ELECTRIC POWER RESEARCH INSTITUTE

Optimization of Fire Protection Impairments at Nuclear Power Plants

Phase 1—Development of a Framework

Technical Report

Optimization of Fire Protection Impairments at Nuclear Power Plants

Phase I—Development of a Framework

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Final Report, August 2006

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PRODUCT DESCRIPTION

In recent years, risk-informed and performance-based (RI/PB) fire protection is gaining further acceptance by the Nuclear Regulatory Commission (NRC) and the industry. In addition, fire risk assessment methods are gaining some level of maturity since the first industrywide experience with individual plant examination for external events (IPEEE). RI/PB methods can reduce the cost of operating fire protection programs and maintaining fire safety.

Results & Findings

This report documents results of the first phase of a three-phase study to risk-inform the practice of responding to fire protection impairments in nuclear power facilities. Consistent with the scope of Phase 1, the following tasks were completed and documented in this report:

1. A comprehensive list of fire protection impairments characterized by defining partial degraded states and expected performance for those partially degraded states.
2. A comprehensive list of compensatory measures currently used by the U.S. nuclear power plants in response to fire protection impairments.
3. A process (or framework) for risk-informing fire protection compensatory measures that addresses the following questions:
    a. Is the impairment severe enough to require a compensatory measure?
    b. If needed, what is an appropriate compensatory measure (in the context of risk-benefit) and what is the timeframe for instituting the compensatory measure?
    c. How long (within the context of risk) can an impaired condition with a compensatory measure be maintained?
    d. What are other non-risk factors (for example, core damage frequency, or CDF, and large early release frequency, or LERF) should be considered when making such decisions?
    e. How do plants implement a decision into the fire protection program?

Developing the methodology to address these questions is deferred to future phase(s) of this project.

Challenges & Objective(s)

This program's objective is to develop a method with the corresponding technical bases for risk-informing the response to an impairment in the fire protection program of a commercial nuclear power plant.

Applications, Values & Use

Fire protection impairments and the corresponding compensatory measures are significant elements of operating and maintaining effective fire protection programs in the nuclear power industry. This report documents the first step in an effort to build on improved fire risk assessment methods and data to risk-inform the practice of responding to fire protection impairments.

EPRI Perspective

The move towards RI/PB fire protection is gaining momentum in the United States and overseas. Use of these methods is increasing under the current regulatory environment (for example, the fire protection Significance Determination Process) and the new voluntary RI/PB fire protection rule that adopts National Fire Protection Association (NFPA) 805, *Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants,* 2001 Edition.

In 2005, EPRI and the NRC Office of Regulatory Research (RES) jointly published EPRI 1011989 and the Nuclear Regulatory Commission document NUREG/CR-6850, *Fire PRA Methodology for Nuclear Power Facilities*. This document was reviewed by NRC and the Advisory Committee on Reactor Safeguards (ACRS) and is being used to support the transition to NFPA 805.

Use of RI/PB methods to develop cost-effective approaches to fire protection is one of the goals of the EPRI fire protection program. Fire protection impairments and compensatory measures were identified by the EPRI fire protection Technical Advisory Group (formed by fire protection practitioners from nuclear power plants and Nuclear Energy Insurance Limited) as a high-priority cost-saving opportunity.

Approach

This program will be conducted in the following three phases:

Phase 1: Develop a framework and define the project scope.

Phase 2: Develop methods and testing. This phase will develop the necessary methods and data identified in Phase 1 for the framework's application. The framework and developed methods will be tested in this phase for their effectiveness and efficiency in supporting the fire protection decisionmaking process.

Phase 3: Publish the method and process for inclusion in a plant's fire protection program.

Keywords

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1 INTRODUCTION

Through considerable work at EPRI, NRC and other organizations, the fire risk methods and data are evolving considerably such that these tools may be used in applications that can benefit the industry.

Fire protection impairments and the required compensatory measures are significant part of operating and maintaining fire protection programs in the nuclear power industry.

This program is an effort to build on these activities to improve the practice of responding to fire protection impairments.

1.1 Objective

The principal objective of this program is to develop the method and technical bases that will use Risk-Informed, Performance-Based (RI/PB) methods for decision-making on how to respond to an impaired fire protection condition. This includes decision on the need for and timing (i.e., urgency) of a compensatory measure after impairment is discovered. This program will be conducted in the following three phases.

Phase 1: Development of a Framework. This phase will involve defining the project scope and a conceptual framework. The specific objectives of the first phase are:

1. Define the industry issues and needs in the area of impairments. This includes fire protection systems and features that are to be covered by this program.
2. Define fire protection impairments and develop a method to describe the performance of the degraded fire protection system and feature resulting from the impairment.
3. Identify potential compensatory measures that may be appropriate for the identified impairments/degradations to the fire protection systems and features.
4. Develop a straw-man process to optimize the process of responding to fire protection impairments. The process should account for such factors as: risk, current industry practices and ease of application within those practices, and rules and requirements that influence decision-making such as those by the NRC, NEIL, INPO, OSHEA, and other organizations. The process should also define interfaces and integrate with other EPRI tasks and programs including; Fire Impairment Database, EPRI/NRC Fire PRA Guide and Fire Workstation.

Phase 2: Development of Methods and Testing. This phase will develop the methods and data needed to solve the problem defined in phase 1 and pilot testing of method for ease of application and validity of suggested decisions.

It is anticipated that the method should meet two fundamental criteria. First, the method should have simplicity that allows for quick solution and response that is needed to support plant decision-making. This time-frame ranges from 30 minutes to a few hours for outlining a course of action in response to the impairment. Second, the method should have the level of sophistication that allow for cost-effective decisions where is helpful to the end users. This would mean a gradual decision approach that allows quick early decisions based on qualitative risk assessments followed be more quantitative risk evaluations in some cases.

Phase 3: Publication of the method and process for its implementation as part a plant's fire protection program.

This report documents the results of phase I of this program and therefore indicates a work-in-progress. The information contained in this report is likely to be updated as lessons are learned in phase 2. The final methodology will be documented following completion of Phase 3.

1.2 Background

Nuclear power plant fire protection programs are based upon the principles of defense-in-depth:

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

Fire protection features are designed, installed and maintained in order to preserve these principles. However, in the day-to-day operation of a nuclear power plants, impairments and degradations can and do occur that may potentially impact the fire protection program.

1.2.1 Fire Protection Technical Specifications

In general, impairments to plant fire protection program elements were historically addressed by fire protection technical specifications for fire detection systems, fire suppression systems, and fire barriers. These technical specifications, which typically implemented in the 1970s, varied from plant to plant but had many similarities and were consistent in organization.

1.2.2 Generic Letters 86-10 and 88-12

Generic Letter 86-10 included a "standard license condition" for adoption by licensees. Through the implementation and adoption of a standard license condition, a licensee was allowed to make changes to its fire protection program without prior notification to the NRC in accordance with the provisions of 10 CFR 50.59, *provided the changes did not adversely affect the plant's ability to achieve and maintain post-fire safe shutdown*. The licensee, upon modification of the license to adopt the standard condition, could also amend the license to remove the fire protection technical specifications. Generic Letter 88-12, Removal of Fire Protection Requirements from Technical Specifications, gave licensees additional guidance for implementation of the standard license condition and removal of the technical specifications associated with fire detection and suppression, fire barriers, and fire brigade staffing. The technical specifications associated with safe shutdown equipment and the administrative controls related to fire protection audits were to be retained under the guidance of the generic letter.

1.2.3 10 CFR 50.59 Program Changes

Changes were implemented to 10 CFR 50.59 in October 1999. With the changes to the 10 CFR 50.59 rule in effect, it is no longer a requirement for plants to use 10 CFR 50.59 analyses to implement changes to fire protection programs. NEI 96-07, Guidelines for 10 CFR 50.59 Implementation, Revision 1, provides information on making changes to approved fire protection programs.

NEI document 02-03, "Guidance for Performing a Regulatory Review of Proposed Changes to the Approved Fire Protection Program", provides industry guidance on how to make changes to an approved fire protection program, including changes involving fire protection compensatory measures.

1.2.4 Initiatives to Risk-Inform Fire Protection

1.2.4.1 NRC

In July 2004 the NRC amended 10 CFR Part 50.48 "Fire protection" to add a new subsection, 10 CFR 50.48(c), that established acceptable fire protection requirements (69 FR 33536). The change to 10 CFR 50.48 endorses with exceptions the National Fire Protection Association's (NFPA) 805, "Performance-Based Standard for Fire Protection for Light Water Reactor Electric Generating Plants – 2001 Edition," as a voluntary acceptable approach for demonstrating compliance with 10 CFR 50.48 Section (b) and Section (f).

Fire protection requirements, predating the July 16, 2004 Amendment to 10 CFR 50.48, are prescriptive in nature and were established well before the emergence of risk-informed, performance-based analytical techniques. Consequently, the prescriptive requirements do not include the benefits of probabilistic risk assessments (PRAs) for fires, nor do they reflect insights into fire risk evident from the significant body of operating experience developed through risk-based assessments.

The NRC has also recently endorsed the use of risk-insights to allow assignment of resources commensurate with the safety significance of the subject matter. For example, the NRC's use of a Fire Protection Significance Determination Process (Fire Protection SDP) for measuring the importance of findings during inspection of fire program is an indication of growing acceptance of a risk-informed approach for dealing with fire protection impairments.

1.2.4.2 NEIL

Currently the NEIL Loss Control Standards are primarily prescriptive. NEIL does allow performance-based options to be used for fire protection system testing, inspection and maintenance activities. This is in conjunction with the EPRI Fire Protection Equipment Surveillance Optimization and Maintenance Guide.

NEIL has established a Risk Informed Applications Task Force to review the NEIL Loss Control Program and Loss Control Standards. This Task Force is making recommendations for risk informed methods to be used in the future for rating and Loss Control Standards development.

NEIL is in the process of obtaining training for the NEIL Loss Control Staff in the area of risk informed and performance based fire protection.

1.2.4.3 NFPA

NFPA codes, standards, recommended practices, and guides ("NFPA Codes and Standards") are developed through a consensus standards development process approved by the American National Standards Institute (ANSI). Often times these Codes are adopted by Federal, State and local authorities resulting compliance with the applicable testing requirements becoming mandatory. Failure to comply with the applicable adopted NFPA standards could result in regulatory action. The majority of NFPA standards that contain requirements for compensatory measures such as fire watch also contain an "Equivalency" statement. This statement is intended to prevent the contents of the document from limiting or restricting the use of other methods that provide an equivalent level of performance.

With respect to OSHA compliance, with the requirements of current applicable industry consensus standards, such as the standards published by National Fire Protection Association (NFPA), is accepted as compliance with the Occupational Safety and Health Act (OSH Act), if the consensus standards provide for equal or greater personnel protection than corresponding OSHA standards. This is know as the "de minimus" policy and related violations may not be cited and may not be required to be abated

Users of this document should consult applicable federal, state, and local laws and regulations to determine requirements in regard to the contents of this document. EPRI does not intend to urge action that is not in compliance with applicable laws. The authority having jurisdiction shall be consulted and approval obtained for such alternative programs.

1.2.5 Traditional Fire Protection Impairments and Compensatory Measures

Impairments to a plant's fire protection features require evaluation to establish temporary compensatory measures and identify appropriate permanent corrective actions. A typical approach for implementing the immediate compensatory action may include evaluations and decisions based on prescriptive guidelines established in accordance with the plant's fire protection program. Compensatory measures are typically the same that existed in original fire protection technical specifications or have been derived or evolved from those technical specifications.

The process that is used to address the impairment can be complex because typically multiple documents need to be reviewed and operators frequently have to consult with Fire Protection System engineers to identify and interpret different documents.

A typical process does not consider the risk significance of the impairment. Therefore, overly conservative compensatory measures may be employed. There is also a potential for non-conservative measures to be put in place for some risk-significant impairments because the compensatory measures are typically general in nature and do not focus on the specifics of the feature or impairment. Prescriptive and overly conservative compensatory actions may contribute to excessive cost without enhancing safety, while non risk-informed and non-conservative compensatory actions may result in a reduction in safety.

1.2.6 NRC Guidance on Impairments –Fire Protection Compensatory Measures

Regulatory guidance from the NRC on the use of fire protection compensatory measures has been provided by:

Information Notice 97-48, Inadequate or Inappropriate Interim Fire Protection Compensatory Measures [Ref. 19] – Alerted addressees to potential problems associated with the implementation of interim compensatory measures for degraded or inoperable plant fire protection features or degraded or inoperable conditions associated with post-fire safe shutdown capability.

NRC Regulatory Issue Summary (RIS) 2005-07 - Compensatory Measures to Satisfy the Fire Protection Program Requirements [Ref. 21] - Informed addressees that alternate compensatory measures as otherwise required by the approved fire protection program may be used for a degraded or inoperable fire protection feature under certain circumstances, in accordance with the discussion in the RIS. This RIS describes the proper method for changing the approved fire protection program to use an alternate compensatory measure.

1.2.7 Background Summary

Based on the preceding discussions, it is noted that:

- Management of fire protection impairments is largely based on original fire protection technical specifications.
- Risk-informed processes, including processes for fire protection programs, are gaining momentum in the industry.
- Changes to approved fire protection programs are allowed in accordance with the fire protection license conditions.

2
FIRE PROTECTION FEATURES, IMPAIRMENTS, AND COMPENSATORY MEASURES

This section is a description of the problem divided into the following discussions.

- Definition of fire protection features and elements.
- Identification of the types of impairments/degradations that could occur to these fire protection features and elements.
- Performance of the degraded conditions.
- Identification of the potential compensatory measures that **may** be appropriate for the identified impairments/degradations to the fire protection features and elements.

2.1 Definition of Fire Protection Features and Elements

Fire protection features and elements were identified as the first step of Phase 1. This identification of features and elements was intended to be comprehensive. A significant effort was not expended to screen out features/elements that may not be practical candidates for risk-informing impairments. Future phases would make that determination based upon items such as safety implications, availability of risk information, and potential for reduction of unnecessary burden.

In an effort to align with significant industry information, fire protection features and elements were organized in a manner consistent with the Fire Protection SDP [Ref. 11]. Alignment with the Fire Protection SDP provides consistency with a major industry effort that addresses degradations in fire protection features and elements. Although risk-informing and optimizing fire protection impairments are not the focus of the SDP, consistency with methods is seen as a benefit.

The finding categories and associated fire protection program elements from the Fire Protection SDP are:

Table 2-1
Categorization of Degradations

Degradation/Impairment Category	Fire Protection Program Elements
Cold Shutdown	• Findings related to the ability to achieve and maintain cold shutdown only
Fire Prevention and Administrative Controls	• The plant combustible material controls program • Other administrative controls such as work permit programs • Hot work fire watches • Roving or periodic fire watches • Training programs • Compliance documentation
Fixed Fire Protection Systems	• Fixed fire detection systems • Fixed fire suppression systems (automatic or manual) • Fire watches posted as a compensatory measure for a fixed fire • Protection system outage or degradation
Fire Confinement	• Fire barrier elements that separate one fire area from another • Penetration seals • Water curtains • Fire and/or smoke dampers • Fire doors
Localized Cable or Component Protection	• Passive physical features installed for the thermal/fire protection of cables, cable raceways, or individual components • Raceways or component fire barriers (e.g., cable wraps) • Radiant heat shields protecting a component or cable • Spatial separation (e.g., per Appendix R section III.G.2)
Post-fire SSD (Note 1)	• Systems or functions identified in the post-fire safe shutdown analysis • Systems or functions relied upon for post-fire safe shutdown • Post-fire SSD component list (e.g., completeness) • Post-fire SSD analysis (e.g., completeness) • Post-fire plant response procedures • Alternate shutdown (e.g., manual actions) • Remote shutdown and control room abandonment • Circuit failure modes and effects (e.g., spurious operation issues)

Note 1: During development of the Phase 1 approach, discussions were held regarding focus on impairments to post-fire safe shutdown capability. Due to the large amount of technical and regulatory uncertainty due to changing interpretations of key areas such as circuit failures and post-fire manual operator actions, it was decided that detailed assessment of this subject matter was premature and best suited for longer term efforts.

2.2 Degradation Rating Definitions

Degradation ratings were developed as part of the Fire Protection SDP [Ref. 11, Step 1.2 and Attachment] in order to assign a degradation rating to an observed deficiency. The following degradation ratings are assigned from the Fire Protection SDP.

- A **LOW** degradation reflects a fire protection program element whose performance and reliability will be minimally impacted by the inspection finding. That is, the system, feature, or provision impacted by the finding is expected to display nearly the same level of effectiveness and reliability as it would have the degradation not been present.
- A **MODERATE** degradation implies that a fire protection program element displays significant degradation that will impact performance and/or reliability. However, the element impacted by the finding is still expected to provide some substantial defense-in-depth benefit despite the noted deficiency. (For some defense-in-depth elements, moderate degradations may be further subdivided, e.g., Moderate A and Moderate B.)
- A **HIGH** degradation implies that the performance or reliability of the fire protection program element is severely degraded such that little or no fire protection benefit is anticipated given the deficiency. High degradation implies that no credit will be given to the degraded fire protection program element in quantification of risk significance.

