure 1). The event trees should generally be in terms of the availability or proper operation of certain systems, plant components and operator actions. From this collection of systems, components and operator actions, a list of components (block 2) and a list of specific chain of operator actions (block 10) can be prepared. The list of components would lead to the circuit analysis set. Circuit analysis (block 3), in addition to establishing the possibility of occurrence of the failure modes considered, would also provide the location of cables where the components of concern would be affected. Parallel to the circuit analysis, location of the components of concern should also be noted. From this information (i.e., combined locations of component and cables), those plant areas that can affect the finding are identified (block 4). For each area, the exact position of the cables, components of concern and ignition sources should be identified. The exact location of these items provides the bases for the fire scenarios (block 5) that should be analyzed in some level of detail. An integral part of fire scenario definition should include the affected target set, which in combination with manual actions identified earlier would allow CCDP estimation for the scenario.

Fire ignition frequency (block 6) is generally based on the ignition sources accounted for in the fire scenario. Fire propagation analysis (block 7) yields the possibility of damage to the target set (i.e., cables and components) of each scenario. If damage is not possible, the scenario can be screened out. Otherwise, the time to damage is estimated. In addition, the severity factor (i.e., the conditional probability that fire damage is possible given fire ignition) is established in this task. A fire detection and suppression analysis (block 8) is conducted based on time to damage and available fire protection features to estimate the probability of non-suppression before damage occurs. By combining the ignition frequency with the severity factor and non-suppression probability, a fire scenario occurrence frequency is estimated (block 9).

CCDP is estimated (block 11) for each fire scenario separately using the event tree developed earlier for the Phase 3 analysis. From the CCDP and fire scenario frequency, the CDF of each fire scenario can be calculated and total CDF relevant to the finding established (block 12).

Figure 1 SDP Phase 3 Fire PRA Process



It is important to note that, as it is discussed in Section 2.3, an overall analysis strategy may be necessary to focus the level of effort. The strategy can be developed only after the analysts have gained an understanding of all the elements of the findings, relevant conditions and availability of supporting information and data. As part of the analysis strategy development, the analysts should develop a general plan on how each task will be conducted. The analysts may need to develop a list of scenarios to be considered and a complete set of analysis steps.

In the case of cable tunnel hatch example, potential cable tunnel fire scenarios caused by a main transformer area fire were identified first. The scenarios started with a fire event at the main transformer area. The possibility of propagation of the fire into the cable tunnel via the hatch was examined next. The scenario was completed by establishing fire detection and suppression failure before cable damage, operators' response to the tunnel fire and finally the possibility of cable damage inside the tunnel. It should be noted that the operators' response included an elaborate and coordinated set of actions by several operators at a wide range of areas in the plant. In this case the analysts chose to first ascertain that indeed burning oil would pass through the hatch and continue to burn inside the tunnel. After that was established using deterministic models, the various failure modes of the main transformer and other high voltage oil-filled equipment were examined using a cursory review of equipment layout and characteristics. This step established the possibility and frequency of occurrence of burning oil on top of the hatch. The possibility of fire suppression before damage was examined next. Fire propagation analysis was not conducted because the analysts deemed that little would be gained from it. Cable damage would occur in a short time because of the short distances between the cables and possible locations of the fires. Finally, human error analysis was conducted using the specific conditions of the large fire event of the main transformer affecting some of the areas where the operators had to pass through or conduct certain tasks. This example illustrates that the level of detail and focus of the analysis depends on the specifics of the problem addressed in a Phase 3 analysis.

3.4. Step 4: Report

Documentation of the Phase 3 analysis is provided in the form of a letter report. The content of the report should include the following topical sections:

> The letter report should begin with a very brief (one sentence) statement of the fire protection issue being analyzed.
>
> *1. Performance Deficiency*
> Provide a brief, one or two paragraph, statement of the fire protection finding being analyzed. This description should identify the specific fire areas of concern, the potential consequence of a fire on reactor safety, and any aggravating circumstances identified. This statement should follow closely the description of the performance deficiency provided in the Phase 2 analysis.

2. Analysis Approach
Provide a listing of the specific steps taken to complete the Phase 3 analysis. The steps are usually listed individually first, followed by a 1-2 paragraph summary of the purpose and activities associated with each step of the analyses.

3. Walk Down and Preliminary Conclusions
This section provides a complete description of the fire area walk downs conducted during the on-site visit along with any pertinent information or details noted. This is where any of the "facts" discovered during the plant visit and concurrent interviews with personnel are documented. Such facts form the foundation of the remaining steps of the Phase 3 analysis.

4. Assumptions
A list of the assumptions that were incorporated into the analysis is provided along with the technical or practical reasons for including them.

5. Fire Scenarios Considered and Qualitative Screenings
This section provides a detailed discussion of each fire scenario proposed by the analysis team and offers the basis for inclusion or exclusion from further analysis. Use of charts, tables or drawings may be required to clarify the scenario or basis for inclusion/exclusion. The justification for screening any scenario out of the analysis should be well documented and supported by defensible reasons.

Note, more than one fire scenario for a single fire area may be postulated for the remaining steps in the Phase 3 analysis process. As long as any fire scenario is credible and has risk significance to reactor safety, it should be carried forward in the analysis.

6. Fire Ignition Frequencies
The initiation frequency of each scenario is based on the fire ignition frequencies of potential ignition sources (e.g., components or combustibles-either fixed or transient) identified for each fire scenario. The information sources used to establish the frequencies and any additional analysis leading to the final frequencies should be described in this section.

7. Fire Scenario Analysis
Each fire scenario not screened out in Section 5 is described in detail, from fire initiation, through fire growth and propagation, and, finally, expected plant/personnel response. Here the mitigation of conservatisms should be applied in designating frequencies, fire growth, propagation, and non-suppression where possible. Generous use of tabular and graphical data should be made in support of the fire scenario analysis and underlying assumptions. Any supporting calculations and applied methodologies should be documented in an appendix to the report.

8. Conditional Core Damage Probability
Event trees are used to estimate the conditional core damage probability for each fire scenario. The event trees and their associated split fractions should be provided in an appendix, but the significant aspects and results of the CCDP determination should be discussed in this section. Particular mention should be made of those event tree sequences that are significant contributors to the CCDP estimate. Also, any governing assumptions made during the development of the event tree logic and during the assignment of split fraction values should be presented and justified.

9. Integrated Assessment of Fire-Induced Core Damage Frequency
The CDF for each fire scenario is calculated by multiplying the scenario's occurrence frequency (Section 7) and its associated CCDP (Section 8). A tabulated summary of these values should be provided with the sum of the separate scenario CDFs representing the overall risk estimated for the performance deficiency being studied. In addition, any known uncertainties and remaining conservatisms should be noted and discussed with respect to their impact on the result.

10. Conclusions
A very brief summary of the performance deficiency, the analyses performed and the results is provided. It is usual practice to assign a color value to the total risk significance (CDF estimate) of the finding as determined in Section 9, where Green indicates a risk level less than 1E-6, White for risk levels between 1E-6 and <1E-5, Yellow for those between 1E-5 and <1E-4, and Red for risk levels found to be equal to or greater than 1E-4.

11. References
Any cited references in the report, especially the documents used, are listed sequentially. The precise date and revision number of each cited reference should be noted in the list of reference.

Appendices
Supporting information of the circuit analyses, fire propagation and suppression analyses, event trees, etc. may be provided in the appendices.

It should be noted that because of the sensitivity of certain words and phrases, the report should be reviewed carefully prior to release. Words that have special significance in other contexts, and thus should not be used in the Phase 3 report, include "operability," "inoperable," "non-operational," "unavailable," among others. Suitable synonyms should be used in place of these and similar terms.

4.0 GUIDANCE ON SPECIFIC ELEMENTS OF THE PHASE 3 SDP ANALYSIS

The SDP Phase 3 analysis of a fire protection issue, as summarized in Section 3.3, can be divided into a set of discrete steps or tasks. Figure 1 provided the sequence of these tasks. In this section, each step or task is described in detail. However, the discussions are not exhaustive. Reference 2 is an excellent starting point for in depth treatise of the topics touched on in this Section.

4.1 PRA Model

Establishing the PRA model that applies to the identified Phase 3 issue is the first step of the analysis. It is important to understand that prior to this point, a site visit should be completed and gathered plant-specific information thoroughly reviewed. The analysts should gain a clear understanding of various aspects of the identified issue, relevant existing PRA models and other related analyses.

A PRA model, generally expressed in terms of an event tree, is necessary to establish the sequences of events leading to core damage and to estimate the CCDP. Since the purpose of the Phase 3 analysis is to establish the increase in CDF associated with the identified issue, the PRA model should only address those chains of events that are relevant to the issue. All other sequences are not to be considered.

To establish the plant model, the analysts should have a clear understanding of plant systems, their interrelationships and functions for core cooling and core inventory makeup. There are several sources that the analysts can use for developing the PRA model that addresses the identified issue. For example, the Independent Plant Evaluation (IPE), which is typically an internal events PRA, offers a comprehensive list of initiating events, event trees associated with those initiating events, systems analyses for the branch-points of the event trees and component failure rate analyses for system unavailability estimation. Operator actions and related human error probabilities (under internal events conditions) are also provided in the IPE. A PRA, that includes a fire analysis, may be available from the licensee.

These information sources can serve as the starting point for developing the needed event trees. An event tree starts with an initiating event. For internal events analysis, initiating events are expressed as a transient, loss of offsite power (LOOP), loss of coolant accident (LOCA), etc. In fire risk analysis, scenarios start with fire ignition involving a specific ignition source. The fire then grows and damages the postulated target set (e.g., cables). The effect of target set damage on plant safety can be expressed in terms of system failures (event tree branch points) and internal events initiating events (e.g., transients). Therefore, the analysis for establishing the PRA model should start with a process for establishing the internal events initiating event corresponding to each postulated target set.

Often a circular process is employed to ultimately arrive at the most appropriate initiating event. The plant areas relevant to the identified issue are examined for the safe shutdown cables and

components that are present in that area. From that list, the most restricting initiating event is selected for initial development of the event tree. At later stages of the analysis, this choice may be relaxed based on the specifics of the fire scenarios and new information gleaned from the circuit analysis.

For safe shutdown related to the identified issue, the sequences of events of the event tree should include branch points that specifically address the conditions of the finding. For example, if timely recovery of RCP seal injection is the focus of the problem definition, this action could be one of the branch-points of the event tree. Also, those sequences that do not include the conditions of the finding do not need to be developed completely and may be ignored during the CCDP calculations. For example, if there are branches of the event tree (e.g., irrecoverable loss of seal injection) that do not call out timely recovery of RCP seal injection, those branches need not be addressed in the Phase 3 analysis.

It is preferable for the branch-points of the event tree to have matching branch-points in the IPE or other PRA models so that the corresponding system unavailability analyses can be employed in this study as well. Finally, the end states of the event sequences should be identified as "OK" (meaning that core damage would be averted), "core damage" or "not applicable". Only the core damage sequences should be used in later steps to calculate the CCDP. Fault trees may be employed to model the occurrence of a branch point in terms of component failures or other basic events (e.g., fire damage to cables or manual actions). These fault trees would then be used in estimating the split fractions of the branch points. It should also be noted that the event tree may need to be modified in the later stages of the analysis as new information is obtained. For example, based on the information gained from circuit analysis, the analyst may chose to alter the event tree model to include additional failure modes of the circuits for a certain component.

Figure 2 provides a sample event tree from a Phase 3 analysis where the Phase 3 problem definition was focused on the proper recovery of RCP seal injection. From a review of plant cable routings, it had been concluded that a switchgear fire would challenge the RCP seal injection demanding manual recovery actions. A number of the top events in this event tree are focused on RCP seal integrity. The rest of the top events address systems or parts of systems for which fault trees and other failure models could be readily found in the plant-specific PRA model. The initiating event was assumed to be general transient. It must be noted that the two bottom sequences of the tree (i.e., sequences 17 and 18) do not involve RCP seal failure and do not impact the issues addressed in that SDP Phase 3 analysis. Therefore, they are not developed further and are considered as not applicable (N/A) to the problem.

Figure 2 Plant Model Example – Event Tree for Modeling RCP Seal Injection Recovery

Fire Initiation	RCP Shutdown in 5 minutes	No RCP Seal Failure (1)	Establish Cross Connect With Unit 2	No RCP Seal Failure (2)	Turbine Driven AFW Pump	Maintain Makeup Integrity	Recover 1H Bus Functions	High Pressure Recirculation Cooling	Seq #		CCDP	%
FI	RP1	RP2	U2X	RP3	AFW	U2M	R1H	HPR				
1.0E+00	1.0E+00	9.0E-01	9.0E-01	8.0E-01					1	OK		
				RP3-1								
				2.0E-01	9.8E-01	9.9E-01	0.0E+00	9.2E-01	2	OK		
								HPR-1				
								7.8E-02	3	CD	0.0E+00	0%
							R1H-2					
							1.0E+00	1.0E+00	4	CD	1.6E-01	62%
						U2M-1						
						1.3E-02	0.0E+00	9.2E-01	5	OK		
								HPR-1				
								7.8E-02	6	CD	0.0E+00	0%
							R1H-2					
							1.0E+00		7	CD	2.1E-03	1%
					AFW-1							
					1.9E-02				8	CD	3.1E-03	1%
			U2X-1									
			9.6E-02						9	N/A		
		RP2-1										
		1.0E-01	9.0E-01		9.8E-01	9.9E-01	0.0E+00	9.2E-01	10	OK		
								HPR-1				
								7.8E-02	11	CD	0.0E+00	0%
							R1H-2					
							1.0E+00	1.0E+00	12	CD	8.7E-02	35%
						U2M-1						
						1.3E-02	0.0E+00	9.2E-01	13	OK		
								HPR-1				
								7.8E-02	14	CD	0.0E+00	0%
							R1H-2					
							1.0E+00		15	CD	1.2E-03	0%
					AFW-1							
					1.9E-02				16	CD	1.7E-03	1%
			U2X-1									
			9.6E-02						17	N/A		
	RP1-1											
	1.0E-03								18	N/A		
										Total CCDP	2.5E-01	

* A severe fire is assumed in Switchgear Room B resulting in loss of both emergency buses without possibility of recovery.

4.2 Relevant Systems and Component List

A component list needs to be developed as the leading step for circuit analysis and identification of plant areas of concern. The list should generally include those components and instruments that affect the branch-points in the event tree. Each branch-point should be reviewed carefully and associated components and instrument loops identified. Some of the components are required to remain in their original position. For these components and instrument loops, a circuit analysis may need to be conducted to identify circuit failures that can lead to spurious operation of each component. Other components may need to move position to satisfy the needed core cooling function. For these components, circuit failures preventing the component from achieving the desired position should be investigated. In the case of instrumentation loops, the analysis should ascertain whether or not circuit failure can lead to erroneous readings on the control boards or inadvertent actuation of systems or components.

4.3 Circuit Analysis

The purpose of performing circuit analysis in the Phase 3 assessment is to determine the impact a fire may have on the functionality of specific components required for safe shutdown. If a fire damages a cable associated with a component, the response of the component may be detrimental to the operator's ability in putting the plant in a safe shutdown condition. The analyst is to first identify the cables of safe shutdown components that might be damaged by fire, then perform an analysis of the circuits associated with those cables to determine the possible impacts on the circuit or component serviced by the cable, and finally to estimate the likelihood that the adverse response or behavior will in fact occur.

The first step in performing the circuit analysis is to identify the raceways and cables important to post-fire safe shutdown that are exposed to the defined fire scenarios. The cable raceways vulnerable to fire damage resulting from the assumed fire scenarios are generally identified during the plant area walk-down. In the event that the direct identification of specific raceways is prevented (e.g., congestion in the area), the use of conduit/tray routing plan drawings for the locations of interest may be required. Once the vulnerable raceways have been identified, the next task is to identify those cables contained within the raceways (at the locations of interest) that are important for safe shutdown. The cables may be identified from the cable and raceway data system employed at the plant. In some cases, the cable routing for the SSD components of interest may have to be requested from plant personnel (e.g., annotated mark ups on conduit/tray plans).

The second step of the Phase 3 circuit analysis process is to identify the possible effects of fire damage to the cables of concern on the functionality of the SSD equipment. That is to determine if complete loss of function (loss of power, loss of control) or spurious operations are potential effects from hot shorts or shorts to ground resulting from cable damage.

To determine the behavior of the affected component, the electrical drawings for the component circuits associated with those cables are reviewed to evaluate what, if any, circuit effects are possible if the cables are damaged by fire. This circuit analysis only assumes that intra-cable

conductor-to-conductor or conductor-to-ground shorting is possible. Recent experience indicates that cable-to-cable shorting events leading to spurious actuation of a device employing thermoset cables is very unlikely. However, the possibility of external source cable interactions with the target cable is implicitly included in the equations used to estimate the probabilities of failure for non-armored cables. Another assumption to make is that the only failures important for the purpose of the analysis are those that (1) cause loss of power (LOP) to the component making it non-functional, (2) cause loss of control (LOC) of the component by remote means making it effectively non-functional, and (3) cause spurious operation (SO) of the component. Any other results of the postulated shorting of the cable's conductors to ground or to each other will probably be defined as having "No Effect," (those instances would include those cases resulting in spurious indications, loss of indication, and spurious alarms, among others).

The analysis of hot short effects is most easily conducted by postulating individual faults on each conductor in the cable (i.e., the "hot probe" method). In this approach, the analyst assumes the presence of an energized conductor (the hot probe) capable of energizing the circuit conductor under consideration. The "hot probe" is intended to represent a single "source conductor" without reference to its circuit association (i.e., it could be an intra-cable (internal) source or inter-cable (external) source). The hot probe is postulated to make contact with each individual conductor in the cable and the equipment response to the postulated hot short is determined (e.g., spurious operation, etc.). This analysis approach is a practical means of identifying the equipment failure modes for a majority of circuit types. Each of these circuit responses are documented and attributed as possible outcomes for damage affecting that cable.

In a similar fashion, identify the equipment response to ground faults on each conductor contained in the cable by assuming contact by a grounded probe.

Circuit failure evaluations should be performed with the components in their normal operating state. This requires that the devices making up the circuit be represented appropriately. For example, if relay contacts included as part of the circuit are closed in the normal operating state, then the circuit should be analyzed assuming that those contacts are closed. It is recommended that the analysis be performed using a marked-up circuit schematic that represents the normal operating condition of the circuit under review. If a component state is indeterminate (i.e., varies as a result of normal plant operation, e.g., two motors that are run for alternating periods to even out run time), the worst-case functional state should be selected for analysis.

