Pacific Northwest NATIONAL LABORATORY

PNNL-31243

A Risk-Informed, Performance-Based Methodology to Manage Fire Protection Systems in Nuclear Facilities

April 2021

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Summary

Fire protection systems (FPSs) and features are installed in U.S. Department of Energy (DOE) Hazard Category 1, 2, or 3 nuclear facilities to protect property (maximum possible fire loss thresholds), programs, and life consistent with the general DOE fire protection program directives. The FPS and features may also be credited in nuclear safety analyses for prevention or mitigation of fire events leading to radiological release or the protection of structures, systems, and components that prevent or mitigate accidents. These FPSs and features are designed and maintained in accordance with the prescriptive guidance provided in applicable building codes and National Fire Protection Association (NFPA) codes and standards, although additional nuclear safety driven design or control elements may be applied . Management, operations, and maintenance activities of FPSs involve significant effort. A DOE facility's documented safety analysis or other safety basis document may designate FPSs and features as providing either a safety significant or safety class function to mitigate fire hazards and minimize radiological consequences or to protect other safety significant or safety class elements. In some cases, the designation of safety significant or safety class may be determined to provide a layer of defense-in-depth to minimize nuclear safety risks independent of the fire risk. DOE fire protection standards allow the use of performance-based design alternatives developed by the fire industry to evaluate fire protection objectives, but do not consider the defense-in-depth layers of protection provided in DOE facilities to prevent or mitigate the risks associated with unintended release of radioactive materials into the environment. Pacific Northwest National Laboratory developed a decision-making methodology tailored for DOE non-reactor nuclear facilities to manage FPSs and features by integrating nuclear safety risk insights into a performance-based analysis. This risk-informed, performance-based (RIPB) methodology can be used to provide the technical basis for classifying an FPS as safety class and safety significant, tailoring administrative controls (e.g., technical safety requirements), and ranking the importance of FPSs to prioritize maintenance, upgrades, and replacement activities. The RIPB methodology is a graded approach to inform DOE facility owners and Fire Protection Program managers of the most risk-significant FPSs and equipment. This graded approach provides a consistent method to classify a FPS (Safety Class or Safety Significant) and rank the importance of fire protection systems. The RIPB methodology can also be used to support a technical basis for tailoring fire controls (e.g., technical safety requirements) to prioritize maintenance, upgrades, and replacement activities. This graded approach would aid in managing the Fire Protection Program such that top priority could be given to systems that are most risk-significant equipment. For lower risk- significant systems, this approach could be used to provide a technical basis for relaxing rigor or deviating from prescriptive design requirements in DOE and NFPA standards. This paper describes the framework used to develop the RIPB methodology and the outcome of implementing this methodology in a use-case nuclear facility. The impact to DOE policies and standards, benefits of implementing an RIPB methodology, and the impact it would have on safety margins and defense-in-depth measures credited in a facility's documented safety analysis are also discussed in this paper.

Acknowledgments

Pacific Northwest National Laboratory would like to thank Mr. Patrick Frias, Program Manager of the Department of Energy's Nuclear Safety Research and Development Program for the opportunity to develop a risk-informed, performance-based methodology for fire protection systems and equipment. Acknowledgements are also extended to Mr. Jim Bisker, a Fire Protection Engineer and Fire Protection Program Manager in the Department of Energy's Office of Environment, Health, Safety & Security, for providing insights on the DOE standards on fire protection, fire hazards analyses, and the use of risk-informed and performance-based methods.

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Acronyms and Abbreviations

AHJ	authority having jurisdiction
CFAST	Consolidated Model of Fire and Smoke Transport
CW	co-located worker
DOE	U.S. Department of Energy
DSA	documented safety analysis
FPS	fire protection system
FPP	fire protection program
FW	facility worker
LFS	limiting fire scenario
MEFS	maximum expected fire scenario
MOI	maximally exposed offsite individual (public)
NFPA	National Fire Protection Association
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
PRA	probabilistic risk assessment
RIPB	risk-informed, performance-based
RPL	radiochemical processing laboratory
SC	safety class
SFPE	Society of Fire Protection Engineering
SS	safety significant
SSCs	systems, structures, and components

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1.0 Introduction

The U.S. Department of Energy (DOE) owns and manages facilities that handle nuclear materials and has established facility and programmatic design requirements that govern nuclear safety, fire protection, and criticality safety. Multiple layers of defense-in-depth are integrated into the design and safety requirements for these Hazard Category 1, 2, or 3 nuclear facilities to provide adequate protection for the facility workers (FWs), the public, and the environment from operation of these facilities. Fire protection systems (FPSs) and features are installed in DOE nuclear facilities to protect life, programs, and property (maximum possible fire loss thresholds). The FPS and features may also be credited with minimizing the consequence of fire events/accident or protecting systems, structures, and components (SSCs) important to maintain nuclear safety. A facility's documented safety analysis (DSA) or other safety basis document evaluates the radiological consequence of an unmitigated fire scenario and identifies SSCs that will prevent or mitigate the scenario and subsequently reduce the exposure for a co-located worker (CW), the public, and the environment. The FPS and features in the facility may be designated as safety class (SC) if needed to directly meet accident dose evaluation guidelines or to protect other safety class SSCs. The FPS and features may be designated as safety significant (SS) if the system is credited in the safety basis for defense-in-depth or worker protection as described in DOE standards.

Fire protection engineers and risk analysts at Pacific Northwest National Laboratory (PNNL) developed a methodology that facility owners can use to rank FPSs and features in a nuclear facility based on their importance in mitigating radiological consequences as evaluated in the facility's DSA. This methodology leverages risk insights from the nuclear safety analysis and the performance-based analysis of the fire hazards in the facility. The risk-informed, performance-based (RIPB) methodology can be followed to prioritize FPS and features and support decisions related to management of these systems (e.g., design, installation, operation, and maintenance). This methodology can also be used to support re-analysis of fire scenarios in the DSA and justify re-categorization of FPSs and features as either SC, SS or non-safety related.

The report is organized as follows. Section 2 of this report discusses the background of DOE's nuclear safety and Fire Protection Program (FPP) and the use of risk insights and performance-based methods to address design and safety processes.

Section 3 discusses the approach used to develop the RIPB methodology and assess the implications of using a methodology on DOE policies and standards.

Section 4 discusses the development of the RIPB methodology and a use case to demonstrate the application of the methodology.

Section 5 of this report discusses the implications of implementing the RIPB methodology on the current DOE guidance and standards, the management of fire protection systems, and the impact on safety margins and defense-in-depth built into the fire hazards analysis and nuclear safety analysis.

Lastly, the conclusions of this research are included in Section 6 of this report.

2.0 Background

An RIPB methodology integrates risk insights, engineering analysis, the principles of defense-in-depth, and performance history into an informed decision-making process. For over 20 years, the integration of risk insights and performance-based information has been used by fire protection engineers and risk analysts to determine the FPS and features necessary to protect SSCs required for nuclear safety from the effects of a fire (Alvarez 2014 and NFPA 2012). The consideration of risk insights adds another dimension to fire safety and fire analysis by bridging the gap between a qualitative and quantitative fire risk assessment (Barry 2002). DOE policies and standards emphasize integrating nuclear safety into the designs for fire safety, but there a formal methodology does not exist currently. Application of this methodology provides an alternative approach to comply with the prescriptive requirements imposed by DOE policies and standards, building codes, and fire codes.

The DOE requirements and guidance for fire protection in nuclear facilities are included in 10 CFR 851, *Worker Safety and Health Program*[1], DOE Order 420.1C, *Facility Safety* (DOE 2018), and DOE-STD-1066-2016, *Fire Protection* (DOE, 2016). The installation of FPS and features in DOE facilities are based on these DOE requirements. These FPSs and features are designed, installed, and maintained in accordance with applicable building codes, NFPA codes, and standards. These codes and standards provide deterministic and prescriptive requirements for design, installation, inspection, testing, and maintenance for these systems. Deviations from codes and standards would need to be approved by the authority having jurisdiction (AHJ). DOE is the AHJ for FPS and features installed in DOE facilities, including nuclear facilities. The DOE fire protection standards recognize that strict compliance with the code and standard may not be feasible and thus allow the use of performance-based design alternatives, which are based on methodologies described in the *Society of Fire Protection Engineering (SFPE) Engineering Guide to Performance-Based Fire Protection* (SFPE 2000). However, these industry-developed performance-based methodologies do not consider specific defense-in-depth layers of protection within a DOE facility to prevent or mitigate the risks associated with an unintended release of radioactive materials into the environment. This research integrates risk insights from the nuclear safety analysis.

Nuclear safety requirements for DOE facilities are governed by the regulations described in 10 CFR 830, *Nuclear Safety Management.* [2] The facility's nuclear safety analysis is typically documented in a DSA, which is developed using guidance provided in DOE-STD-1189-2016, *Integration of Safety into the Design Process* (DOE 2016d), and DOE-STD-3009-2014, *Preparation of Nonreactor Nuclear Facility Documented Safety Analysis* (DOE 2014). These DOE standards provide guidance for performing a consequence analysis (mitigated or unmitigated) for plausible accident scenarios (i.e., fire scenarios). The DSA hazards analysis presents the unmitigated dose consequence from a criticality accident based on material quantity, form, location, and dispersibility due to the postulated fire. The DSA documents the classification of FPSs and features (i.e., SS or SC) based on whether they are credited in an unmitigated or mitigated consequence analysis. In the DSA, the frequencies of various postulated fire scenarios are classified as either anticipated, unlikely, extremely unlikely, or beyond extremely unlikely. The fire scenarios are qualitatively analyzed further to determine if

[1] Title 10, Part 851 of the Code of Federal Regulations (10 CFR 851), *Worker Safety and Health Program,* https://www.energy.gov/gc/10-cfr-851-worker-safety-and-health-program

[2] Title 10 Part 830 of the Code of Federal Regulations (10 CFR 830), *Nuclear Safety Management,* https://www.energy.gov/sites/prod/files/2013/06/f1/011001_rule.pdf

the consequence to the public, CW, or FW is low, moderate, or high. The consideration of risk insights focuses attention on fire protection design and operational issues commensurate with their importance in protecting the worker, public, and environment from the effects of radiological consequences if a fire occurs. The nuclear safety risk insights, when integrated with performance-based information on the fire scenario, can aid in decision-making processes related to FPSs that are credited in the DSA.

The use of an RIPB methodology to make decisions involving nuclear safety has been successfully applied at nuclear power plants (NPPs). The Nuclear Regulatory Commission (NRC) has developed RIPB regulations to allow NPP owners to focus on the most important activities and provide an approach to monitoring and evaluating performance (NRC 1999). The NRC regulations[3] allow NPPs to adopt the methods provided in NFPA 805, *Performance-based Standard for Fire Protection for Light Water Reactor Electric Generating Plants* (NFPA 2012) to meet the fire protection requirements (NRC 2009).