Fire barrier degradations are discussed in detail in the Fire Protection SDP. Degradation levels of fire barriers in the Fire Protection SDP are defined as:

- **Low:** Minor defects observed that will have no effect on fire endurance. No performance reduction is applied.
- **Moderate A:** Fire barrier performance is reduced to approximately 65% of nominal fire endurance rating.
- **Moderate B:** Fire barrier performance is reduced to approximately 35% of nominal fire endurance rating.
- **High:** No Fire barrier or fire barrier/penetration integrity is severely challenged and no credit is given for the barrier.

2.3 Identification of Potential Compensatory Measures

2.3.1 Current Industry Practice

Fire protection compensatory measures are actions taken to compensate for a degradation or impairment of a fire protection feature. These actions are intended to provide a reasonable balance of the fire protection defense-in-depth principles.

Typical fire protection compensatory measures are often still in alignment with compensatory measures that were established in the fire protection part of the technical specifications developed by the vendors during plant design and construction. These specifications defined action(s) required to deal with loss of fire protection equipment and specified completion time for those actions which was often within 1 hour. During the 80s most plants moved their fire protection requirements out of technical specifications via the license amendment, 10 CFR 50.59, and/or fire protection license condition change process. These requirements now reside plants fire protection program documentation.

A listing of typical fire protection compensatory measures that have been derived from original fire protection technical specifications provided in section 2.3.2 to this report.

2.3.2 Potential Fire Protection Compensatory Measures

As part of a risk-informed fire protection impairment process, it is expected that a number compensatory measures may be employed (and in various combinations). These measures may or may not be in alignment with current practices that were derived from original fire protection technical specifications

The following are a list of potential compensatory measures and options that may be used (by themselves or in combinations):

Table 2-2
Potential Fire Protection Compensatory Measures

No.	Compensatory Measure	Discussion
1	Continuous fire watch	Use of permanently stationed fire watch to monitor for changing plant conditions, storage of combustibles, and to detect a potential fire in its initial stages.
2	Roving fire watch	Periodic monitoring (at specified intervals) of changing plant conditions, storage of combustibles, etc. A roving fire watch would also detect a potential fire in its initial stages.
3	Portable lighting	Providing portable lighting such as flashlights, lanterns, and miners hats for use by operators in the absence of permanently installed lighting or to supplement installed lighting.
4	Backup suppression system	Configuring a backup means of suppression to compensate for a degraded condition. Examples include backup pumping capability and/or water source, portable fire extinguishers, extra fire hose installed to provide coverage, valving in a backup water source.
5	Temporary seal repair	Repairing a damaged or missing penetration seal, with the intent of performing a permanent repair at a later time. This would provide some level of fire resistance and help restrict the passage of smoke/hot gases.
6	Fire brigade briefing	Providing instructions to fire brigade staff on degraded conditions and possible changes in strategies to compensate the degradation.
7	Operations briefing (night orders)	Providing instructions to operations staff on degraded conditions and possible changes in strategies to compensate the degradation. Examples include potential shutdown strategies that may not be completely protected against fire but that should be considered, pathways that may be obstructed, the potential need for special tools, preferred shutdown strategies that are not yet fully implemented in procedures.
8	Remote video monitoring	Use of remote surveillance to monitor changing plant conditions, improper storage, potential fire in its early stages.
9	Temporary emergency lighting	Providing temporary but fixed in the absence of permanently installed lighting or to supplement installed lighting.
10	Portable detection system	Use of temporary portable detection system to account for missing or degraded permanently installed detection systems.
11	Temporary administrative controls on combustible loading	Restriction on the introduction of combustible material or types of combustible materials into a plant area.
12	Temporary administrative controls on ignition sources	Restriction on ignition sources (welding, grinding, heaters, etc.) in a plant area.
13	Temporary modification or hardware	A short-term change such to compensate for a fire protection deficiency such as mounting a ladder to assist operators, a temporary penetration seal, staging tools or operator assist mechanisms.
14	No compensatory measures	Category for conditions where no compensatory measures are warranted.
15	Other compensatory measures	Category for measures not listed above.

Potential compensatory measures associated with the identified impairments/degradations are provided in Appendix C to this report.

3 A FRAMEWORK FOR OPTIMIZATION OF FIRE PROTECTION COMPENSATORY MEASURES

This chapter provides the following information: 1) general background on risk-informed practice in nuclear power industry outside of fire protection, 2) general background on fire risk assessment, 3) definition of fire risk parameters, and 4) detailed description of a framework for optimization of fire protection compensatory measures.

3.1 Background

3.1.1 Risk-Informed Practice in Nuclear Power Industry

For over a decade the risk-informed methods have been developed for application to nuclear power plant operation and maintenance. These methods include:

- Risk-informed in-service testing (IST) [Ref. 5]
- Graded Quality Assurance [Ref. 6]
- Risk-informed in-service inspections (ISI) [Ref. 8]
- Risk-informed containment leak rate testing
- 10 CFR 50.69, *Risk-Informed Categorization and Treatment of Structures, Systems and Components for Nuclear Power Reactors* [Ref. 2]
- Maintenance Rule, which established requirements under paragraph (a)(4) for the assessment and management of risk associated with maintenance activities, and
- Risk-informed or Risk-managed Technical Specification (RITS or RMTS), which allows for allowed outage time for components covered by technical specification.

These initiatives and their associated methodologies, for the most part, are not aimed at fire protection systems, features and program elements. However, there are specific considerations that do apply to risk-informing fire protection practices.

3.1.1.1 Risk Acceptance Criteria

Risk-informed decision making requires establishment of the risk acceptance criteria by the Authority Having Jurisdiction (AHJ). The AHJ in the case of the nuclear power facilities include the NRC, Nuclear Energy Insurance Limited (NEIL), and may include others. The risk-informed initiatives, some of which are discussed above, resulted in the development of such risk acceptance criteria by the NRC.

The first of these documents is the Regulatory Guide 1.174 [Ref. 4], which describes an acceptable method to use in assessing the nature and impact of Licensing Basis (mostly permanent) changes when the licensee chooses or is requested by the staff to support the changes with risk information. As part of this method the RG 1.174 contains risk-acceptance guidelines that are shown in figures 3-1 and 3-2 below.

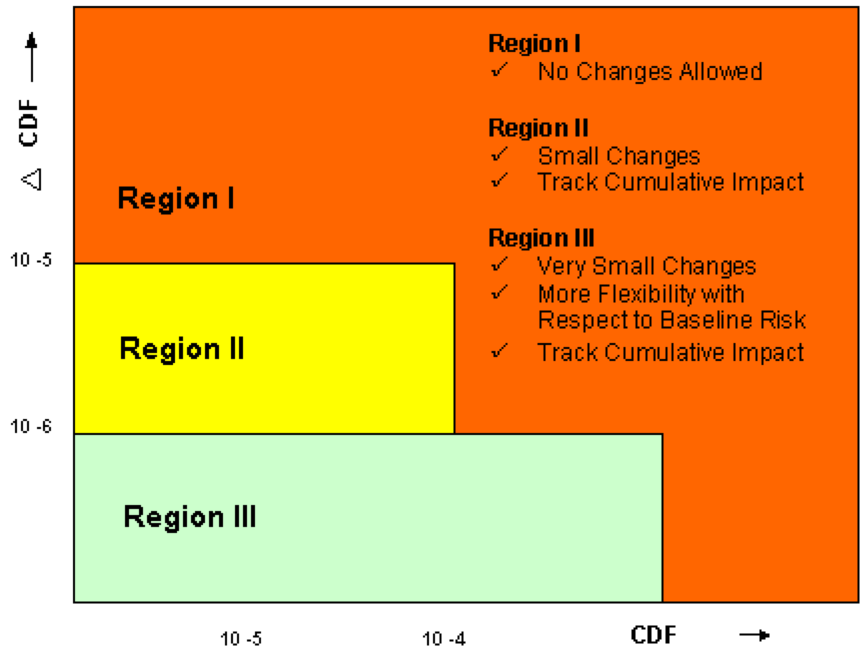

Figure 3-1
ΔCDF Acceptance Criteria

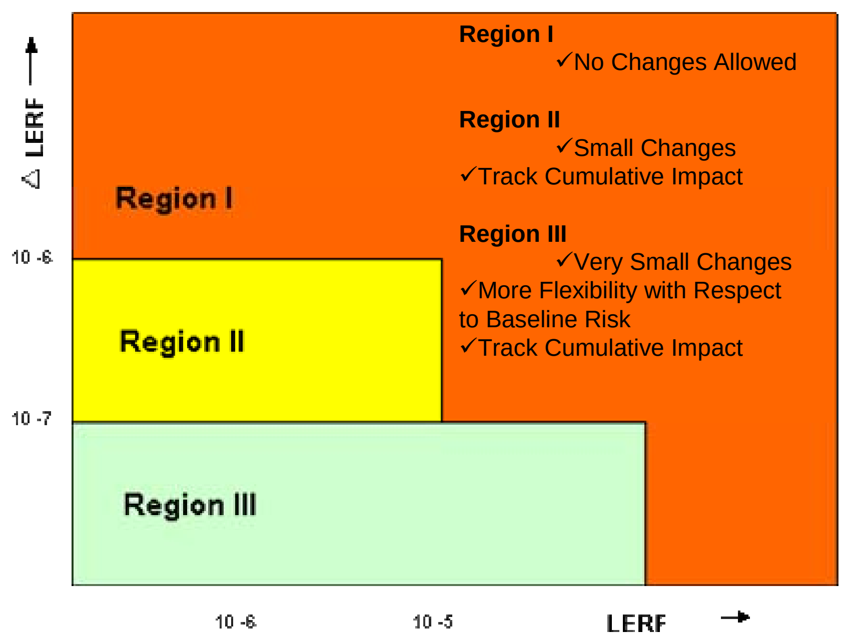

Figure 3-2
ΔLERF Acceptance Criteria

In these figures, regions are established in the two planes generated by a measure of the baseline risk (Core Damage Frequency, CDF or Large Early Release Frequency, LERF) along the x-axis, and the change in risk (ΔCDF or ΔLERF) along the y-axis. These guidelines are intended for comparison with a full-scope (including internal events, external events, full power, low power, and shutdown) assessment of the change in risk metric, and when necessary, as discussed below, the baseline value of the risk metric (CDF or LERF). However, it is recognized that many PRAs are not full scope and PRA information of less than full scope may be acceptable as discussed in Section 2.2.5 of this regulatory guide.

The risk acceptance guidelines are established for each region in RG 1.174 and are listed below.

There are two sets of acceptance guidelines, one for CDF and one for LERF, and ***both*** sets should be used.

- If the application clearly can be shown to result in a decrease in CDF, the change will be considered to have satisfied the relevant principle of risk-informed regulation with respect to CDF. (Because Figures 3-1 and 3-2 are drawn on a log scale, this region is not explicitly indicated on the figures.)
- When the calculated increase in CDF is very small, which is taken as being less than 10^{-6} per reactor year, the change will be considered regardless of whether there is a calculation of the total CDF (Region III). While there is no requirement to calculate the total CDF, if there is an indication that the CDF may be considerably higher than 10^{-4} per reactor year, the focus should be on finding ways to decrease rather than increase it. Such an indication would result, for example, if (1) the contribution to CDF calculated from a limited scope analysis, such as the individual plant examination (IPE) or the individual plant examination of external events (IPEEE), significantly exceeds 10^{-4}, (2) a potential vulnerability has been identified from a margins-type analysis, or (3) historical experience at the plant in question has indicated a potential safety concern.
- When the calculated increase in CDF is in the range of 10^{-6} per reactor year to 10^{-5} per reactor year, applications will be considered only if it can be reasonably shown that the total CDF is less than 10^{-4} per reactor year (Region II).
- Applications that result in increases to CDF above 10^{-5} per reactor year (Region I) would not normally be considered.

AND

- If the application clearly can be shown to result in a decrease in LERF, the change will be considered to have satisfied the relevant principle of risk-informed regulation with respect to LERF. (Because Figures 3-1 and 3-2 are drawn with a log scale, this region is not explicitly indicated on the figures.)
- When the calculated increase in LERF is very small, which is taken as being less than 10^{-7} per reactor year, the change will be considered regardless of whether there is a calculation of the total LERF (Region III). While there is no requirement to calculate the total LERF, if there is an indication that the LERF may be considerably higher than 10^{-5} per reactor year, the focus should be on finding ways to decrease rather than increase it. Such an indication would result, for example, if (1) the contribution to LERF calculated from a limited scope analysis, such as the IPE or the IPEEE, significantly exceeds 10^{-5}, (2) a potential vulnerability has been identified from a margins-type analysis, or (3) historical experience at the plant in question has indicated a potential safety concern.
- When the calculated increase in LERF is in the range of 10^{-7} per reactor year to 10^{-6} per reactor year, applications will be considered only if it can be reasonably shown that the total LERF is less than 10^{-5} per reactor year (Region II).
- Applications that result in increases to LERF above 10^{-6} per reactor year (Region I) would not normally be considered.

Later in this document this criteria will be used to evaluate the risk-acceptance of impairment(s).

Different risk acceptance criteria are defined in case of the risk-informed initiatives that deal with temporary changes in plant configuration, e.g., when one or more components are removed from service. Risk acceptance criteria for these cases was proposed in NEI 96-03 [Ref. xx] and accepted by the NRC [Ref. 9, NRC Regulatory Guide 1.182, "Guidance for Implementation of 10 CFR 50.65(a)(4)."]. The criteria are shown in table 3-1.

Table 3-1
Acceptance Criteria for ICDP or ILERP

ICDP	ACTION	ILERP
$> 10^{-5}$	• configuration should not normally be entered voluntarily	$> 10^{-6}$
10^{-6} to 10^{-5}	• assess non-quantifiable factors • establish risk management actions	10^{-7} to 10^{-6}
$< 10^{-6}$	• normal work controls	$< 10^{-7}$

The acceptance criteria introduce the terms Incremental Core Damage Probability (ICDP) and Incremental Large Early Release Probability (ILERP). These terms are defined as:.

$$ICDP = (CDF_{equipment\text{-}out\text{-}of\text{-}service} - CDF_{base}) * \text{Outage time}$$

$$ILERP = (LERF_{equipment\text{-}out\text{-}of\text{-}service} - LERF_{base}) * \text{Outage time}$$

Later in this document this criteria will be used to determine risk-acceptance of the temporary plant configuration changes that result from impairment(s) and compensatory measure(s).

3.1.1.2 Other Considerations

An important concept used in RITS (or RMTS) is Risk-Informed Completion Time or RICT. This term is used to assess the risk-significance of temporary change in plant configuration as a result of equipment out of service, e.g., due to preventive or corrective maintenance. This is similar to change in configuration resulting from fire protection impairment. The distinction on the other hand is the requirement for compensatory measure in the case of many of these fire protection impairments. This means that, in reality there are two possible configurations resulting from fire protection impairment. The first configuration is with impaired fire protection system feature or program element. The second configuration is with the impaired fire protection system feature or program element AND the compensatory measures. The concept of RICT in the first configuration means how long before a compensatory measure is put in place ($RICT_{imp}$). This time is a function of how much the impaired condition deteriorates plant risk. In fact a compensatory measure may not be needed at all based on the risk-significance of the impairment. The concept of RICT in the second configuration means for how long is it acceptable to maintain the impairment and the compensatory measure ($RICT_{imp+comp}$). Note that if it is demonstrated or assumed that the compensatory measure fully compensates for the impairment by bringing the risk back to the level that it was before the impairment, then $RICT_{imp+comp}$ is not determined by risk considerations.

Another important consideration is cumulative risk impact of multiple impairments and compensatory measures. Examination of this issue is deferred to the 2nd phase of this project.

3.1.2 Fire Risk Analysis

This section provides background information on the calculation of fire risk in various stages of a fire PRA and establishes the relationships between identified impairments and the basic parameters for calculating fire risk. The fire PRA defines the base fire risk in a given compartment. If an identified impairment affects the fire risk, its effects should be reflected in some or all the parameters in the fire PRA, assuming that it truly captures the fire risk in the compartment.

The fire risk in a selected room is calculated as follows:

$$CDF = \sum_{all\quad s}\left(\lambda_s \cdot SF_s \cdot P_{ns-s} \cdot CCDP_s\right)$$

Where CDF is the core damage frequency, λ_s is the ignition frequency, SF is the severity factor, P_{ns} is the probability of no suppression, CCDP is the conditional core damage probability, and the subscript -*s*- refers to a specific fire scenario in a compartment. Notice that the equation is the aggregate of all the scenarios postulated in the room. These scenarios may include only one compartment or extend beyond the initial compartment across fire barrier boundaries.