During the process of identifying equipment responses to cable failure modes, a hot short circuit failure on the appropriate conductor(s) should conservatively be assumed to occur with sufficient electrical contact to impose full voltage on the "target conductor." For example, if a hot short between two conductors can produce a spurious actuation, the short is assumed to occur in manner that permits sufficient energy transfer to cause the spurious actuation.

Open circuits (a condition that is experienced when an individual conductor within a cable loses electrical continuity) need not be considered as a primary cable failure mode of concern when

conducting the detailed circuit failure analysis. However, it is recognized that the effects on a circuit due to shorts-to-ground or hot shorts will likely cause circuit protective device actuation(s) that result in an "effective" open circuit condition (expected circuit state following overcurrent protective action). The effects of this resultant circuit condition must, however, be considered in determining the functional impact on the equipment.

Ground faults on ungrounded systems should be treated differently than for grounded systems. A single ground fault on an ungrounded system has no immediate functional affect; however, multiple ground faults can energize conductors via backfeed paths through grounded surfaces (tray, conduit, etc.). For ease of analysis when analyzing ungrounded circuits for the effects of a short-to-ground, it should be assumed that an existing ground fault from the same power source is present.

In general, the analysis of individual components should only consider failures of the specific circuit conductors that are contained within the cable under evaluation. Other conductors making up the circuit, but contained in a separate cable, should be assumed to represent otherwise normal circuit paths (i.e., other cables connected to the cable under evaluation should be assumed to be unaffected by the fire).

The detailed circuit failure analysis is a deterministic "static" analysis. As such, dynamic aspects of the cable faults are not considered. Each cable fault should be evaluated as to the possible equipment response it could elicit. Timing aspects and the ultimate circuit/equipment state are not factored into the criteria. For example, if a hot short between two conductors can produce a spurious opening of a solenoid valve (SOV), the analysis should identify "fail open" as an equipment response. When the hot short occurs and how long the hot short will persist before the fault degrades to a ground fault and terminates the spurious operation are not factors considered by the analysis.

Once a cable is analyzed for one fire compartment/scenario situation, the results of its circuit analysis are applicable for the same cable in any other compartment/scenario. Hence, each cable need be analyzed only once to satisfy the objectives of this procedure. Note that the actual analysis is conducted on a conductor-by-conductor basis. The final list of equipment responses for any one cable is a culmination of the responses for the individual conductors in the cable.

Note that only those failure modes of interest concerning the particular component under review are analyzed further for their likelihood of occurrence. For example, if the control cable for a power operated relief valve is being analyzed using the hot probe technique, usually only the spurious operation response mode of the valve will be considered as important. In this case, LOP will not be a concern.

Once the <u>possibility</u> of the failure mode(s) of interest is established, the analyst should attempt to estimate the <u>probability</u> of its occurrence. The preferred method for the purposes of Phase 3 is to calculate the probability from a set of formulas based on known cable characteristics. An

alternative method, to be used, if certain cable characteristics cannot be determined, is to employ the probability values provided in the Expert Panel Report (Reference 3).

Finally, the probability of occurrence for each of the identified failure modes is estimated using the quasi-empirical method developed during a recent NRC sponsored project at the Sandia National Laboratories on fire PRA methods development (Reference 2). Note that the formula method (as specified in Chapter 10 of Reference 2) was selected for use in this analysis to estimate failure probabilities because circuit design details are usually readily available, whereas use of tabulated probability estimates (for examples, refer to References 2 and 3) are assigned on the basis of very broad cable characteristics and do not allow the analyst any consideration of circuit-specific design features.

The method used to estimate the failure mode probabilities of the cables due to damage by fire employs the use of empirically derived formulas (see Appendix J in Reference 2 for the technical basis of these formulas). The likelihood of occurrence for a specific failure mode ($\mathbf{P}_{FM}$) is estimated by

$$P_{FM} = P_{CC} * CF$$

Where:

P_{FM}: The probability that the specific failure mode of interest (e.g., SO, LOC, etc.) will occur in a specific circuit given a fire of sufficient intensity to cause cable damage

P_{CC}: The probability that a conductor-to-conductor short will occur prior to a short-to-ground or short to a grounded conductor

CF: Configuration Factor - A factor applied to P_{CC} that accounts for the relative number of source conductors and target conductors located within the cable under investigation

Target conductors are those conductors of a circuit that, if energized by an electrical source of proper magnitude and voltage, will result in spurious actuation of the circuit, component, or device of concern. Source conductors represent energized conductors that are a potential source of electrical energy needed to realize the spurious actuation effect.

The calculation of P_{CC} is based on the following formula.

$$P_{CC} = (TC - GC) / [(TC - GC) + (2 * GC) + F_G]$$

where:

TC: Represents the total number of conductors contained within the cable of interest (including spare conductors),

GC: The number of grounded (or common) conductors in the cable

F_G: A factor that represents the potential of ground plane interactions with the cable conductors that is based on the type of raceway in which the cable is routed and the nature of the electrical ground (if any) employed by the circuit. Refer to the table below

for the appropriate values of F_G to use for different circuit-ground configurations.

F_G	**Circuit-Ground Features**
0	ungrounded circuits
1	grounded circuits in cable trays
3	grounded circuits in conduit or armor

The cable's configuration factor, CF, is calculated as follows:

$$CF = \{TGC * [SC + (0.5 / TC)]\} / TC$$

where:

TGC: Represents the total number of target conductors located within the cable that are capable of forcing the component or circuit into the undesired state or condition (e.g., causing spurious actuation),

SC: The total number of source (energized) conductors in the cable under evaluation,

TC: The total number of conductors contained within the cable as previously defined.

Note that the term (0.5 / TC) in the formula is used to account for external source cables that could initiate a spurious actuation due to inter-cable shorting. This term becomes important only in those cases where there are no source conductors contained within the cable.

By similar processes, the probabilities of loss of control, loss of power, loss of or erroneous status indication can be determined. Note that P_{CC} remains constant for a given cable no matter the failure mode of interest. Also, the sources (energized conductors) within the cable will remain the same. However, the identification of target conductors will depend on the failure mode of concern. Targets will likely differ for spurious operation failures than for loss of control or erroneous indication failures. For example, to cause the spurious operation of an SOV, the likely target is the conductor connected to the solenoid coil. On the other hand, to cause erroneous status indication of the SOV, the target would be a status lamp conductor.

A quick way to estimate loss of control probabilities for simple circuits, where a blown fuse removes power to the circuit, is to take the complement of P_{CC} (i.e., $P_{LOC} = 1 - P_{CC}$). However, for more complex circuits, where, for example, lockout relays or trip coils (typical of pump control circuits) can cause loss of power or control, the more rigorous approach of calculating the CF should be followed.

When more than one cable can cause the component failure mode of concern, and those cables are within the area of influence for the fire scenario under investigation, the probability estimates associated with all affected cables should be considered when deriving a failure likelihood estimate for the component. In general, the probabilities should be combined as an "Exclusive OR" function, as shown:

$$P_{\text{Component failure}} = P_{\text{Failure Cable A}} + P_{\text{Failure Cable B}} - (P_{\text{Failure Cable A}} * P_{\text{Failure Cable B}})$$

Where the failure probabilities for cables A and B are determined individually using the fundamental equations discussed earlier.

Finally, if specific failures on two separate cables, exposed in the same fire scenario, are required to result in the equipment failure mode of concern (e.g., a spurious actuation) then the individual probability of failure for each cable is first calculated using the formulas and then the results are combined in an "AND" function:

$$P_{\text{Component failure}} = P_{\text{Failure Cable A}} * P_{\text{Failure Cable B}}$$

4.4 Component and Cable Locations

In this step, the location of components and cables are formally cataloged. Location of components is relatively simple to identify. It can be done either by reviewing plant layout drawings or through a plant walkdown. Cable locations are identified in the preceding step (Section 4.3).

Cable location should be established as precisely as practically possible. For example, in some cases it may only be possible to identify the routing of a cable within a stack of cable trays and not within specific trays of that stack.

It will be helpful to the following steps if circuit analysis results are also included with the component / cable location tabulations. The circuit analysis results will indicate the component failure modes that are possible from a fire at a specific location. For example, for one compartment, the segment of the cables present may include the possibility of spurious operation of a specific component, whereas for another compartment and the same component, the segment of the cable present can only lead to loss of power.

In addition, the exact location of the cable trays (the stack of trays in case of insufficient information) and components within a compartment is often needed. This information can be used in the next step to identify sub-areas within a compartment where fire damage would lead to unique consequences. Such sub-areas can be used to establish fire scenarios where a limited number of cables and components are exposed to the postulated fire event.

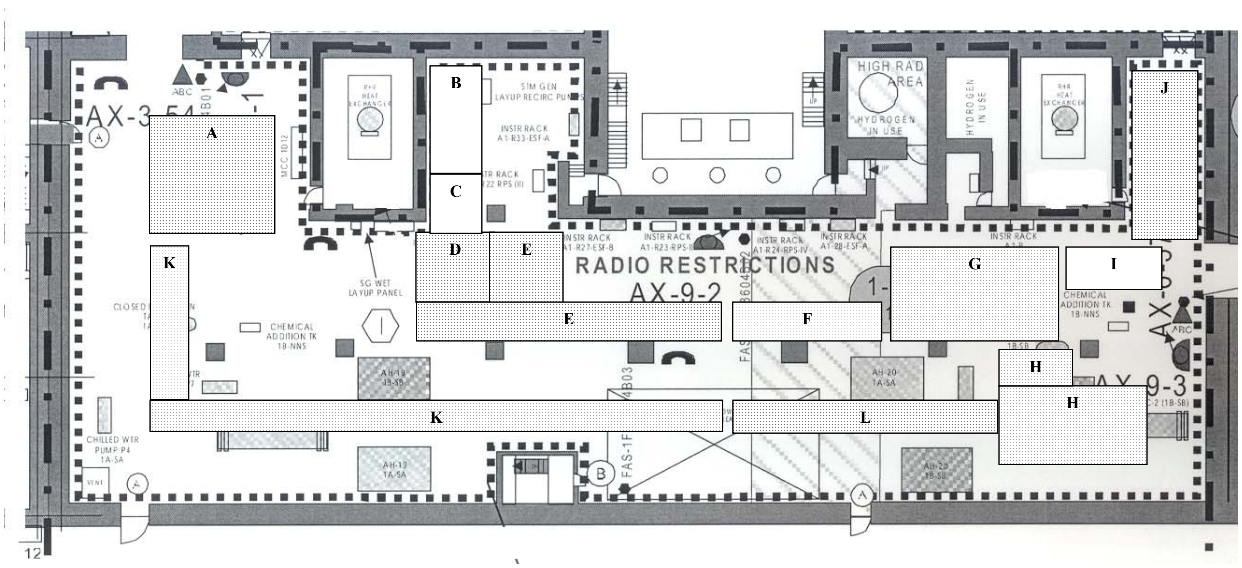
4.5 Fire Scenarios and Associated Target Sets

A fire scenario is defined as a set of elements that describes a fire event (Reference 2). In this context, the fire scenario should be defined in terms of a specific ignition source or a collection of ignition sources and specific set of items from the target set present in the area. It would then be assumed that there will be a sufficiently severe fire starting from the selected ignition source that would damage the selected target set. The fire propagation analysis in the following steps would establish whether or not a sufficiently severe fire can occur.

Two examples are provided here to illustrate the fire scenario identification process. At one plant, the licensee had not properly identified the routing of certain safe shutdown related cables.

One large compartment, where those cables were present, became the focus of the analysis (see Figure 3). From a review of the location of various cables and the function and failure modes of the affected components, a set of localized sub-areas within the compartment were established with a unique combination of cables present in each sub-area. The shaded areas in Figure 3, identified with letters A through L, present the boundaries of those sub-areas.

Figure 3 Example - Areas with Unique set of Cables of Interest



Fire scenarios postulated for this compartment included: 1) a severe fire affecting all the cable trays under the ceiling along the entire length and width of the compartment and 2) localized fires affecting the cables of a sub-area. One fire scenario was postulated for each sub-area, assuming that a fire in the vicinity of a given sub-area would damage all the cables of that sub-area. Table 1 provides a sample of the scenarios postulated.

Table 1 Example - Fire Scenarios

Sub-Area	Postulated Ignition Source Type	Representative Target
B	Motor and lubricating oil associated with small pumps, junction boxes, transient combustibles and welding	One cable tray 14 ft above the floor
C	Junction boxes, transient combustibles and welding	One cable tray 14 ft above the floor
G	Wall mounted electrical cabinets, junction boxes, transient combustibles and welding	Two cable trays stacked, with bottom tray 14 ft above the floor
H	Large motor and lubricating oil associated with a chiller, insulating material on chiller and associated piping, motor and associated lubricating oil pump, junction boxes, transient combustibles and welding	Two cable trays stacked, with bottom tray 14 ft above the floor and 5 feet above a large motor

In the second example, two safety related switchgear rooms containing electrical equipment from the opposite trains were located next to each other with open passageways between them. Normal access to Switchgear Room B was through Switchgear Room A. Two classes of scenarios were considered: 1) a very severe fire in one room affecting equipment and cables in both rooms and 2) severe fire in one room affecting key equipment and cables in the affected room and loss of the other bus due to a fire fighting mishap. The possibility of a fire fighting mishap, damaging equipment in an unaffected room, was established through the event tree of Figure 4. Even though all the events of the event tree are related to fire fighting, since it was developed solely for establishing the extent of damage (i.e., affected target set), it was developed as part of the fire scenario identification process.

4.6 Fire Ignition Frequency Estimation

The initiation frequency of each scenario is based on the fire ignition frequencies of potential ignition sources (e.g., components or combustibles-either fixed or transient) identified for each fire scenario. The plant's IPEEE can serve as a convenient starting point for identifying ignition sources, fuel loadings contained within a particular fire area, and associated ignition frequencies. This information should be verified during the plant walk downs. The easiest approach to assigning ignition frequencies for specific components is to employ those values used in the plant's analyses (IPEEE, Fire PRA, etc.) unless the team has or finds a basis for other, different values.

Figure 4 Example - Event Tree Used for Establishing Fire Scenarios for Two Interconnected Adjacent Switchgear Rooms

Severe Fire Occurs in Room B	Gas System Discharge	Smoke Purge	Handheld Extinguisher Success	Water Hose Integrity	Brigade Error	Seq. #	Seq. Prob.	Damage State	Water Spray on Both Buses	%	Comments
FI	GS	SP	HH	WT	BR						
1.00	0.95		0.70			1	6.7E-01	1 bus			If gaseous system discharges successfully, it is assumed that there will be no need to initiate smoke purge activities.
			HH1 0.30	1.00	1.00	2	2.8E-01	1 bus			
					BR4 2.5E-04	3	7.1E-05	2 buses	7.1E-05	4%	
				WT1 5.0E-03		4	1.4E-03	2 buses	1.4E-03	86%	A hose break in the room A is very likely to affect room A equipment causing failure of both power trains.
	HL1 5.0E-02	0.97		1.00	1.00	5	4.8E-02	1 bus			
					BR5 2.5E-03	6	1.2E-04	2 buses	1.2E-04	7%	
				WT1 5.0E-03		7	2.4E-04	1 bus			
		SP1 3.0E-02		1.00	0.975	8	1.5E-03	1 bus			
					BR6 2.5E-02	9	3.7E-05	2 buses	3.7E-05	2%	
				WT1 5.0E-03		10	7.5E-06	2 buses	7.5E-06	0%	A hose break in the room A is very likely to affect room A equipment causing failure of both power trains.
								Total 2 bus	1.7E-03		

Sometimes it may be beneficial to review the events underlying the frequency estimate. In at least one case, the Phase 3 analysis involved a unique situation that detailed review of the underlying event data was necessary to gain a better understanding of the extent of damage that the postulated event could yield. Catastrophic, energetic failure of a large transformer was the focus of the analysis. Eight such events could be identified in the information provided in Reference 2 and its underlying event database. A review of the events revealed that an internal fault of a main transformer can breach the transformer tank and eject burning dielectric oil as far as 40 feet from the source.

4.7 Fire Propagation Analysis

The purpose of fire propagation analysis is to establish the possibility of and time to target set damage given a fire of specific severity has initiated at the postulated ignition source. Fire propagation analysis should be conducted for every postulated scenario. The final outcome of fire propagation analysis should be the following:

1) Whether or not target set damage is possible
2) Severity factor, P_{SF} (if damage is possible)
3) Time to damage (if damage is possible)

Sophistication of the analysis, as discussed in Section 2.3, would depend on the risk significance of the scenario. Initially, as it is commonly practiced in Fire PRA, the analysts may use a conservative approach. References 2 and 4 through 6 provide formulations and guidelines on how to conduct fire propagation analysis. It must be added that in Reference 2, the severity factor is quantified in conjunction with the non-suppression probability (P_{NS}). That methodology is based on a probability distribution assigned to the heat release rate of an ignition source.

4.8 Fire Detection and Suppression Analysis

Fire detection and suppression analysis should be conducted for those cases where damage is possible. The final outcome of this task is the probability of non-suppression (P_{NS}) given a damaging fire has occurred. A relatively sophisticated model using an event tree is presented in Appendix P of Reference 2 for accounting for prompt or delayed detection, automatic suppression and fire brigade actions. Often that model needs to be modified to allow proper modeling of plant-specific conditions.

In its simplest form, detection and suppression can be envisioned of two parts: availability of suppression systems and timely fire control before target set damage. Thus, in its simplest form, P_{NS} can be written as:

$$P_{NS}(t) = \Pr\{\text{Suppression Systems Failure}\} + \Pr\{\text{Fire Control After Damage at time } t\}$$

The first term is independent of time and often industry-provided unavailability values are used to quantify it. For the second term, the time to damage obtained in the preceding task can be matched against suppression times found in the suppression curves provided in References 2 and 4. Of course, the most conservative approach, especially in the initial stages of the analysis, would be to assign $P_{NS} = 1.0$ until the dominant fire scenarios are identified.