One of the performance-based methods described in NFPA 805 is a fire risk evaluation. This type of evaluation provides a measurable method that informs the impact on a plant's risk based on the plant-specific probabilistic risk assessment (PRA) model, including human reliability analysis to evaluate the performance of operator recovery action. These operator actions are conducted to recover a safety function that was affected by fire-induced damage of a cable or equipment. NPPs use guidance in NUREG/RES-6850, *Fire PRA Methodology for Nuclear Power Facilities* (NRC 2005) to develop plant-specific fire PRA for use in an NFPA 805 licensing application. A fire risk evaluation models an unsuppressed fire and integrates fire damage to cables and equipment into the plant's PRA models and assesses the impact on the plant's risk by determining the change in core damage frequency and large early release frequency. This methodology requires knowledge of specific equipment and cable location and the development of a PRA model. Thus, implementing the NFPA 805 approach in a DOE nuclear facility would not be practical for the following reasons:

- Despite guidance provided in DOE-STD-1628-2013, *Development of Probabilistic Risk Assessments for Nuclear Safety Applications* (DOE 2013), DOE nuclear facilities have not developed a PRA because it may be cost-prohibitive, as revealed by NPP owners that have transitioned to RIPB FPP.
- DOE facilities do not generally manage the specific location of equipment and associated cables for SSCs that are credited to mitigate radiological consequences, so it may be a challenge to know specific SSCs that are affected by a fire scenario.
- Lastly, DOE nuclear facilities may not strictly track the location, type, and quantity of combustible materials (in situ or transient) stored throughout the facility, so it may be a challenge to bound fire scenarios.

This research relies on risk insights obtained from the facility's DSA instead of a PRA model and performance-based information obtained from the facility's fire hazards analysis (FHA). Thus, the RIPB methodology developed in this research is a semi-quantitative approach.

[3] Title 10, Part 50 of the Code of Federal Regulations (10 CFR 50.48), *Fire Protection,* https://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0048.html

3.0 Plan for Developing the RIPB Methodology

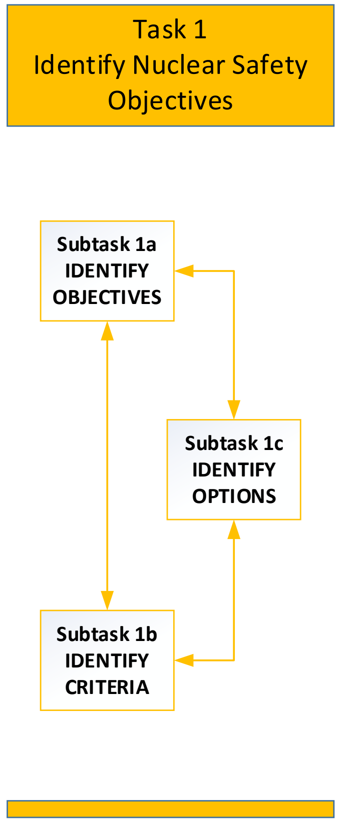
As discussed in Background section, DOE standards and guidance documents allow the use of performance-based methods to identify the need for SS or SC controls that could prevent or mitigate operational events. Performance-based methods can also be used to support the basis for acceptable alternatives to meet DOE fire protection requirements. The RIPB methodology will use existing FHAs and control allocation results from the DSA to develop a semi-quantitative characterization of the scenarios analyzed in a DSA. The following sections describe the technical methods and goals for three major tasks outlined in this research project:

- Identify the nuclear safety objectives (Task 1)
- Develop the RIPB methodology (Task 2)
- Identify implementation impacts (Task 3).

3.1 Task 1 – Identify the Nuclear Safety Objectives

The first task involved identifying the nuclear safety objectives to ensure that the methodology is bounded. Task 1 involved reviewing existing DOE's policy and standards related to nuclear safety and fire safety. The task also reviewed DOE guidance for developing risk-informed or performance-based methods to ensure that the outcome of this research conformed to DOE's policy. Three subtasks were associated with Task 1:

- Identify the nuclear safety objectives (subtask 1a)
- Identify the performance criteria for categorizing FPSs as SS or SC in a facility's DSA (subtask 1b)
- Identify design options to meet nuclear safety objectives (subtask1c).

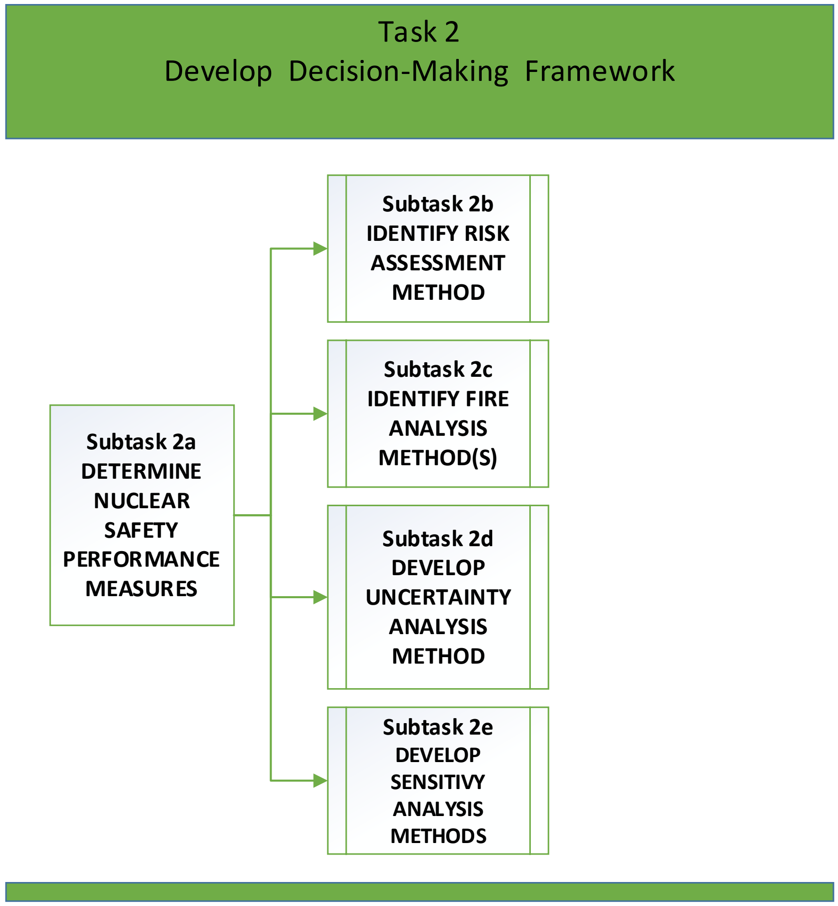


The results of this task were used to define the risk and performance limitations of the decision-making methodology that was developed in Task 2. Section 4.1 of this report discusses the results of Task 1.

3.2 Task 2 – Development of Decision-Making Framework

The second task involved the steps needed to develop the RIPB methodology. Five subtasks were associated with Task 2:

- Identify criteria to measure performance of the FPS (subtask 2a)
- Develop a semi-quantitative method to analyze radiological risks that were evaluated in a facility's DSA (subtask 2b)
- Develop a method to evaluate fire hazards and the impact a fire scenario would have on materials that would result in radiological consequences (subtask 2c)
- Develop a method to identify design features or input that would contribute to the uncertainty with the results of the risk analysis and the fire hazards analysis (subtask 2d)
- Develop a method to assess the sensitivity of the results of the RIPB methodology (subtask 2e).



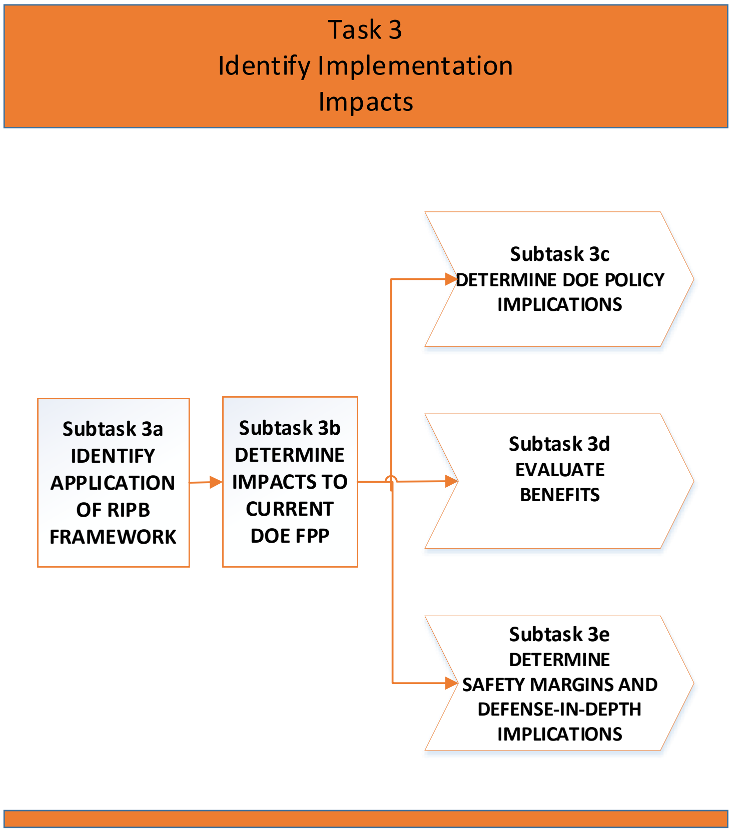
The outcome of these tasks provides the basis for the RIPB decision-making framework that a facility owner can implement to rank the FPSs and features based on their importance in mitigating radiological consequences as evaluated in the facility's DSA. Section 4.2 of this report discusses the results of Task 2. Risk insights are generally not applied in identification of SS and SC systems at DOE facilities because the consequence analysis typically assumes an unmitigated event. Therefore, the implications of applying a RIPB methodology was evaluated further in Task 3.

3.3 Task 3 – Identify Implementation Impacts

This third task focused on the application of an RIPB decision-making methodology to manage a facility's FPP and how it would affect existing DOE policies and current operational costs, safety margins, and defense-in-depth design. Five sub-tasks were performed to assess the implications of implementing the RIPB framework at DOE facilities:

- Demonstrate how a facility owner can apply the RIPB framework on a use-case facility (Subtask 3a)
- Identify DOE policies (e.g., orders, regulations, and standards) that would be affected by implementing this methodology (Subtask 3b)
- Identify pros and cons of implementing the RIPB method to meet the DOE fire protection policy (Subtask 3c)
- Identify metrics to evaluate the cost-benefits of risk-ranking FPSs (Subtask 3d)

- Identify the impact on safety margins and defense-in-depth on a facility's DSA and FPP (Subtask 3e)



Implementation of this RIPB methodology not only provides insights on FPSs that are necessary to protect the worker, public, and environment from the effects of a fire involving radiological materials but also provides the basis for prioritizing maintenance, upgrades, and repairs of these systems. Except for Subtask 3a, Section 5 of this report discusses the results of Task 3. The results of the use-case demonstration (Subtask 3a) are discussed in Section 4.2.6 of this report.