In a typical fire PRA, compartments are quantitatively screened at various stages of the process. This avoids the need of analyzing detailed fire scenarios in every room in the power plant. Three screening stages can be generally identified:

1. Preliminary quantitative screening: In this stage compartments are screened considering only the fire ignition frequency at the compartment level and a CCDP estimated assuming everything in the room is lost due to fire. The fire risk for a compartment is then calculated as follows

   $$CDF = CCDP_s \cdot \sum_{all\quad s}\lambda_s$$

   Where λ_s is the ignition frequency of a compartment, and $CCDP_s$ is the conditional core damage probability assuming everything in the room is lost due to fire.

2. Secondary quantitative screening: In this stage, the fire ignition frequency, severity factors (SF), and a re-evaluated ignition source weighting factor are used for recalculating fire risk. The CCDP in this stage may still assume that all the equipment in the room is lost by fire. Notice that at this point, the fire risk should include all the contribution from transient fires. The fire frequency for a compartment is estimated as:

   $$CDF = CCDP_s \cdot \sum_{all\quad s}\left(\lambda_s \cdot SF_s\right)$$

Where λ_s is the ignition frequency of a specific ignition source is, SF is the severity factor assigned to s, and $CCDP_s$ is the conditional core damage probability assuming everything in the room is lost due to fire.

3. Detailed quantitative screening: At this stage of the fire PRA, the fire risk in the compartment is calculated as the cumulative contribution of individual fire scenarios. That is, the compartment risk is an aggregate of the fire risk of individual fire scenarios. Passive and active fire suppression features are credited for each scenario. Furthermore, CCDP's are also individually calculated based on the predicted fire damage in each scenario. Both the results from any detailed fire modeling analysis required for estimating extent of fire damage, and the credit to the fire protection features are captured by the probability of no suppression, $P_{ns\text{-}s}$. The fire risk is calculated using the following equation:

$$CDF = \sum_{all\ \ s} \left(\lambda_s \cdot SF_s \cdot P_{ns-s} \cdot CCDP_s \right)$$

The parameters in the equation above are further described below.

3.1.2.1 Fire Ignition Frequency

The fire ignition frequency defines the frequency of initiation of various types of fire. This is the first trigger point of starting a potentially risk contributing fire event. The determination of fire frequencies typically start with generic experience-based likelihood of various fire types, which is then apportioned into the plant-specific compartment or scenario frequencies.

Generic fire ignition frequencies has been calculated and documented for both fixed and transient ignition sources in nuclear power plants. In the case of fixed ignition sources, the generic frequencies are apportioned using the ignition source-weighting factor. The ignition source-weighting factor is calculated dividing the total number of a particular ignition source located in a room by the total plant count [Ref. 12, Volume 2, Chapter 6].

In the case of transient ignition sources, the generic frequency values reflect normal and customary industry-wide maintenance, storage, and occupancy practices. Accordingly, the generic fire frequencies are then apportioned to the different compartments based on plant specific maintenance, storage, and occupancy practices [Ref. 12, Volume 2, Chapter 6].

3.1.2.2 Severity Factors

This parameter defines the characteristics of the initial fire (the ignition source) by capturing scenario specific geometries that are important in the development of the fire event. The initial fire is a critical contributor to the extent and timing of the fire growth. In a Fire PRA, this parameter may be defined by the probability of fire sizes where the undesired consequence of the fire scenario, i.e., damage to a target-set or ignition of an intervening combustible(s), is possible. A single multiplier may be derived from a corresponding heat release rate probability distribution as described in Ref. 12.

3.1.2.3 Non-Suppression Probability

In addition to the severity factor, the probability of no suppression captures all the necessary detailed fire analysis in a scenario. That includes, detailed fire modeling, and fire detection and suppression analysis.

The detailed fire modeling addresses fire growth and fire generated conditions assuming no active fire detection or suppression features available. Detailed fire modeling however may include passive fire protection features. In general, detailed fire modeling is used for determining the following information:

- Time to target damage
- Time to fire detection
- Habitability conditions in rooms where manual action may be performed

This information is necessary for determining the non-suppression probability generated from the detection-suppression analysis.

The detection suppression analysis captures most active detection and suppression features available for each particular fire scenario. Active fire detection and suppression features include prompt, automatic and manual detection and suppression. Recall that these features were not considered in the detailed fire modeling analysis described above.

EPRI 1019989 & NUREG/CR-6850 recommend incorporating all these active fire detection and suppression features in an event tree format. Accordingly, their effects are quantified using probabilistic values, which form the input set to a logic model.

The following fire detection and suppression features may be included in the detection and suppression analysis:

- Prompt detection – Refers in most cases to detection actions by a continuous or welding fire watch, or detection by an incipient fire detection system.
- Automatic Detection – Refers to automatic detection devices such as smoke and heat detectors connected to a control panel.
- Delayed manual detection – Refers to detection by plant personnel such as a roving fire watch.
- Fire suppression analyses include credit for prompt, automatic, and manual suppression activities.
- Prompt Suppression: Many fires in a NPP are suppressed by plant personnel in their incipient stage. This is typical of fires initiated by humans as part of operation and/or maintenance activities. Prompt detection may be credited in case of electrical panels with in-cabinet detectors and main control room. Prompt suppression is generally developed specific to the fire scenario in a fire PRA.
- Automatic Suppression - This parameter covers the reliability/availability of the automatically activated fixed suppression systems in the description of a fire scenario.

Effectiveness of the automatic suppression is determined while defining and evaluating the fire effects of fire scenario. Impaired fixed suppression systems affect this parameter.

- Fixed Suppression - This parameter covers the unavailability/unreliability of the fixed suppression systems. These systems are generally similar in mechanical design to those automatically actuated but the activation of the system requires action by individuals authorized to do so.
- Manual Suppression - This parameter models the suppression activity by fire brigade. Impairments related to standpipe, hose stations, brigade organization and training impact this parameter.

3.1.2.4 Conditional Core Damage Probability (CCDP)

This parameter is the failure probability associated with the systems, components, and manual actions credited for safe shutdown (remain free of the fire damage) for the fire scenario. In the Appendix R space this may be a single string of components that are separated by fire barriers. In the risk space all components that remain unaffected by the consequence of the fire scenario may be credited. In most cases, the CCDP is calculated using a logic model.

3.2 Discussion of Fire Protection Impairments and Compensatory Measures Within the Context of Risk

The process of risk informing compensatory measures requires the mapping of the individual impairments and compensatory measures to specific inputs to the fire risk analysis. This section describes such mapping in detail. Each impairment described in Chapter 2 is associated with one or more specific inputs to the fire risk analysis that is described in section 3.2.1. A similar mapping is provided for the compensatory measures in section 3.2.2.

3.2.1 Fire Protection Impairments

Impairments can generally be grouped into the following categories: 1) cold shutdown, 2) fire prevention and administrative controls, 3) fixed fire protection systems, 4) fire confinement, 5) localized cable and component protection and 6) post-fire safe shutdown. Depending on which impairment occurs, different parameters in the fire PRA may need to be re-evaluated in order to assess the impairments impact on the fire risk.

Fire Protection Program – Impairments in the fire protection program include those related to work permits, use of fire watch, combustibles control programs, and adequacy of fire procedures. Given this broad range of impairments, more than one risk parameter may be affected. Affected parameters would include the fire frequency, the severity factor, the probability of no suppression and the CCDP. Analysts can expect that impairments related to combustible control programs and work permits will affect the fire frequency and severity factors. Those impairments related to fire watches would affect the non-suppression probability. Impairments related to fire procedures would impact the CCDP.

Fixed Fire Protection System – Fire protection systems include primarily detection and suppression features. Fire detection is usually credited in the fire PRA as part of the detailed fire-modeling task. Notice that the risk impact of the detection impairments is not likely to be captured if the compartment was screened in early stages of the Fire PRA, where detection and suppression features are not credited. The time to detection is when all the suppression and plant response activities are triggered. Therefore, fire detection impairments will most likely impact the probability of no suppression (P_{ns}), the plant response model and manual operator actions. The last two are captured by the CCDP parameter.

Fire suppression is also modeled in a fire PRA in the detailed fire-modeling task. This suggests that the impairment may not have a significant risk impact (or no impact at all) in compartments screening out before the detection and suppression analysis. Similar to the case of fire detection impairments, suppression impairments will influence the probability of no suppression (Pns), and the plant response model, represented quantitatively by the CCDP.

Fire Confinement – Fire confinement refers to elements that separate one fire area or compartment from another. These elements include water curtains, doors, walls, penetration seals etc. For the most part, these elements can be referred as fire barriers. In a fire PRA, fire barriers are an important consideration in partitioning the plant in fire compartments. Therefore, fire barrier impairments generate the need for evaluating combinations of multi-compartment fire scenarios. Consider for example the case of two adjacent rooms with no connecting doors between them. Since there is no opening between the rooms, this combination may not have been considered in the fire PRA as a multi-compartment fire scenario. The specific impairment in this example is a crack on the dividing wall. As a result, a multi-compartment fire analysis may be necessary for assessing the impact on fire risk.

Localized Cable and Component Protection – Barrier systems are credited when detailed fire modeling studies are conducted. In most cases, fire barriers effects cannot be modeled using analytical tools. Barriers are instead credited based on empirical evidence. The consequences of the fire scenario in terms of the extent and timing of thermal damage are determined considering the effects of the barrier.

For example, consider a wrapped cable tray above a switchgear cabinet. The wrapped is rated for 1 hour. As part of the detailed fire modeling, the analyst calculated the time to target damage assuming a fire in the switchgear cabinet and no wrapped. In order to credit the wrap, the analyst conservatively added 30 minutes to the calculated time to target damage. Notice that in this example, the analysts choose not to credit the barrier to its full rated thermal capacity.

As in the case of fire detection and suppression, if the compartment was screened in the preliminary and secondary screening stages, passive fire protection was not credited and the impairment may not have a significant impact on fire risk. For the case of unscreened compartments, the analyst will need to identify in each postulated scenario where and how the passive barriers were credited.

Post Fire Safe Shutdown – Most impairments associated with post fire safe shutdown will be associated with the CCDP parameter, including the human reliability inputs.

The risk parameters affected by the fire protection impairments are summarized in Table 3-1.

Table 3-2
Summary of Risk Parameters Affected by Fire Protection Impairments.

Degradation/Impairment Category	Fire Protection Program Elements	Impairment	Impacted Risk Parameter	Comment
Fire Prevention and Administrative Controls	Combustible control program	Improperly stored combustibles	$\lambda_{t\text{-}g}$, $W_{is\text{-}T}$, SF, P_{ns}	The ignition frequency, severity factor and non-suppression probabilities will be affected due to the changes in the nature of transient combustibles.
		Unauthorized Ignition sources	$\lambda_{t\text{-}g}$, $W_{is\text{-}T}$, SF, P_{ns}	The ignition frequency, severity factor and non-suppression probabilities will be affected due to the changes in the nature of the ignition sources
	Hot work permit & fire watch program	Improper continuous fire watch implementation	P_{ns}	Impairment will affect prompt detection capability. Time to detection will be impacted and reflected in the non-suppression probability.
		Improper roving fire watch implementation	P_{ns}	Impairment will affect "manual" detection capability. Time to detection will be impacted and reflected in the non-suppression probability.
		Improper or inadequate equipment	P_{ns}	Impairment will affect time to prompt suppression. This is reflected in the non-suppression probability.
		Improperly trained fire watch personnel	P_{ns}	Impairment will affect time to prompt detection and suppression. This is reported in the non-suppression probability.
	Surveillance program	Missed surveillance frequencies	P_{ns}	Impairment will affect time to suppression, which is reflected in the non-suppression probability.
	Fire brigade, organization and training	Inadequate staffing of fire brigade	P_{ns}	Impairment will affect the brigade effectiveness and maybe the response time. This is usually reflected in the non-suppression probability.

Table 3-2
Summary of Risk Parameters Affected by Fire Protection Impairments (continued)

Degradation/Impairment Category	Fire Protection Program Elements	Impairment	Impacted Risk Parameter	Comment
Fixed Fire Protection Systems	Detection	Loss of power	P_{ns}	The time to automatic detection will be affected. This is reflected in the non-suppression probability.
		Maintenance - Malfunction/inoperable	P_{ns}	The time to automatic detection will be affected. This is reflected in the non-suppression probability.
	Fire pumps	Loss of power	P_{ns}, CCDP	Impairment will affect automatic and manual suppression activities. This is reflected in the non-suppression probability. May also affect CCDP if fire pumps are credited for SSD activities.
		Loss of water supply	P_{ns}, CCDP	Impairment will affect automatic and manual suppression activities. This is reflected in the non-suppression probability. May also affect CCDP if fire pumps are credited for SSD activities.
		Mechanical failure	P_{ns}, CCDP	Impairment will affect automatic and manual suppression activities. This is reflected in the non-suppression probability. May also affect CCDP if fire pumps are credited for SSD activities.
	Gaseous Suppression	Inadequate concentration	P_{ns}	Impairment will affect either manual or automatic gaseous suppression actions. This is reflected in the non-suppression probability.
		Room layout	P_{ns}	Impairment will affect either manual or automatic gaseous suppression actions. This is reflected in the non-suppression probability.
		Room seals	P_{ns}	Impairment will affect either manual or automatic gaseous suppression actions. This is reflected in the non-suppression probability.

Table 3-2
Summary of Risk Parameters Affected by Fire Protection Impairments (continued)

Degradation/Impairment Category	Fire Protection Program Elements	Impairment	Impacted Risk Parameter	Comment
		Other impairments: malfunction/inoperable	P_{ns}	Impairment will affect either manual or automatic gaseous suppression actions. This is reflected in the non-suppression probability.
		Time delay	P_{ns}	Impairment will affect either manual or automatic gaseous suppression actions. This is reflected in the non-suppression probability.
	Hydrants	Loss of flow/damaged	P_{ns}	Impairment will affect fire brigade actions, which are reflected in the non-suppression probability.
	Portable extinguishers	Not available	P_{ns}	Impairment will affect fire brigade actions, which are reflected in the non-suppression probability.
	Stand pipes and hose stations	Incorrect nozzle for area	P_{ns}	Impairment will affect fire brigade actions, which are reflected in the non-suppression probability.
		Insufficient hose length	P_{ns}	Impairment will affect fire brigade actions, which are reflected in the non-suppression probability.
		Loss of flow/damaged	P_{ns}	Impairment will affect fire brigade actions, which are reflected in the non-suppression probability.
	Valves	Supply valve found locked	P_{ns}, CCDP	Impairment will affect automatic and manual suppression activities. This is reflected in the non-suppression probability. May also affect CCDP if fire pumps are credited for SSD activities.

Table 3-2
Summary of Risk Parameters Affected by Fire Protection Impairments (continued)

Degradation/Impairment Category	Fire Protection Program Elements	Impairment	Impacted Risk Parameter	Comment
		Valve failure	P_{ns}, CCDP	Impairment will affect automatic and manual suppression activities. This is reflected in the non-suppression probability. May also affect CCDP if fire pumps are credited for SSD activities.
	Water supply	Lack of required inventory	P_{ns}, CCDP	Impairment will affect automatic and manual suppression activities. This is reflected in the non-suppression probability. May also affect CCDP if fire pumps are credited for SSD activities.
		Lack of water supply confirmation	P_{ns}, CCDP	Impairment will affect automatic and manual suppression activities. This is reflected in the non-suppression probability. May also affect CCDP if fire pumps are credited for SSD activities.
	Water Based suppression	Loss of flow	P_{ns}	Impairment will affect fixed fire suppression, which are reflected in the non-suppression probability.
		Heads inoperable or obstructed	P_{ns}	Impairment will affect fixed fire suppression, which are reflected in the non-suppression probability.
Fire Confinement	Boot seals	Miscellaneous	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
	Cement based grout seals	Cracks found	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Depth of seal found inadequate	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Other	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.

Table 3-2
Summary of Risk Parameters Affected by Fire Protection Impairments (continued)

Degradation/Impairment Category	Fire Protection Program Elements	Impairment	Impacted Risk Parameter	Comment
	Conduit penetrations	Penetrations unsealed	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
	Elastomer barriers or Pen seals	Cracks found	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Depth of seal found inadequate	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Other impairments	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Poor quality	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
	Fire dampers	Gaps outside manufacturers specifications	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Inadequate closure/non-functioning/excessive corrosion	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Other impairments	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
	Fire doors	Door gaps	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.

Table 3-2
Summary of Risk Parameters Affected by Fire Protection Impairments (continued)

Degradation/Impairment Category	Fire Protection Program Elements	Impairment	Impacted Risk Parameter	Comment
		Door in maintenance	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Door latch working properly	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Hardware problems	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Holes/gaps found	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Other impairments	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
	Structural steel fire proofing	Damage/missing	TBD	
	Walls, floor and ceiling	Defects/Thickness	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
	Water curtain	Heads inoperable or obstructed	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
		Loss of flow	CCDP, multi-compartment	Impairment may cause damage to targets outside the room of fire origin and may create the need for evaluating additional multi-compartment fire scenarios.
FP Equipment & Maintenance	Brigade equipment	Equipment available for manual suppression	P_{ns}	Impairment will affect fire brigade actions, which are reflected in the non-suppression probability.