As noted above, in the methodology described in Reference 2, P_{NS} is quantified in conjunction with the severity factor P_{SF}, taking into account the range of heat release rates that can be assigned to the ignition source. As a simplified approach, the analyst may use the smallest heat release rate that can cause target set damage to establish the severity factor and the time to damage associated with the largest heat release rate of the distribution to establish the second term of the non-suppression probability. This approach may later be modified to include other heat release rate values and damage times, if the scenario is found to contribute to a CDF value other than Green.

4.9 Fire Scenario Occurrence Frequency Estimation

Fire scenario occurrence frequency is simply the product of frequencies and probabilities estimated in the preceding tasks:

$$\lambda_{\text{Fire Scenario}} = \lambda_{\text{Ignition Source}} \sum_{i} P_{SF,i}\, P_{NS,i}$$

where:

$\lambda_{\text{Fire Scenario}}$ = Occurrence frequency of the fire scenario

$\lambda_{\text{Ignition Source}}$ = Ignition source frequency

$P_{SF,i}$ = Severity factor associated with i-th value of heat release rate from the discretized probability distribution associated with the ignition source.

$P_{NS,i}$ = Non-suppression probability based on target set damage time associated with i-th value of the heat release rate

Additional conditional probabilities may need to be multiplied to this formula depending on the specifics of the analysis. For example, in the case of the two adjacent switchgear rooms, the probability of fire fighting mishap leading to two-bus failure should be included in this formulation. These calculations must be conducted for every fire scenario separately.

4.10 Manual Actions Outside the Control Room

The PRA model may include several manual actions outside the control room. In some cases, the manual actions become the focus of the Phase 3 analysis. Chapter 12 of Reference 2 provides a separate discussion on human error probability estimation in the context of Fire PRA. It is important to note that a fire event may create conditions that are not normally encountered. For important manual actions, the following is recommended:

1. During the site visit, request the appropriate version of the procedures where the actions are addressed.
2. Review the procedures with a knowledgeable plant operator
3. Walk the procedure down with that operator, if possible
4. Postulate the conditions that the fire event may pose with respect to the areas where the operators have to travel through or execute steps of the procedure.

The exercise will shed much light on the possibility of conducting the specific procedure given the range of fire events that will be postulated in the analysis. For example, in the case of cable tunnel fires mentioned in the preceding sections, several operators had to follow an elaborate set of steps to ensure that the proper level of core cooling is established. The steps included actions in areas that the postulated fire scenario could potentially affect safety of the personnel. Also, steps were noted that required operators to manipulate equipment at locations where the fire brigade would also be active. The operator error probabilities were evaluated using these specific conditions as part of the influencing factors and then included in the split-fraction estimates for the appropriate branch-points in the PRA model.

In addition to case-specific conditions, dependencies among various actions in the event tree should be modeled explicitly. Certain sequences of the event tree may include multiple operator actions in consecutive branch-points. Separate human error probability evaluations should be conducted for each sequence of events to ensure that all potential dependencies are explicitly modeled.

4.11 CCDP Estimation

A CCDP value is evaluated for each fire scenario. The PRA model established in the first step is used for this purpose. All event tree branch points should be evaluated separately for each fire scenario based on the component failures and operator action probabilities specific to the fire scenario. For components that are not affected by the fire scenario, the values established in the internal events analysis may be used.

4.12 CDF Estimation

The CDF associated with a Phase 3 problem is the sum of the CDFs associated with each fire scenario, k:

$$\lambda_{\mathrm{CDF},k} = \sum_{k} \lambda_{\mathrm{Fire\ Scenario},k}\, \mathrm{CCDP}_k$$

The purpose of a Phase 3 analysis is to determine the increase in plant CDF. Since the plant model (e.g., the event tree) covers only those event sequences that are relevant to the Phase 3 problem, it can be argued that the calculated CDF represents the increase in risk.

As part of this step, as a final task, it is recommended that the analyst review the complete analysis process with uncertainties and conservatisms in mind. Generally, analysts have to make

conservative assumptions to cover for lack of sufficient information, to circumvent difficult modeling problems, etc. For example, recently installed monitoring devices may make the occurrence of an energetic fault in a large transformer less likely than before. However, since statistical data is not available for the modified transformer configuration, the analyst may have to use old data that does not include the safety gained from the new devices.

Uncertainties are an inherent part of a quantitative risk analysis, such as Phase 3 SDP analysis of fire protection issues. Uncertainties can be attributed to potential variation in the statistical data (e.g. fire ignition frequencies) and insufficient knowledge (e.g., heat release rate profile of an ignition source). For example, in a large transformer fire analysis, the analysts credited the execution of a specific emergency procedure. Drills were conducted on that procedure, but had never been tested in real conditions. In past events (i.e., energetic transformer failure), oil has been ejected from the affected transformer. However, practically no quantitative information existed on the amount of oil lost. The analysts needed to know the quantity of oil spilled for estimating the extent of damage beyond the transformer itself. Also, if a large quantity of oil was ejected, there is the potential for oil fire propagation into the Turbine Building. In that specific analysis it was assumed that the latter scenario was very unlikely. Clearly, large uncertainties existed associated with the extent of the oil spill and damage potential. Chapter 15 of Reference 2 provides useful guidance on how to identify and analyze uncertainties.

5.0 REFERENCES

1 *Fire Dynamics Tools (FDTs) Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program,* NUREG-1805, U.S. Nuclear Regulatory Commission, Office of Nuclear Reactor Regulation, Washington, DC, December 2004.

2 *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities: Volume 2: Detailed Methodology*, EPRI, Palo Alto, CA, and U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research (RES), Rockville, MD: 2004. EPRI TR-1011989 and NUREG/CR-6850, September 2005.

3 *Spurious Actuation of Electrical Circuits Due to Cable Fires: Results of an Expert Elicitation,* EPRI, Palo Alto, California, EPRI TR-1006961, May 2002.

4 Appendix F to Inspection Manual Chapter 0609, "Fire Protection Significance Determination Process", U.S. Nuclear Regulatory Commission, February 28, 2005.

5 *Fire-Induced Vulnerability Evaluation (FIVE)*, EPRI, Palo Alto, CA: April 1992. TR-100370.

6 *Fire PRA Implementation Guide*, EPRI, Palo Alto, CA: December 1995. TR-105928.

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APPENDIX - Phase 3 SDP Analysis: An Example

A hypothetical example is provided in this appendix to illustrate a Phase 3 Fire SDP Analysis for fire protection issues. This appendix is organized around the overall steps of a typical analysis.

A.1 Problem Statement

The Phase 2 analysis report was reviewed and the Phase 3 problem statement was developed from the Phase 2 findings statements. The report presented that the cables for three valves were located in the same compartments. The three valves consisted of one Charging System valve and two Component Cooling System valves. Spurious closure of these valves would cause simultaneous failure of the Charging System and Component Cooling System leading to loss of Reactor Coolant Pump (RCP) seal injection and cooling. This situation, if it occurs, could result in RCP seal failure and a potential seal LOCA. The Phase 2 report also included discussions on possible recovery actions and the operating procedures related to those actions. Compartments B1, B2 and B3 of the Auxiliary Building in this PWR were identified as the locations where control cables of the three valves were present.

The following brief problem statement was formulated:

> *A review of the fire protection program had revealed that the licensee had not properly identified the routing of certain safe shutdown related cables. These cables were associated with valves CS-012 (a Charging System valve), CC-009 and CC-010 (Component Cooling System valves). Spurious closure of these valves can cause loss of Charging and Component Cooling Systems supplies to the RCP seals. The cables associated with these valves are located in compartments B1, B2, and B3. The Phase 2 SDP Analysis concluded that, because the cables of these valves were not protected, the fire risk of compartments B1, B2, and B3 is other than Green. It was determined that a Phase 3 analysis of the finding is warranted.*

A.2 Preparation – Informational Needs

Clearly, the first document reviewed was the Phase 2 analysis report. From that report a list of documents were identified as necessary for the Phase 3 analysis. The list included the following items:

- Layout drawings for compartments B1 through B3.
- Control and power cable routing information for the three valves
- Control circuit diagrams for the three valves
- Sections of Appendix R and Fire Hazard Analysis that address compartments B1 through B3
- Fire pre-plans for compartments B1 through B3
- System descriptions and piping and instrumentation diagrams (P&IDs) for the Charging System and Component Cooling System
- Plant's Individual Plant Examination of External Events (IPEEE) report submitted to the NRC

- Event tree and related discussions and systems analyses for small LOCA, that models Reactor Coolant Pump (RCP) seal failure
- Component failure frequencies and probabilities

The licensee provided the analysis team with a compact disc (CD) containing a comprehensive set of fire protection, fire hazard analysis and Appendix R related documents. The document set included the layout drawings of the plant. Separately, an electronic version of the PRA model of the plant was provided that contained event trees, fault trees and failure frequencies and probabilities. P&IDs, cable routing and control circuit related documents were provided during the site visit.

A.3 Preparation - Planning and Communication with Plant Personnel

Parallel to Phase 2 report review and document requests, the site visit plan was put together. The planning activities included determination of the following:

- Three consecutive days for the site visit
- Travel plans
- Arrival time at the site for the first day
- Names of plant contacts
- The analysis team, which consisted of:
  - An expert in Fire PRA
  - An expert in control circuit analysis
  - Region inspector familiar with the case
  - NRR Risk Analyst

Also, certain actions were taken as part of the planning process:

- The following plant areas were requested to be visited:
  - Compartments B1 through B3
  - Main Control Room
  - Locations of Charging System flow control valves (especially CS-012)
  - Location of Component Cooling valves CC-009 and CC-010
- Requested permission to bring a camera into the plant
- Requested the following documents to be made available at the plant:
  - Cable routing related documents
  - Control circuit drawings of the three valves identified in the finding
  - P&IDs of the systems
  - PRA report
  - Operating procedures for responding to Loss of Offsite Power and to Small LOCAs
- Requested availability of personnel who are responsible for or are familiar with the following:
  - Appendix R
  - Plant PRA
  - Fire PRA and / or IPEEE
  - Fire hazard analysis and / or fire plans

- Auxiliary operator
- Control room operator

The plant visit was scheduled for the time period when the plant would be in full operation. A Main Control Room visit was requested so that the analysis team would obtain a visual image of the environment where the operators would be responding to any of the postulated scenarios and understand the layout of the controls used to bring the plant to a safe shutdown condition.

A.4 Site Visit

A site visit was conducted as scheduled. The following activities took place during the site visit:

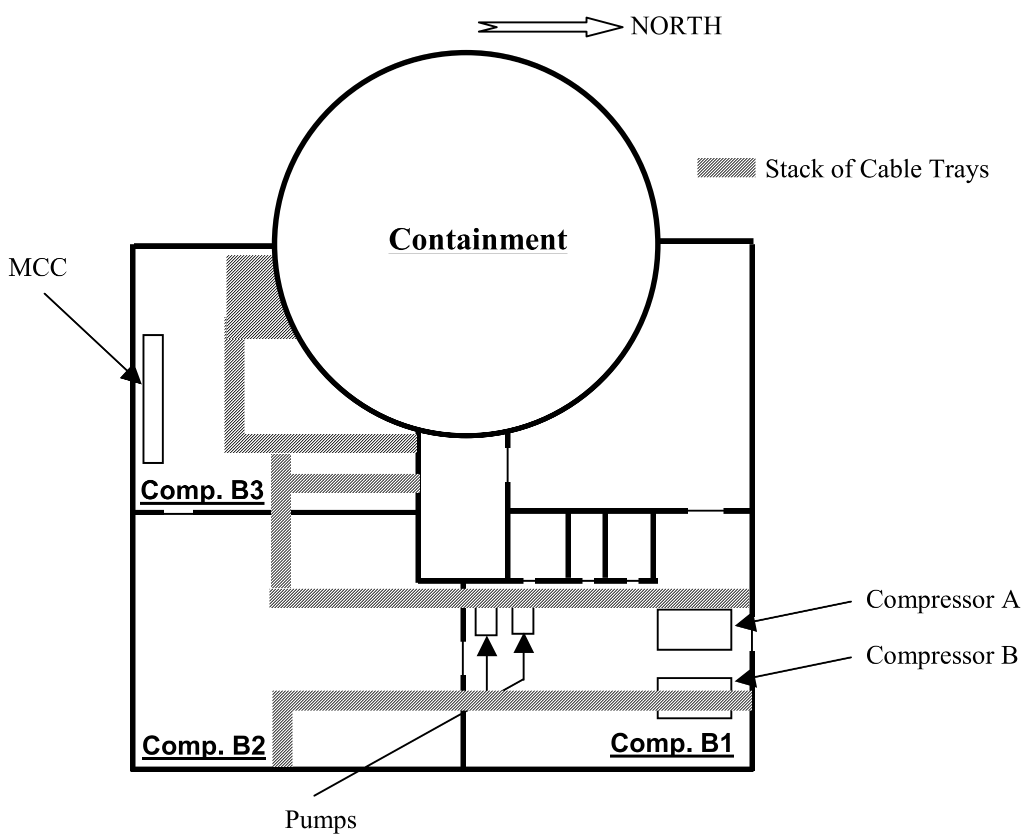
1. Site entry initial orientation and paper work was completed.
2. Site contact person met with the analysis team and took the team to the meeting room that was set aside for the team for the duration of the visit.
3. An informal opening meeting was held with the plant management (included plant manager's representative and various department heads). The purpose of the visit, a general agenda and the overall approach were presented. It was stressed that the purpose of the site visit was to observe and obtain the necessary information to enable the analysts to perform the Phase 3 review. It was also stressed that licensee personnel were welcome to participate in the analysis team's discussions and site walkdowns.
4. The analysis team started a review of the available documents. The following items were specifically reviewed:
   - Control circuit diagrams of the three valves of interest,
   - Cable routing diagrams for the circuits associated with the three valves,
   - Layout drawings of compartments B1 through B3, and
   - Operating procedures that were used for establishing hot shutdown under small LOCA and LOOP conditions. Also, the procedures for relevant recovery operations were reviewed. The reviews were done with licensee personnel present, who participated in the process as well.
5. The cable routing of several items, including the three valves, were established.
6. Compartments B1 through B3 were visited. Photographs were taken to provide visual references of the areas during the post visit analysis.
7. A preliminary analysis strategy was formulated (see Section A.6).
8. A discussion session was held about walk-down observations and the PRA model that could be used to estimate the CCDP and CDF. Licensee PRA personnel participated in these discussions. Several issues came up about the integrity of the PORVs, steam generator power operated relief valves, charging pumps, and additional valves that should remain in their normal position.
9. Cable routing of the additional components were also reviewed.
10. A second site walk-down was conducted to verify the earlier observations.
11. An informal exit meeting was held. No results or direct observations of the status of the findings were relayed to plant management.

A.5 Site Observations

An important purpose of the site visit is to gain an overall understanding of the conditions at the site relevant to the Phase 3 problem statement. In this case, the following observations were made during the site visit (see Figure A-1):

- A large number of cable trays are located near the ceiling in all three rooms. The stacks of trays are shown in Figure A-1. Some trays have solid bottoms and others are open. Power cables (4.16kV) are contained within these cable trays. They are generally in the top tray of each stack.
- Compartment B1 contains the following ignition sources:
  - Two large compressor units
  - Two water pumps
- Compartment B2 contains cables only. There are no other items in this compartment.
- Compartment B3 is one of the electrical penetration rooms of the plant. It contains a large number of instrumentation, control and power cables near the ceiling.
- There is a motor control center (MCC) in an isolated part of Compartment B3.

Figure A-1 Site Layout Relevant to Phase 3 Analysis



A.6 Analysis Strategy

Based on the information obtained during the site visit, an analysis strategy was developed. It was initially assumed that the cables associated with the three valves of interest were present in all three compartments (i.e., B1, B2 and B3). From a cursory review of the control circuit diagrams, it was concluded that not all cable damage scenarios in Compartments B1 through B3 would lead to the spurious closure of the three valves. It was also concluded that only at a few locations exist where the cables for all three valves are present. Also, given the characteristics of the circuits, the probability of spurious closure could be small. Therefore, a screening analysis may be warranted, where in the initial stages of screening, simplified analysis methods would be employed.

Two general categories of fire scenarios were postulated for each compartment:

1) A severe fire in a compartment affecting all the cables close to the ceiling (regardless of their relative location), and
2) Localized fires that affect a limited volume within each compartment.

The three compartments were separated by fire rated walls and doors. The doors were normally kept closed. Also, piping and cable penetrations through the walls were found to be well sealed. Therefore, it was assumed that the core damage risk associated with inter-compartment fire propagation is so small that an explicit analysis of those scenarios was not warranted.

The overall strategy was therefore decided to include the following:

- For the severe fire affecting all the cables of a compartment, frequency of occurrence would be established first. If this scenario cannot be screened based on frequency of occurrence, the associated CCDP would then be established.
- The exact location of the cables associated with the three valves would be established.
- The probability of spurious closure given cable damage would be estimated for each cable segment in the three compartments.
- An event tree for CCDP estimation would be developed to model all possible chains of events that include the three valves.
- Based on the layout of the cable trays in each compartment, fire scenarios with localized damage zones would be postulated. Only those scenarios would be considered that could affect at least one of the three valves.
- For those cable tray segments that contain a subset of cables for the three valves (i.e., only one or two of the valves), initially a simplified analysis would be used. If the scenario does not screen out, a detailed analysis would then be attempted.
- For those cable tray segments that cables for all three valves are present, a detailed fire propagation and suppression analysis and recovery actions analysis would be necessary.

Since compartments B2 and B3 do not contain any ignition sources under the cable trays, there could be a possibility of screening these two compartments based on frequency of occurrence of fire scenarios. Compartment B1 contained compressors, and pumps that may affect the cables

near the ceiling. For this compartment, a detailed fire propagation, detection and suppression analysis was deemed warranted.

The various specific methodologies and data (e.g., severity factor, fire propagation and detection and suppression) provided throughout Reference A-1 were used in this Phase 3 analysis. The overall analysis followed the flow chart provided in Figure 1 of the main body of this report[1]. The analysis conducted for each block of that flow chart is described separately below.