4.0 Proposed Risk-Informed Performance-based Methodology

> **Defense-in-Depth**
>
> The act of incorporating multiple layers of protection into the design of a facility to prevent or mitigate the unintended release of radiological materials

DOE is committed to ensuring the adequate protection of workers, the public, and the environment. Thus, as described in DOE P 420.1, *Department of Energy Nuclear Safety Policy*, DOE's policy is to develop standards and guidance documents that are focused on minimizing the risks to radiological exposure on the life and health of individuals as a result of operating nuclear facilities during their life cycle (e.g., design, construction, operation, and decommission). The goal of developing the RIPB methodology is to ensure that the decision-making tool meets the nuclear safety policy discussed in DOE P 420.1. Current methods used to comply with DOE's nuclear safety and fire protection requirements will not be affected by this methodology. This section describes the results of the following first two tasks discussed in Section 3 of the report:

- Task 1 – Identify Nuclear Safety Design Objectives
- Task 2 – Develop the RIPB Methodology

Thus, the RIPB methodology provides an alternative approach that could be used to classify FPSs and features that are credited to mitigate a fire or to protect SSCs that are credited to mitigate radiological consequences (i.e., SC) or for defense-in-depth (i.e., SS). Section 4.1 discusses the nuclear safety design objectives that bound the RIPB methodology. Section 4.2 discusses the RIPB methodology.

4.1 Nuclear Safety Design Objectives

Integration of safety within the nuclear facility design is paramount to compliance with the federal regulation established in 10 CFR Part 830[4]. Chapter I of DOE O 420.1C outlines the nuclear safety design criteria, which are focused on protecting workers, the public, and the environment from the effects of a radiological release from a hazard category 1, 2, and 3 nuclear facility (DOE 2019). The nuclear safety goals include the following:

1. Protect individual members of the public such that significant additional risk to life and health is not introduced from the consequences of DOE operations.
2. Protect the health and safety of DOE workers consistent with or better than the level of protection provided to workers in similar industries.

To ensure these goals are achieved, multiple layers of defense-in-depth protection are integrated into the facility design to prevent or mitigate the unintended release of radiological materials into the environment (DOE 2019). Some examples of defense-in-depth include

[4] 10 CFR Part 830 can be accessed at https://www.govinfo.gov/content/pkg/CFR-2011-title10-vol4/pdf/CFR-2011-title10-vol4-part830.pdf

minimizing the quantity of materials at risk, using physical barriers to protect against a radioactive release, providing multiple means to ensure the safety functions are met (e.g., controlling processes), providing preventive or mitigating controls for accidents (e.g., fire), or using equipment to respond to accidents to achieve a safe condition.

The RIPB methodology uses risk insights from the facility’s DSA or other safety basis document. The DSA identifies SSCs and administrative controls that are needed to meet a safety function, SC, or SS. The DSA also identifies SSCs that are credited to prevent and/or mitigate the consequences of design basis accidents and hazards analysis. In particular, the DSA identifies FPSs and features that are credited to mitigate fire hazards. This methodology uses performance-based methods to evaluate the consequences of fire scenarios evaluated in the DSA. The results of the methodology can then be used to rank the FPS and features based on their importance to mitigating risk. Therefore, decisions made using the methodology continues to meet the nuclear safety basis evaluated in the facility’s DSA when evaluating FPSs and features that are required to protect SSCs to meet the safety function.

Specific administrative controls could also be provided to fulfill a safety function as described in DOE-STD-1186-2016, *Specific Administrative Controls* (DOE 2016). In the case of a fire, administrative controls could involve controlling the storage of combustible materials or use of ignition sources. The administrative controls provide a layer of defense-in-depth by providing measures to prevent fires from occurring.

4.1.1 Fire Protection Objectives

DOE Order 420.1C, *Facility Safety* and associated standard DOE-STD-1066-2016, *Fire Protection* (DOE 2016) establish programmatic and other criteria to protect the public, the worker, and the environment from effects of a fire. The primary objectives of an FPP are as follows:

1. Minimize the likelihood of occurrence of a fire-related event.
2. Minimize the consequences affecting the public, workers, environment, property, and missions from the effects of a fire.
3. Provide a level of safety protection consistent with “highly protected risk” class of industrial risks.

The DOE FPP requires dedicated staff and resources to manage different elements of the program. Appropriate staffing levels, organizational structure (e.g., roles and responsibilities), and training requirements are required to manage and implement the FPP. Qualified and trained fire protection staff, including fire protection engineers, technicians, and fire-fighting personnel, are important in implementation of the FPP. Emergency response training and qualifications are based on established industry criteria described in applicable DOE directives and NFPA standards.

DOE-STD-1066-2016 requires that the site’s FPP meet specific operational requirements, which involve programmatic controls that influence the performance of FPSs and features. The following programmatic controls are required in an FPP:

- Inspection, testing, and maintenance program for FPS and features
- Control of the use and storage of combustible, flammable, radioactive, and hazardous materials

- Control of hot work and ignition sources
- Tracking of FPS impairments, compensatory measures, and timely return to service

These programmatic controls are paramount to the effectiveness of the FPP and are relied upon in a performance-based analysis. For example, successful performance of inspection, testing, and maintenance required by the NFPA codes and standards provides a level of assurance on the reliability of the FPS's and features' ability to perform during a fire. Other examples include the control of hot work and ignition sources and management of combustible materials that contribute to minimizing the likelihood of occurrence of a fire and limiting the propagation if a fire occurs.

The design, construction, maintenance, and operation of the FPS and features are governed by the NFPA codes and standards, and building codes that are in effect when design criteria are approved. In some cases, the applicable codes and standards may be determined by the AHJ.

Government-owned or government-leased facilities and contractor-leased facilities used for DOE mission purposes have established an FPP in accordance with DOE Order 420.1C and DOE-STD-1066-2016. Fire protection systems and features are required for facilities that exceed a floor area of 5000 square feet. The value of property loss is the threshold criterion used to determine the level of fire protection needed. The property loss thresholds are described in DOE Order 420.1C as shown in Table 1.

Table 1. Fire Protection Needed Based on Maximum Possible Fire Loss

Maximum Possible Fire Loss *** (2018 Dollars)**	**Required Fire Protection Systems**
> $5.9Million	Automatic fire suppression systems
> $177Million	Automatic fire suppression, fire detection, and alarm systems
Max $412Million	Fire barriers to compartmentalize building areas to limit fire loss, in addition to automatic fire suppression, fire detection, and alarm systems

In addition to the maximum possible fire loss threshold, an automatic fire suppression system would be installed if it is required to prevent loss of safety functions or for defense-in-depth based on the safety basis document. An automatic fire suppression system is also required if significant life safety hazards exist or if an unsuppressed fire will interrupt a facility's mission or program.

Section 2.2.5 of DOE-STD-1066 also allows the use of performance-based design alternatives as an option to meet a code requirement. Performance-based methods are described in the *SFPE Guide to Performance-based Fire Protection* (2000).

4.1.2 Options to Meet Nuclear Safety Requirements

DOE's policy allows the use of quantitative and probabilistic risk assessments if they supplement qualitative or deterministic processes for hazard assessments and development of hazard controls (DOE 2019). The hazards analysis in the DSA determines if additional controls, such as SSC or administrative controls, are necessary to eliminate, limit, or mitigate the consequences of the unmitigated accident. A fire is an operational accident. As discussed earlier, SSCs that are designated "SC" indicate that the function is necessary to limit radioactive material exposure to the public below guidelines. SSCs that are designated “SS” indicate that the function is a major contributor to defense-in-depth and/or worker safety. Analysis is performed to justify the effectiveness of an administrative control as an option to meet nuclear safety requirements.

Appendix A of DOE-STD-1066-2016 describes the general design criteria for an FPS or feature that is categorized as SC or SS. Fire suppression systems, fire detection, fire water supply, fire barriers, or other FPS or features that are classified as safety-related indicate that it is essential to protect the public and/or the worker from a fire in a nuclear facility. The DSA describes the safety function of an FPS designated as SC or SS (e.g., preventive or mitigative). Designating an FPS or a feature as either SC or SS implies that the performance of the system or feature is relied upon to meet a nuclear safety function, as opposed to an FPS and feature that were installed primarily to meet property or building occupant life safety requirements. Therefore, design, operation, and testing of the classified safety-related systems may exceed normal requirements. DOE O 420.1C and DOE-STD-1066-2016 require that these FPS and features meet or exceed applicable NFPA standards, building codes, and highly protected risk criteria for all fire protection systems.

The hazards analysis in the DSA may be based on the conservative assumption of a fire spreading throughout an entire facility, or otherwise impacting the radioactive material inventory in a manner to determine the bounding dose and consequences for the material at risk in the facility. This assumption is conservative because the presence of combustible materials is assumed to disperse throughout the facility to enable the fire to propagate across the entire building. It is also assumed that there are no fire barriers that will effectively prevent the fire from spreading (e.g., barriers in the building are either non-rated or nonexistent) or fire suppression action, either automatic or by emergency response. Programmatic controls related to managing ignition sources and the storage of combustible materials, in conjunction with the installation of rated barriers and active systems would prevent the spread of a fire throughout the entire building, including spreading to different floor elevations.

The consequence analysis of fire scenarios determines if specific controls will need to be credited, which include identifying the FPS and/or features to aid in preventing or mitigating fire propagation. Thus, the FPS and/or feature credited to prevent or mitigate the fire scenario will be classified as SC or SS, respectively.

4.1.3 Options to Meet Fire Protection Requirements

Section 5.2.3 of DOE-STD-1066-2016 describes the process for obtaining a relief from meeting strict compliance with DOE directives, mandatory codes and standards, and the building code. A process for evaluating equivalencies, exemptions, modifications, or variances to the fire protection requirements is required to provide assurance that the alternate compliance method is acceptable and would not reduce the effectiveness of the FPP. The process includes developing, reviewing, approving, and re-evaluating variances and exemptions. Table 2 describes the different types of relief, such as a variance, exemption, alternative, or equivalency method of meeting the DOE reference.

Table 2. Options to Meet Fire Protection Requirements

DOE Reference	Type of Relief	Concurrence	Approval Authority
10 CFR Part 851	Variance	Office of Environment, Health, Safety and Security	Under Secretary
DOE O 420.1C	Exemption or Equivalency	Central Technical Authority for nuclear facilities only	Program Secretarial Officer
NFPA Codes and Standards	Equivalency	Subject Matter Expert	Head of Field Element
Building Code	Alternative	Subject Matter Expert	Head of Field Element
DOE-STD-1066-2016	Alternative	Subject Matter Expert	As designated by Head of Field Element

Source: Table 5.1 of DOE-STD-1066-2016

A relief from a DOE requirement requires concurrence and approval from the identified authority in Table 2. The relief would be documented in a facility's FHA. The use of the RIPB methodology could serve as the basis for obtaining approval for relief from strict compliance with DOE requirements for FPS systems that may not be as important for nuclear safety.