Table 3-2
Summary of Risk Parameters Affected by Fire Protection Impairments (continued)

Degradation/Impairment Category	Fire Protection Program Elements	Impairment	Impacted Risk Parameter	Comment
Localize Cable or Component Protection	Radiant energy shields	Combustibility	CCDP, SF, P_{ns}	Impairment may generate damage to additional targets, which is reflected in the CCDP. The severity factor and non-suppression probability may be affected since different fire sized may be postulated to generate target damage given the barrier impairment.
		Installation deficiency	CCDP, SF, P_{ns}	Impairment may generate damage to additional targets, which is reflected in the CCDP. The severity factor and non-suppression probability may be affected since different fire sized may be postulated to generate target damage given the barrier impairment.
	Sacrificial or non-sacrificial board or blanket barriers or cable wrap	Cracks found	CCDP, SF, P_{ns}	Impairment may generate damage to additional targets, which is reflected in the CCDP. The severity factor and non-suppression probability may be affected since different fire sized may be postulated to generate target damage given the board/blanket impairment.
		Depth found to be inadequate	CCDP, SF, P_{ns}	Impairment may generate damage to additional targets, which is reflected in the CCDP. The severity factor and non-suppression probability may be affected since different fire sized may be postulated to generate target damage given the board/blanket impairment.
		Other impairments	CCDP, SF, P_{ns}	Impairment may generate damage to additional targets, which is reflected in the CCDP. The severity factor and non-suppression probability may be affected since different fire sized may be postulated to generate target damage given the board/blanket impairment.
Post-fire SSD (Note 1)	Emergency lighting	Inadequate lighting	CCDP	The impairment may affect the human actions included in the Fire PRA model used to calculate CCDP.

Table 3-2
Summary of Risk Parameters Affected by Fire Protection Impairments (continued)

Degradation/Impairment Category	Fire Protection Program Elements	Impairment	Impacted Risk Parameter	Comment
	Various SSD degradations		CCDP	The impairment may decrease safe shutdown capabilities, which are reflected in the Fire PRA model used to calculate CCDP.
	Post fire safe shutdown with manual actions	Known degradation in safe shutdown capability with reliance on manual actions	CCDP	The impairment may decrease safe shutdown capabilities, which are reflected in the Fire PRA model used to calculate CCDP.
	Post fire safe shutdown without manual actions	Known degradation in safe shutdown capability without reliance on manual actions	CCDP	The impairment may decrease safe shutdown capabilities, which are reflected in the Fire PRA model used to calculate CCDP.

In the following phases of this project, individual models for calculating the risk impact of the impairments listed in Table 3-1 will be developed to the extent supported by the state of the art.

3.2.2 Fire Protection Compensatory Measures

Compensatory measures usually include the following: continuous or roving fire watches, use of portable or temporary emergency lighting systems, staging of backup suppression systems, temporary seal repairs, fire brigade or operation briefings, use of portable detection systems, combustible and ignition source control programs, and temporary hardware modifications. Other types of compensatory measures may be available at a given impairment. Also, no compensatory measure can be an option.

Depending on the identified impairment, different parameters in the fire PRA may need to be re-evaluated in order to assess the impairments impact on the fire risk. The risk parameters affected by the compensatory measures are summarized in Table 3-2.

The use of fire watches as a compensatory measure directly affects the time to detection. In the case of a continuous fire watch, the time to detection can be assumed to be 0. Therefore, the time available for suppression activities before target damage increases. On the other hand, a roving fire watch may not have such an immediate impact on risk, since the time to detection will depend on the roving schedule.

Similarly, using portable detection systems as a compensatory measure can provide a relatively quick detection time, increasing the time available for suppression before target damage. A portable detection system (depending in its specific characteristics) would be credited in the Fire PRA as an automatic detection system.

Compensatory measures based on remote video monitoring can also provide the ability of detecting fires in a relatively short period of time. However, as opposed to a continuous fire watch, remote video monitoring does not have the advantage of the human sense of smell, which is very effective for fire detection. Remote video monitoring can also help determining smoke migration through rooms, which is important information for operators conducting manual actions.

Compensatory measures implemented for controlling combustible loads and ignition sources directly affect the influence factors apportioning the transient ignition sources [Ref 12, Volume 2, Chapter 6]. It is recommended that analysts review the methodology for developing influence factors, and account for the implemented administrative controls accordingly.

The compensatory measures affecting the fire brigade include fire brigade briefings and staging backup fire suppression equipment. These measures affect the effectiveness of the fire brigade. At this point, there is no specific input to a Fire PRA associated with brigade effectiveness. In most cases, the Fire PRA assumes that the fire brigade will reach the fire compartment at some pre-defined time after detection. Once the brigade reaches the fire room, the non-suppression probability is obtained from generic suppression curves. It can be argued that the shape of the suppression curve could be adjusted based on these compensatory measures. However, current state-of-the art Fire PRA methods do not incorporate such features.

In the following phases of this project, individual models for calculating the risk impact/benefit of the compensatory measures listed in Table 3-2 will be developed to the extent supported by the state-of-the-art.

Table 3-3
Summary of Risk Parameters Affected by Compensatory Measures

No.	Compensatory Measure	Discussion	Impacted Risk Parameter	Comments
1	Continuous fire watch	Use of permanently stationed fire watch to monitor for changing plant conditions, storage of combustibles, and to detect a potential fire in its initial stages.	P_{ns}	The continuous fire watch provides prompt detection capability. Therefore, time to detection may be assumed to be 0.
2	Roving fire watch	Periodic monitoring (at specified intervals) of changing plant conditions, storage of combustibles, etc. A roving fire watch would also detect a potential fire in its initial stages.	P_{ns}	The roving fire watch provides “manual” detection capability. It affects the time to detection.
3	Portable lighting	Providing portable lighting such as flashlights, lanterns, and miners hats for use by operators in the absence of permanently installed lighting or to supplement installed lighting.	CCDP	Portable lighting can affect human actions included in the Fire PRA model used to calculate CCDP.
4	Backup suppression system	Configuring a backup means of suppression to compensate for a degraded condition. Examples include portable fire extinguishers, extra fire hose installed to provide coverage, valving in a backup water source.	P_{ns}	Backup suppression systems can affect the brigade effectiveness and time to suppression, which are reflected in the calculation of the non-suppression probability.
5	Temporary seal repair	Repairing a damaged or missing penetration seal, with the intent of performing a permanent repair at a later time. This would provide some level of fire resistance and help restrict the passage of smoke/hot gases.	CCDP & Multi-compartment fires	A temp seal repair will prevent smoke from migrating to adjacent rooms. This can simplify human actions included in the Fire PRA model to be conducted in those rooms. Analysts should also review the contribution of multi-compartment fire events given that the seal has been temporarily repaired.

Table 3-2
Summary of Risk Parameters Affected by Compensatory Measures (continued)

No.	Compensatory Measure	Discussion	Impacted Risk Parameter	Comments
6	Fire brigade briefing	Providing instructions to fire brigade staff on degraded conditions and possible changes in strategies to compensate the degradation.	P_{ns}	Fire brigade briefings can improve the brigade effectiveness and response time which are reflected in the non-suppression probability.
7	Operations briefing (night orders)	Providing instructions to operations staff on degraded conditions and possible changes in strategies to compensate the degradation. Examples include potential shutdown strategies that may not be completely protected against fire but that should be considered, pathways that may be obstructed, the potential need for special tools, preferred shutdown strategies that are not yet fully implemented in procedures.	CCDP	Operations briefings can impact the human or other actions included in the Fire PRA model used to calculated CCDP.
8	Remote video monitoring	Use of remote surveillance to monitor changing plant conditions, improper storage, potential fire in its early stages.	P_{ns}	The use of remote surveillance can provide detection capabilities, which can be reflected in the calculation of the non-suppression probability.
9	Temporary emergency lighting	Providing temporary but fixed in the absence of permanently installed lighting or to supplement installed lighting.	CCDP	Temp emergency lighting can affect human actions included in the Fire PRA model used to calculate CCDP
10	Portable detection system	Use of temporary portable detection system to account for missing or degraded permanently installed detection systems.	P_{ns}	Portable detection systems provide detection capabilities in the room, which is reflected in the non-suppression probability.

Table 3-2
Summary of Risk Parameters Affected by Compensatory Measures (continued)

No.	Compensatory Measure	Discussion	Impacted Risk Parameter	Comments
11	Temporary administrative controls on combustible loading	Restriction on the introduction of combustible material or types of combustible materials into a plant area.	$W_{is\text{-}T}$	Control on combustible loadings can directly affect the apportioning of the transient frequency. This is reflected primarily in the transient ignition source weighting factors.
12	Temporary administrative controls on ignition sources	Restriction on ignition sources (welding, grinding, heaters, etc.) in a plant area.	$W_{is\text{-}T}$	Control on combustible loadings can directly affect the apportioning of the transient frequency. This is reflected primarily in the transient ignition source weighting factors.
13	Temporary modification or hardware	A short-term change such to compensate for a fire protection deficiency such as mounting a ladder to assist operators, a temporary penetration seal, staging tools or operator assist mechanisms.	TBD	
14	No compensatory measures	Category for conditions where no compensatory measures are warranted.	N/A	
15	Other compensatory measures	Category for measures not listed above.	Undetermined	The impacted risk parameter will depend on the nature of the selected compensatory measure.

3.3 A Framework for Selection of Fire Protection Compensatory Measures

Previous sections provided an introduction to fire risk assessment and described how impairments can affect the different parameters of the risk equation throughout the screening stages in the PRA process. This section builds on this general information by presenting a framework to risk-inform the process of selecting a compensatory measure in response to a fire protection impairment.

A generalized time frame related to fire protection impairments and compensatory measures is illustrated in Figure 3-3.

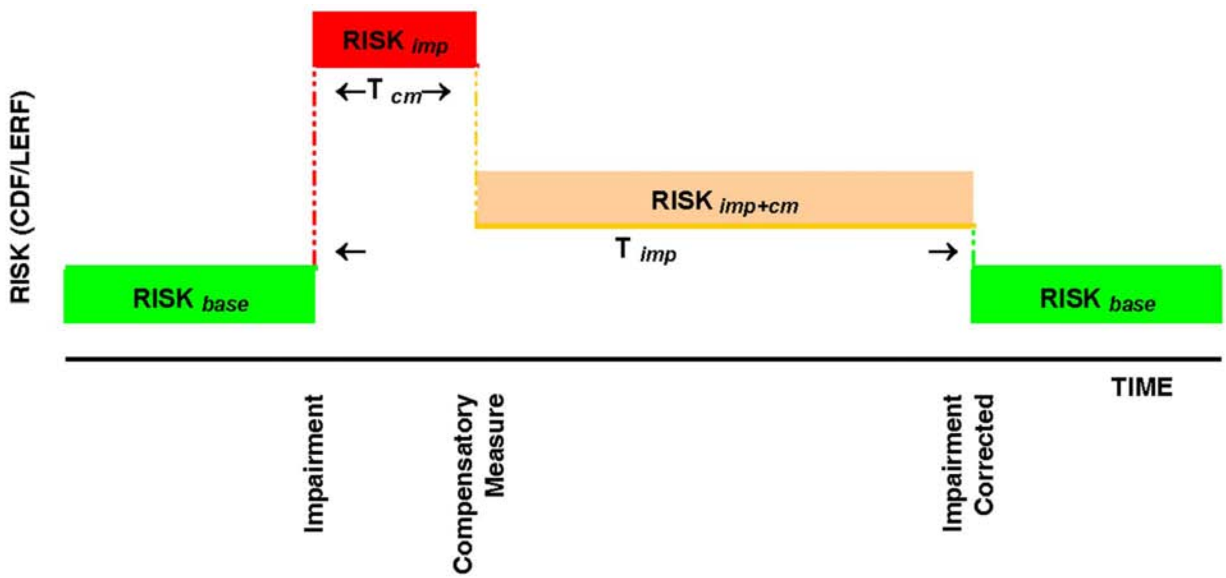

Figure 3-3
Time Illustration of the Impairment and Compensatory Measure

In Figure 3-3, the X-axis represents the time and the Y-axis represents plant fire risk as defined by CDF and/or LERF. Three distinct risk levels can be identified in the timeline:

1. The plant is operating at a "base" risk level. This is the phase that plant runs with no fire protection impairment. The risk associated with this plant configuration is $\mathbf{RISK}_{base}$.
2. The plant is operating at a risk level higher than the base risk due to the identification of an impairment. This is the timeframe when an impairment is identified and decision is needed on; a) is a compensatory measure necessary, b) if yes, what compensatory measure is appropriate and c) what is the time ($\mathbf{T}_{cm}$ or time-to-compensatory measure) within which the compensatory measure is to be put in place. The risk associated with this plant configuration is $\mathbf{RISK}_{imp}$.

3. The plant is operating at a risk level between $\mathbf{RISK}_{base}$ and $\mathbf{RISK}_{imp}$. This configuration is maintained until the impairment is restored to its original (or a risk-equivalent) state. The period of time that the plant stays in this configuration is $\mathbf{T}_{imp} - \mathbf{T}_{cm}$ where $\mathbf{T}_{imp}$ is the impaired time. The risk associated with this plant configuration is $\mathbf{RISK}_{imp+cm}$.

Once the impairment is corrected, the plant operates at its $\mathbf{RISK}_{base}$ level.

The framework includes the following steps:

STEP 1: Evaluation of the impairment(s). This step consists of identifying the impairment and the compartment or compartments it may affect. It also defines and characterizes partially degraded fire protection systems, features or program elements.

STEP 2: Assessment of the risk impact of the impairment(s). The purpose of this step is to quantify the risk impact of the impairment as the basis for determining if compensatory measure may be required. This decision is checked in step 5 for other considerations.

STEP 3: Selection of compensatory measure(s). Different compensatory measure alternatives are evaluated in this step. This can be an iterative step.

STEP 4: Determination of time to implement compensatory measure(s) and time to correct the impaired condition. Once the appropriate compensatory measure(s) has been identified (in step 4), the time for implementing the compensatory measure can be determined. The time that the plant may be maintained in the post-CM state depends on the effectiveness of the compensatory measure(s) in terms of risk.

STEP 5: Other considerations. This step is for verifying that the risk-informed decision can be implemented against the various requirements governing the plant's fire protection program.

STEP 6: Program implementation. This step (to be added in future phases of this project) provides guidance as to how implement such decision at a plant.

One assumption inherent in this approach is that the risk impact of the impairment and compensatory measure remain constant throughout the time-frame. For example, a continuous fire watch is assumed to be as effective (in terms of its risk benefit) the first day as it would be a year later.

Figure 3-4 provides a pictorial representation of this framework.