A.7 PRA Model

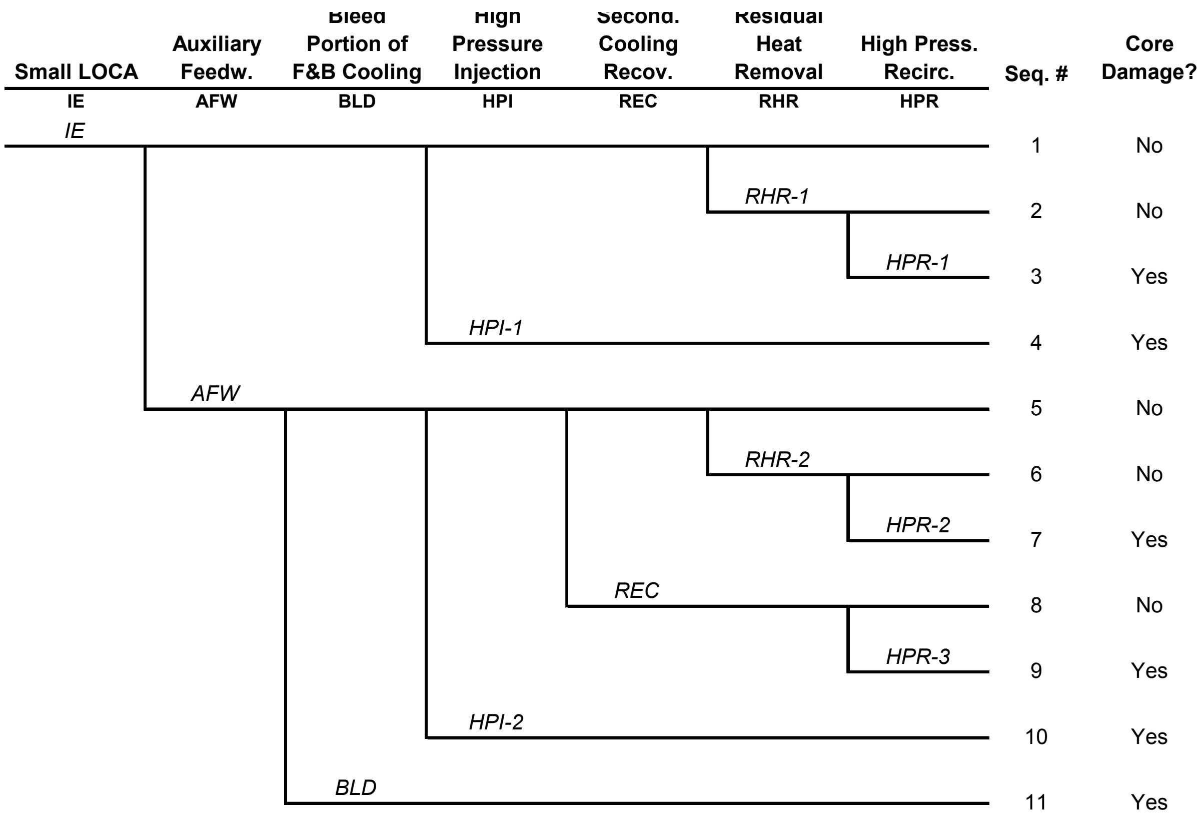
This is the first task in Figure 1 of the main body of this report. The three valves of interest affect charging, high-pressure safety injection, and the component-cooling path for RCP seal cooling. Loss of these functions has the potential for causing a small LOCA via RCP seal failures and/or loss of safety injection. Therefore, two initiating events were possible: small LOCA and general transient (if RCP seal failure is prevented). Since small LOCA poses more stringent conditions and safety injection is partly affected, it was determined that the small LOCA event tree should be used for estimating the core damage probability. Starting with the event trees in the PRA reports of the plant, the event tree of Figure A-2 was developed to model the chain of events relevant to the failure of the three valves. Every chain of events leading to core damage in Figure A-2 assumes spurious closure of the three valves. Also, it was assumed that reactor trip would be initiated as soon as the operators realize that there is a fire in the plant that is affecting safe shutdown equipment and those effects are evident on the status of the displays and controls on the control board. The event tree depicts the possibility of cooling the reactor using secondary cooling (auxiliary feedwater branch point) or using bleed and feed option. High-pressure injection is needed in either case to makeup coolant lost through the RCP seals (high pressure injection branch point). Long term cooling and primary loop makeup is possible through either low-pressure injection or high-pressure recirculation. Secondary cooling is necessary to reduce primary pressure below low-pressure injection system setpoint. If secondary cooling is lost in the first branch point, the possibility of manual recovery of secondary cooling using the steam generator power operated relief valves and steam driven auxiliary feedwater pump is considered as a separate branch point after high pressure injection. Residual Heat Removal (RHR) system provides low-pressure primary makeup and a means for long term cooling. If primary pressure is not reduced, high-pressure recirculation should be used for long term cooling and makeup.

The following statements describe the top events of the event tree:

- **Small LOCA (IE)** – This represents RCP seal failure due to simultaneous failure of the seal injection and seal cooling. The three valves of interest are a part of this event. Therefore, spurious closure of the three valves underlies all the event sequences of the event tree. In the following sections it will be shown, that occurrence of this initiating event is not necessarily guaranteed. The probability of occurrence given fire damage to cables is estimated using the probability values for circuit failure leading to spurious actuation of each valve.

[1] It may be noted that Reference A-1 also provides a flow chart for conducting a Fire PRA. Since we are analyzing a specific set of compartments addressing a specific fire protection issue, the flow chart in Figure 1 of the main part of this report was deemed more appropriate than that provided in Reference A-1.

Figure A-2 PRA Model – Event Tree for RCP Seal Failure



- **Auxiliary Feedw. (AFW)** – This models the availability of the auxiliary feedwater system to provide secondary side cooling using either a motor-driven or turbine-driven pump and the steam generator relief valves.
- **Bleed Portion of F&B Cooling (BLD)** – This event (branch point) models the success of opening a PORV to establish the bleed portion of feed and bleed cooling.
- **High Pressure Injection (HPI)** –This event represents the High Pressure Injection pump, not affected by spurious closure of a feed valve, that can be started manually from the control room to provide inventory makeup in the case of successful secondary cooling and core cooling in support of feed and bleed (i.e., feed function).
- **Secondary Cooling Recov. (REC)** – If secondary cooling could not be established and feed and bleed was established successfully, to reduce primary pressure the operators can recover secondary cooling by opening power operated steam generator relief valves and manually, locally starting the turbine driven Auxiliary Feedwater pump.
- **Residual Heat Removal (RHR)** – After HPI has successfully provided RCS makeup and the RCS pressure has dropped below the low pressure injection setpoint (using secondary

cooling), the Residual Heat Removal (RHR) System can be initiated by the operators to provide long term low pressure makeup and cooling.

- **High Press. Recirc. (HPR)** – If either RHR fails or primary pressure reduction fails, High Pressure Recirculation can be used to provide the necessary long term makeup and core cooling function.

In this event tree, the following six sequences lead to core damage:

- **Sequence # 3** – In this sequence, the operators are successful in safely depressurizing the RCS using the AFW and HPI. For long term core cooling and RCS makeup, the RHR system is needed. RHR failure leads to a pressure increase. The operators could use the HPR at this point for high-pressure recirculation and makeup. Core damage is experienced because HPR fails.
- **Sequence # 4** – In this sequence, the operators are successful in aligning AFW for heat removal through the secondary side. Core damage is experienced because HPI fails to provide RCS makeup.
- **Sequence # 7** – In this sequence, the operators fail to establish AFW for secondary side heat removal, but are successful in establishing core cooling and makeup by using the PORVs for bleeding and HPI for feeding the RCS. The operators depressurize the RCS by recovering secondary cooling via the SRVs and turbine driven AFW pump. For long term core cooling and RCS makeup the RHR is needed. RHR failure leads to a pressure increase. The operators could use the HPR at this point for high-pressure recirculation and makeup. Core damage is experienced because HPR fails.
- **Sequence # 9** – In this sequence, the operators fail to establish AFW for secondary side heat removal, but are successful in establishing core cooling and makeup by using the PORVs for bleeding and HPI for feeding the RCS. RCS remains at high pressure because secondary side cooling recovery fails. For long term core cooling and RCS makeup, the operators could use the HPR at this point. Core damage is experienced because HPR fails.
- **Sequence # 10** – In this sequence, the operators fail to establish AFW for secondary side heat removal. HPI fails as well. Core damage is experienced because there are no methods for depressurizing the RCS while providing makeup water at high pressure.
- **Sequence # 11** – In this sequence, the operators fail to establish AFW for secondary side heat removal. Operators also fail to bleed steam from the RCS. Core damage is experienced because there are no methods for depressurizing the RCS to allow any of the pumps to provide makeup water at high pressure.

<u>A.8 Relevant Systems and Component List</u>

This is Task 2 in Figure 1 of the main body of this report. The event tree provided the basis for identifying the relevant systems and components. The following systems were considered:

- Component Cooling System – RCP seal cooling related parts
- Chemical and Volume Control System – RCP seal injection and HPI portions
- Auxiliary Feedwater System
- Pressurizer PORVs

- Steam Generator Relief Valves (SRVs)
- Residual Heat Removal (RHR) System
- High Pressure Recirculation parts of the HPI

From these systems the following components were specifically identified for possibility of circuit failure due to a fire.

- PORVs – RC-114, RC-116 and RC-118
- PORV block valves – RC-113, RC-115 and RC-117
- HPI pumps – HPIP-A, HPIP-B, and HPIP-C
- Volume Control Tank Isolation Valves – CS-012 and CS-013
- RCP Thermal Barrier Isolation Valves – CC-009 and CC-010
- SRVs – SR-01, SR-02 and SR-03
- Motor driven AFW pumps – AFWP- A and AFWP- B
- RHR pumps – RHRP-A, RHRP-B and RHRP-C
- Component Cooling pumps – CCWP-A, CCWP-B and CCWP-C

An analysis of the control mechanisms and control circuits of the auxiliary feedwater system was conducted and it was confirmed that control and instrumentation circuit damage could not affect startup and operation of the turbine driven AFW pump due to a fire in compartments B1, B2 or B3.

A.9 Circuit Analysis

This is Task 3 in Figure 1 of the main body of this report. From the information provided during the site visit, cable routing, potential failure modes and their associated probabilities were established for a subset of the components listed in Section A.8 above. Table A-1 provides the list of components for which circuit analysis was conducted. For the rest of the components (i.e., AFW and Component Cooling pumps), the information provided in Appendix R documents was used.

The electrical schematics were examined for each of the components for the selected cables that are routed within Compartments B1, B2 and B3 in order to determine the potential effects, if any, of fire damage to the cable. Specifically, the possibilities for loss of power (LOP), loss of control (LOC) and spurious operations (SO) were identified. If none of these effects appeared to be possible, from an electrical circuit analysis point of view, then that result was indicated as "No Effect." Finally, the probability of occurrence for each of the identified failure modes was estimated.

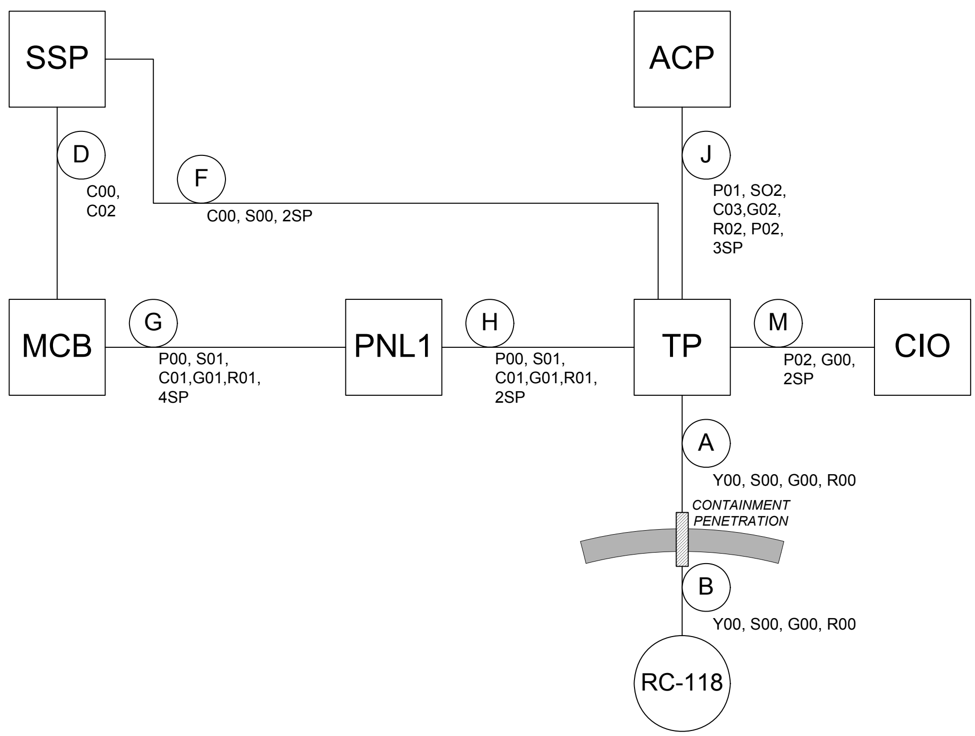
For example, the process of analyzing one of the PORVs, RC-118, for the failure modes of concern first required the use of applicable electrical drawings for the circuit. Figure A-3 is a block diagram of the valve circuit. It identifies all of the cables associated with the valve as well as their endpoints. For example, Cable A runs from the transfer panel ("TP" in the figure) to the containment penetration seal. This block diagram also provides information concerning the

specific conductors contained within each cable. Here the figure indicates that Cable A contains the four conductors identified as Y00, S00, G00 and R00.

Figure A-4 is the electrical schematic of the power and control circuit for RC-118. Here the individual conductors are again identified and shown in electrical relationship with the various subcomponents that make up the circuit. For example, the figure shows that conductor S00 connects the valve solenoid to the positive side of the power source (when switch CS-1(A) is closed) and Y00 connects the solenoid to the negative side of the power supply.

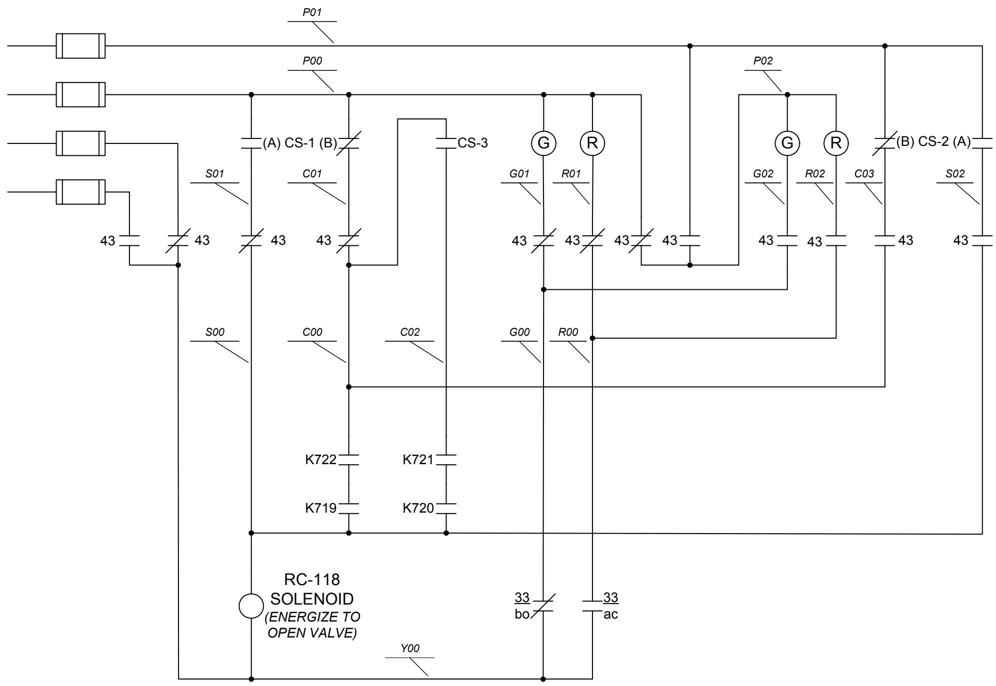
Furthermore, the cable routing information provided for the RC-118 cables (not reproduced here) showed that only cables A, F, H, J and M were located in the fire areas of concern. Consequently, cables B, D and G were excluded from further analysis for this example.

Figure A-3. Block Diagram for RC-118[2]



[2] SSP: Safe Shutdown Panel; MCB: Main Control Board; ACP: Alternate Control Panel; PNL1: Panel 1; TP: Transfer Panel; CIO: Computer Input/Output.

Figure A-4. Electrical Circuit Diagram for RC-118



The hot probe methodology was employed to analyze the five cables of concern to determine the possibility that the failure modes of concern (SO, LOP or LOC) could be induced. In the case of Cable A, a positive 125VDC hot probe touching Y00 could induce the circuit fuse to blow thus causing a loss of control to the circuit. Note that in this case, not all power to the circuit is lost, consequently the loss of one power fuse is defined as a loss of control condition rather than as a loss of power. This same result could occur if the positive hot probe made contact with conductor G00. On the other hand, the positive probe could induce a spurious operation of the valve solenoid when in contact with conductor S00. Finally, a positive hot probe contacting R00 would have no effect on the circuit. The following table summarizes the findings of the hot probe analysis for Cable A.

Results of Hot Probe Analysis on Cable A of RC-118

Conductor ID	Effect of +125 VDC Hot Probe
Y00	LOC
S00	SO
G00	LOC
R00	--

In the case of Cable F, a positive 125VDC hot probe touching C00 would have no effect on the circuit. On the other hand, the positive probe could induce a spurious operation of the valve solenoid when in contact with conductor S00. It should be noted that, for the purposes of circuit analysis, it is assumed that hot probe contacts from any source will not affect circuit operation or functionality when in contact with a spare conductor (identified as "SP" in Figure A-3). The following table summarizes the findings of the hot probe analysis for Cable F.

Results of Hot Probe Analysis on Cable F of RC-118

Conductor ID	Effect of +125 VDC Hot Probe
C00	--
S00	SO

The +125 VDC hot probe analysis of Cable H reveals no effect when it contacts conductors P00, C01 or R01. Contact with conductor S01 will cause a spurious actuation of the solenoid and a loss of control will result from contact with conductor G01.

Results of Hot Probe Analysis on Cable H of RC-118

Conductor ID	Effect of +125 VDC Hot Probe
P00	--
S01	SO
C01	--
G01	LOC
R01	--

None of the conductors in Cable J will have any effect on the circuit if put into contact with a positive 125 VDC hot probe. This is because they are either already at that voltage, as in the case for P01, P02 and C03, or they (i.e., conductors S02, G02 and R02) are isolated from the rest of the circuit by the transfer panel switches, identified as “43” devices.