4.2 Performance and Risk Insights

The RIPB methodology incorporates elements of the NFPA 805 standard, which includes a method to obtain risk insights and a method to assess performance of FPSs and features. This section discusses the performance criteria that will be used to measure FPSs identified in the DSA (Section 4.2.1) and the assessments required in the proposed RIPB methodology (Sections 4.2.2 and 4.2.3). Identification of uncertainties associated with the methodology and a method to analyze the sensitivity of the results are described in Sections 4.2.4 and 4.2.5. Finally, an example nuclear facility is used to demonstrate implementation of the RIPB methodology, which is discussed in Section 4.2.6.

4.2.1 Performance Criteria for Fire Protection Systems

Performance criteria characterize the specific operational responses and capabilities necessary to meet functional requirements of the FPS. For example, the performance of the fire suppression system should not affect the design and operation requirements of the applicable NFPA code. Similarly, the outcome of the FPS evaluated using the RIPB methodology should not affect the ability of the SSC to meet the performance criteria in the DSA.

The RIPB methodology can be used in a decision-making process to assist facility owners and FPP managers in determining whether an FPS or feature is required to prevent or mitigate the consequences of the fire scenario. The DSA currently identifies FPSs classified as SS or SC using a "judgment-based process." The process considers a hierarchy of controls that gives preference to passive engineered safety features over active features, engineered safety features over administrative controls, and preventive controls over mitigative controls. Implementation of the RIPB methodology aids in determining if the current FPS classification credited in the DSA is appropriate. The RIPB methodology can also aid in determining whether a more restrictive control should be applied on an FPS or feature (e.g.., SS classification may need to be upgraded to SC).

As described in DOE-STD-3009-2014, the identification of hazard controls incorporates a defense-in-depth approach that builds layers of defense against the release of radioactive or other hazardous materials so that reliance is not placed on any individual layer. Other hazard controls designated in the DSA (i.e., not SC and SS) have more flexibility in the design and functional requirements. For example, these controls can be designed to applicable NFPA codes and standards, but the specific evaluations associated with these controls do not have to be documented in the DSA.

4.2.2 Method to Analyze Radiological Risks

As stated in the nuclear safety objectives, DOE nuclear safety policies and standards require that design features be provided to protect the FW, the CW, and the public from the effects of a radiological release in hazard category 1, 2, and 3 nuclear facilities. For the purposes of identifying SC and SS FPSs, an evaluation of CW consequences and off-site consequences is performed as part of the accident analysis in the DSA. This evaluation also determines the need to administratively control SSC (e.g., FPS and features) to protect the FW. The effectiveness of the SC and SS controls is determined by comparing an unmitigated analysis to a mitigated analysis.

The DSA documents the accident analysis for design basis events, including fire. The likelihood of a fire scenario is either qualitatively or quantitatively determined by subject matter experts with input from the fire hazards analysis for the facility. Table 3 identifies the range of classifications assigned to the likelihood of a fire scenario evaluated in the DSA, which are anticipated, unlikely, extremely unlikely, and beyond extremely unlikely.

Table 3. Qualitative Likelihood Classification

Description	Likelihood Range (/year)	Definition
Anticipated	Likelihood > 10^{-2}	Events occur several times during the lifetime of the facility.
Unlikely	10^{-2} > likelihood > 10^{-4}	Events not expected to occur over the lifetime of the facility
Extremely Unlikely	10^{-4} > likelihood > 10^{-6}	Events that will probably not occur during the lifetime of the facility
Beyond Extremely Unlikely	Likelihood < 10^{-6}	All other accidents

Source: Table 2 of DOE-STD-3009-2014

Classification of the scenario in the DSA is determined qualitatively. The bases for the likelihood are based on the prediction of the number of times the postulated fire scenario will occur during the lifetime of the facility. DOE nuclear facilities report fire or fire-protection-related events into the DOE Occurrence Reporting Processing System, and the events are summarized in the Annual Fire Protection Program Summary for each calendar year. [5] Not all events reported involve an actual fire that initiates within a nuclear facility. Some events that are reported as a "fire" involve wildland fires, fire protection equipment degradation or actuation, or safety issues. Since 1991, 19 fire events were reported in the Occurrence Reporting Processing System that

[5] DOE Fire Protection Database comprises data from the Fire Protection Program Summary Annual Reports submitted by nuclear facilities, which can be accessed at the following site: https://www.energy.gov/ehss/corporate-reporting-analysis/databases/fire-protection-database

appear to involve an actual fire that would be considered beyond a transient-type fire (e.g., fire greater than 15 minutes). The 19 fire events are summarized in Appendix B. This data provides a perspective on the likelihood that a fire scenario described in a facility's DSA will occur.

***Risk** is a quantitative or qualitative expression that considers both the likelihood that an event will occur and the consequences of that event.*

In DOE-STD-3009-2014, a graded approach is used to evaluate the consequences of unmitigated hazards. An accident analysis is performed to determine the consequences and hazard controls associated with a hazard event (e.g., fire event). Estimated consequences to maximally exposed offsite individuals (MOIs) (i.e., the public) are compared to the performance criteria identified in the evaluation guideline. Accident analysis is not necessary for facilities with unmitigated off-site consequences that do not have the potential to challenge the evaluation guideline values. An accident consequence analysis determines the potential effects on MOI, CW, and FW. The threshold for consequence levels is defined in DOE-STD-3009-2014 as shown in Table 4.

Table 4. Hazard Scenario Consequence Threshold

Consequence Level	MOI/Public	Co-located Worker	Facility Worker
High	≥ 25 rem TED Or ≥ PAC[5]-2	≥ 100 rem TED Or ≥ PAC-3	Prompt death, serious, injury, or significant radiological and chemical exposure
Moderate	≥ 5 rem TED Or ≥ PAC-1	≥ 25 rem TED Or ≥ PAC-2	No distinguishable threshold
Low	< 5 rem TED Or < PAC-1	< 25 rem TED Or < PAC-2	No distinguishable threshold

Source: Table 1 of DOE-STD-3009-2014

DOE established an evaluation guideline to identify a criterion for determining when an SC SSC is needed to mitigate an unacceptable exposure to MOI. The 25 rem total effective dose(TED) criterion for an unmitigated accident is determined by DOE to help identify and define what measures and controls are necessary. For a dose to the CW, a criterion of 100 rem TED is applied to determine if there is a need for an SC SSC to mitigate exposure to CW.

Risk is a function of likelihood and consequence, which, in traditional PRA, is determined for undesired scenarios that have been defined through a rigorous assessment process. As shown in Table 5, DOE-STD-3009-2014 describes a qualitative risk-ranking threshold for hazard evaluated in the DSA. This risk-ranking method does not constitute a PRA, but it does qualitatively or semi-quantitatively provide a perspective of risk. For example, in Table 5, anticipated or unlikely events that have a high consequence are situations of major concern in the DSA risk analysis (e.g., Risk Rank I). Consequently, extremely unlikely or beyond extremely unlikely hazard events that have a low consequence are situations that are of minimal concern in the DSA risk analysis, as defined in Tables 3 and 4 respectively.

Table 5. Qualitative Risk Ranking Bins in Documented Safety Analysis

Consequence Level	Beyond Extremely Unlikely ($<10^{-6}$/yr)	Extremely Unlikely (10^{-4} to 10^{-6}/yr)	Unlikely (10^{-2} to 10^{-4}/yr)	Anticipated ($>10^{-2}$/yr)
High Consequence	III	II	I	I
Moderate Consequence	IV	III	II	II
Low Consequence	IV	IV	III	III
I: Situations of major concern in the DSA risk analysis II: Situations of concern in the DSA risk analysis III: Situations of minor concern in the DSA risk analysis IV: Situations of minimal concern in the DSA risk analysis				

Source: Table 1 of DOE-STD-3009-2014

Following a similar method to risk-ranking hazards in the DSA, the risk insights used in the RIPB methodology uses a similar binning process to rank the risk associated with fire scenarios evaluated in a facility's DSA. The fire risk of a given area is determined by the likelihood that a fire will occur and the consequences and severity of the fire damage. As shown in Table 6, the risk significance of a fire scenario is based on the likelihood determined by the facility's DSA and the consequences (e.g., low, moderate, or high) to MOI, CW, and FW identified in the hazards analysis. The risk insights are color-coded as follows:

GREEN: Fire scenarios of low significance to the DSA's risk analysis

YELLOW: Fire scenarios of moderate significance to the DSA's risk analysis

RED: Fire scenarios of major significance to the DSA's risk analysis

Table 6. Ranking of Fire Scenarios by Risk Significance

Likelihood	Consequence as Determined by DSA		
	Low Consequence to MOI and CW and No to FW	Moderate Consequence to CW and Yes to FW	Moderate or High Consequence to MOI or High Consequence to CW
Anticipated	Low Significance	Moderate Significance	Major Significance
Unlikely	Low Significance	Moderate Significance	Major Significance
Extremely Unlikely	Low Significance	Low Significance	Moderate Significance

Red is used to characterize a scenario as high risk based on its likelihood and consequence. In this case, scenarios that are assigned to a moderate or high consequence category, in which the radiological consequence thresholds for a moderate or high consequence have been exceeded for the CW and FW, and have been assigned to a likelihood category of "anticipated" or "unlikely" are defined to be high risk.

Yellow is used to characterize a scenario as moderate risk based on its likelihood and consequence. In this case, scenarios that are assigned to a moderate consequence category, in which the radiological consequence thresholds for a moderate consequence have been exceeded for the CW and FW, and have been assigned to a likelihood category of “anticipated” or “unlikely” are defined to be moderate risk.

Green is used to characterize a scenario as low risk when it is assigned to a low consequence category regardless of the scenario likelihood. A scenario is also defined to be low risk when it is assigned to a consequence category that exceeds the radiological consequence thresholds for a moderate consequence but has an extremely unlikely likelihood.

4.2.3 Performance-based Method to Evaluate Fire Hazards

The NFPA 805 standard provides two performance-based methods to evaluate the effects of a fire: 1) fire modeling and 2) fire risk evaluations. Because fire risk evaluations would typically require a PRA model and most DOE facilities do not have a PRA model, the RIPB methodology determines the risk significance of a fire scenario as discussed in Section 4.2.2 of this report. In the NFPA 805 standard, fire modeling is used to evaluate an unsuppressed fire scenario to determine if the damage thresholds are exceeded for equipment and cables required to meet the nuclear safety performance criteria. The fire modeling method determines if FPSs would need to limit the damage to SSCs and cables. In the NFPA 805 standard, fire damage thresholds between a maximum expected fire scenario (MEFS) (i.e., modeling a fire based on existing fire hazards) and the limiting fire scenario (LFS) (i.e., modeling a fire that would affect SSC’s cables and equipment necessary to meet nuclear safety performance criteria) are compared to determine if a desired margin exists. In the fire modeling method, the definition of an “acceptable desired margin” between the LFS and MEFS may vary based on physical layout of the area (e.g., high ceilings) or the function of the SSCs and cables affected. Figure 1 illustrates a typical model of a fire and how the location of targets could be affected or not affected by a fire scenario.