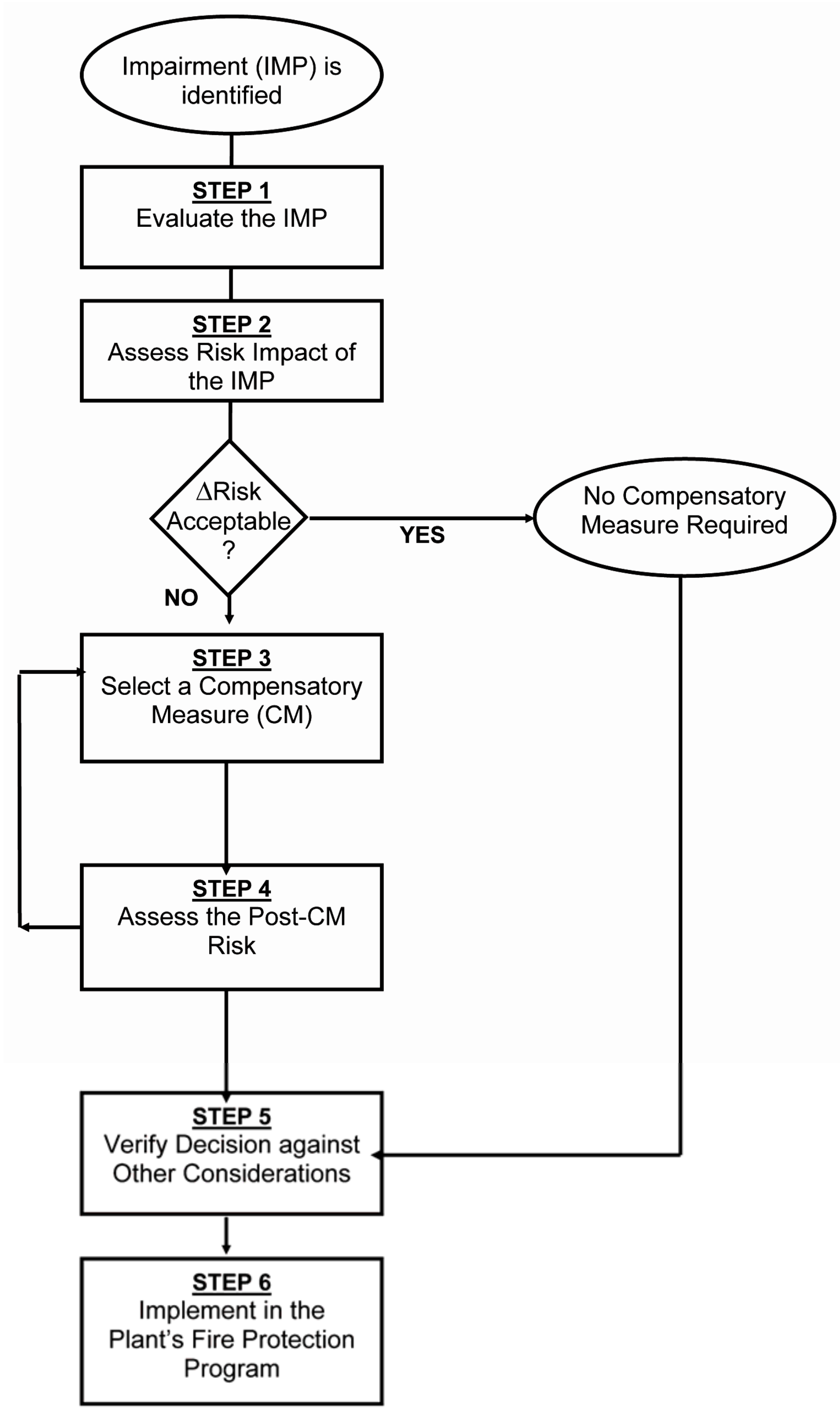

Figure 3-4
Pictorial Representation of the Process for Risk Informing Fire Protection Impairments and Compensatory Measures

3.3.1 Step 1: Evaluation of the Impairment

3.3.1.1 Step 1.1: Impairment and Compartment Identification

The impaired condition should be identified and clearly defined in terms of relevant attributes in the fire risk assessment, namely, the quantitative input parameters and the compartment or compartments affected by the impairment. Table 3-2 above listed the different impairments and the corresponding affected parameters in the risk analysis.

Identifying which compartment is affected by the impairment should be a straightforward step for the case of single compartment fire scenarios. In this case, the analyst can determine from fire PRA records if and why the room was screened.

In the case of an impairment that may affect multi-compartment fire scenarios, the analyst must determined if:

- The specific room combination was evaluated as part of the fire PRA, and
- The impairment is related to a credited fire protection feature in the analysis (some compartment combinations may have been screened by a determination that a fire in the exposing room will not create hazardous conditions in the exposed room regardless of any fire protection feature).

In order to proceed with the next steps in the process, the analyst should document:

- the identified impairment,
- the compartment(s) affected by the impairment,
- at what stage of the fire PRA the compartment(s) affected was(were) screened
- the reason why the compartment(s) was(were) screened,
- the parameters in the risk equation affected by the impairment.

3.3.1.2 Step 1.2: Assign a Degradation Level for the Identified Impairment

This step requires characterization of the impaired condition. This requires that that following information is selected using the information in section 2 and Appendix A of this report.

1. a level of degradation for the impairment, i.e., low, moderate or high degradation, and
2. the performance of the degraded system, feature or program element.

Assignment of partial degradation while helpful in some cases is not critical to use of this framework. A user may assume any degradation leads to total loss of the fire protection component or system performance. Such assumption is effective in the case of localized impairments (e.g., detectors in one room) but may be less effective in the case of low to moderate degradation of plant-wide impairments (e.g. plant-wide inoperable fire penetration seals due as the result of finding some seals that do not have the required thickness).

3.3.2 Step 2: Assessment of the Risk Impact of the Impairment

This step consists of calculating the delta risk given the impairment.

The Fire PRA parameter(s) affected in by the impairments were discussed in section 3.2.1 of this report. In step 1.2 level of degradation is assigned to the parameter(s). At this point in the analysis, the analyst should determine in quantitative terms how each fire risk analysis is affected by the impairments. That is, the value for each affected parameter should be adjusted from its base value, to one reflecting the impairment.

Individual sub-models will be developed in the next phase for quantifying the impact of the impairment of the different risk parameters.

Perhaps the easiest way for quantifying the delta risk is to assume that the only change in the risk profile in the plant is due to the identified impairment. With that assumption, the determination of risk impact is reduced to evaluating the CDF / LERF for the compartment or combination or compartments affected by the impairment. Some difficulties in calculating this CDF / LERF may include:

- No detailed fire modeling analysis is available for the compartment of interest. That is, there is no quantitative framework
- The impairment has generated the need of evaluating new fire scenarios in the compartment
- The impairment has generated the need of evaluating new multi-compartment combinations not previously analyzed

The outcome of this step is the risk associated with the impaired configuration, CDF_{imp} / $LERF_{imp}$, where:

CDF_{imp} is the fire-induced core plant core damage frequency with plant in the impaired configuration

$LERF_{imp}$ is the fire-induced plant large early release frequency with plant in the impaired configuration

The criteria described in Figure 3-1 and 3-2 should be used for determining the need for a compensatory measure. A compensatory measure based on risk considerations may not be necessary if the ΔRisk fall in Region III for both CDF_{imp} and $LERF_{imp}$. This implies that the risk impact of the impairment falls within acceptable levels as a permanent change.

If above criteria is not met, the incremental risk associated with the impairment should be checked against the criteria in Table 3-1. This evaluation requires conservative estimate of the maximum impairment duration, or $\mathbf{T}_{imp(MAX)}$.

$$ICDP_{imp} = (CDF_{imp} - CDF_{base}) * T_{imp(MAX)}$$

$$ILERP_{imp} = (LERF_{imp} - LERF_{base}) * T_{imp(MAX)}$$

A compensatory measure based on risk considerations may not be necessary if the incremental risk increase for CDF_{imp} and $LERF_{imp}$ are below 1E-6 and 1E-7 respectively. This implies that the incremental risk impact of the impairment is acceptable if it is corrected by $\mathbf{T}_{imp(MAX)}$.

Risk-informed fire protection applications require consideration of Defense-in-Depth and Safety Margin, i.e.,

- Fire protection defense-in-depth is maintained by demonstrating an acceptable balance among fire prevention, fire detection and suppression, and post-fire safe-shutdown capability.
- Method of engineering analysis used to ensure that sufficient safety margins would be maintained.

The concepts of DiD and SM for fire protection are introduced in the NFPA 805 [Ref. 16] and Voluntary Fire Protection Requirements for Light Water Reactors [Ref 11]. NEI 04-02 [Ref. 14] provides additional guidance on meeting the requirements for Defense-in-Depth (section 5.3.5.2) and Safety Margin (5.3.5.3).

Regardless of risk impact, a compensatory measure may be required due to other considerations, which include (but are not limited to) NEIL OSHA requirements, plant specific restrictions, etc. These requirements are discussed in step 5 and will be further investigated in the next Phase.

3.3.3 Step 3: Selection of Compensatory Measure(s)

In this step a compensatory measure is selected. In contrast with evaluating the delta risk due to an impairment, the determination of an appropriate compensatory measure can be an iterative process. Usually more than one alternative compensatory measure will be evaluated for its risk impact and other considerations including cost. Table 2-2 shows a list of typical compensatory measures currently used in the U.S. nuclear power industry. This table may be used as a starting point for selecting a compensatory measure that will be evaluated in the following steps. This list is intended as a guide and not rule. In the long run, this list may be improved to produce information on strength and weaknesses of different compensatory measures. Such information will be very valuable to the fire protection practice in the nuclear power plants.

Some of the considerations in selecting a compensatory measure include:

- Does the compensatory measure improve the same function (or element of fire protection defense in depth) that is degraded as the result of the impairment? While it may be acceptable to compensate for loss of one function (e.g., impaired suppression system) with another (e.g., Temporary administrative controls on ignition sources), it is desirable and more defensible to maintain the same level of defense in depth that existed prior to the impairment.
- Is the compensatory measure effective with the type of fire hazards and scenarios that are important to the fire risk of the plant and/or the room? For example, establishing a roving fire watch in a switchgear room that its fire risk is dominated by high-energy arcing fault in the switchgear may not be effective to compensate for impaired automatic suppression system.

3.3.4 Step 4: Assessment of Post-Compensatory Measure Risk

3.3.4.1 Time to Implement Compensatory Measure(s), T_{cm}

The time to implement compensatory measures in a risk informed environment should be established quantitatively using the base risk (CDF / LERF with no impairment) and the post-impairment risk (CDF_{imp}, / $LERF_{imp}$). These two values are obtained from the fire risk model.

Once the values are calculated, the incremental risk (ICDF / ILERF) is obtained by subtracting the baseline risk from the post-impairment risk. That is,

$$ICDF_{imp} = CDF_{imp} - CDF_{base}\,, \quad \text{or} \quad ILERF_{imp} = LERF_{imp} - LERF_{base}$$

Finally, the incremental core damage or large early release probabilities (ICDP or ILERP) are calculated by multiplying the ICDF or ILERF by the duration of the impairment[1]. Similar to step 2, this requires estimating the anticipated duration of the impairment.

From Table 3-1, the probability values of 10^{-6} and 10^{-7} are selected as the criteria for calculating the time to establish the compensatory measure for ICDP and ILERP respectively. These are the limit values for establishing risk management actions. Therefore, the time to establish the compensatory measure can be obtained from:

$$T_{cm} = \frac{10^{-6}}{ICDF} \quad \text{or} \quad T_{cm} = \frac{10^{-7}}{ILERF}$$

for ICDF and ILERF respectively. In the equation above, $\mathbf{T_{cm}}$ is the time to implement the compensatory measure, usually in units of years since CDF and LERF are typically described in reactor-years.

The time to implement a CM is a function of risk-impact of the impairment, i.e., the more severe the impairment the quicker the need for a CM.

3.3.4.2 Time to Correct the Impairment, T_{imp}

Once compensatory measure(s) is in place following an impairment, the plant enters a configuration that its risk ($\mathbf{RISK_{imp+cm}}$) will likely fall somewhere between the base (where the plant was before the impairment, $\mathbf{RISK_{base}}$) and impaired risk (where the plant risk was after the impairment but before the compensatory measure, $\mathbf{RISK_{imp}}$). In the context of risk acceptance, this configuration may be maintained longer with more effective compensatory measure(s). Refer to figure 3-3 for illustration.

Similar to calculation of time to compensatory measure, this time may be calculated as follows:

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[1] Multiplication based on the fact that $P = \lambda t e^{-\lambda t} \approx \lambda t$ for small λt values. In this formulation, P is the ICDP or ILERP, λ is the CDF or LERF and t is the duration of the impairment.

$$ICDF_{imp+cm} = CDF_{imp+cm} - CDF_{base}, \quad \text{or} \quad ILERF_{imp+cm} = LERF_{imp+cm} - LERF_{base}$$

$$T_{imp} - T_{cm} = \frac{10^{-6}}{ICDF_{imp+cm}} \quad \text{or} \quad T_{imp} - T_{cm} = \frac{10^{-7}}{ILERF_{imp+cm}}$$

If $\mathbf{RISK}_{imp+cm}$ is lower than $\mathbf{RISK}_{base}$ the compensatory measure has more than made up for the level of risk lost due to impairment. In such conditions, the time for correcting the impairment is not driven by risk consideration.

The $T_{imp} - T_{cm}$ is the maximum duration that the plant configuration can be maintained at "impaired + comp measure" before unacceptable incremental level of risk is reached (see acceptance criteria in table 3-1). Shorter impairment durations are expected to render lower levels of incremental risk and therefore both acceptable and desirable.

The time to correct an impairment (bring the system or program elements to their original or an equivalent condition) is a function of the risk-benefit of the CM, i.e., the more effective CM the longer the plant can be maintained (from a purely risk perspective) in the impaired plus CM configuration.

3.3.4.3 Selection of Compensatory Measure(s)

The calculation of the $\mathbf{T}_{cm}$ and $\mathbf{T}_{imp}$ may render the following results and possible actions.

Result	Note	Action
Long $\mathbf{T}_{cm}$, e.g., > 1 day	With low and moderate impairment of fire protection systems, features and program elements, particularly those impacting one or few fire areas or scenarios, it is likely that calculated T_{cm} may extend into days or even months.	Select maximum $\mathbf{T}_{cm}$ as 1 day or justify a decision on non-risk factors.
Short $\mathbf{T}_{cm}$, e.g., < 1 hour	This is an indication that the impairment has significant potential risk implications.	A CM should be selected an implemented within $\mathbf{T}_{cm}$.
$\mathbf{T}_{imp}$ <= $\mathbf{T}_{cm}$, i.e., time to correct an impairment is in the range of time to put in place CM.	This means that the compensatory measure is not very effective in reducing the risk-impact of the impairment.	Select another compensatory measure. Impaired condition may need to be corrected if no effective CM is found.
$\mathbf{T}_{imp}$ <= 0		
Long $\mathbf{T}_{imp}$, i.e., months	This means that the combination of impairment and comp measure has created a configuration that is equivalent to the pre-impairment configuration in risk terms.	Put the selected CM in place and the impairment in the plant corrective action program (CAP).

The configuration that results from the impairment and compensatory measure should be checked to ensure that the requirements of Defense-in-Depth and Safety Margin are met. Guidance for meeting these requirements may be obtained from NEI 04-02 [Ref. 14] sections 5.3.5.2 and 5.3.5.3 respectively.

3.3.5 Step 5: Other Considerations

Risk considerations may not be the only criteria for determining an appropriate compensatory measure. Other considerations may include requirements related to NEIL, OSHA or other standards that the plant may have adopted.

This step would involve development of criteria for each of these requirements. Consider as an example the following list of NEIL requirements:

- Duration (anticipated and/or actual) of the impairment
- Impairment shall be of a duration as short as possible
- Type of the system impaired, i.e. water supply, fire pump, fire suppression system, fire detection, fire barrier, etc.
- Hazard and/or area protected (safety significance, high value)
- Type of impairment and level of degradation, can the system still function as designed?

In phase 2, we will develop a comprehensive list of such requirements, develop/collect criteria for those requirements and develop a decision-tree type approach that offers recommendations based collectively on risk and these requirements.

3.3.6 Step 6: Program Implementation

In next phase of this project we intend to investigate and describe possible processes for implementation this methodology into the plant's fire protection program.

4
SUMMARY

This report documents the results of the first phase of a three-phase study to risk-inform the practice of responding to fire protection impairments in nuclear power facilities. The three phases are:

Phase 1: Development of a Framework. This phase will involve defining the project scope and developing a conceptual framework.

Phase 2: Development of Methods and Testing. This phase will develop the necessary methods and data identified in phase 1 for the application of the Framework. The framework and developed methods will also be tested in this phase for their effectiveness and efficiency in supporting the fire protection decision making process.

Phase 3: Publication of the method and process for its implementation as part a plant's fire protection program.

Consistent with the scope of Phase 1, the following tasks were completed and documented in this report:

1. A comprehensive list of fire protection impairments has been defined. This list is derived from the current US nuclear power industry practice and is intended to cover most fire protection systems, features and program elements.
2. The fire protection impairments have been further characterized by defining partial degraded states and expected performance for those partially degraded states.
3. A comprehensive list of compensatory measures currently used by the US nuclear power plants in response to fire protection impairments has been compiled.
4. A process (or framework) for risk-informing fire protection compensatory measures has been developed. This process addresses the following questions:
    a. Is the impairment severe enough, in terms of its risk-impact, to require a compensatory measure?
    b. If needed, what is an appropriate compensatory measure (in the context of risk-benefit) and what is the timeframe within which the compensatory measure should be instituted?
    c. How long (within the context of risk) can an impaired condition with a compensatory measure be maintained?
    d. What are other non-risk (i.e., CDF and LERF) factors that are to be considered while making such decisions?, and

e. Once a decision is reached, how may it be implemented into the fire protection program at a plant?

The methodology necessary to address these questions is deferred to the future phase(s) of this project.

5 REFERENCES

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20. NRC Inspection Manual 0609, *Significance Determination Process, Appendix F, Fire Protection Significance Determination Process*, May 28, 2004.

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22. Regulatory Guide 1.189, *Fire Protection Programs for Operating Nuclear Power Plants*, April 2001.

A
FIRE PROTECTION IMPAIRMENTS

This Appendix contains detailed list of fire protection impairments. Following information is developed for each impairment:

- Group – Impairments are grouped for ease of development and use. Classifications include; 1) fire confinement, 2) fire prevention & administrative control, 3) fixed fire protection systems, 4) fire protection equipment and maintenance, 5) localized cable or component protection, 6) post-fire safe shutdown.
- System/component/element – This field cover the systems, components and elements in each group, e.g., hydrants in fixed fire protection system group.
- Impairment type – Type of impairment for each system,/component element, e.g., loss of flow/function in the fire hydrant.
- Impairment level – This field describes a defined degradation, e.g., two adjacent fire hydrants in-operable.