Results of Hot Probe Analysis on Cable J of RC-118

Conductor ID	Effect of +125 VDC Hot Probe
P01	--
P02	--
S02	--
C03	--
G02	--
R02	--

Contact of conductor P02 in Cable M by a positive 125 VDC probe will have no effect on the circuit. On the other hand, contact by a positive probe on conductor G00 will cause a loss of circuit control.

Results of Hot Probe Analysis on Cable M of RC-118

Conductor ID	Effect of +125 VDC Hot Probe
P02	--
G00	LOC

Estimating the likelihood of the possible failure modes associated with each cable requires knowledge about the cables' configuration and installation. Fortunately much of this information is available from the block and circuit diagrams used previously to determine the possible failure modes for the cables.

The equations to be used to estimate the failure mode probabilities are empirically derived formulas. The likelihood of occurrence for a specific failure mode (P_{FM}) is estimated by

$$P_{FM} = P_{CC} * CF$$

Where:

P_{FM}: The probability that the specific failure mode of interest (e.g., SO, LOC, etc.) will occur in a specific circuit given a fire of sufficient intensity to cause cable damage

P_{CC}: The probability that a conductor-to-conductor short will occur prior to a short-to-ground or short to a grounded conductor

CF: Configuration Factor - A factor applied to P_{CC} that accounts for the relative number of source conductors and target conductors located within the cable under investigation

The calculation of P_{CC} is based on the following formula.

$$P_{CC} = (TC - GC) / [(TC - GC) + (2 * GC) + F_G]$$

Where:

TC: Represents the total number of conductors contained within the cable of interest (including spare conductors),

GC: The number of grounded (or common) conductors in the cable

F_G: A factor that represents the potential of ground plane interactions with the cable conductors that is based on the type of raceway in which the cable is routed and the nature of the electrical ground (if any) employed by the circuit. Refer to the table below for the appropriate values of F_G to use for different circuit-ground configurations.

F_G:	Circuit-Ground Features
0	ungrounded circuits
1	grounded circuits in cable trays
3	grounded circuits in conduit or armor

The cable's configuration factor, CF, is calculated as follows:

$$CF = \{TGC * [SC + (0.5 / TC)]\} / TC$$

Where:

TGC: Represents the total number of target conductors located within the cable that are capable of forcing the component or circuit into the undesired state or condition (e.g., causing spurious actuation),

SC: The total number of source (energized) conductors in the cable under evaluation,

TC: The total number of conductors contained within the cable as previously defined.

Target conductors are those conductors of a circuit that, if energized by an electrical source of proper magnitude and voltage, will result in spurious actuation of the circuit, component, or device of concern. Source conductors represent energized conductors that are a potential source of electrical energy needed to realize the spurious actuation effect.

Note that the term (0.5 / TC) in the formula is used to account for external source cables that could initiate a spurious actuation due to inter-cable shorting. This term becomes important only in those cases where there are no source conductors contained within the cable. If the cable is protected from interaction with other energized source cables (e.g., the cable is armored or routed in dedicated conduit) then the 0.5 / TC term is not applicable and the configuration factor formula becomes:

$$CF = (TGC * SC) / TC$$

Calculation of the conductor-to-conductor shorting probability for Cable A results in

$$P_{CC(A)} = (TC - GC) / [(TC - GC) + (2 * GC) + F_G]$$

Where TC is 4 conductors, GC is 2 of those conductors (Y00 and G00) connected to the negative side of the DC power supply, and F_G is determined to be 0 based on the fact that we are dealing with an ungrounded circuit. Hence,

$$P_{CC(A)} = (4 - 2) / [(4 - 2) + (2 * 2) + 0] = 2 / [2 + 4 + 0] = 2 / 6 = 0.33$$

The configuration factor for spurious operation is based on the equation

$$CF_{SO(A)} = (TGC * SC) / TC$$

because the cable routing information for Cable A indicates that it is run through dedicated conduit throughout its run in compartment B2, hence no external cable interactions are deemed credible. Here, TGC is determined to be 1 (conductor S00) and it is also determined that there are no source conductors within the cable (i.e., SC = 0). Consequently,

$$CF_{SO(A)} = (1 * 0) / 4 = 0$$

Using these results, we can now estimate the probability of spurious operation occurring as a result of fire damage to Cable A:

$$P_{SO(A)} = P_{CC(A)} * CF_{SO(A)} = 0.33 * 0 = 0$$

For estimating the probability that Cable A will cause a loss of control condition, the cable configuration factor is determined to be

$$CF_{LOC(A)} = (TGC * SC) / TC$$

Where TGC is 2 (conductors Y00 and G00) and SC is 0 (i.e., there are no sources within the cable).

$$CF_{LOC(A)} = (2 * 0) / 4 = 0$$

And the estimated the probability of loss of control occurring as a result of fire damage to Cable A is

$$P_{LOC(A)} = P_{CC(A)} * CF_{LOC(A)} = 0.33 * 0 = 0$$

Since the probabilities for both possible failure modes are 0, it is determined that Cable A in fact can have no effect on the proper operation of RC-118.

Cable F is a four-conductor cable with no negative voltage conductors. Thus,

$$P_{CC(F)} = (4 - 0) / [(4 - 0) + (2 * 0) + 0] = 4 / [4 + 0 + 0] = 4 / 4 = 1$$

Because Cable F is routed in cable trays through compartments B1 and B2, the following equation is used to determine the configuration factor for spurious operation.

$$CF_{SO(F)} = \{TGC * [SC + (0.5 / TC)]\} / TC$$

Where, TGC is 1 (S00) and SC is 1 (C00). The remaining conductors are spares (i.e., not connected to the control circuit). Using this information we find

$$CF_{SO(F)} = \{1 * [1 + (0.5 / 4)]\} / 4 = \{1 * [1.125]\} / 4 = 1.125 / 4 = 0.28$$

Then, the estimated probability of spurious operation from Cable F becomes

$$P_{SO(F)} = P_{CC(F)} * CF_{SO(F)} = 1 * 0.28 = 0.28$$

In similar ways, we estimate the probability of spurious actuation for Cable H as follows:

$$P_{CC(H)} = (TC - GC) / [(TC - GC) + (2 * GC) + F_G]$$
$$= (7 - 1) / [(7 - 1) + (2 * 1) + 0] = 6 / [6 + 2 + 0] = 6 / 8 = 0.75$$

And

$$CF_{SO(H)} = \{TGC * [SC + (0.5 / TC)]\} / TC$$
$$= \{1 * [2 + (0.5 / 7)]\} / 7 = \{1 * [2.07]\} / 7 = 2.07 / 7 = 0.30$$

Thus

$$P_{SO(H)} = P_{CC(H)} * CF_{SO(H)} = 0.75 * 0.30 = 0.23$$

For the probability of loss of control condition

$CF_{LOC(H)}$ = {1 * [2 + (0.5 / 7)]} / 7 = {1 * [2.07]} / 7 = 2.07 / 7 = 0.30

Giving a probability of

$P_{LOC(H)}$ = 0.75 * 0.30 = 0.23

No possible failure modes of concern were identified for Cable J, thus it is determined to have no effect on the proper operation of RC-118.

Cable M was determined to be able to cause a loss of control condition with the estimated probability of

$P_{CC(M)}$ = (4 - 1) / [(4 - 1) + (2 * 1) + 0] = 3 / [3 + 2 + 0] = 3 / 5 = 0.60

$CF_{LOC(M)}$ = {1 * [1 + (0.5 / 4)]} / 4 = {1 * [1.125]} / 4 = 1.125 / 4 = 0.28

$P_{LOC(M)}$ = 0.60 * 0.28 = 0.17

All other components requiring circuit analysis (e.g., RC-114, CS-012, etc.) were evaluated using this process.

The list of components reviewed and a summary of the corresponding results of this review are provided in Table A-1. The column headings in Table A-1 have the following meanings:

- Tag No. - This is a unique number identifying the cables associated with a particular component.
- Component - This is the component's identifier (e.g., CS-012, etc.).
- Description - This indicates the component's intended function.
- Cable ID - This is the suffix of the cable number (i.e., Tag No. + Suffix letter) as employed on the cable routing tables and electrical schematics for the component.
- Raceway - These are the identities of the cable trays carrying the cable within B1, B2 or B3.
- B1, B2 and B3 - "X" indicates that the cable is routed somewhere within the area.
- No Effect - "X" indicates that the portion of the circuit is not capable of adversely affecting the function of the component in the event of fire damage. However, other effects may occur such as loss or erroneous indications/alarms, for example, but the component itself should remain available.
- Prob. LOP - The value provided is the estimated probability that the primary power supply to the component would be lost or disrupted if the cable is damaged by fire.
- Prob. LOC - The value provided is the estimated probability that remote control of the component would be lost or severely impaired if the cable is damaged by fire.
- Prob. SO - The value provided is the estimated probability that fire damage to the cable would result in the component changing state (e.g., from open to shut, or from stopped to running) without operator action.

Table A-1 Circuit Analysis Results

Tag No.	Component	Description	Cable ID	Raceway	B1	B2	B3	No Effect	Prob. of LOP	Prob. of LOC	Prob. Of SO
10156	RC-114	Pressurizer PORV		*(No cables routed in B1, B2 or B3)*							
10157	RC-118	Pressurizer PORV	A	C1302, C1350		X		X			
			F	C1302, C1350	X	X					0.28
			H	C1302, C1350	X	X				0.23	0.23
			J	C1302, C1310, C1350	X	X	X	X			
			M	C1302, C1350	X	X				0.17	
10158	RC-116	Pressurizer PORV	A	C1205		X		X			
			J	C1216	X	X	X	X			
10160	RC-117	Pressurizer Block Valve	H	C1213	X			X			
			K	C1205	X	X		X			
			L	C1205	X	X		X			
			M	C1205	X	X	X	X			
			N	C1216	X	X	X	X			
10161	RC-115	Pressurizer Block Valve	H	C1213	X		X	X			
10162	RC-113	Pressurizer Block Valve	E	C1200, C1213	X					0.21	0.4
			H	C1201, C1213	X		X	X			
			N	C1213	X		X	X			
10221	HPIP-A	High Pressure Injection Pump	A	X1300		X			0.9998		
			B	C1301		X		X			
			D	C1309	X	X	X				0.23
			F	C1310	X	X	X	X			
			G	C1309	X	X	X	X			
			J	L1301		X		X			
			L	C1301	X	X	X	X			
			M	C1301	X	X	X	X			
10222	HPIP-B	High Pressure Injection Pump	B	C1812	X		X	X			
10223	HPIP-C	High Pressure Injection Pump	B	C1301		X		X			
			D	C1309	X	X					0.23
			F	C1310	X	X	X	X			
			G	C1309	X	X	X	X			

Table A-1 Circuit Analysis Results

Tag No.	Component	Description	Cable ID	Raceway	B1	B2	B3	No Effect	Prob. of LOP	Prob. of LOC	Prob. Of SO
			J	L1301		X		X			
			M	C1301	X	X	X	X			
10243	CS-012	VCT Outlet Isolation Valve	B	C1302	X	X	X	X			
			C	C1309	X	X				0.25	0.31
			D	C1300	X	X					0.42
			G	C1302	X		X	X			
			H	C1302	X		X	X			
10245	CS-013	VCT Outlet Isolation Valve		*(No cables routed in B1, B2 or B3)*							
10947	CC-009	RCP Thermal Barrier Isol. Valve	A	P1716	X			X			
			B	C1704	X		X	X			
			C	C1704	X	X				0.25	0.38
10955	CC-010	RCP CCW Isolation Valve	C	C1309	X	X				0.25	0.31
			F	C1309	X		X	X			
11254	SR-01	Steam Generator PORV	B	C1301, C1309, C1310	X	X			0.9998		
			C	L1301	X					0.16	
			E	C1309		X		X			
			F	L1301	X		X	X			
			J	C1310	X	X		X			
			K	C1310	X	X	X	X			
			L	C1301		X		X			
			N	L1301	X	X				0.16	
			P	L1301	X	X				0.14	
			Q	C1309	X	X			0.67		
11255	SR-02	Steam Generator PORV	L	C1301	X	X	X	X			
11256	SR-03	Steam Generator PORV	B	C1310	X				0.9998		
			C	L1301	X					0.16	
			E	C1310	X	X	X	X			
			F	L1301	X			X			
			H	L1301	X	X				0.14	
			J	C1309	X	X			0.67		

Even though in Table A-1 "no effect" is noted only for those cases that no other failure mode is possible, it is important to understand that all cable failures lead to "no effect" unless otherwise noted. Therefore, for each cable, the entire set of possible failure modes includes "No Effect" and one or more of the other three failure modes. For example, in the case of CS-012, Cable C leads to P(LOC) = 0.25 and P(SO) = 0.31. Therefore, for that cable the probability of having no effect on circuit function, P(No Effect) = 1 - (0.25 + 0.31) = 0.44.

If for the same valve more than one cable is present in the same fire scenario, it is assumed that failure of each cable is mutually exclusive from the other cable failures. For example, in the case of PORV RC-118 the following possibilities exist:

- Cable F, $P_{SO(F)} = 0.28$
- Cable H, $P_{SO(H)} = 0.23$
- Cable H $P_{LOC(H)} = 0.23$
- Cable M $P_{LOC(M)} = 0.17$

However, it is important to note that LOC dominates. In other words, if one of the cables leads to LOC, it does not matter if another cable has experienced SO. Also, in this specific example, Cable H can only fail in one mode (i.e., LOC or SO). To estimate the probability of spurious operation of the valve, the following truth table was put together defining all mutually exclusive combinations of cable failure modes. Each line in the truth table represents one set of possible failure modes of the three cables. In the last column (titled RC-118) the effect of the combination of failure modes on RC-118 is shown.

Case	Cable			RC-118
	F	H	M	
1	SO	SO	LOC	LOC
2	SO	SO	NE*	SO
3	SO	LOC	LOC	LOC
4	SO	LOC	NE	LOC
5	SO	NE	LOC	LOC
6	SO	NE	NE	SO
7	NE	SO	LOC	LOC
8	NE	SO	NE*	SO
9	NE	LOC	LOC	LOC
10	NE	LOC	NE	LOC
11	NE	NE	LOC	LOC
12	NE	NE	NE	NE

*NE = No Effect

Of the 12 possible failure mode combinations shown in the truth table, the following three combinations lead to spurious operation of RC-118:

Cable	Case # 2		Case # 6		Case # 8	
	FM	Prob.	FM	Prob.	FM	Prob.
F	SO	0.28	SO	0.28	NE*	0.72
H	SO	0.23	NE	0.54	SO	0.23
M	NE	0.83	NE	0.83	NE	0.83
Case Probability		5.35E-02		1.25E-01		1.37E-01

* NE = No effect

As it is shown in the truth table, all other combinations of the failure modes would either lead to LOC or would have no effect on the valve. Since all three cables should simultaneously fail in the postulated failure mode, the probability of each case should be the multiplication of the three probabilities in each column. The overall probability of spurious operation of RC-118 should then be the sum of the three probabilities. It must be noted that since the three cases are mutually exclusive, the sum of the probabilities should not be corrected with the product of the probabilities.

$$P_{SO(RC118)} = P_{SO(F)}\, P_{SO(H)}\, (1-P_{LOC(M)}) + P_{SO(F)}\, (1 - P_{SO\,(H)} - P_{LOC(H)}\,)\, (1-P_{LOC(M)}) + $$
$$+ (1 - P_{SO(F)}\,)\, P_{SO(H)}\, (1-P_{LOC(M)})$$
$$= 0.28 * 0.23\, (1 - 0.17) + 0.28\, (1 - 0.23 - 0.23)\, (1 - 0.17) +$$
$$+ (1 - 0.28\,)\, 0.23\, (1 - 0.17) = 0.0535 + 0.125 + 0.137 = 0.32$$

Finally, from a review of the Appendix R documents, it was concluded that cables associated with AFWP-B and CCWP-A are routed through Compartments B1 and B2. In addition to the cables associated with these two pumps and the components listed in Table A-1, a large number of other cables are present in Compartments B1 and B2. However, failure of those other cables was found to have no effect on the safe shutdown process modeled in the event tree of this Phase 3 analysis.

A.10 Component and Cable Locations

This is Task 4 in Figure 1 of the main body of this report. A walkdown of Compartments B1 through B3 was conducted by the analysis team. During the walkdown, the specific and relevant features of each compartment were noted. The following discussions summarize salient features of each compartment and observations made as a result of the information gained during the walkdown. In this part of the analysis, the ignition characteristics of the combustible materials and especially cables were established. It was assumed that the typical cable of interest was not a qualified cable (i.e., qualified per IEEE-383) and its damage threshold temperature is 400^{o}F.

Compartment B1

This compartment measures 50’ long, 20’ wide, and 15’ high with a 15’x 10’ alcove on the northwestern corner. This compartment contains a large number of cables in two stacks of cable trays that are 15’ apart horizontally. Each stack carries cables from only one safety train (i.e., train A or B). The bottom cable tray is 12’ off the floor and there is a one-foot vertical separation between trays. The trays traverse the length of the compartment in the North-South

direction. Some trays have solid bottoms. Power (including 6.9kV), control and instrumentation cables are present in this compartment. Generally, power cable trays are run above the other trays and control cables are run above instrumentation trays. The Eastern half of the compartment contains the 6.9kV bus bars that provide offsite power connection to various plant switchgears. The bus bars also traverse the length of the compartment (i.e., North-South direction).

There are two large compressors located at the North end of the compartment. Each compressor contains 3 gallons of lubricating oil. There are two small pumps in the northwest corner of the compartment, each containing 2 gallons of lubricating oil.

From a review of the cables present in this compartment (see Table A-1), it was concluded that there is a possibility of spurious closure of the three valves of interest. Therefore, it was decided that further analysis of Compartment B1 is warranted.

Compartment B2

This compartment measures 60' long, 30' wide, and 15' high. This compartment contains a large number of cables in two stacks of cable trays that are 15' apart horizontally. Each stack carries cables from only one safety train (i.e., train A or B). The bottom cable tray is 12' off the floor and there is a one-foot vertical separation between trays. In this compartment the trays traverse a little over half the length of the compartment in the North-South direction. The cables are in cable trays and conduits. Power (including 6.9kV), control and instrumentation cables are present in this compartment. Generally, power cable trays are run above the other trays and control cables are run above the instrumentation trays. The Eastern half of the compartment contains the 6.9kV bus bars that provide offsite power connection to various plant switchgears. The bus bars also traverse the length of the compartment (i.e., North-South direction). There are no other devices in this compartment.