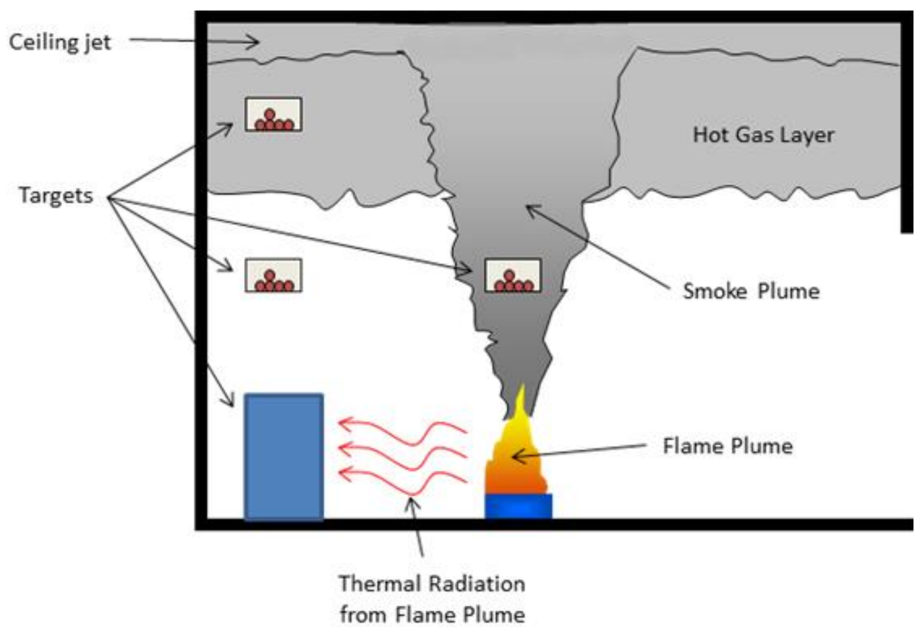


Figure 1. Fire Model Characteristics and Targets [Source: NUREG-1938, Figure 1.1 (NRC, 2012)]

If a facility is assessing the impact on electrical power or control to safety SSCs, comparing the LFS and MEFS may be a challenge because the specific location of cables and SSCs credited to mitigate a radiological consequence might not be documented or identified in the DSA. Therefore, it will be difficult to determine the damage threshold between an MEFS and LFS. In the RIPB methodology, the performance-based objective is re-defined as the expected fire and a fire that results in a specified consequence (e.g., rad release challenging guidelines or whatever). The MEFS is the expected fire based on conditions/assumptions, and the LFS is defined by consequence objective(s) evaluated in the facility's DSA. A quantitative approach (fire modeling) will be used to assess the MEFS and LFS and a qualitative approach will be used to determine if an "acceptable desired margin" exists between the MEFS and the LFS. The FHAs for a nuclear facility may already have fire models to assess fire hazards, but a fire model might not exist for the LFS associated with the fire scenario evaluated in the DSA.

Facilities may use fire models that are performed by qualified personnel to evaluate the fire hazards. Appendix B of DOE-STD-1066 provides guidance on using fire modelling software tools included in DOE's Central Registry Toolbox.[6] The "toolbox" contains codes that have been evaluated in accordance with DOE's Safety Software Quality Assurance requirements stipulated by DOE O 414.1D, Quality Assurance (DOE, 2020), and DOE G 414.1-4, Safety Software Guide (DOE 2010). Allowable fire model software codes include those developed by the National Institute of Standards and Technology, such as Consolidated Model of Fire and Smoke Transport (CFAST)[7] and those used by the NPP industry (NRC 2004). Assumptions limiting conditions of operation or specific administrative controls would need to be maintained if fire models are used to support the FHA. Short descriptions of the fire modeling tools available to use in DOE facilities are provided below:

1. ***CFAST***: CFAST is a two-zone fire model that can calculate the time-evolving distribution of smoke, hot gases, and temperature throughout compartments of a building during a fire. CFAST V3.1.7, V5.1.1, and V7.1.1 are acceptable safety analysis toolbox codes. CFAST is the most used method to simulate a fire and its impact on a specific building configuration and environment. CFAST can also be used with Smokeview to develop a visualization of the fire model that will include specific fire temperatures, gas concentrations and growth and movement of smoke layers across multiple rooms.
2. The Fire Dynamics Simulator[6] and Smokeview[8], developed by the National Institute of Standards and Technology, are computational fluid dynamic models of fire-driven fluid flow.

In the RIPB methodology, the importance of the FPS and features credited in the DSA can be evaluated further based on the risk significance of the fire scenario and the MEFS modeled. In applying the RIPB method, the prioritization levels (1, 2, or 3) for the FPSs are established based on risk insights from the consequence analysis in the DSA as determined by the color-coded risk significance matrix (green, yellow, and red) and the results of a performance-based analysis of the MEFS (i.e., size of the fire) using either qualitative or quantitative means, such as a fire model. A graded approach was also used to differentiate between the different types of MEFS relative to each other (e.g., small, medium, and large). The MEFS is based on modeling an unmitigated fire scenario (i.e., fire suppression is assumed to not actuate). LFS is the worst-

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[6] Information on Central Registry Toolbox codes can be found at http://energy.gov/ehss/safety-software-quality-assurance-central-registry.

[7] Consolidated Model of Fire Growth and Smoke Transport Modeling can be accessed at https://www.nist.gov/el/fire-research-division-73300/product-services/consolidated-fire-and-smoke-transport-model-cfast

[8] Fire Dynamics Simulator and Smokeview can be accessed from the National Institute of Standards and Technology at https://pages.nist.gov/fds-smv/.

case unmitigated fire that is evaluated in the facility's DSA. The MEFS and LFS would be based on fire duration. The three priority levels of FPSs and features (PRI1, PRI2, PRI3) are shown in Table 7.

Table 7. Qualitative Prioritization Matrix for Fire Protection Systems

Maximum Expected Fire Scenario (MEFS) [Note1]	**Risk Significance of Fire Scenario** [Note 2]		
	Low	Moderate	High
Small MEFS < (0.25) LFS [Note3]	PRI 3	PRI 3	PRI 3
Medium (0.25) LFS < MEFS < (0.75) LFS	PRI 3	PRI 2	PRI 1
Large MEFS > (0.75) LFS	PRI 2	PRI 2	PRI 1

Notes:

1. MEFS is determined by modeling the fire scenario evaluated in the DSA's Hazards Analysis.
2. Risk significance is determined by ranking the fire scenarios as described in Table 6.
3. LFS is determined by modeling the fire scenario that is assumed to result in an unmitigated radiological release evaluated in the DSA.

Priority 1: MEFS is expected to be a medium or large fire, and the fire scenario is characterized as high-risk significance based on likelihood and consequence.

For example, if the LFS for a facility assumes an unmitigated fire that lasts for one hour, then Priority 1 FPSs are those that are credited to mitigate fire scenarios that would result in fires lasting 45 minutes (0.75 x LFS) or longer. As described in the Risk-Informed Matrix, fire scenarios assigned to a high-consequence category (e.g., exceeding radiological thresholds established in the evaluation guideline for high consequence) and assigned an "anticipated" or "unlikely" likelihood category are defined to be high fire risk (red).

Priority 2: MEFS is expected to be a medium or large fire, and the fire scenario is characterized as moderate risk based on its likelihood and consequence.

For example, if the LFS for a facility assumes an unmitigated fire that lasts for one hour, then Priority 2 FPSs are those that are credited to mitigate fire scenarios that would result in 45 minutes (0.75 x LFS) or longer. As described in the Risk-Informed Matrix, fire scenarios assigned to a moderate consequence category, in which the radiological consequence thresholds for a moderate consequence have been exceeded for the CW and FW, and assigned an “anticipated” or “unlikely” likelihood category are defined to be moderate fire risk (yellow).

Priority 3: MEFS is expected to be a small or medium fire for a low risk-significant fire scenario or MEFs is expected to be a small fire for either a moderate or high risk-significant scenario based on the likelihood and consequences.

For example, if the LFS for a facility assumes an unmitigated fire that lasts for one hour, then Priority 3 FPSs are those that are credited to mitigate fire scenarios that would result in a small fire (less than 15 minutes [0.25 x LFS] duration) to medium fire (15-45 minutes [0.75 x LFS] duration). As described in the Risk-Informed Matrix, fire scenarios assigned to a consequence category in which the radiological consequence thresholds for a moderate consequence have been exceeded for the CW and FW and assigned an “extremely unlikely” likelihood category are defined to be low fire risk (green).

Based on the risk significance of a fire scenario determined by Table 6 (low, moderate, or high), the FPSs and features that are credited in the hazards analysis can be ranked by priority.

The priority numbers (i.e., PRI1, PRI2, and PRI3) provide the facility owner and FPP Manager with a graded characterization of the nuclear safety risk importance associated with the FPSs and features. We propose that facility resources in terms of health and life cycle management of FPSs and features be proportioned according to these values. For example, Priority 3 FPS may not need the same level of attention as FPSs with higher priority number, and therefore, incremental (or bigger) changes can be made on Priority 3 FPSs or on the health and life cycle management of Priority 3 FPSs without an increase to facility risk and without increasing the facility to an unacceptable level.

The proposed matrix is one potential approach for combining risk-informed and performance-based information into FPS and feature priority numbers. There are other possible algorithms that combine different types of risk measures and performance information in different ways. For example, performance history is a performance-based measure that might also be used.

4.2.4 Method to Assess Uncertainty

Uncertainty in the RIPB methodology is influenced by factors that might be unknown or the information about them might not be available at the time. Uncertainty could exist in modeling a fire and in risk insights from the radiological consequences of a fire. For example, modeling a fire involving transient combustibles is challenging because parameters, such as room layout, ceiling height, and ventilation effects, contribute to the fire model (i.e., flame height, smoke plumes, and thermal radiation) and the subsequent targets that could be affected by the fire. Another example of treating uncertainties is an approach used in developing fire PRAs for an NPP. The treatment of uncertainties in the fire PRA varies from quantitative estimations and propagation of uncertainties (e.g., fire frequency and non-suppression probability) to identification of sources without quantitative estimations (NRC 2005).

Uncertainty reflects the limitations of the analysis.

This methodology integrates fire models to quantitatively assess fire risks. Fire models are used to predict fire growth, which in turn is used to determine if “targets” are affected based on whether the “target” is within the fire plume. Fire model predictions include certain limitations, assumptions, and uncertainties. The limits of applicability of a particular fire model should be understood by the user. Errors in or assumptions about input data are a common contributor to uncertainty. Uncertainty in the results of the fire model can also be compounded from the uncertainty of input variables that propagate through the model (Li et al. 2018).