It is important to point out that there is little to no data, either from applicable fire experiments or operating experience, to provide valid technical basis for the impairment levels and the performance of the impaired conditions.

In the absence of experimental or operating experience data, we developed the information documented in this appendix using the collective judgment of experienced nuclear power plant fire protection engineers. These judgments will be reviewed after pilot application of the method in phase 2 and review of the results and recommendations it provides.

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
Fire Confinement							
	Boot seals						
		Miscellaneous	Severe tears, loose bands, open bands, outer boot missing or both boots missing*SDP.	Support Missing*SDP.	2-3” of seal*SDP.	No ceramic fiber*SDP.	Att. 2, F2-4 (Fire Confinement)
	Cement-Based Grout Seals						
		Cracks found	surface cracks<1/16”;cracks<1/8” not >50% of required thickness;1/16” through crack*SDP.	Through crack does not interfere with structural integrity	N/A	Cracks determined to interfere with structural integrity*SDP.	Att. 2, F2-4 (Fire Confinement)
		Depth of seal found to be inadequate	<30% of required depth missing	>30% of required depth missing*SDP.	Seal / Barrier is <4.5 inches thick*SDP.	Seal / Barrier is <2 inches thick*SDP.	Att. 2, F2-4 (Fire Confinement)
		Other	N/A	N/A	Seal or barrier found to have large surface area deformations (>50% of surface) which would cause higher heat absorptions*SDP.	N/A	Att. 2, F2-4 (Fire Confinement)

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
	Conduit Penetrations						
		Penetration Unsealed	Conduits smaller than 1 inch in diameter that extend <3 feet from each side of barrier*SDP.	Conduits >= 4 inches in diameter that extend greater than 5 feet from each side of barrier or >2 inches in diameter that extend greater than 3 feet fromn each side of barrier*SDP.	Conduits > 4 inches in diameter that extend less than than 5 feet from each side of barrier or > 2 inches in diameter that extend less than 3 feet from each side of barrier.*SDP.	Conduits > 4 inches in diameter that extend less than 5 feet from each side of barrier or > 2 inches in diameter that extend less than 3 feet from each side of barrier.*SDP.	Att. 2, F2-4 (Fire Confinement)
	Elastomer Barriers or Pen. Seals						
		Cracks found	Through cracks <1/8" in seal material that are <50% of the seal depth *SDP. 1/8" thru barrier gaps or cracks *SDP.	Through cracks >1/8" in seal material that are >50% of seal depth	>3/8" cracks in seal extend to opposite face*SDP.	through crack or equivalent diameter >1"*SDP.	Att. 2, F2-4 (Fire Confinement)
		Depth of seal found to be inadequate	<10% of the required seal depth is missing *SDP.	10 to 25% of the required seal depth is missing *SDP.	>25% of the required seal depth missing	>50% of the required seal depth missing or seal removed *SDP.	Att. 2, F2-4 (Fire Confinement)
		Other impairments	No tested or evaluated configuration >= 12" depth *SDP. Barrier/component not in the inspection/ preventive maintenance program *SDP. Seal material not listed in the program *SDP.	No tested or evaluated configuration between 9-11" depth *SDP.	No tested or evaluated configuration between 6-9" depth *SDP.	No tested or evaluated configuration <6" depth *SDP.	Att. 2, F2-4 (Fire Confinement)

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
		Poor quality	Poor quality foam cell structure (falls within Dow Corning's #6 category) over <25% of the surface area *SDP.	Poor quality foam cell structure (falls within Dow Corning's #6 category) over >25% of the surface area*SDP.	N/A *SDP.	N/A *SDP.	Att. 2, F2-4 (Fire Confinement)
	Fire Dampers						
		Gaps outside manufacturers specifications	Damper frames with >3/8" thru gap *SDP.	N/A *SDP.	N/A *SDP.	No external gap	Att. 2, F2-4 (Fire Confinement)
		Inadequate Closure (e.g. excessive corrosion, non-functioning motor)	N/A	Damper will close >95% *SDP.	Damper will close >90% *SDP.	Damper sealing =<90%, will not close *SDP.	Att. 2, F2-4 (Fire Confinement)
		Other Impairments	Damper not in maintenance inspection program *SDP.	Temperature of fusible link excessively high or improperly installed*SDP.	Damper unable to close against anticipated ventilation flow*SDP. No damper installed in steel ductwork. *SDP.	Latch broken (where latch is required) *SDP. No damper installed. *SDP.	Att. 2, F2-4 (Fire Confinement)
	Fire Doors						
		Door gaps	Door frames with greater than 1/8" thru gap *SDP.	Fire door to frame of floor clearance up to 1". *SDP. Bent or warped fire door fire door with gaps less than 1" *SDP.	N/A	N/A	Att. 2, F2-4 (Fire Confinement)
		Door in Maintenance	Retains functionality while in maintenance	N/A	N/A	Door removed or propped open while in maintenance*SDP.	Att. 2, F2-4 (Fire Confinement)

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
		Door latch working properly	N/A	N/A	Door latch not functional *SDP. Latch engaging <1/2" *SDP.	Latch broken *SDP.	Att. 2, F2-4 (Fire Confinement)
		Hardware problems	N/A	Hardware (other than latch, i.e. hinges) not properly installed.*SDP.	Closure mechanism not functional.	N/A	Att. 2, F2-4 (Fire Confinement)
		Holes / gaps found	Several small open exposed holes in doors, door gap issues not exceeding 25% of manufacturer's recommended specifications or up to 3/8" gap *SDP. Multiple holes in door on one side of a door surface with less than 1/8" opening. *SDP.	Small screw holes in door <3/8" on both sides. *SDP.	Multiple holes in door surface with >1" opening *SDP.	N/A *SDP.	Att. 2, F2-4 (Fire Confinement)
		Other Impairments	Improper door labeling material or combustible signage or missing appropriate approval labels	N/A	N/A	Obstructed	Att. 2, F2-4 (Fire Confinement)
	Structural Steel Fireproofing						
		Damaged/Missing	Minor holes, chips, gouges, etc. with less than 4 sq. in of exposed steel surface.	N/A	N/A	Missing structural steel fire proofing without engineering evaluation.	N/A
	Walls, Floors, Ceilings						
		Defect / Thickness	Minor defect with no effect on fire endurance *SDP	N/A	N/A	Barrier integrity severely challenged.	Att. 2, F2-4 (Fire Confinement)

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
	Water Curtain						
		Heads inoperable or obstructed	<10% of heads inoperable or obstructed and no adjacent heads impaired*SDP.	N/A*SDP.	N/A*SDP.	>10% of heads inoperable or obstructed or two adjacent heads impaired*SDP.	Att. 2, F2-8 (Fire Confinement)
		Loss of flow	N/A	N/A	N/A	System inoperable*SDP.	Att. 2, F2-8 (Fire Confinement)
Fire Prevention and Admin Controls							
	Combustible Control Program						
		Improperly stored combustibles	Low flashpoint combustible liquids (200 deg. F) in quantities above those allowed by plant regulations but in approved containers*SDP.	N/A *SDP.	N/A *SDP.	A measurable quantity of a low flashpoint combustible liquid (200 deg. F) beyond the quantity allowed by the plants combustible loading controls, unattended, and not in an approved container *SDP. Unattended storage of self heating materials such as oily	Att. 2, F2-1, (Fire Prevention and Admin Controls)
Fixed Fire Protection Systems							
	Detection						
		Loss of Power	Loss of one source of power in a multi-power source system	N/A	N/A	Complete loss of power including possible battery back-up	

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
		Maintenance / Malfunctioning / Inoperable	Redundant detection system in the area, or <10% of the detectors are impaired and there is detection near combustibles of concern, or there are <25% of detectors impaired and the area is continuously occupied*SDP.	No redundant system in the area, or >10% of the detectors are impaired and there is not detection near combustibles, or there are >25% of the detectors impaired in a continuously occupied area	No redundant system in the area, or >10% of the detectors are impaired and there is not detection near combustibles, or there are >25% of the detectors impaired in a continuously occupied area	System in fire area fails to function. Power off. Detectors incompatible with system. Annunciators disabled, inaudible, or nonfunctional *SDP.	Att. 2, F2-3 (Fixed Fire Protection Systems)
	Fire Pumps						
		Loss of power (electric pumps)	N/A	Redundant pump available (that meets flow requirements)	Redundant pump available (that meets flow requirements)	Redundant pump not available	N/A
		Loss of water supply	N/A	Redundant pump available (that meets flow requirements)	Redundant pump available (that meets flow requirements)	Redundant pump not available	N/A
		Mechanical failure	N/A	Redundant pump available (that meets flow requirements)	Redundant pump available (that meets flow requirements)	Redundant pump not available	N/A
	Gaseous Suppression						
		Automatic actuation Not Available	Manual Actuation of System available and expected to control / suppress fire.	N/A	N/A	Manual actuation of system either not available or expected to control / suppress fire.	N/A

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
		Enclosure Integrity Breached	hole in wall or floor (could be door/hatch) less than area of a 5" penetration; hole in ceiling (not to control room or remote shutdown area) up to 100 sq inches*SDP.	N/A	N/A	Hole in wall or floor > 5" or in ceiling > 100 sq in (could be door/hatch); hole in ceiling to control or remote shutdown room. Failure of damper/ hatch to shut.	Att. 2, F2-3 (Fixed Fire Protection Systems)
		Inadequate Carbon Dioxide concentration (inadequate volume/weight or discharge duration)	Available concentration is 50% (where 60% is committed)*SDP. Lack of test data *SDP. Discharge time exceeds allowable by less than 25% *SDP. Test data shows concentration for 15 minutes (were 20 minutes are required for licensing basis) *SDP.	Concentration is adequate but can not be maintained for sufficient time to ensure fire extinguishment*SDP.	Concentration is adequate but can not be maintained for sufficient time to ensure fire extinguishment*SDP.	Inadequate agent to achieve required concentration for deep seated fires, less than 40%*SDP.	Att. 2, F2-3 (Fixed Fire Protection Systems)
		Inadequate Halon concentration (inadequate volume/weight or discharge duration)	Available concentration is 6% (where 7% is committed)*SDP. Lack of test data *SDP. Test data shows concentration for 15 minutes (were 20 minutes are required for licensing basis) *SDP.	Concentration is adequate but can not be maintained for sufficient time to ensure fire extinguishment*SDP.	Concentration is adequate but can not be maintained for sufficient time to ensure fire extinguishment*SDP	Inadequate agent to achieve required concentration for deep seated fires, less than 5%*SDP.	Att. 2, F2-3 (Fixed Fire Protection Systems)
		Other Impairment	Discharge heads are obstructed*SDP.	N/A	N/A	Loss of power*SDP.	Att. 2, F2-3 (Fixed Fire Protection Systems)
		Time delay problem (predischarge circuit)	Time delay to discharge exceeds design by less than or equal to 60 sec.*SDP.	Time delay to discharge exceeds design by greater than 60 sec. but less than for equal to 300 sec. (5 minutes).	Time delay to discharge exceeds design by greater than 60 sec. but less than for equal to 300 sec. (5 minutes).	Time delay to discharge exceeds design by greater than 300 sec. (5 minutes).	Att. 2, F2-3 (Fixed Fire Protection Systems)

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
	Hydrants						
		Loss of flow / Damaged	One hydrant inoperable (not primary means of manual suppression)	Two adjacent hydrants inoperable	Two adjacent hydrants inoperable	More than two adjacent hydrants inoperable.	N/A
	Standpipe and Hose Stations						
		Incorrect nozzle for area	Hose stream is capable of suppressing fire	N/A	N/A	Insufficient or damaged nozzle	N/A
		Insufficient hose length	Less than design but sufficient to cover designated area	N/A	N/A	Insufficient length to fight the fire	N/A
		Loss of flow / Damaged	Less than 65 psi and 100 gpm at the standpipe valve (NFPA 14) but capable of fire suppression/control	N/A	N/A	Insufficient flow and pressure to fight the fire.	N/A
	Valves						
		Sectionalizing or Isolation valve is failed in position or in maintenance	Redundant flow path available to deliver water to required suppression equipment; possible pipe breaks can be isolated; or valve is not in desired position, but sufficient flow is available for fire control.	No ability to isolate possible breaks	No ability to isolate possible breaks	Required flow is impaired to fire suppression equipment	N/A

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
	Water Supply						
		Lack of required inventory	Redundant capability to supply large system and hose streams.	No redundant capability to supply large system and hose streams.	No redundant capability to supply large system and hose streams	No capability to supply large system and hose streams	N/A
		Lack of water supply confirmation	Level indication out of calibration, but within 10% accuracy.	Level indication not available due to instrument or power supply failure, but water levels verified to be above minimum levels	N/A	N/A	N/A
	Water-Based Suppression						
		Automatic actuation Not Available	Manual actuation of system available and expected to control / suppress fire.	N/A	N/A	Manual actuation of system either not available or expected to control / suppress fire.	N/A
		Heads inoperable or obstructed / proximity to combustibles	Less than 10% of heads are non functional and there is an functional head is within 10 feet of combustibles of concern, and system is nominally code compliant. *SDP.	Less than 25% of the heads are non functional or The closest functional head is between 10 and 20 feet of combustibles of concern. *SDP.	Less than 25% of the heads are non functional or The closest functional head is between 10 and 20 feet of combustibles of concern. *SDP.	Non functional system, or25% or more of heads out of service, or Nearest head greater than 20 feet from combustibles of concern. *SDP.	Att. 2, F2-3 (Fixed Fire Protection Systems)
		Loss of flow	Loss of flow <10%	Loss of flow <25%	Loss of flow <25%	Loss of flow >25%	

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
FP Equipment & Maintenance							
	Brigade Equipment						
		Equipment not available for manual suppression	Degrades one of many suppression or communication tools of brigade, Others remain available.	N/A	N/A	Prevents suppression/control activities of fire brigade	N/A
Localized Cable or Component Protection							
	Radiant Energy Shield						
		Installation Deficiency	Barrier completely obstructs line of sight between the target of interest and potential fire sources that could affect redundant targets, and it is noncombustible.*SDP.	Barrier provides partial line of sight obstruction between target of interest and potential fire sources that could affect redundant targets, or " It is combustible, but of rated material (Thermo-Lag).*SDP.	Barrier provides partial line of sight obstruction between target of interest and potential fire sources that could affect redundant targets, or it is combustible, but of rated material (Thermo-Lag).*SDP.	Barrier does not provide line of sight obstruction between target of interest and potential fire sources that could affect redundant targets, or it is combustible and not made of a rated material.*SDP.	Att. 2, F2-4 (Localized Cable or Component Protection)

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
	Sacrificial and Non-Sacrificial Board or Blanket Barriers or Cable Wrap						
		Cracks found	through crack or equivalent diameter <1/2”*SDP.	through crack or equivalent diameter >1/2” but <1”*SDP.	through crack or equivalent diameter >1” but <2”	through crack or equivalent diameter >2”	Att. 2, F2-4 (Localized Cable or Component Protection)
		Depth found to be inadequate	<10% of barrier depth material removed or never installed*SDP.	10% to 25% of depth is of barrier material removed or never installed over 6 sq. in. area*SDP.	25% to 50% of depth is of barrier material removed or never installed over 6 sq. in. area*SDP.	>50% barrier depth removed or never installed*SDP.	Att. 2, F2-4 (Localized Cable or Component Protection)
		Other impairments	Material compressed *SDP.	Large metallic cross section support or large cross section cable without 2 to 6” of wrap*SDP.	Large metallic cross section support or large cross section cable with <2” of wrap*SDP.	No tested or evaluated barrier configuration*SDP.	Att. 2, F2-4 (Localized Cable or Component Protection)
Post-fire SSD							
	Emergency Lighting						
		Inadequate Lighting	Adequate lighting of required path from permanent fixtures and temporary lights (flashlights) are pre-staged and accessible	N/A	N/A	Loss of function of emergency lightings and no other light sources available	

System / Subject (Level 1)	Specific Feature (Level 2)	Degradation - Impairment	Low	Moderate – Low (A)	Moderate – High (B)	High	SDP Ref & (Finding Category)
RCP Lube Oil Collection System							
	RCP Lube Oil Collection System						
		Damaged system	Oil leakage from RCP that is not exposed to a hot surface or ignition source.	N/A	Low flashpoint/ignition Temperature combustibles in quantities above those allowed by plant regulations but in a sprinkled area.	Collection system that does not collect oil from pressurized and unpressurized sites. Leakage onto a hot pipe/surface or insulation.	N/A

B

TYPICAL CURRENT PRACTICE FIRE PROTECTION COMPENSATORY MEASURES AT U.S. NUCLEAR POWER PLANTS

This Appendix contains a summary of current practice in the U.S. commercial nuclear power industry in the use of compensatory measure in response to fire protection impairments.