From a review of the cables present in this compartment (see Table A-1), similar to Compartment B1, it was concluded that there is a possibility of spurious closure of the three valves of interest. Therefore, it was decided that further analysis of Compartment B2 is warranted.

Compartment B3

This compartment is one of the electrical penetration areas. It contains a large number of cables near the ceiling and the floor. It contains a 480 VAC MCC and 6.9kV power cables. From a review of the cables present in this compartment and their likely failure modes (see Table A-1), it was concluded that if all the cables associated with the three valves of interest located in compartment B3 were to be damaged by a fire, additional independent failures are necessary for the initiating event of the event tree of this analysis to occur. In other words, RCP seal injection or cooling flow will be maintained barring additional, random failures. Since the additional failures have a low probability of occurrence, no further analysis was deemed to be necessary.

This was the first screening of the analysis. It may also be noted that the location of only the cables associated with the components listed in Section A.8 were determined in Compartments

B1 through B3. Therefore, as it is discussed below, the focus of the Phase 3 analysis was solely on cable damage.

A.11 Fire Scenarios and Target Sets

This is Task 5 in Figure 1 of the main body of this report. The targets (i.e., items of interest that may be adversely affected by a fire) were defined in terms of cables associated with the components listed in Section A.8. Table A-2 provides this list, the location of their cables (limited to Compartments B1 and B2) and the potential impact of cable damage on each component. The information summarized in Table A-2, with the exception of the AFW and CCW pumps, is based on the results of the circuit analysis (summarized in Table A-1). As noted in Section A.10, Appendix R related documents were used to establish the presence of cables related to the AFW and CCW pumps. From Appendix R information it was concluded that only AFWP-B and CCWP-A related cables are present in Compartments B1 and B2.

As Section A.6 above indicated, two general categories of fire scenarios were considered for each compartment: 1) a severe fire damaging all the cables in a compartment and 2) localized fires affecting a limited volume within each compartment. To establish the localized fire scenarios, cable locations had to be established. From the documents (i.e., drawings, computerized databases and other documents), the cable routing of the components listed in Table A-1 could be established. The cable routings of AFWP-B and CCWP-A was not readily available. Therefore, it was conservatively assumed that the cables for these two pumps are present in every cable tray of the Compartments B1 and B2 with corresponding train designation. That is, AFWP-B cables are present in every train B cable tray and CCWP-A cables present in every train A cable tray.

From a review of the location of various cables and the function and failure mode of the affected component, a set of localized sub-areas within Compartments B1 and B 2 were established that have a unique combination of cables. Figure A-5 presents the approximate boundaries of these localized sub-areas. Table A-3 provides a list of the sub-areas, the target set within each sub-area and ignition sources.

The target list in Table A-3 does not include those valves for which the circuit failure modes did not affect the event tree top events. For example, cables for SR-02 are present in Compartments B-1 and B-2, but as it is shown in Table A-2, cable failure would have no effect on this valve. Additionally, the basis of the initial fire inspection findings was the effect on safe shutdown due to the possible spurious closure of three specific valves. Since the cables for those valves are not routed in sub-areas B, F and G, the CDFs for those sub-areas were expected to remain unaffected by the SDP finding. Therefore, no further analysis of those sub-areas was required. Only fire damage in sub-areas A, C, D and E can lead to the initiating event modeled in this Phase 3 analysis. The rest of the sub-areas were screened out.

Table A-2 Targets by Compartment

Component	Description	B1	B2	Cable Damage Impact
RC-114	Pressurizer PORV	-	-	No cables in Compartments B1 or B2
RC-118	Pressurizer PORV	X	X	Possibility of LOC or SO
RC-116	Pressurizer PORV	X	X	No effect
RC-117	Pressurizer Block Valve	X	X	No effect
RC-115	Pressurizer Block Valve	X	-	No effect
RC-113	Pressurizer Block Valve	X	-	Possibility of LOC or SO
HPIP-A	High Pressure Injection Pump	X	X	Possibility of LOP or SO
HPIP-B	High Pressure Injection Pump	X	-	No effect
HPIP-C	High Pressure Injection Pump	X	X	Possibility of SO
CS-012	VCT Outlet Isolation Valve	X	X	Possibility of LOC or SO
CS-013	VCT Outlet Isolation Valve	-	-	No cables in Compartments B1 or B2
CC-009	RCP Thermal Barrier Isol. Valve	X	X	Possibility of LOC or SO
CC-010	RCP Thermal Barrier Isol. Valve	X	X	Possibility of LOC or SO
SR-01	Steam Generator PORV	X	X	Possibility of LOP or LOC
SR-02	Steam Generator PORV	X	X	No effect
SR-03	Steam Generator PORV	X	X	Possibility of LOP or LOC
AFWP-A*	AFW Pump A	-	-	No cables in Compartments B1 or B2
AFWP-B*	AFW Pump B	X	X	Possibility of LOP or LOC
AFWP-C*	AFW Pump C	-	-	No cables in Compartments B1 or B2
CCWP-A*	CCW Pump A	X	X	Possibility of LOP or LOC
CCWP-B*	CCW Pump B	-	-	No cables in Compartments B1 or B2
CCWP-C*	CCW Pump C	-	-	No cables in Compartments B1 or B2

* The information is based on Appendix R documents. No circuit analysis was conducted as part of the Phase 3 analysis. Therefore, Table A-1 does not address these pumps.

Figure A-5 Site Layout Relevant to Phase 3 Analysis

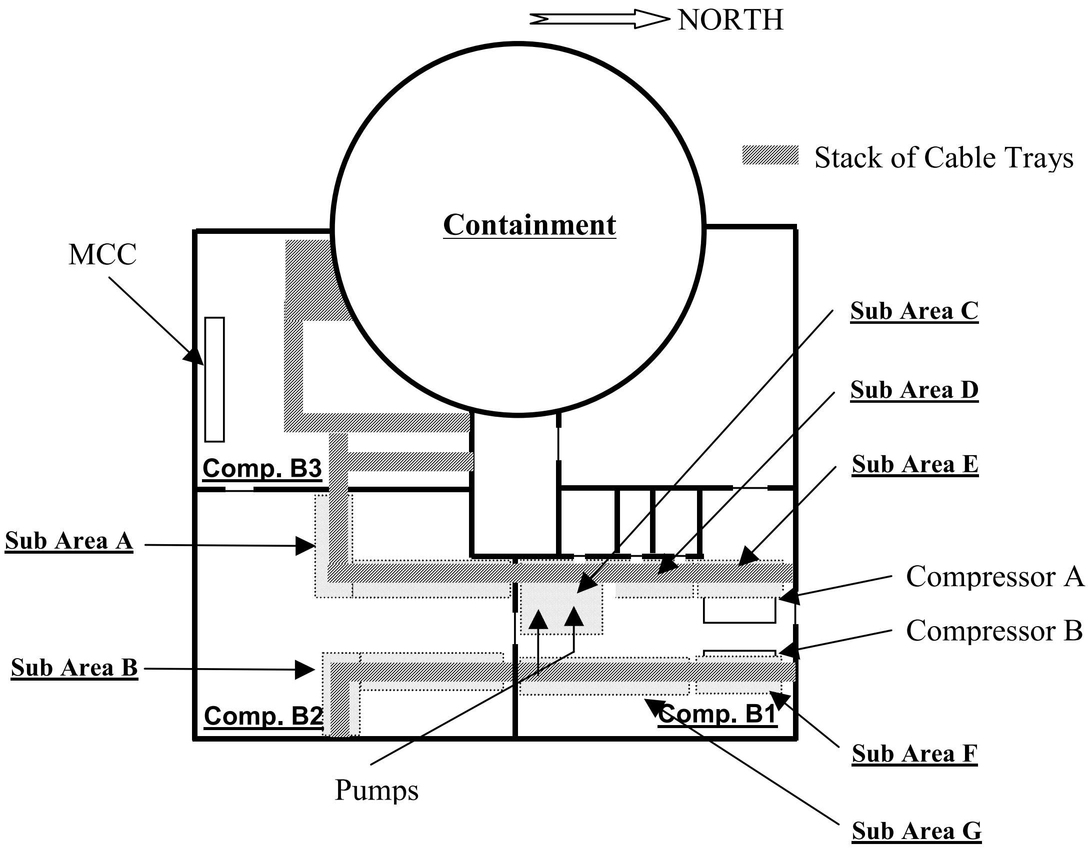


Table A-3 Sub-Areas, Targets and Ignition Sources

Sub-Area	Target Set	Ignition Sources
A	CCWP-A HPIP-A CS-012 CC-010 SR-01	Self-Ignited Cable Transient Combustible Fire
B	AFWP-B RC-118 HPIP-C	Self-Ignited Cable Transient Combustible Fire
C	CCWP-A CS-012 CC-009 CC-010 SR-01	Self-Ignited Cable Transient Combustible Fire Two pumps

Table A-3 Sub-Areas, Targets and Ignition Sources (continued)

Sub-Area	Target Set	Ignition Sources
D	CCWP-A CS-012 CC-009 CC-010 SR-01	Self-Ignited Cable Transient Combustible Fire
E	CCWP-A CS-012 CC-009 CC-010 SR-01	Self-Ignited Cable Transient Combustible Fire Compressor
F	AFWP-B RC-118 RC-113 HPIP-C SR-03	Self-Ignited Cable Transient Combustible Fire Compressor
G	AFWP-B RC-118 RC-113 HPIP-C SR-03	Self-Ignited Cable Transient Combustible Fire

The following fire scenarios were identified:

- Scenario B1S – In this scenario, a severe fire in Compartment B1 damages all the cables in all cable tray stacks. Ignition sources for this scenario include the two pumps, the compressors, cables (self ignited fires) and transient fires (all categories).
- Scenario B1C – In this scenario, a localized fire affects the cables in sub-area C. Ignition sources for this scenario include the two pumps, cables (self ignited fires) and transient fires (all categories).
- Scenario B1D – In this scenario, a localized fire affects the cables in sub-area D. Ignition sources for this scenario include cables (self ignited fires) and transient fires (all categories).
- Scenario B1E – In this scenario, a localized fire affects the cables in sub-area E. Ignition sources for this scenario include one compressor, cables (self ignited fires) and transient fires (all categories).
- Scenario B2S – In this scenario, a severe fire in Compartment B2 damages all the cables in all cable tray stacks. Ignition sources for this scenario include cables (self ignited fires) and transient fires (all categories).
- Scenario B2A – In this scenario, a localized fire affects the cables in sub-area A. Ignition sources for this scenario include cables (self ignited fires) and transient fires (all categories).

Each fire scenario was analyzed separately.

A.12 Ignition Frequency

This is Task 6 in Figure 1 of the main body of this report. A number of methods are available to estimate the ignition frequencies associated with each fire scenario: 1) the data and method prescribed in Reference A-1, 2) the plant's IPEEE and 3) the SDP Phase 2 guide (Reference A-2). Reference A-1 includes a set of fire frequencies for a large number of ignition source types (see Table 6-1 in Reference A-1). However, to establish fire frequencies at a specific compartment that method requires some knowledge of the total number of items in the plant (e.g., total number of pumps) so that the total frequency provided in Reference A-1 is properly scaled down to the compartment level. The information needed for this purpose may be available in the plant's IPEEE supporting documentation.

The supporting documents for the plant's IPEEE, in principal, should include an analysis of fire ignition frequencies by compartment that can be used in a Phase 3 analysis (the second method noted above). The IPEEE frequencies could be outdated or may not address the specific conditions of interest of the Phase 3 analysis. If the first two sources fail to provide the necessary information, Reference A-2 ignition frequencies can be used (see Table A1.3 in Reference A-2). However, the frequencies given in Table A1.3 of Reference A-2 are regarded as conservative estimates. If those frequencies are used and the final results yield a CDF other than Green, further ignition frequency analysis may be warranted.

In this example, it is assumed that the IPEEE supporting documents provided the necessary equipment counts and cable loading by compartment. Table A-4 provides a list of the ignition source types found in Compartments B1 and B2. In Table 6-1 of Reference A-1, the ignition source types are referenced by a bin number, which are also provided in Table A-4. The frequencies listed in Table A-4 are also taken from Table 6-1 of Reference A-1. They are the frequency of fire ignition associated with an ignition source type across the entire plant unit. For example, if there are 90 pumps in the unit. The total fire ignition frequency associated with all 90 put together is 2.1E-02 per year according to Table 6-1 of Reference A-1.

Table A-4 Ignition Source Distribution Data

Ignition Source	Bin #(1)	Plant-wide Frequency (per ry) (1)
Pumps	21	2.1E-02
Compressors	9	2.4E-03
Cables (self ignited fires)	12	4.1E-03
Cable fires caused by welding and cutting	11	2.0E-03
Transient fires caused by welding and cutting	24	4.9E-03
Transients	25	9.9E-03

(1) Taken from Table 6-1 of Reference A-1.

Each plant-wide frequency of Table A-4 is modified based on an ignition source weighting factor determined from the total contents of items in the plant. For transient fires, the weighting factor is based on qualitative evaluation of three influencing factors: maintenance, occupancy and storage (see Section 6.5.7.2 of Reference A-1 for details).

The following information was gleaned from the IPEEE for establishing the ignition source weighting factor:

- There are 90 pumps in the plant with characteristics matching the definition of Bin # 21 as provided in Section 6.5.6 of Reference A-1.
- There are 10 air compressors in the plant with characteristics matching the definition of Bin # 9.
- 5% by weight of all open cables in the plant are located in Compartment B1.
- 7% by weight of all open cables in the plant are located in Compartment B2.
- The *Maintenance* level in Compartment B1 is *medium* (per Section 6.5.7.2 of Reference A-1, medium reflects the average level of this factor).
- The *Occupancy* level in Compartment B1 is *medium*.
- The *Storage* level in Compartment B1 is *low* (per Section 6.5.7.2 of Reference A-1, low reflects the minimum level of this factor).
- The *Maintenance* level in Compartment B2 is *low*.
- The *Occupancy* level in Compartment B2 is *medium*.
- The *Storage* level in Compartment B2 is *low*.

As noted, the terms medium and low are defined in Section 6.5.7.2 of Reference A-1 and numerical ratings of 3 and 1 are assigned to these levels, respectively. To calculate the ignition source weighting factor, these values are divided by the total rating values for all plant compartments. The following are the total rating values for all plant locations:

- Total rating value for *Maintenance* was found to be 432[3]
- Total rating value for *Occupancy* was found to be 226
- Total rating value for *Storage* was found to be 112

To calculate the ignition source weighting factor for cable fires caused by welding and cutting, the following formulations provided in Section 6.5.7.2 of Reference A-1 were used:

$W_{CF,J} = n_{m,J} W_{Cable,J} / N_{CF}$

$N_{CF} = \Sigma\, n_{m,i,L} W_{Cable,I}$ (summed over i, all compartments of location L),

[3] This and the other two values (i.e., 226 and 112) are the results of assigning maintenance, occupancy and storage numerical rating to each compartment in the plant and adding them together. For example, for maintenance, of the 92 compartments in the plant, 39 were rated as *low (numerical rating* 1) 31 rated as *medium (3)*, 20 rated as *high* (10) and 2 rated as *very high* (50). The total plant rating value for maintenance as 39 x 1 + 31 x 3 + 20 x 10 + 2 x 50 = 432. The other two total ratings were calculated in a similar manner.

where:

$n_{m,i,L}$ = Maintenance influence factor rating of compartment i of location L,

$W_{Cable,i}$ = Cable load of compartment i, based on the ratio of quantity of cables in compartment i over the total quantity of cables in the location.

The percentage by weight of open cables (i.e., cables that are not in conduits or fully enclosed cable trays) in every compartment was estimated. The average percentage of open cables was determined to be 10.95%. The total weighted rating (i.e., N_{CF}) was, therefore, found to be 432 x 10.95% = 47.3.

Using the information provided above, the ignition source weighting factors and corresponding ignition source frequencies of the two compartments were calculated. See Table A-5. From these frequencies, the ignition source frequencies associated with each fire scenario can be calculated. It must be noted that more than one ignition source may be associated with one fire scenario. For example, Scenario B1C includes two pumps, cables and transients as ignition sources.

To calculate the ignition frequency of cables and transients, it was assumed that the likelihood of ignition is uniformly distributed across corresponding surface areas. It was assumed that transient fires may occur anywhere on the floor of the compartment, but cable fire may only occur in the open cable trays. It was additionally assumed that all stacks of cable trays have the same number of open cable trays. In the case of transients, the fraction of compartment floor area occupied by the footprint of the sub-area was used to adjust the overall compartment transient frequency. In the case of cable fires, the total footprint of the stacks of cable trays was computed. The fraction of cable tray footprint of the sub-area was then estimated for adjusting the overall cable fire frequency of the compartment. For example, for Scenario B1C, the floor footprint of the sub-area (see Figure A-5 of this Appendix) is approximately 20% of compartment floor area and cable stack footprint is 15% of all the cable stacks of the compartment. These fractions are provided in Table A-6.

Using the information and data gathered we can now estimate the frequencies of the scenarios identified in Section A.12 above. Table A-7 provides a summary of the calculations performed to estimate scenario frequencies, which are obtained by adjusting the frequencies listed in Table A-5 per number of ignition sources or the fractions provided above. Ignition source frequencies of each scenario and the total ignition frequency associated with each fire scenario is obtained.