Caution should also be exercised when interpreting the fire modeling results. In some cases, the fire modeling results can provide a high level of confidence, especially in scenarios where the predicted fire hazards are well below the damage threshold. The use of engineering judgment is a primary method of handling modeling uncertainties. Among other things, this judgment is reflected in the selection of appropriate fire scenarios, hazard criteria, and fire modeling techniques (NRC 2004).

4.2.5 Method to Perform Sensitivity Analysis

To understand the impact of uncertainties on the outcome of the RIPB methodology, a sensitivity analysis can be performed to evaluate the variation of the individual parameters that contribute to uncertainty. Performing a sensitivity analysis can determine the significance that an uncertainty factor will have on the output and provide an understanding of the variables that are dominant.

Sensitivity analysis determines the degree that the predicted fire model will vary given a change in an input parameter.

When fire modeling is used to support decisions made in the safety analysis, special attention should be made to identify assumptions and inputs that could influence the result (i.e., predictions of the fire). As specified in Appendix B.3.2 of DOE-STD-1066, limiting conditions of operation and specific administrative controls would need to be established to ensure the inputs used in the fire model remain valid because a small variation in an assumption could have a major impact on the outcome. For example, a fire model may assume a fire door is closed to determine the fire intensity. However, it would not be realistic to assume that the fire door will be closed throughout the lifetime of the facility. Therefore, a sensitivity analysis should be considered with the door open to determine how the configuration will influence the results.

The fire models that are performed to support this RIPB method are unmitigated to assess the worst-case fire. Therefore, actuation of smoke detectors and suppression systems or initiation of manual firefighting activities is not credited. However, there are some input factors that would influence the results of the predicted fire model, and a sensitivity analysis should be performed to evaluate how the uncertainty would affect the outcome of the fire model. Sensitivity analysis should be performed to address uncertainty with the following.

Fire Hazards: The fire models will rely on fire hazards described in the facility’s FHA and building layout described in the DSA and the FHA. Combustible loading may not be rigorously controlled or managed (i.e., permits are used to track combustible materials brought into an area or limits on combustible loading are enforced). In addition, fire hazards may change over time and information in the FHA may not accurately reflect the hazards in the facility until the FHA is updated.

Fire Areas/Rooms/Compartments: Although structural materials in Hazard Category I, 2, or 3 facilities are required to be non-combustible per DOE-STD-1066, fire scenarios analyzed in the DSA may be based on the conservative assumption of an unmitigated fire propagating throughout the facility to determine the worst-case fire that would result in a conservative radiological consequence. It is typical for fire models to credit fire barriers to limit the spread of fire with a defined fire area, room, or compartment boundary. Fire barriers between compartments or rooms on the same elevation may openings or unsealed penetrations, so a sensitivity analysis would assume the fire model propagates to adjacent rooms. However, it can be reasonably assumed that in facilities with multiple elevations the floors, floor-ceiling, and roof-ceiling assemblies have some level of fire resistive ratings as required by ASTM E-119-20, *Standard Test Methods for Fire Tests of Building Construction and Materials* (ASTM 2020). Thus, it is reasonable to assume that there is a low probability that a fire would propagate between elevations. However, there may be facilities that have non-combustible construction and highly compartmented, but no rated separations vertically or horizontally. In those cases, the sensitivity analysis may need to assume propagation across different elevations. In addition, per Appendix B of DOE-STD-1066, the FHA may credit fire area analysis, where the barriers that make up the boundary of the fire area are 2-hour fire rated. Fire-rated compartmentalization may be credited to separate and manage hazardous materials (chemicals) from other areas of the facility. Passive fire barriers assumed to survive a fire that would otherwise lead to a significant consequence should have its configuration and design strictly managed, such as by implementing a technical safety requirement.

Target Location: As described in DOE-STD-3009, fire scenarios evaluated in the DSA assess the fire effects on radioactive or hazardous materials considering the quantity, form, and dispersibility. Unmitigated fires may be assumed to fully engulf the facility to assess the radiological consequences of materials at risk. The RIPB methodology involves the use of fire models to provide a more realistic prediction of the fire scenario and propagation. Sensitivity analysis should be performed to assess the uncertainty with the location of the “targets” (i.e., materials at risk), support equipment, or cables that are needed to maintain the function of equipment credited in mitigating strategies.

4.2.6 Use Case of Implementing the RIPB Methodology

Although DOE standards exist to develop DSAs and FHAs, the hazards analysis, consequence analysis, physical layout, and level of documentation will vary between facilities due to the radiological and non-radiological hazards present at the facility, the quantity of the hazards involved, and the programmatic mission of the facility. The RIPB methodology was developed with the intent of using risk insights in a facility’s DSA and using the facility’s FHA and DSA to assess the fire scenario using a performance-based method (i.e., fire modeling). To further validate the process and the level of effort, a use-case facility was used to implement the RIPB methodology.

Appendix C includes an analysis of fire scenarios evaluated in the DSA for a nuclear facility. The use-case was a research facility that contained general fire hazards and relatively insignificant amount of radiological materials in comparison to other similarly categorized DOE nuclear facilities.

The facility is a multistory radiochemical processing laboratory (RPL) that is approximately 64,500 square feet (6000 square meters). The building is non-rated steel-framed and stands 40-ft high (12 m),approximately 269-ft (82 m) long, and 354-ft wide (108 m). The building’s exterior walls are constructed of insulated fluted steel panels, and the basement and foundation walls are concrete. The building's roof is metal decking with customized covering made of limited-combustible or noncombustible materials. The layout of the RPL consists of mostly individual laboratory space, offices, and administrative areas for staff support, mechanical equipment spaces, and shielded facilities. The fire hazards in the RPL generally consist of Class A combustible materials (ordinary hazards such as plastics and paper), hazardous chemicals, reactive metals, and compressed gases. Ignition sources include hot work (open flame, welding, cutting), high temperature heat sources, reactive chemicals and pyrophoric metals. The building is equipped with a fire alarm system that reports to a site fire department and is protected throughout by automatic wet-pipe sprinkler systems.

The hazards analysis in the DSA evaluated explosive hazards and fire hazards. Risk insights from Table C.1 indicate that Scenario F4, although unlikely to occur (i.e., likelihood of occurrence is not expected over the lifetime of the facility), is a major significance to the MOI (public) and moderate significance to CW and FW. On the other hand, Scenario F14, which has an "anticipated" likelihood (event could occur several times over the lifetime of the facility), would be considered low risk significance to the MOI and CW but a moderate risk significance to the FW. Both these scenarios credited the fire suppression system.

Scenario F14 was further evaluated using the performance-based method (fire modeling). The fire model was performed using CFAST. The MEFS for Scenario F14 was determined to be small or medium because fire is not expected to propagate beyond the hot cell area. The MEFS for the hot cell area was determined to potentially result in structural collapse of the portion of the building that involves the hot cells. The hot cell fire is a "small" fire compared to the LFS, which would involve a fire that propagates across the entire RPL. When determining the priority of this FPS using Table 7, this system would be a priority 3 system. This priority level indicates that if this FPS becomes inoperable for any reason (e.g., loss of water flow, damage to piping, isolation of water supply, etc.), unavailability of this FPS would not adversely affect the consequences previously evaluated in the DSA.

5.0 Implementation Impacts and Strategies

Although the use of a RIPB methodology is an accepted approach to meet prescriptive or deterministic requirements, several factors may further influence the decision to implement this approach. Factors such as ease of use, compliance with DOE standards, cost-benefits, and the impact on design safety margins and defense-in-depth were explored further. The following sections discuss the benefits, challenges, and caveats of implementing the proposed RIPB methodology.

5.1 Impacts on Current DOE FPP Policy

This RIPB methodology can be used as an alternate method for facilities to integrate fire safety and nuclear safety. Compliance with DOE's policy and standards is generally prescriptive and deterministic, but there are performance-based methods that allow the use of risk insights. This section evaluates the applicable standards to determine if the use of the RIPB methodology will meet existing requirements. The three standards that would apply to FPSs include DOE-STD-3009, DOE-STD-1066, and DOE-STD-1189.

DOE-STD-3009-2014, Preparation for Non-reactor Nuclear Facility Documented Safety Analysis

Section 3.1.3 of the standard provides the general criteria and guidance for performing hazards evaluations. The hazards evaluation is an assessment of facility hazards, such as fire hazards, to determine if controls are needed to prevent or mitigate the hazardous condition. Unmitigated scenarios can be evaluated using qualitative and/or semi-quantitative techniques to determine if controls (e.g., FPS and features, administrative, and/or programmatic controls) would be needed to prevent or mitigate the fire scenario evaluated in the DSA. The RIPB methodology can be used to support the basis for determining whether a FPS or feature would be required to prevent or mitigate the fire hazard.

DOE-STD-1066-2016, Fire Protection

Section 2.2.5 of the standard allows the use of performance-based designs that are based on the SFPE Engineering Guide to Performance-based Fire Protection, 2nd edition as an alternative to an NFPA code requirement. Performance-based design alternatives are required to be prepared under the direction of a Fire Protection Engineer and approved by the AHJ.

Section 3.1.5 of the standard specifies that the site-wide FPP shall identify any alternative methods approved to the required methods described in this standard and identify where the bases for these alternative methods may be found. As such, the FPP would also identify applicable variances, equivalencies, exemptions, and performance-based designs.

DOE-STD-1189-2016, Integration of Safety in the Design Process

Section 4.1.4 of the standard describes the hierarchy of controls to select to prevent or mitigate releases of hazardous materials and to provide defense in depth, which is in the following preferred order:

1. SSCs are preferred over administrative controls.
2. Passive SSCs are preferred over the active SSCs.

3. Preventive controls are preferred over mitigative controls.
4. Controls closest to the hazard may provide protection to the largest population of potential receptors, including workers and the public.
5. Controls that are effective for multiple hazards can be resource effective.

The use of the RIPB methodology will not affect this hierarchical process for determining controls required to ensure an inherently safer design. The RIPB methodology can assist in determining whether the FPS would be adequate to meet fire protection design requirements.

5.2 Benefits of Implementing RIPB Methodology

Risk-informed and performance-based methods can be used as an alternative approach to demonstrating compliance with prescriptive or deterministic design requirements. Risk insights from a facility's nuclear safety analysis and performance-based information from the fire hazards analysis are the two primary inputs for this methodology. Although there may be several reasons to use the RIPB methodology to help with decision-making, the intended use is to prioritize the relative importance of a facility's FPS and features to aid facilities and FPP managers with decisions involving FPS and features credited in the DSA.

Section 5.2.3 of DOE-STD-1066-2016 allows facilities to develop a process for requesting AHJ approval of fire protection equivalencies and exemptions to fire protection requirements. The RIPB methodology can be used to develop the basis for assessing the acceptability of variances, exemptions, and equivalencies to NFPA codes and standards and fire protection requirements.