System / Subject	Degradation - Impairment	Compensatory Measures
Fire Confinement		
Boot seals	Miscellaneous	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Cement-Based Grout Seals	Cracks found	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Cement-Based Grout Seals	Depth of seal found to be inadequate	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Cement-Based Grout Seals	Other	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Conduit Penetrations	Penetration Unsealed	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Elastomer Barriers or Pen. Seals	Poor quality	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Elastomer Barriers or Pen. Seals	Depth of seal found to be inadequate	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Elastomer Barriers or Pen. Seals	Other impairments	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Elastomer Barriers or Pen. Seals	Cracks found	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Fire Dampers	Other Impairments	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Fire Dampers	Inadequate Closure (e.g. excessive corrosion, non-functioning motor)	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Fire Dampers	Gaps outside manufacturers specifications	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Fire Doors	Door in Maintenance	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Fire Doors	Holes / gaps found	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Fire Doors	Hardware problems	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Fire Doors	Other Impairments	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Fire Doors	Door latch working properly	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Fire Doors	Door gaps	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.

System / Subject	Degradation - Impairment	Compensatory Measures
Structural Steel Fireproofing	Damaged/Missing	(Typical) Continuous fire watch when no operable fire detection in the area. Hourly fire watch with operable detection in the area.
Walls, Floors, Ceilings	Defect / Thickness	(Typical) Continuous fire watch on at least one side of the barrier when no operable fire detection is on either side of the barrier. Hourly fire watch with operable fire detection on one side of the barrier.
Water Curtain	Loss of flow	Not a typical installation. Would probably be treated as an inoperable fire barrier.
Water Curtain	Heads inoperable or obstructed	Not a typical installation. Would probably be treated as an inoperable fire barrier.
Fire Prevention and Admin Controls		
Combustible Control Program	Improperly stored combustibles	Not typically part of fire protection administrative requirements, since not part of original fire protection Technical Specifications. Fire watches, additional suppression, or restriction on work activities could be used.
Detection	Maintenance / Malfunctioning / Inoperable	(Typical) Establish hourly fire watch of the affected area or make special provisions for detection located inside of containment.
Fire Pumps	Loss of water supply	Restore to operable within 7 days or provide backup pump or supply.
Fire Pumps	Loss of power (electric pumps)	Restore to operable within 7 days or provide backup pump or supply.
Fire Pumps	Mechanical failure	Restore to operable within 7 days or provide backup pump or supply.
Gaseous Suppression	Automatic actuation Not Available	(Typical) Either continuous fire watch with backup fire suppression or hourly fire watch.
Gaseous Suppression	Time delay problem (predischarge circuit)	(Typical) Either continuous fire watch with backup fire suppression or hourly fire watch.
Gaseous Suppression	Inadequate Halon concentration (inadequate volume/weight or discharge duration)	(Typical) Either continuous fire watch with backup fire suppression or hourly fire watch.
Gaseous Suppression	Other Impairment	(Typical) Either continuous fire watch with backup fire suppression or hourly fire watch.
Gaseous Suppression	Enclosure Integrity Breached	(Typical) Either continuous fire watch with backup fire suppression or hourly fire watch.
Gaseous Suppression	Inadequate Carbon Dioxide concentration (inadequate volume/weight or discharge duration)	(Typical) Either continuous fire watch with backup fire suppression or hourly fire watch.
Hydrants	Loss of flow / Damaged	(Typical) Provide additional lengths of hose within a specified time period (e.g., 24 hours).
Standpipe and Hose Stations	Incorrect nozzle for area	(Typical) Establish backup fire hose protection (e.g., routing of additional hose).
Standpipe and Hose Stations	Loss of flow / Damaged	(Typical) Establish backup fire hose protection (e.g., routing of additional hose).
Standpipe and Hose Stations	Insufficient hose length	(Typical) Establish backup fire hose protection (e.g., routing of additional hose).
Valves	Sectionalizing or Isolation valve is failed in position or in maintenance	(Typical) If system inoperable establish a hourly or continuous fire watch with backup fire suppression equipment.
Water Supply	Lack of water supply confirmation	Would probably involve visual verification of water supply.
Water Supply	Lack of required inventory	(Typical) Establish a backup fire protection water supply system within 24 hours or perform plant shutdown.

System / Subject	Degradation - Impairment	Compensatory Measures
Water-Based Suppression	Automatic actuation Not Available	(Typical) Either continuous fire watch with backup fire water supply or hourly fire watch.
Water-Based Suppression	Loss of flow	(Typical) Either continuous fire watch with backup fire water supply or hourly fire watch.
Water-Based Suppression	Heads inoperable or obstructed / proximity to combustibles	(Typical) Either continuous fire watch with backup fire water supply or hourly fire watch.
FP Equipment & Maintenance		
Brigade Equipment	Equipment not available for manual suppression	No typical compensatory measures, since fire brigade equipment is not specifically addressed in the fire protection administrative requirements (former Technical Specifications).
Localized Cable or Component Protection		
Radiant Energy Shield	Installation Deficiency	Typically used inside of containment. Hourly or continuous fire watch not practical.
Sacrificial and Non-Sacrificial Board or Blanket Barriers or Cable Wrap	Cracks found	(Typical) Continuous fire watch when no operable fire detection in the area. (Often not specifically included in original Technical Specifications since most fire wrap was post-Appendix R installation)
Sacrificial and Non-Sacrificial Board or Blanket Barriers or Cable Wrap	Other impairments	(Typical) Continuous fire watch when no operable fire detection in the area. Hourly fire watch with operable detection in the area. (Often not specifically included in original Technical Specifications since most fire wrap was post-Appendix R installation
Sacrificial and Non-Sacrificial Board or Blanket Barriers or Cable Wrap	Depth found to be inadequate	(Typical) Continuous fire watch when no operable fire detection in the area. (Often not specifically included in original Technical Specifications since most fire wrap was post-Appendix R installation)
Post-fire SSD		
Emergency Lighting	Inadequate Lighting	Typically not part of original fire protection or plant technical specifications. Typical compensatory measures include alerting operators of deficient conditions, establishing backup or temporary lighting and crediting portable lanterns or flashlights.
RCP Lube Oil Collection System		
RCP Lube Oil Collection System	Damaged system	Not typically part of fire protection administrative requirements, since not part of original fire protection Technical Specifications.

C
SAMPLE FLOWCHARTS FOR RISK-INFORMING FIRE PROTECTION IMPAIRMENTS

The following pages are an example of one plant's practice for risk-informing fire protection impairments. This approach is based on qualitative rules that interpret various grades of risk.

This approach is documented here for illustrative purposes and shows a good starting point toward the development of a more rigorous qualitative/quantitative method in phase 2 of this program.