Table A-5 Ignition Source Weighting Factors and Frequencies

Ignition Source	Plant-wide Frequency (per ry) (1)	Ignition Source Weighting Factor	Frequency (per ry) (2)
Compartment B1			
Pump (each pump)	2.1E-02	1/90 (3)	2.3E-04
Compressor (each compressor)	2.4E-03	1/10 (3)	2.4E-04
Cables (self ignited fires)	4.1E-03	5% (4)	2.1E-04
Cable fires caused by welding and cutting	2.0E-03	(5% x 3)/47.3 (5)	6.3E-06
Transient fires caused by welding and cutting	4.9E-03	3/432 (5)	3.4E-05
Transients	9.9E-03	(3 + 3 + 1)/(432 + 226 + 112) (5)	9.0E-05
Compartment B2			
Cables (self ignited fires)	4.1E-03	7% (4)	2.9E-04
Cable fires caused by welding and cutting	2.0E-03	(7% x 1)/47.3 (5)	3.0E-06
Transient fires caused by welding and cutting	4.9E-03	1/432 (5)	1.1E-05
Transients	9.9E-03	(1 + 3 + 1)/(432 + 226 + 112) (5)	6.4E-05

(1) From Table A-4
(2) Frequency is determined by multiplying the Plant-wide Frequency value by the Ignition Source Weighting Factor.
(3) 90 and 10 are the total number of pumps and compressors in the plant, respectively.
(4) 5% and 7% are percentage by weight of plant cables found in compartments B1 and B2 respectively.
(5) 3 (medium) and 1 (low) are the influence factor ratings for maintenance, occupancy and storage. These formulations were taken from Section 6.5.7.2 of Reference A-1.

Table A-6 Adjustment Factors for Cable and Transient Fire Frequencies

	Fraction of Floor Area / Cable Stack Footprint						
	Compartment B2		Compartment B1				
	A	B	C	D	E	F	G
Cable Fire or Cable Fire due to Welding or Cutting	50%	50%	15.0%	20.0%	15.0%	15.0%	35.0%
Transients and Transient due to welding and cutting	12.5%	12.5%	19.6%	8.7%	6.5%	6.5%	15.2%

Table A-7 Fire Scenario Frequencies

Fire Scenario	Ignition Sources	Overall Source Frequency	Adjustment Factor	Frequency (per ry)
Scenario B1S	Pumps	2.30E-04	2 (1)	4.6E-04
	Compressors	2.40E-04	2	4.8E-04
	Cables	2.10E-04	100.0% (2)	2.1E-04
	Cable fires caused by welding and cutting	6.30E-06	100.0%	6.3E-06
	Transient fires caused by welding and cutting	3.40E-05	100.0%	3.4E-05
	Transients	9.00E-05	100.0%	9.0E-05
		Total Scenario Frequency		*1.3E-03*
Scenario B1C	Pumps	2.30E-04	2	4.6E-04
	Cables	2.10E-04	15.0% (3)	3.2E-05
	Cable fires caused by welding and cutting	6.30E-06	15.0%	9.5E-07
	Transient fires caused by welding and cutting	3.40E-05	19.6%	6.7E-06
	Transients	9.00E-05	19.6%	1.8E-05
		Total Scenario Frequency		*5.2E-04*
Scenario B1D	Cables	2.10E-04	20.0%	4.2E-05
	Cable fires caused by welding and cutting	6.30E-06	20.0%	1.3E-06
	Transient fires caused by welding and cutting	3.40E-05	8.7%	3.0E-06
	Transients	9.00E-05	8.7%	7.8E-06
		Total Scenario Frequency		*5.4E-05*
Scenario B1E	Compressor	2.40E-04	1	2.4E-04
	Cables	2.10E-04	15.0%	3.2E-05
	Cable fires caused by welding and cutting	6.30E-06	15.0%	9.5E-07
	Transient fires caused by welding and cutting	3.40E-05	6.5%	2.2E-06
	Transients	9.00E-05	6.5%	5.9E-06
		Total Scenario Frequency		*2.8E-04*
Scenario B2S	Cables	2.10E-04	100.0%	2.1E-04
	Cable fires caused by welding and cutting	6.30E-06	100.0%	6.3E-06
	Transient fires caused by welding and cutting	3.40E-05	100.0%	3.4E-05
	Transients	9.00E-05	100.0%	9.0E-05
		Total Scenario Frequency		*3.4E-04*
Scenario B2A	Cables	2.10E-04	50.0%	1.1E-04
	Cable fires caused by welding and cutting	6.30E-06	50.0%	3.2E-06
	Transient fires caused by welding and cutting	3.40E-05	12.5%	4.3E-06
	Transients	9.00E-05	12.5%	1.1E-05
		Total Scenario Frequency		*1.2E-04*

(1) Number of pumps or compressors within the area covered by the scenario.
(2) Since this scenario covers the entire compartment, 100% is used.
(3) From Table A-6

A.13 Manual Actions

This is Task 10 in Figure 1 of the main body of this report. It is discussed here in preparation for estimating the CCDPs of the even sequences (discussed in the following section). Based on the locations and accessibility of the valves, it is assumed that the operators will not have sufficient time to diagnose and manually correct a spurious valve closure. The event sequences leading to core damage were reviewed and operator actions of each sequence were identified. The following is a list of actions/human error probabilities that were considered:

- **Sequence # 3 -** In this sequence, control room operators successfully align a motor driven AFW pump and an HPI pump. A plant operator is dispatched to check on the valve lineup for both systems to verify that all the valves are in the proper position and the intended pump is working. The plant operator does not have to enter Compartments B1 through B3 to accomplish these tasks. The remainder of the sequence is composed of RHR and HPR failures. Part of the contribution to RHR failure is control room operator error in starting the system within the available time. Use of the HPR function requires the operators to realign the HPI system for high pressure recirculation cooling and makeup. Therefore, operator error to realign the HPI system is part of the contribution to the HPR failure probability estimation. The probability of operator error to realign the HPI system for high pressure recirculation cooling and makeup was estimated assuming the RHR system has failed. (Human error probability estimation is presented as part of CCDP estimation process discussed in the next Section.)
- **Sequence # 4** – In this sequence, control room operators successfully align a motor driven AFW pump, but HPI pumps fail to function as intended. A plant operator is dispatched to check on the valve lineup for both systems to verify that all the valves are in the proper position and the intended pump is working. The plant operator does not have to enter Compartments B1 through B3 to accomplish these tasks. Part of the contribution to HPI failure probability was attributed to operator error.
- **Sequence # 7** – In this sequence, the AFW system fails. Part of the contribution to AFW failure probability was attributed to control room operator error. Operators, in this sequence are successful in establishing core cooling and makeup by using the PORVs for bleeding and HPI for feeding the RCS. The operators successfully depressurize the RCS by recovering secondary cooling via the SRVs and turbine driven AFW pump. The remainder of the sequence is composed of RHR and HPR failures. Part of the contribution to RHR failure is control room operator error in starting the system within the available time. Use of the HPR function requires the operators to realign the HPI system for high pressure recirculation cooling and makeup. Therefore, operator error to realign the HPI system is part of the contribution to the HPR failure probability estimation. The probability of operator error to realign the HPI system for high pressure recirculation cooling and makeup was estimated assuming RHR has failed.
- **Sequence # 9** – In this sequence, similar to Sequence # 7, the AFW system fails. Part of the contribution to AFW failure probability was attributed to control room operator error. Operators, in this sequence are successful in establishing core cooling and makeup by using the PORVs for bleeding and HPI for feeding the RCS. However, the operators fail to recover secondary cooling via the SRVs and turbine driven AFW pump. The human error probability for this event was estimated assuming failure of the AFW system. Use of the HPR function requires the operators to realign the HPI system for high pressure recirculation

cooling and makeup. Therefore, operator error to realign the HPI system is part of the contribution to the HPR failure probability estimation. The probability of operator error to realign the HPI system for high pressure recirculation cooling and makeup was estimated assuming that secondary cooling recovery has failed.

- **Sequence # 10** – In this sequence, the AFW and HPI systems fail. For both of these systems, a part of the system failure probability can be attributed to operator error. The human error probability for HPI was estimated assuming AFW has failed.
- **Sequence # 11** – In this sequence, AFW fails and control room operators fail to establish the bleeding part of feed and bleed. The human error probability for failing to establish bleed function was estimated assuming AFW has failed.

A.14 Conditional Core Damage Probabilities

The sequence of analysis steps in Figure 1 of the main body of this report suggests that fire propagation analysis be conducted after scenario frequencies are established. However, it is possible to minimize the fire propagation analysis effort, if the CDF of each scenario is estimated (Task 12 in Figure 1) based only on the ignition frequency and the CCDP (Task 11). Scenarios with CDFs much smaller than 1.0E-06/yr may not need to be analyzed further. Therefore, the CCDPs of the scenarios are evaluated before the rest of the steps are attempted.

The split fractions of the event tree shown in Figure A-2 were evaluated for each fire scenario described in Section A-12. Table A-8 presents the split fractions used for each scenario along with a brief description about how each was estimated. It must be noted that these split fractions were estimated for this example using overly simplified methods. In a Phase 3 analysis, conservative estimation may be used for screening purposes only. Actual PRA fault trees and data should be used to estimate the split fractions.

Using the split fractions of Table A-8, the CCDPs of each fire scenario can be calculated using the event tree in Figure A-2. Figure A-6 presents one example using the split fractions for Scenario B1S. Table A-9 provides the CCDPs for each scenario.

A.15 First Quantitative Screening

Screening is a key part of analysis strategy discussed in Section 2.3 of the main body of this report. It is not included in the flow chart (Figure 1 of the main body of this report) because it may be attempted whenever sufficient information is gathered to support a quantitative screening of the fire scenarios. At this stage of our example, the estimated CCDPs could be multiplied by the scenario frequencies presented in Table A-7 to calculate a screening CDF. Table A-9 provides these CDFs. The total CDF is other than Green. Therefore, the analysis cannot be stopped here and further analysis is warranted. The CDFs associated with Scenarios B1S and B2S are above 1.0E-06 per reactor year. Therefore, these two scenarios should be analyzed further using fire propagation analysis steps. From the remaining scenarios, the largest CDF belongs to B1C, then B1E and finally B2A. These scenarios should also be analyzed further in the order of their screening CDFs. Given the small CDF, Scenario B1D can be screened from further analysis at this stage.

Table A-8 Event Tree Split Fractions

#	Top Event	Split Fraction Value							Discussion
		Symbol	B1S	B1C	B1D	B1E	B2S	B2A	
1	Initiating Event	IE	6.2E-02	6.2E-02	6.2E-02	6.2E-02	6.2E-02	6.2E-02	For a small LOCA to occur valves CS-012, CC-009 and CC-010 should close spuriously. Assuming independence among the three valve failure processes, the probability of small LOCA given fire damage to the cables becomes 0.53x0.38x0.31 = 0.062. See Table A-1 for the failure mode probabilities.
2	Auxiliary Feedwater System	AFW	5.2E-02	1.25E-04	1.25E-04	1.25E-04	5.2E-02	1.25E-04	Scenarios B1S and B2S affect AFWP-B. The rest of the scenarios have no effect on the AFW system. For B1S and B2S, only the turbine driven AFW pump was assumed to remain available. PRA model and data was used to estimate the failure probability. The hardware failure contribution is 4.2E-02 and human error probability is 0.01[4]. The following parameter settings were used to estimate this HEP: available time >5x the time required, extreme stress level, moderately complex, poor ergonomics (all other parameters set at nominal level).[5] For the rest of the scenario where AFW is not affected, it was assumed that turbine driven and one motor driven AFW pump can be lined up for secondary cooling. Again PRA model and data was used. TDAFW unavailability is 0.052 (=0.042 + 0.01) and MDAFW unavailability is 0.0024. When both pumps are unaffected, the total unavailability becomes 0.0024x0.052 = 1.25E-04.

[4] A number of methodologies are available to conduct human reliability analysis and to estimate human error probability (HEP) values. All HEPs in this example were estimated using the methodology and the Action Worksheet described in Reference A-4. The Action Worksheet was selected to simplify the calculation process for this example.

[5] It must be stressed that the selected influencing factors used for estimating the HEPs are presented as an example. In an actual analysis, the analyst should carefully consider all the influencing factors affecting the actions being analyzed and the dependencies among various actions.

Table A-8 Event Tree Split Fractions

#	Top Event	Symbol	B1S	B1C	B1D	B1E	B2S	B2A	Discussion
			Split Fraction Value						
3	Bleed Portion of Feed and Bleed	BLD	4.8E-02	4.8E-02	4.8E-02	4.8E-02	4.8E-02	4.8E-02	This split fraction is the sum of PORV failure probabilities (3 PORVs at 0.0093 each per the PRA data) and human error probability (estimated as 0.02 in the PRA). Thus, bleed portion is estimated as 0.0093x3 + 0.02 = 0.048.
4	High Pressure Injection	HPI-1	3.36E-02	3.0E-02	3.0E-02	3.0E-02	9.0E-02	3.36E-02	In Fire Scenario B1S and B2A, one of three HPI trains is affected. In the case of B2S, two of three HPI trains are affected. For the rest of the scenarios none of the trains are affected. In all cases, per the information provided in the PRA, one HPI train unavailability is equal to 0.06. The probability of operators failing to initiate HPI is concluded to be 0.03. The following parameter settings were used to estimate this HEP: available time >5x the time required, extreme stress level, moderately complex, low experience and training, poor ergonomics (all other parameters set at nominal level). Therefore, if all three trains are not affected, system unavailability is $(0.06)^3 + 0.03 = 0.03$. If one train is affected, system unavailability is $(0.06)^2 + 0.03 = 0.0336$. If two trains are affected, system unavailability is $0.06 + 0.03 = 0.09$.
		HPI-2	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.6E-01	1.0E-01	This split fraction is based on the assumption that AFW has failed. The human error probability for this split fraction should be greater than that used for HPI-1. HEP = 0.1 was used in this case. The HEP for HPI-1 was multiplied by 0.33 (based on analyst judgment) to account for this increase. Therefore, if all three trains are not affected, system unavailability is $(0.06)^3 + 0.1 = 0.1$. If one train is affected, system unavailability is $(0.06)^2 +$

Table A-8 Event Tree Split Fractions

#	Top Event	Split Fraction Value							Discussion
		Symbol	B1S	B1C	B1D	B1E	B2S	B2A	
									0.1 = 0.1036. If two trains are affected, system unavailability is 0.06 + 0.1 = 0.16.
5	Secondary Cooling Recovery	REC	8.2E-02	8.2E-02	8.2E-02	8.2E-02	8.2E-02	8.2E-02	Operator error dominates this split fraction. Since AFW failure has occurred prior to this event and local actions may need to be taken to start the TDAFW, HEP=0.03 and TDAFW pump failure probability (0.052) are used.
6	Residual Heat Removal	RHR-1	5.2E-02	5.2E-02	5.2E-02	5.2E-02	5.2E-02	5.2E-02	It was assumed that one RHR train would not be available because of CCW failure (part of the three valves). From PRA model and data one RHR train unavailability is 0.052.
		RHR-2	5.2E-02	5.2E-02	5.2E-02	5.2E-02	5.2E-02	5.2E-02	The time to RHR actuation could be several hours after the fire event. Therefore, failure of AFW was not deemed to have a significant impact on the RHR split fraction.
7	High Pressure Recirculation	HPR-1	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	HPR failure probability was taken from the PRA. The unavailability is dominated by operator error in successfully completing the switchover to recirculation cooling. Human error probability is concluded to be 0.002. Hardware failure is deemed to be an insignificant contributor.
		HPR-2	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	It was assumed, given the length of the available time, preceding failures would not have a significant effect on the human error probability. Therefore, the same split fraction is used for all three HPR cases.
		HPR-3	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	2.0E-03	See above comment.

Figure A-6 Event Tree Quantified for Fire Scenario B1S

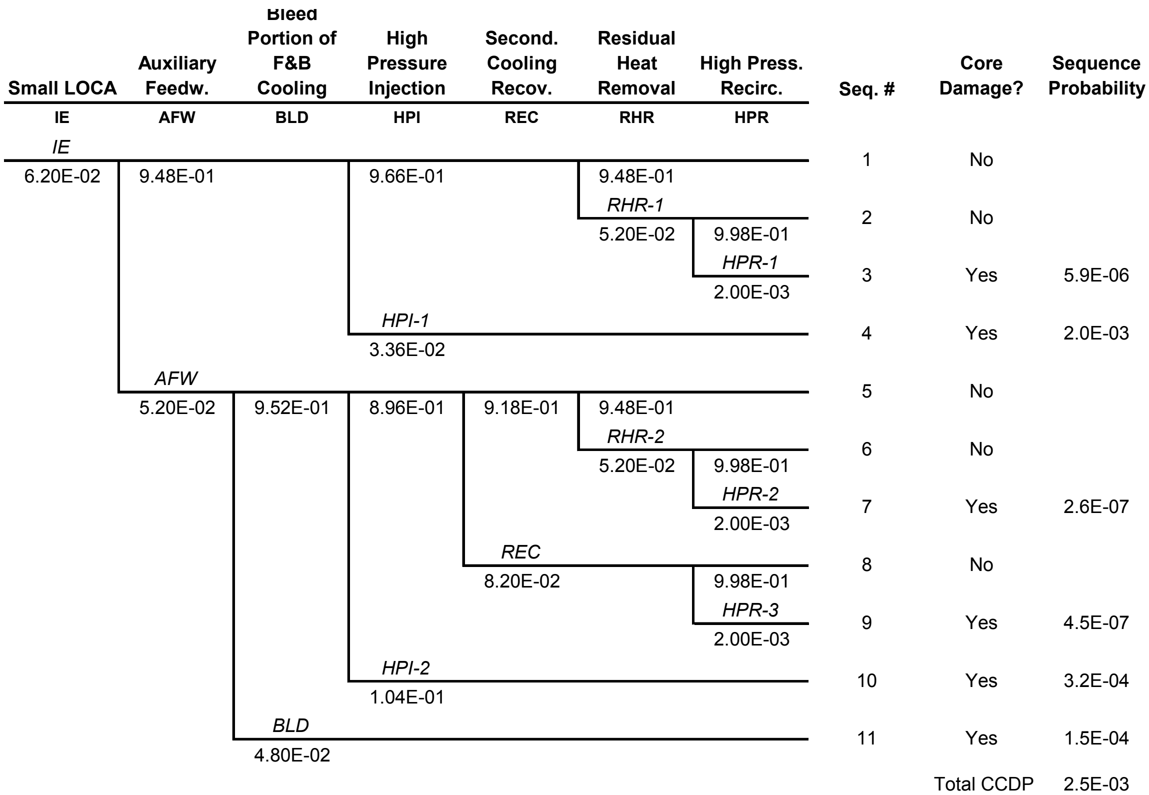


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Table A-9 First Screening CDFs

Fire Scenario	Ignition Frequency	CCDP	CDF (per/ry)	Percent of total
Fire Scenario B1S	1.28E-03	2.45E-03	3.14E-06	44.7%
Fire Scenario B1C	5.17E-04	1.88E-03	9.72E-07	13.8%
Fire Scenario B1D	5.40E-05	1.88E-03	1.02E-07	1.4%
Fire Scenario B1E	2.81E-04	1.88E-03	5.27E-07	7.5%
Fire Scenario B2S	3.40E-04	5.94E-03	2.02E-06	28.8%
Fire Scenario B2A	1.24E-04	2.09E-03	2.58E-07	3.7%
		Total Screening CDF	7.0E-06	

A.16 Fire Propagation Analysis

This is Task 7 in Figure 1 of the main body of this report. Fire propagation analysis is conducted for each ignition source to establish whether or not target damage from a specific source is possible. If target damage is possible, the severity factor and time to damage is established. In this section the fire propagation analysis conducted for the unscreened scenarios (i.e., B1S, B1C, B1E, B2S and B2A) are presented. The results of the analyses is summarized in Table A-10, which provides a list of ignition sources for each fire scenario, corresponding ignition frequencies as calculated in Table A-7, and the severity factors and non-suppression probabilities as estimated in this analysis. In the case of pumps and compressors, the fire may either involve the lubricating oil or electrical parts of those devices. Table 6-1 of Reference A-1 gives the fraction of fire events associated with each fire type (i.e., oil or electrical) given that a device (e.g., pump) fire has occurred. Frequencies are adjusted according to these fractions and separate fire propagation analyses are conducted for each fire type. Table A-10 lists these values and computational results.