5.3 Impact on Safety Margins and Defense-in-Depth in DSA

As discussed earlier in the report, multiple layers of defense-in-depth protection are integrated into the facility design to prevent or mitigate the unintended release of radiological materials into the environment. (DOE 2019). Some examples of defense-in-depth include minimizing the quantity of material at risk, using physical barriers to protect against a radioactive release, or providing multiple means to ensure the safety functions are met, such as controlling processes, providing preventive or mitigating controls for accidents (e.g., fire), or using equipment to respond to accidents to achieve a safe condition.

The standard for developing DSAs (DOE-STD-3009) assumes a likelihood of fire scenarios to be 1. This is consistent with the fire standard when determining the necessary fire protection features to protect SSCs from the fire hazard. Subject matter experts in the fields of nuclear safety, fire protection, criticality, and risk analysis identified credible fire events to evaluate in the DSA and qualitatively determine the likelihood of the occurrence of the fire event. The fire events are generally based on the types of hazards and targets in the facility's fire hazards analysis. The likelihood designation is qualitative and is based on professional judgment. However, probabilistic calculations may also be used to quantify the likelihood based on guidance provided in DOE-STD-1628-2013. Other quantitative calculations could also be used to assign qualitative likelihood estimates, such as calculating the likelihood of a fire scenario based on fire event data reported for DOE nuclear facilities and other similar industrial facilities.

Annual FPP Summary reports are prepared by the Office of Environment Protection and Office of Environment, Safety and Health in accordance with DOE Order 231.1B, *Environment, Safety and Health Reporting* (DOE 2011a). The annual reports summarize fire protection data extracted from the DOE Fire Protection Reporting System for nuclear facilities located in the DOE national laboratories, plants, and offices. The annual reports describe fire events and associated fire loss information for the DOE facilities. Non-fire losses that affected fire protection systems, such as leaks, spills, and inadvertent releases, are also reported. Based on data on annual reports prepared between 1991 and 2019, there were 4014 fire events. Of the 4014 events reported in the last 28 years, 19 involved a fire within the DOE facility. A summary of these fire events is included in Table B.1 in Appendix B and is summarized as follows:

- Seven were identified as electrical-related fires; however, one event involved inadvertent actuation of a fire deluge system on an electrical transformer.
- Five were design and material related; however, one event was not fire-related but resulted in manual activation of a carbon dioxide fire suppression system.
- Two were procedure-related (grinding and kitchen fire).
- Five were due to other causes (propane gas leak, static electricity mixed with flammable vapors, and a tank heater)

The DOE Fire Protection Reporting System database indicates that these fires were either extinguished by fire extinguishers or automatic actuation of the fire suppression system (water or CO_2). These events did not affect material at risk or result in a radiological release. Performance-based data indicate that the few fires that initiated within a facility were either small enough to be suppressed by a handheld extinguisher or an automatic fire suppression system (gas or water).

6.0 Conclusion

The RIPB methodology developed from this research superimposes the effects of a fire in an area based on industry-accepted fire modeling methods and consequence analysis to determine the significance of the FPSs and features to mitigate fire risk. The methodology was based on using an existing semi-quantitative approach to evaluate fire hazards (e.g., fire modeling) and a qualitative approach to determine nuclear safety risks (e.g., low, moderate, or high radiological consequences). The fire scenarios analyzed in a facility's DSA can be re-assessed to determine if the FPS or feature is necessary to prevent or limit the consequence to the public, CW, or FW. The results can then be used to identify which FPSs and features are the most important to risk and which are the least important to support decisions related to their design, installation, operation, and maintenance. The methodology can also be used to differentiate the risk impact of varying the control regimes. For example, the use of the RIPB framework will assist the facility owner in understanding the impact to risk and defense-in-depth when removing one control feature from a suite of controls allocated to a specific scenario.

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Appendix A – Definitions

Graded approach. The process of ensuring that the level of analysis, documentation, and actions used to comply with a requirement in this standard is commensurate with the following:

- Relative importance to safety, safeguards, and security
- Magnitude of any hazards involved
- Life cycle stage of a facility
- Programmatic mission of a facility
- Particular characteristics of a facility
- Relative importance of radiological and non-radiological hazards
- Any other relevant factor (10 C.F.R. § 830.3).

Initiating event. The first event, such as an earthquake or an electric short, in a sequence of events in an accident or hazard scenario.

Mitigative control. Any structure, system, component, or administrative control that serves to mitigate the consequences of a release of radioactive or other hazardous materials in a hazard or accident scenario.

Risk. The quantitative or qualitative expression of possible loss that considers both the likelihood that an event will occur and the consequences of that event.

Safety class structures, systems, and components (SC SSCs). Structures, systems, or components, including portions of process systems, whose preventive or mitigative function is necessary to limit radioactive hazardous material exposure to the public, as determined from safety analyses (10 C.F.R. § 830.3).

Safety significant structures, systems, and components (SS SSCs). Structures, systems, and components that are not designated as safety class SSCs but whose preventive or mitigative function is a major contributor to defense-in-depth and/or worker safety as determined from safety analyses (10 C.F.R. § 830.3).

Safety structures, systems, and components (safety SSCs). Both safety class structures, systems, and components, and safety significant structures, systems, and components (10 C.F.R. § 830.3).

Specific administrative control (SAC). An administrative control that is identified to prevent or mitigate a hazard or accident scenario and has a safety function that would be safety significant or safety class if the function were provided by a structure, system, or component.

Note: DOE-STD-1186-2004, *Specific Administrative Controls*, or successor document, provides additional information about SACs.

Technical safety requirements. The limits, controls, and related actions that establish the specific parameters and requisite actions for the safe operation of a nuclear facility and include, as appropriate, for the work and the hazards identified in the DSA for the facility: safety limits, operating limits, surveillance requirements, administrative and management controls, use and application provisions, and design features, and a bases appendix (10 C.F.R. § 830.3).

Appendix B – Fire Events in DOE Nuclear Facilities

Annual FPP Summary reports are prepared in accordance with DOE Order 231.1B, *Environment, Safety and Health Reporting* (DOE, 2011a). The annual reports summarize fire protection data extracted from the DOE Occurrence Reporting Processing System for nuclear facilities. The annual reports describe fire events and associated fire loss information for DOE facilities. Non-fire losses that affected fire protection systems, such as leaks, spills, and inadvertent releases, are also reported. Based on data on annual reports prepared between 1991 and 2019, there were 4014 fire events. Of the 4014 events reported in the last 28 years, 19 involved a fire within the DOE facility. These fire events are described in Table B.1.

Table B.1 Fire Events in DOE Nuclear Facilities

Site	Year	Actuation Mechanism	Cause of Fire	Location	Description	Type of Loss Summary	Fire Related	Auto Suppression	Water Based System	Injury or Death
Hanford (ORP)	2019	Manual	Other	222-S Laboratory Building	A fire that occurred at 222-S Laboratory Building resulted in fire damage to a gas chromatograph and the associated thermal desorption unit. Hanford Fire Department and 222-S Laboratory personnel responded. The fire self-extinguished.		Yes	No	No	No
Y-12	2019	Manual	Internal Failure (Electrical)	Transformer	An internal failure in a transformer that supplied power to a salt bath resulted in a fire destroying the transformer unit. The Fire Department responded and extinguished the fire using two 20-lb. dry chemical fire extinguishers.	Fire Loss Event	Yes			
ORNL	2019	Automatic and Manual	Design/ Material	Building 5800, Laboratory D105	A “haze” was seen in Building 5800, Laboratory D105, followed by fire alarm and subsequent water flow					

Site	Year	Actuation Mechanism	Cause of Fire	Location	Description	Type of Loss Summary	Fire Related	Auto Suppression	Water Based System	Injury or Death
					alarm notifications. The building was evacuated. Fire Department observed an operating sprinkler, smoke, and visible flames in Laboratory D103A coming from a research air-handling unit on the mezzanine level that supplies conditioned air to an environmental chamber. Using a handline, Firefighters attacked the fire fully and extinguished it within 10 minutes.					
SRS	2019	Manual	Other	Office trailer	SRSFD responded to an office trailer on fire. Units arrived to find fire and smoke. Fire attack was initiated, and fire was extinguished with hose lines. An investigation found the area of origin to be near the HVAC unit.	Water-based suppression	Yes	No	Yes	No
Idaho National Laboratory-NE	2018	Manual (Electrical)	Electrical	TRA-670, Reactor Control Room	On 6/24/18, the Advanced Test Reactor Senior Reactor Operator reported flames coming from a single 120V AC relay in the RC-3 relay cabinet located behind the reactor control room alarm panels. Concurrently, a manual fire alarm was activated in the reactor control room and the operator used a handheld dry chemical fire	NonWater-Based Suppression System Actuations	Yes	No	No	No

Site	Year	Actuation Mechanism	Cause of Fire	Location	Description	Type of Loss Summary	Fire Related	Auto Suppression	Water Based System	Injury or Death
					extinguisher, which failed to extinguish the fire. The reactor control room Halon 1301 fire suppression system was manually activated. The fire was then observed to be extinguished.					
Fermi National Accelerator Laboratory	2017	Manual (Electrical)	Electrical	Switchyard Service Building	Fire originated and was contained in ceiling mounted electric heater, extinguished by Fire Department using CO2 fire extinguisher.	Non-water-Based Suppression System Actuations	Yes	No	No	No
Kansas City Plant	2017	Automatic (Mechanical)	Procedure-related	New Mexico Operations, Craddock A	A filter bank caught fire during trailer grinding operations inside a large vehicle paint booth. The fire watch attempted to extinguish the fire with an ABC extinguisher prior to the fire sprinkler activation. The filters and 2 sprinkler heads were replaced.	Water-Based Suppression System Actuations	Yes	No	No	No
Sandia National Laboratory	2016	Automatic (Mechanical)	Design/ Material related	B983 High Bay (aka Z-Machine)	On 11/30/16 at 5:15 (MT) at Z Machine (i.e., Bldg. 983 Hi-Bay) during a routine post-shot process on the Z Machine involves the Marx generators going through an electrical charge and dump cycle, the system reported an "unbalanced trip" due to a Marx failure. The failure resulted in the upward release of energy and heat, reaching the ceiling of the high bay, which, resulted in	Water-Based Suppression System Actuations	Yes	No	No	No