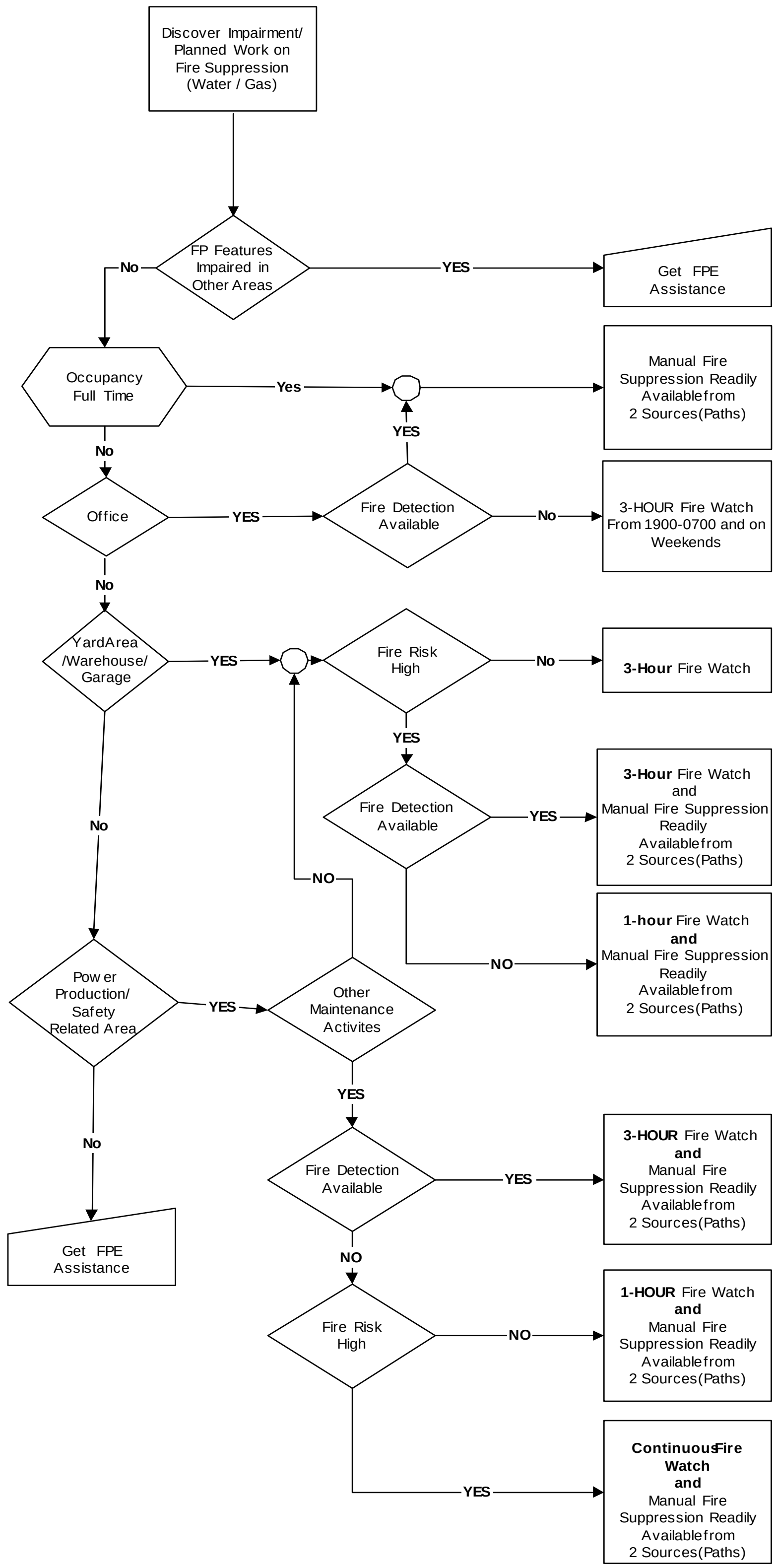

Figure C-1
Fire Suppression System Impairment Chart

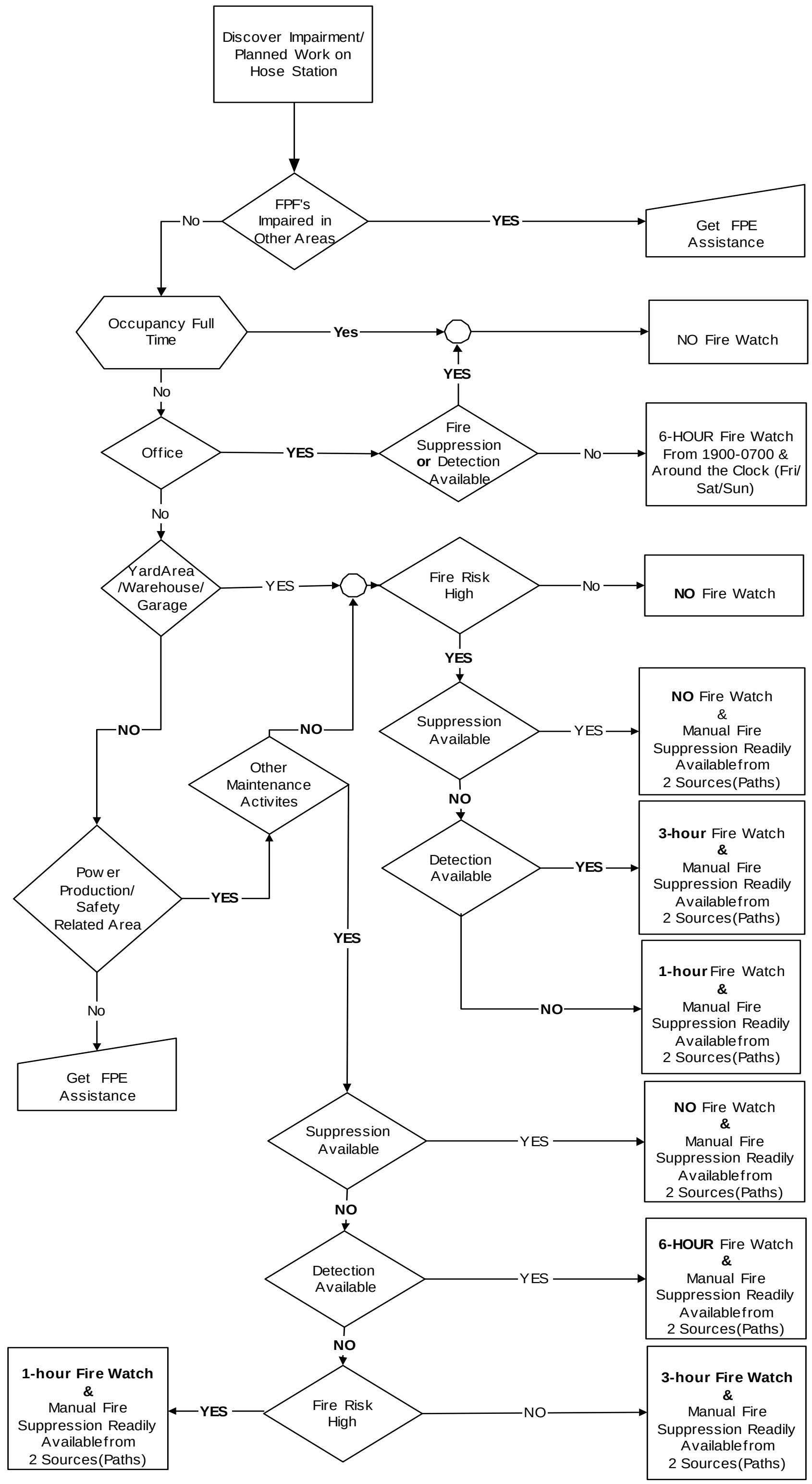

Figure C-2
Fire Hose Station Impairment Chart

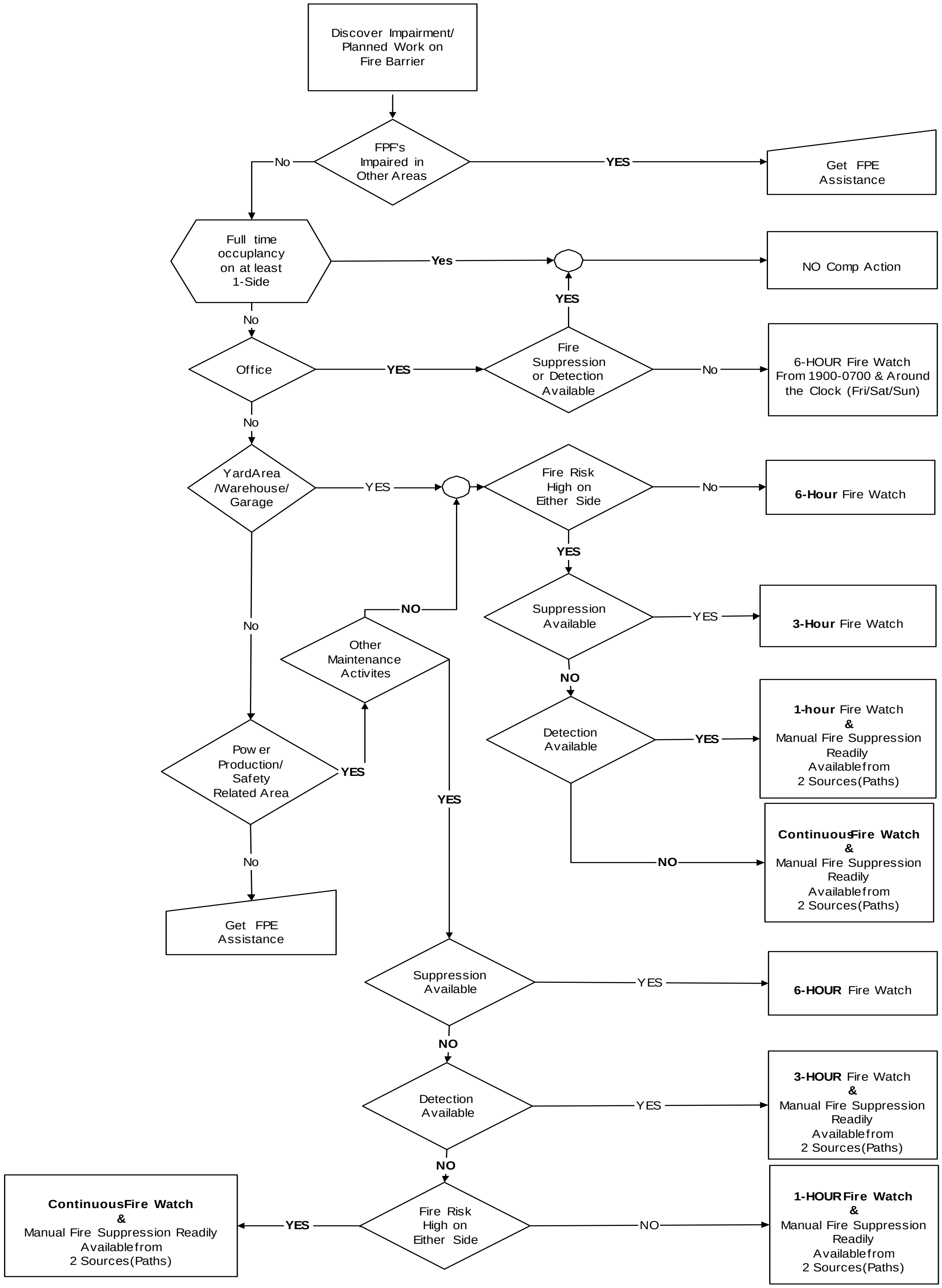

Figure C-3
Fire Barrier Impairment Chart

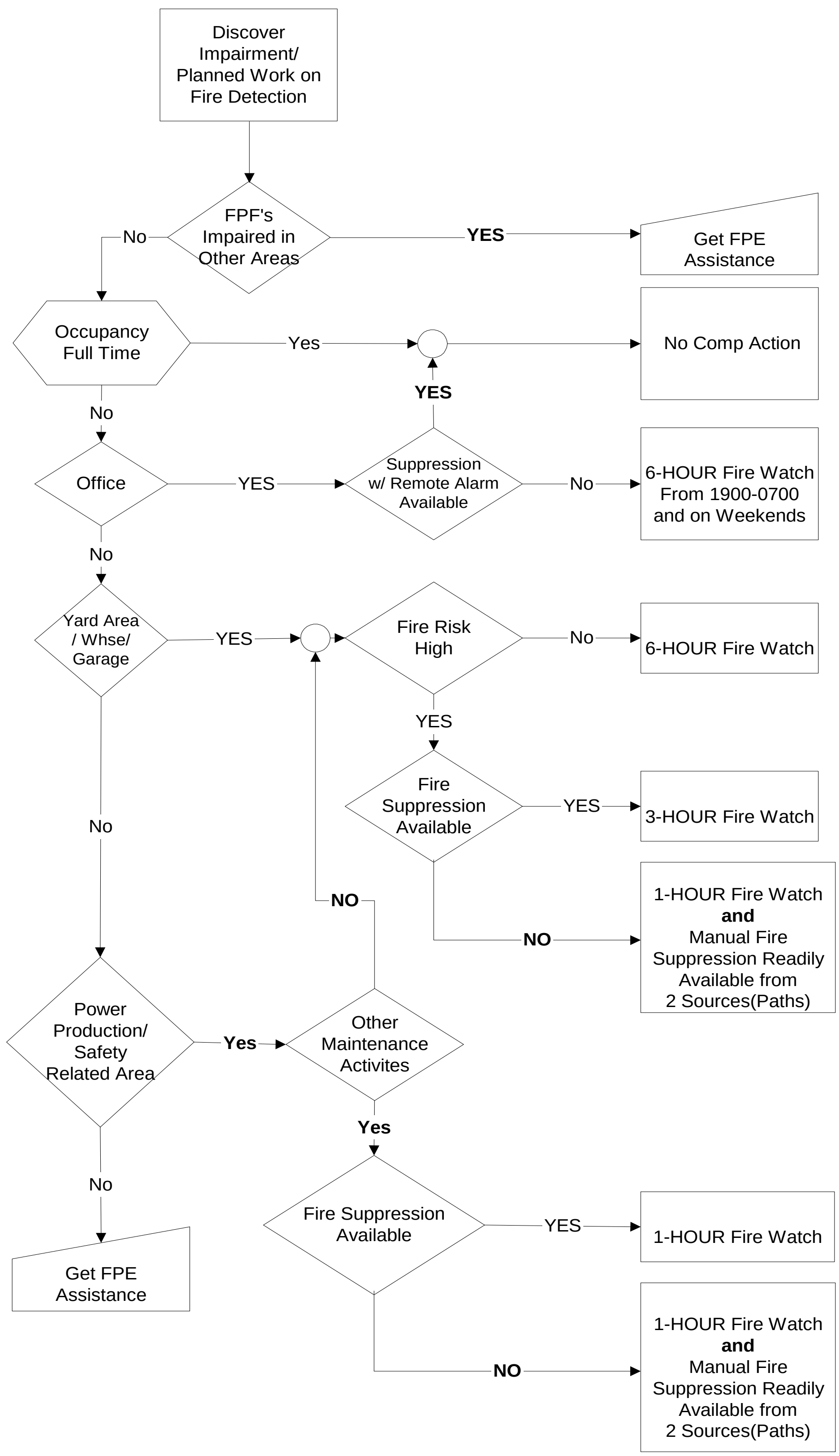

Figure C-4
Fire Detection Impairment Chart

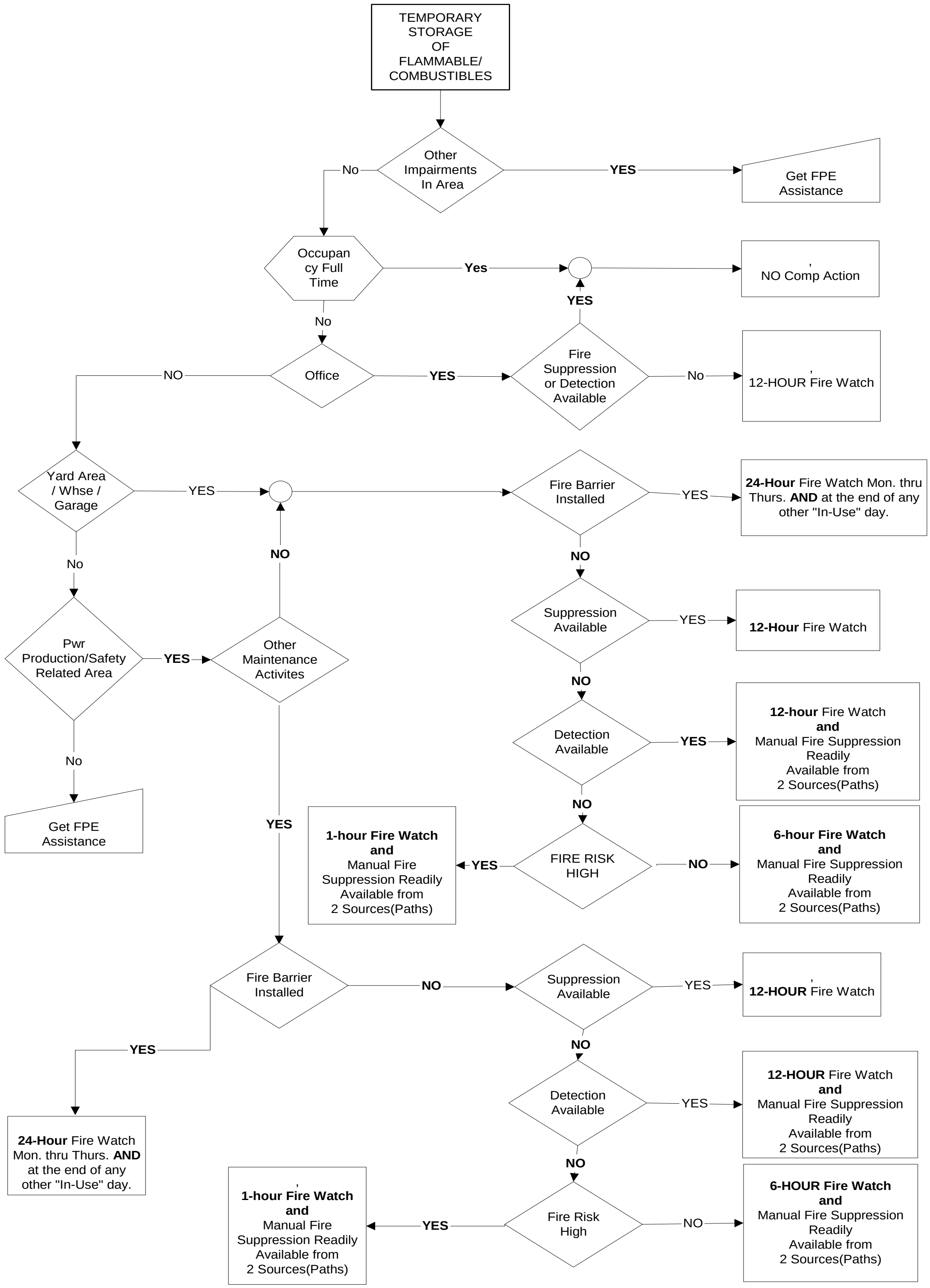

Figure C-5
Temporary Storage Impairment Chart

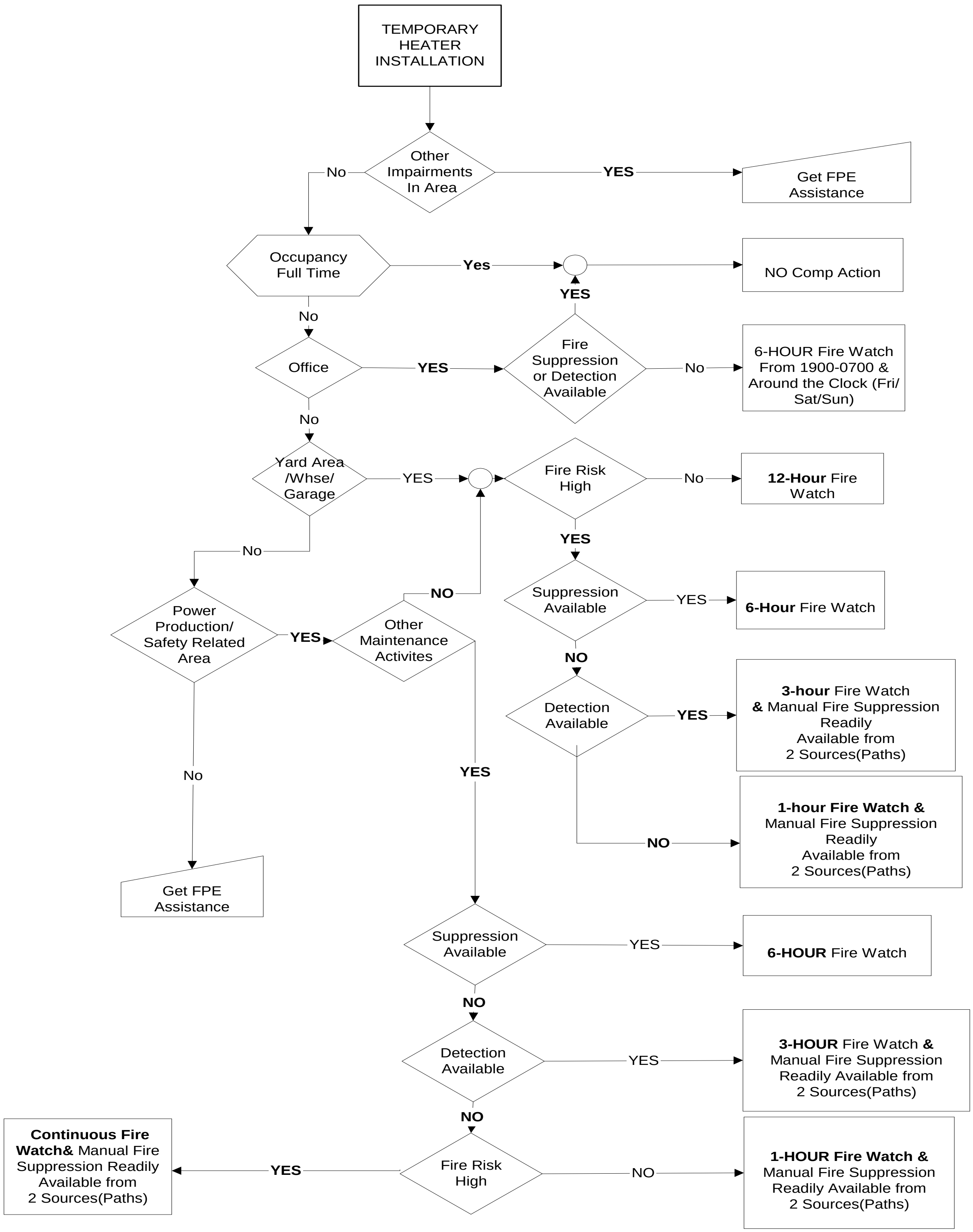

Figure C-6
Temporary Heater Impairment Chart

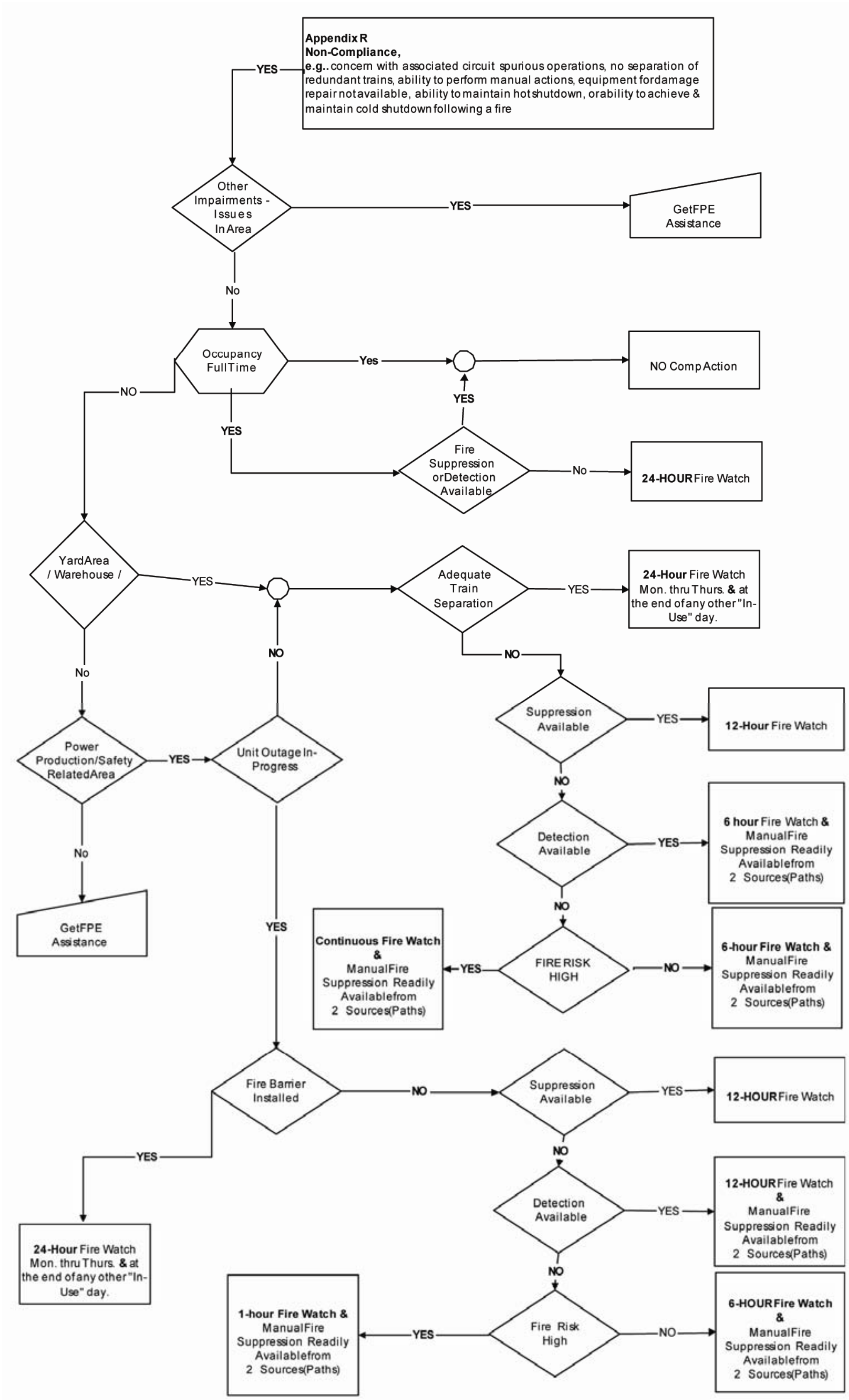

Figure C-7
Appendix R Separation Compensatory Measure Evaluation

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