Each scenario is discussed separately below:

Fire Scenario B1S

In this scenario, as described in Section A.11 above, a severe fire in Compartment B1 damages all the cables in all cable tray stacks near the ceiling. Ignition sources for this scenario include the two pumps, the compressors, cables and transient fires. Since this is a severe fire, the analysis began with an examination of the possibility of experiencing flashover conditions. The spreadsheet on flashover heat release rate estimation provided in Reference A-5 was used to estimate the minimum peak heat release rate needed to experience a flashover condition. The postulated room dimensions were as follows:

- Room depth 50 feet
- Room width 23 feet

The width used includes an adjustment to account for the alcove area. The floor area using this width is the same as the total actual floor area of the compartment. The actual ceiling height was 15 feet. However, a lower height was postulated to account for the equipment and cables in the room. The following ranges of ventilation openings and ceiling heights were assumed:

- Ceiling height: 8 to 12 feet
- Ventilation opening:
  . Width: 0.02 to 3 feet
  . Height: 0.02 to 8 feet

The heat release rates obtained from the spreadsheet provided in Reference A-5 ranged from 2,382 to 4,014 Btu/sec. Other than oil fire, none of the ignition sources postulated for this scenario can generate a heat release rate within this range (see the maximum heat release rate values in Appendix E of Reference A-1). Two ignition sources of this scenario (pumps and compressors) contain oil. In the case of pumps, it was assumed that each pump contains no more than 2 gallons of oil and each compressor no more than 3 gallons. Using 46,000 kJ/kg for heat of combustion and 0.039 kg/m2-sec for mass burning rate, the heat release rates of a series of oil spills were calculated assuming 1cm thick pool on the floor. It was concluded that more than 4

gallons of oil must spill and burn to generate the minimum heat release rate for flashover. Since all oil carrying devices contain smaller quantity of oil than 4 gallons, it was concluded that flashover was improbable.

Hot gas layer caused by a fire may lead to a widespread damage close to the ceiling in a compartment. The possibility of hot gas layer temperature reaching the failure temperature of the cables (i.e., 400^{o}F) was examined. The CFAST computer program (Reference A-3) was used for this purpose. The following is a summary of input parameters used in the CFAST runs:

- Room depth 50 feet
- Room width 23 feet
- Room height 12 feet
- Ceiling, floor and wall materials: concrete
- Opening to outside: width 0.5 feet, sill 0.033 feet, sofitt 0.036
- Location of fire at center of the room

The hot gas layer temperature may reach 400^{o}F only when the peak heat release rate of the combustible material exceeds 1,300 Btu/sec. Appendix E of Reference A-1 provides the severity factors associated with a range of peak heat release rates. For most items noted in that appendix, 1,300 Btu/sec is larger than the upper tail of the distribution. Only oil spill scenarios can exceed this heat release rate. Therefore, for non-oil ignition sources, the smallest severity factor, 0.001, provided in Appendix E of Reference A-1 was used (this can be considered a conservative practice).

It was found that, in the case of a pump lubricating oil fire, more than 98% of the oil has to spill (1 cm thick pool) for the heat release rate to exceed 1,300 Btu/s. In the case of the compressor, more than 65% of the oil has to spill. Using the distribution recommended in Appendix E of Reference A-1, the severity factors for the pumps and compressor were concluded to be 0.02 and 0.38, respectively. Per Step 2 in Section E.2 of Appendix E of Reference A-1, severity factor of 0.02 should be assigned when greater than 98% of the oil has to spill to cause the postulated damage. Severity factor of 0.98 is recommended if 10% of the oil has to spill to lead to the postulated damage. The severity factor for compressor oil fire (i.e., 38%) was estimated from an interpolation of the two extreme severity factors.

Time to damage was not estimated at this point. It was decided to focus on the severity factors, recalculate the CDFs based on a new set of fire scenario frequencies. If the total CDF was concluded to be other than Green, the time to damage and probability of non-suppression would then be introduced.

Fire Scenario B1C

In this scenario, as described in Section A.11 above, a localized fire affects the cables in sub-area C of Compartment B1. Ignition sources for this scenario include the two pumps, cables (self ignited fires) and transient fires (all categories, including cables).

In the case of self-ignited cable fires, it was assumed that the fire immediately damages all the cables of the target set. Therefore, in this case the severity factor is taken to be 1.0.

Using CFAST computer program (Reference A-3) and assuming that target cables are 8 feet above the floor, it was concluded that the minimum peak heat release rate needed to cause cable damage (i.e., temperature to reach 400°F) is 1,000 Btu/sec. Assuming a 1cm thick oil spill, 77% of the pump lubricating oil (i.e., 1.53 gallons) has to spill on the ground. This corresponds with a severity factor of 0.25 using the same approach as for Scenario B1S (i.e., the severity factor scheme provided in Appendix E of Reference A-1.)

The remaining ignition sources cannot generate sufficient heat release rate to damage the cables in this sub-area. Similar to the preceding scenario, the smallest severity factor is assigned to those cases.

Fire Scenario B1D
Since the CDF for this scenario was relatively small, fire propagation analysis was not done. The same frequency is carried forward.

Fire Scenario B1E
This scenario, similar to Fire Scenario B1C, a localized fire affects the cables in sub-area E of Compartment B1. Ignition sources for this scenario include one compressor, cables (self ignited fires) and transient fires (all categories, including cables). The same approach was used for this scenario as for B1C assuming target cables are located 8 feet above the floor and in case of oil spill, a 1cm thick pool is formed.

Similar to the other scenarios, in the case of self-ignited cable fires, the fire immediately damages all the cables of the target set. In the case of lubricating oil (compressor) fire, the severity factor, 0.53 (corresponds with 51% of compressor oil spill), was estimated using the same approach as for Scenario B1S (i.e., Appendix E of Reference A-1.) The remaining ignition sources cannot generate sufficient heat release rate to damage the cables in this sub-area. Similar to the preceding scenarios, the smallest severity factor is assigned to those cases.

Fire Scenario B2S
In this scenario, as described in Section A.11 above, a severe fire in Compartment B2 damages all the cables in all cable tray stacks near the ceiling. Ignition sources for this scenario include cables and transient fires. Similar to Scenario B1S, since this is a severe fire, the analysis began with an examination of the possibility of hot gas layer temperature reaching the failure temperature of the cables (i.e., 400°F). The CFAST computer program (Reference A-3) was used for this purpose. The following is a summary of input parameters used in the CFAST runs:

- Room depth 60 feet
- Room width 30 feet
- Room height 12 feet
- Ceiling, floor and wall materials: concrete
- Opening to outside: width 0.5 feet, sill 0.033 feet, sofitt 0.036
- Location of fire at center of the room

The hot gas layer temperature may reach 400°F only when the peak heat release rate of the combustible material exceeds 1,600 Btu/sec. Following the same approach as for the other scenarios, since for all ignition sources (other than oil) the maximum values in the distributions

for heat release rates given in Appendix E of Reference A-1 are smaller than 1,600 Btu/s, the smallest severity factor, 0.001was used.

Fire Scenario B2A
In this scenario, a localized fire affects the cables in sub-area A of Compartment B2. Ignition sources for this scenario include cables (self ignited fires) and transient fires (all categories). Similar to the other scenarios, a self-ignited cable fire was assumed to damage all the cables of this sub-area and a severity factor of 1.0 was assigned. The remaining ignition sources do not have sufficient heat release rate to damage the desired cables. Therefore, smallest severity factor is assigned.

A.17 Detection and Suppression Analysis
This is Task 8 in Figure 1 of the main body of this report. For this example, it was decided to conduct another screening step before non-suppression probabilities are estimated. If there were a need to estimate non-suppression probabilities, the CFAST output would be reviewed for the time that the hot gas layer temperature reaches 400^{o}F. For example, in the case of Fire Scenario B1S, this was 1,100 seconds. The methodology and data provided in Appendix P of Reference A-1 would be used for this purpose. For this example case, the following approach would then be followed:

- For scenarios that cannot cause target damage, suppression system unavailability would be used for non-suppression probability.
- For oil fires, the damage time inferred from CFAST runs would be used along with suppression system unavailability.

A.18 Second Quantitative Screening
Using the CCDPs provided in Table A-9 and the frequencies obtained in Table A-10, the second screening CDFs can be calculated as shown in Table A-11. Since the total CDF is less than1.0E-06 per reactor year, the analysis can be considered complete and be concluded that the CDF color of the SDP finding is Green.

Table A-10 Fire Scenario Frequencies Including Severity Factor

Fire Scenario	Ignition Sources	Frequency (per/ry)	Fire Type / Split Fraction[1]		Severity Factor[2]	Non Supp. Prob.[3]	Adjusted Frequency
Scenario B1S	Pumps	4.6E-04	Electrical	0.54	0.001	1.00	2.5E-07
			Oil	0.46	0.02	1.00	4.2E-06
	Compressors	4.8E-04	Electrical	0.83	0.001	1.00	4.0E-07
			Oil	0.17	0.38[3]	1.00	3.1E-05
	Cables	2.1E-04	Electrical	1	0.001	1.00	2.1E-07
	Cable fires caused by welding and cutting	6.3E-06	Hot Work	1	0.001	1.00	6.3E-09
	Transient fires caused by welding and cutting	3.4E-05	Hot Work	1	0.001	1.00	3.4E-08
	Transients	9.0E-05	Transient	1	0.001	1.00	9.0E-08
	Total Ignition Frequency of Scenario	1.3E-03			Total Scenario Frequency		3.6E-05
Scenario B1C	Pumps	4.6E-04	Electrical	0.54	0.001	1.00	2.5E-07
			Oil	0.46	0.25[4]	1.00	5.3E-05
	Cables	3.2E-05	Electrical	1	1.00[5]	1.00	3.2E-05
	Cable fires caused by welding and cutting	9.5E-07	Hot Work	1	0.001	1.00	9.5E-10
	Transient fires caused by welding and cutting	6.7E-06	Hot Work	1	0.001	1.00	6.7E-09
	Transients	1.8E-05	Transient	1	0.001	1.00	1.8E-08
	Total Ignition Frequency of Scenario	5.2E-04			Total Scenario Frequency		8.5E-05
Scenario B1D	(No adjustments)	5.4E-05					5.4E-05
Scenario B1E	Compressor	2.4E-04	Electrical	0.83	0.001	1.00	2.0E-07
			Oil	0.17	0.53[3]	1.00	2.2E-05
	Cables	3.2E-05	Electrical	1	1	1.00	3.2E-05
	Cable fires caused by welding and cutting	9.5E-07	Hot Work	1	0.001	1.00	9.5E-10
	Transient fires caused by welding and cutting	2.2E-06	Hot Work	1	0.001	1.00	2.2E-09
	Transients	5.9E-06	Transient	1	0.001	1.00	5.9E-09
	Total Ignition Frequency of Scenario	2.8E-04			Total Scenario Frequency		5.3E-05
Scenario B2S	Cables	2.1E-04	Electrical	1	0.001	1.00	2.1E-07
	Cable fires caused by welding and cutting	6.3E-06	Hot Work	1	0.001	1.00	6.3E-09
	Transient fires caused by welding and cutting	3.4E-05	Hot Work	1	0.001	1.00	3.4E-08
	Transients	9.0E-05	Transient	1	0.001	1.00	9.0E-08
	Total Ignition Frequency of Scenario	3.4E-04			Total Scenario Frequency		3.4E-07

Table A-10 Fire Scenario Frequencies Including Severity Factor

Fire Scenario	Ignition Sources	Frequency (per/ry)	Fire Type / Split Fraction[(1)]		Severity Factor[(2)]	Non Supp. Prob.[(3)]	Adjusted Frequency
Scenario B2A	Cables	1.1E-04	Electrical	1	1	1.00	1.1E-04
	Cable fires caused by welding and cutting	3.2E-06	Hot Work	1	0.001	1.00	3.2E-09
	Transient fires caused by welding and cutting	4.3E-06	Hot Work	1	0.001	1.00	4.3E-09
	Transients	1.1E-05	Transient	1	0.001	1.00	1.1E-08
	Total Ignition Frequency of Scenario	1.2E-04			Total Scenario Frequency		1.1E-04

(1) Fire type split fractions represent the fraction of fire events of an ignition source (e.g., pump) associated with a specific fire type (e.g. oil and electrical). These split fractions are provided in Table 6-1 of Reference A-1.

(2) All 0.011 entries were made as a conservative measure. For these cases, CFAST calculations showed that the hot gas layer temperature would not exceed damage threshold. As a conservative measure, the smallest severity factor (0.001) provided in Tables E-2 through E-9 of Reference A-1 was assigned to those ignition sources.

(3) Since detection and suppression analysis was not conducted, all non-suppression probabilities were set to 1.0.

(4) Per the procedures outlined in Section E.3 of Reference A-1, the severity factor for the oil spills is calculated from first establishing the percentage of oil spilled from a source (e.g., 65%) and then interpolation between the following two endpoints: severity factor of 0.98 for 10% oil spill and severity factor of 0.02 for 98% oil spill.

(5) It is conservatively assumed that a self-ignited cable fire would damage all the cables of interest within a short time. Therefore, the severity factor in this case is taken to be 100%.

Table A-11 Second Screening CDFs

Fire Scenario	Scenario Frequency	CCDP	Scenario CDF	Percent of Total
Scenario B1S	3.6E-05	2.5E-03	8.9E-08	13.2%
Scenario B1C	8.5E-05	1.9E-03	1.6E-07	23.7%
Scenario B1D	5.4E-05	1.9E-03	1.0E-07	15.1%
Scenario B1E	5.3E-05	1.9E-03	1.0E-07	14.9%
Scenario B2S	3.4E-07	6.0E-03	2.0E-09	0.3%
Scenario B2A	1.1E-04	2.1E-03	2.2E-07	32.7%
		Total CDF	6.8E-07	

A.19 Assumptions

Generally, a number of assumptions have to be made for an analysis to be possible. It is recommended that a separate report section be dedicated to this topic and all the assumption be listed. For the example in this Appendix, the following assumptions were made in the course of the analysis:

- No cable failure would lead to sustained spurious closure of “Fail Open” type air operated valves.
- A valve, in case of spurious operation that is an adverse position for the valve, will remain in that position until an operator action (if possible) corrects the condition.
- All protected cables and other equipment will not sustain damage from any of the fire events postulated in this analysis.
- The bus bars near the ceiling are not susceptible to damage from exposure to fire or smoke.
- Based on the locations and accessibility of the valves, operators will not have sufficient time to diagnose and manually correct a spuriously closed valve before RCP seal failure occurs.
- Reactor trip will occur within a short time after the effects of the fire damage is acknowledged by the operators.
- The failure mode of each cable is mutually exclusive from the other cable failure modes.
- The core damage risk associated with inter-compartment fire propagation is very small for this Phase 3 analysis and does not warrant further analysis.
- The cables for pumps AFWP-B and CCW-A are present in every cable tray of Compartments B1 and B2.
- The cables inside cable trays or conduits that are wrapped with fire retardant materials would not adversely fail under all postulated fire scenarios.
- Cables fail when their outside temperature reaches 400^{o}F.
- There are 2 gallons of lubricating oil in each pump.

- There are 3 gallons of lubricating oil in each compressor.

A.20 Conclusion

A phase 3 analysis example is presented in this Appendix using simplified parts of actual cases. Overall, the analysis follows the flow chart of the tasks presented in Figure 1 of the main part of this report. The analysis focused on the finding, which is cable routing of three specific valves and the effect of the finding on core damage. All system failure sequences of events and fire scenarios that did not involve the three specific valves were dropped from further analysis. An overall strategy was devised to focus on the induced failure modes of cable damage and routing of those cables before in depth fire propagation analysis was attempted. This allowed the level of effort to be optimized. For example, one of the three compartment and parts of the other two compartments could be screened out based on the location of the cables that could cause the postulated failure modes of the three valves and other devices needed to mitigate the effects of those failure.

Although the flow chart of Figure 1 provides a logical progression of the needed analysis, as it is illustrated through several screening steps, the level of effort could be further optimized by attempting some of the task before the others. In this example, the CCDPs were evaluated before fire propagation analysis. From that, at least one scenario was determined not requiring fire propagation analysis. Moreover, detection and suppression analysis could be skipped because the CDFs calculated just based on the fire propagation analysis results yielded a total CDF in the Green color range.

A.21 References

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A-2 Appendix F to Inspection Manual Chapter 0609, "Fire Protection Significance Determination Process", U.S. Nuclear Regulatory Commission, February 28, 2005.

A-3 Richard D. Peacock, Paul A. Reneke, Walter W. Jones, Richard W. Bukowski, and Glenn P. Forney, "A User's Guide for FAST: Engineering Tools for Estimating Fire Growth and Smoke Transport", U.S. DEPARTMENT OF COMMERCE, TECHNOLOGY ADMINISTRATION, National Institute of Standards and Technology, Special Publication 921, 2000 Edition.

A-4 Gertman, D., H. Blackman, J. Marble, J. Byers, C. Smith, The SPAR-H Human Reliability Analysis Method, NUREG/CR-6883, October 2005.

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