Site	Year	Actuation Mechanism	Cause of Fire	Location	Description	Type of Loss Summary	Fire Related	Auto Suppression	Water Based System	Injury or Death
					contact with and activation of two sprinklers. Prior to all shots on the Z Machine, the high bay was evacuated and locked and re-entry was not allowed until post-shot activity was complete. Therefore, no personnel were in the high bay at the time of the Marx failure and therefore no injuries. Loss estimates include down time to clean oil tank of water contamination. This event is documented as Occurrence Report SS-SNL-1000-2016-0011.					
Lawrence Livermore National Laboratory	2013	Automatic (Mechanical)	Other	Building 322	On April 20, 2013, at approximately 0140, the LLNL fire department responded to a sprinkler flow alarm from Building 322 (Plating Shop). A fire was discovered in a spent HF + HNO3 "pickling tank" liner. The fire sprinkler system had activated and extinguished most of the fire. Some of the plastic lining material in the tank was still burning. This was extinguished by the fire department with portable extinguishers. Fire damage was limited to the affected tank and an adjacent laminar flow exhaust plenum. The	Water-Based Suppression System Actuations	Yes	No	No	No

Site	Year	Actuation Mechanism	Cause of Fire	Location	Description	Type of Loss Summary	Fire Related	Auto Suppression	Water Based System	Injury or Death
					fire department stated the fire was started by the tank heater					
Savannah River Site	2013	Automatic (Mechanical)	Design/ Material related	684-G	A sprinkler head activated due to wood dust and wood chips igniting on the conveyor outside the Biomass facility. Upon arrival, the site fire department used a 1-inch hose to extinguish the fire inside the conveyor and a small smoldering fire in the wood chip pile below the fire.	Water-Based Suppression System Actuations	Yes	No	No	No
Fermi National Accelerator Laboratory	2012	Automatic (Electrical)	Electrical	Feynman Computing Center	Lighting ballast failure caused Halon 1301 system in computer rm underfloor to discharge.	Non-Water-Based Suppression System Actuations	Yes	No	No	No
Lawrence Berkeley National Laboratory	2011	Automatic (Mechanical)	Design/ Material related	Latimer Hall (University of California property—not DOE property)	While there was damage to the building and surrounding area, the loss for DOE-owned lab-related equipment was relatively minor as most of the damage was caused by water to university equipment and building improvements. The cause of the fire was related to the failure of a defective sealed container in a sprinklered fume hood.	Water-Based Suppression System Actuations	Yes	No	No	No
Nevada-Test Site	2010	Automatic (Mechanical)	Other	NNSS Fire Station #1	NFIRS Incident # 10-524: NNSS Fire Marshal called to advise of an extinguished fire located in the kitchen at	Water-Based Suppressio	Yes	No	No	Yes

Site	Year	Actuation Mechanism	Cause of Fire	Location	Description	Type of Loss Summary	Fire Related	Auto Suppression	Water Based System	Injury or Death
					the new fire station 23-640 in Mercury still under construction. Two of the fire suppression sprinklers activated. The contractors initiated mop-up operations. The fire was started from a propane leak. There was one injured male who was taken to Mercury Medical, suffering minor burns to the back of his hands. He was treated and released from Mercury Medical.	n System Actuations				
Sandia National Laboratory	2010	Automatic (Electrical)	Electrical	858N Room 1702	Reference: SNL/NM-Incident #10-00930. A fire occurred in Building 858N, Room 1702 chase in the control unit for Work Bench #17, which was extinguished by the CO2 fire suppression system prior to discovery of fire. No evidence of a fire or smoke was found by KAFB Fire Department upon arrival. During troubleshooting of the control unit, evidence of an overheated control module and burnt wiring was discovered, which caused the fire.	Non-water-Based Suppression System Actuations	Yes	No	No	No
Fermi National Accelerator Laboratory	2009	Automatic (Electrical)	Electrical	Central Utilities Building	Failure of small Jacuzzi brand #.5 hp Part # 91720279 pump used as a water bath. Plastic on pump	Non-water-Based Suppressio	Yes	No	No	No

Site	Year	Actuation Mechanism	Cause of Fire	Location	Description	Type of Loss Summary	Fire Related	Auto Suppression	Water Based System	Injury or Death
					continued to burn after power was removed.	n System Actuations				
Los Alamos National Laboratory	2008	Unspecified	Other	TA-54	Employee received a first-degree burn while reaching into plastic container to retrieve aerosol container. Flammable vapors ignited by static electricity discharge was likely cause. First aid for burns delivered to left wrist. Employee was wearing leather gloves. NA--LASO-LANL-WASTEMGT-2008-0022	Programmatic Deaths or Injuries	Yes	No	No	No
ORNL-UT/Battelle	2008	Manual (Electrical)	Design/Material related	Building 8300	Events classified as non-fire events where capacitors inside of a modulator fail resulting in release of energy. Typical response to failures includes de-energizing the equipment and manually activating a CO2 system for cooling and equipment salvage. In most cases, there is no fire and no fire is observed during the fire department response to investigate and report. One hundred pounds of CO_2 agent are locally released on the modulator upon receipt of an automatic alarm indicating capacitor failure remotely at the control room. Upon arrival, fire department personnel found debris from	Non-water-Based Suppression System Actuations	Yes	No	No	No

Site	Year	Actuation Mechanism	Cause of Fire	Location	Description	Type of Loss Summary	Fire Related	Auto Suppression	Water Based System	Injury or Death
					the failure burning in the bottom of the modulator. Visible flame was observed. The fire department extinguished the remaining fire with a portable CO2 fire extinguisher.					
Richland Operations Office	2008	Automatic (Mechanical)	Electrical	324 Building	On 12/27/08, a fire deluge system automatically activated on an electrical transformer vault. The transformer is located outside of the 324 Building in the 300 Area of the Hanford site and was providing power to the 324 facility. Firefighters from the Hanford Fire Department responded to the alarm, found no fire, and isolated the deluge system. The 324 facility automatically transferred to alternate power and there were no adverse effects to the facility as a result of the actuation. Inspectors found charring on the transformer buss bars and believe heat from an arc flash caused by a short in the buss bars activated the deluge system.	Water-Based Suppression System Actuations	Yes	No	No	No
Sandia National Laboratory	2008	Automatic (Electrical)	Procedure-related	Building 861 Kitchen	SNL/NM- Incident #08-01766 Responded to building 861 involving a fire in the kitchen. Building evacuated, fire was	Non-water-Based Suppression System Actuations	Yes	No	No	No

Site	Year	Actuation Mechanism	Cause of Fire	Location	Description	Type of Loss Summary	Fire Related	Auto Suppression	Water Based System	Injury or Death
					contained to the kitchen grill, and the fire was extinguished by the fire department activating the wet chemical suppression system.					

Appendix C – Validation of RIPB Methodology

C.1 Radiochemical Processing Laboratory

In accordance with the description in the facility's DSA (PNNL 2017b), the Radiochemistry Processing Laboratory is a 2-story, 64,500 square feet (6000 square meters) steel-framed building that stands 40-ft high (12 m) and approximately 269-ft (82 m) long and 354-ft wide (108 m). The building's exterior walls are constructed of insulated fluted steel panels, and the basement and foundation walls are concrete. The building's roof is metal decking with customized covering that is made of limited-combustible or noncombustible materials (PNNL 2017a). The layout of RPL consists of mostly individual laboratory space, offices, and administrative areas for staff support, mechanical equipment spaces, and a shielded facility.

C.2 Fire Hazards and Fire Protection Systems

The facility's fire hazards analysis (PNNL 2017a) identifies fire hazards in the general laboratory areas consisting of ordinary hazards (e.g., plastics and paper), specific hazards that include chemicals (e.g., flammable, combustible, reactive, and oxidizing), and compressed gases (flammable, nonflammable, and toxic). Ignition sources include open flame equipment (e.g., small torches or maintenance-related welding)), laboratory hot plates, ovens, and furnaces. Chemical inventories, combustible materials, and ignition sources are managed by administrative controls.

C.3 Risk Insights from Documented Safety Analysis

The hazards analysis in the documented safety analysis (DSA) evaluated explosive hazards and fire hazards. Based on the criteria in Table 6, the ranking risk significance of the scenarios F4 and F14 from the RPL DSA are as follows:

GREEN: Hazard scenarios of low significance to the DSA's risk analysis

YELLOW: Hazard scenarios of moderate significance to the DSA's risk analysis

RED: Hazard scenarios of major significance to the DSA's risk analysis

Table C.1. Color-coded Risk Significant Ranking of Example Fire Scenarios

Hazard ID	**Fire Scenario**	**Likelihood**	**MOI**	**CW**	**FW**	**Hazard Controls**
F4	Refueling tanker leak and fuel fire of 3000 gallons	U	M	M	Y	SS SSC: Fire suppression. FP: (Fire alarms). FP: (Life safety).
F14	Flammable liquids and/or solids ignition source present – leads to hot cell fire	A	L	L	Y	SS SSC: Fire suppression. FP: (Fire alarms). FP: (Life safety).

Risk insights indicate that Scenario F4 is a major significance to the maximally exposed off-site individuals (public) and moderate significance to co-located workers and facility workers, although this scenario is determined unlikely (i.e., likelihood of occurrence is not expected over the lifetime of the facility). On the other hand, Scenario F14 that has an “anticipated” likelihood (event could occur several times over the lifetime of the facility) and would be considered low risk significance to maximally exposed off-site individuals and co-located workers but a moderate risk significance to the facility workers. Both of these scenarios credited the fire suppression system .

C.4 Performance-Based Analysis of a Fire Scenario

Scenario F14 was further evaluated using the performance-based method. The fire hazards analysis and fire modeling were used to characterize a fire in the hot cell area (PNNL 2017c). The fire model was performed using the Consolidated Model of Fire and Smoke Transport, and the maximum expected fire scenario for Scenario F14 was determined to be small or medium because fire is not expected to propagate beyond the hot cell area. A qualitative analysis was used to compare the limiting fire scenario, which assumes the fire spreads through the entire building. The maximum expected fire scenario in the hot cell area was determined to potentially result in structural collapse of the portion of the building that involves the hot cells. Compared to the limiting fire scenario (complete building burn), the hot cell fire is much smaller than a fire that would involve the entire RPL building. When determining the priority of this fire protection system (FPS) using Table 7(See Section 4.2.3), the FPS would be a priority 3 system.

The maximum dose consequence from an internal fire event is 49.9 rem TED to CW and 3.2 rem TED to “maximally exposed off-site individuals” are well below the Evaluation Guideline criteria of 25 rem TED for offsite doses. Therefore, none of the fire protection systems were classified SC. However, the DSA credited the FPS protecting the hot cell area for defense-in-depth and designated the FPS as SS.

C.5 Risk-Informed, Performance-Based Conclusion

The FPS and features that are installed to protect the hot cell area are credited for defense-in-depth to mitigate a flammable liquids and solids fire. However, the use of the risk-informed, performance-based methodology indicates that the FPS and features would be a priority 3. This priority level indicates that the unavailability of this FPS relative to other credited FPSs has low impact on nuclear safety. Therefore, we propose that incremental changes in health or lifecycle management of the FPS (such as increasing the maintenance and/or testing intervals) might lead to an incremental increase in the unavailability of the system but is unlikely to increase facility risk or elevate the facility risk to an unacceptable level.

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