Office of Enterprise Assessments
Lessons Learned from Targeted Reviews of Fire Protection Programs at Department of Energy Nuclear Facilities

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Acronyms

AHJ	Authority Having Jurisdiction
AWWA	American Water Works Association
BNA	Baseline Needs Assessment
CFR	Code of Federal Regulations
CRAD	Criteria, Review, and Approach Document
DOE	U.S. Department of Energy
DSA	Documented Safety Analysis
EA	DOE Office of Enterprise Assessments
FHA	Fire Hazard Analysis
FPP	Fire Protection Program
FSS	Fire Suppression System
FY	Fiscal Year
HEPA	High Efficiency Particulate Air
HRR	Heat Release Rate
ITM	Inspection, Testing, and Maintenance
LANL	Los Alamos National Laboratory
LANS	Los Alamos National Security, LLC
MPFL	Maximum Possible Fire Loss
NFPA	National Fire Protection Association
NNSA	National Nuclear Security Administration
ORNL	Oak Ridge National Laboratory
ORPS	Occurrence Reporting and Processing System
PIP	Pre-Incident Plan
psi	Pounds per Square Inch
psig	Pounds per Square Inch Gauge
SAC	Specific Administrative Control
SSC	Structures, Systems and Components
STD	Standard
SWPF	Salt Waste Processing Facility
TSR	Technical Safety Requirement

EXECUTIVE SUMMARY

Unlike commercial nuclear power reactors, U.S. Department of Energy (DOE) nuclear facilities and operations generally do not have enough inherent energy to release or disperse a significant amount of radiological material. Because a fire can provide this energy, fire prevention and fire mitigation are important in reducing the risks that DOE nuclear facilities may pose to workers, the public, and the environment.

To ascertain the effectiveness of DOE's fire prevention and mitigation controls, the DOE's independent Office of Enterprise Assessments (EA) performed a series of targeted reviews of fire protection programs at 12 DOE nuclear facilities, encompassing nine sites, to evaluate the Department's management of the risks associated with fires. DOE Order 420.1C, *Facility Safety*, establishes requirements for fire protection programs for DOE facilities. Proper implementation of these requirements and the corresponding codes and standards (e.g., National Fire Protection Association and state and local building standards) establishes an acceptable level of risk associated with DOE nuclear and other facilities by minimizing the likelihood and consequences of fire-related events.

The fire protection controls for reducing the risk at most of the reviewed nuclear facilities were generally well established and described in safety basis documents, and adequately implemented. Further, the nuclear facility fire protection systems generally were adequately designed, installed, tested and maintained to assure they could perform the required safety functions. The designated fire protection engineers were actively involved in fire protection assessments and oversight. During the targeted reviews, EA identified three best practices that could help other DOE organizations' programs:

- An efficient method for verifying the accuracy and completeness of pre-fire plans and locations of fire protection equipment
- A rating matrix that helps analysts prioritize identified deficiencies based on their severity and probability
- An assessment approach that gives due recognition to the relevance of worker safety and health in fire protection.

However, EA identified several important vulnerabilities that increase the risks associated with fire at some nuclear facilities. The most significant vulnerability at several DOE sites is the impact of age related degradation on the reliability of equipment that supplies water to nuclear facility fire suppression systems. Many DOE nuclear facilities rely on the site's commercial-grade water supply to serve their fire suppression water systems. While upgrades to these systems are planned, under way, or recently completed at some sites, they have not been comprehensive enough to fully address the vulnerabilities (e.g., replacing much of the main system piping but not the aged interface piping to the facilities). At some sites, upgrades have not been initiated or have been deferred. In some cases, testing and maintenance on these systems does not meet the minimum requirements of codes and standards to ensure reliability. Furthermore, the risk associated with current conditions is not always fully understood or managed to provide the level of protection intended by the DOE directive and the codes and standards for nuclear facilities. Reported occurrences at DOE facilities involving failures of fire system equipment underscore the vulnerability of this aging infrastructure.

Additionally, inadequacies in design, installation, maintenance, testing, or technical bases of fire protection systems for some nuclear facilities challenge the facility fire protection systems' ability to perform their intended function of reducing risks by preventing or mitigating fires. Some of these deficient conditions or configurations have not been resolved in a timely manner or properly tracked (via documented impairments), lack adequate compensatory actions, or have not been elevated to senior management's attention through approved exemptions or equivalencies as required.

For most of the reviewed facilities, fire hazard analyses comprehensively describe facility construction and operations, identify the fire hazards, and assess the risk from fire within individual fire areas of the facility. However, EA identified several deficiencies in the development and use of fire hazard analyses across the DOE complex. For example, some fire hazard analyses lack thoroughness in identifying and evaluating the required fire scenarios or do not adequately evaluate the fire water distribution system's capabilities. Safety basis weaknesses, such as a failure to properly analyze a fire hazard and develop an adequate control, have also contributed significantly to occurrences involving fire protection in nuclear facilities across DOE.

Although some DOE site offices provide effective oversight of their contractors' fire protection programs, many had not conducted assessments with sufficient depth to expose the significant vulnerabilities identified during the EA reviews. In these cases, the site offices' assessments were limited in scope, their facility-specific fire protection expertise was inadequate, and/or the assessors were insufficiently independent of the activities being assessed.

Overall, increased management attention and resources are needed throughout the DOE complex to address vulnerabilities in DOE fire protection processes and systems. To support DOE's efforts to improve and ensure the effective implementation of fire protection requirements at DOE nuclear facilities, this report recommends a number of actions for consideration by DOE line management and site contractors. The recommended actions include conducting extent of condition assessments and tracking status of the reliability of the aging water supply infrastructures for fire protection systems to ensure identification, risk-based prioritization, and correction of vulnerabilities in systems and equipment relied upon to prevent and/or mitigate fires at nuclear facilities.

Office of Enterprise Assessments Lessons Learned from Targeted Reviews of Fire Protection at Department of Energy Nuclear Facilities

1.0 INTRODUCTION

The U.S. Department of Energy (DOE) Office of Enterprise Assessments (EA) manages the Department's independent oversight program. The EA assessment program is designed to enhance DOE safety and security programs by providing DOE and contractor managers, Congress, and other stakeholders with an independent assessment of the adequacy of DOE policy and requirements, and the effectiveness of DOE and contractor line management performance in safety and security and other critical functions as directed by the Secretary of Energy. The program is described in and governed by DOE Order 227.1, *Independent Oversight Program,* as well as a comprehensive set of internal protocols and criteria, review, and approach documents (CRADs).

EA's predecessor organization identified fire protection as a targeted assessment area beginning in 2013 in a memorandum to DOE senior line management, *Independent Oversight of Nuclear Safety – Targeted Review Areas starting in FY 2013*, dated November 6, 2012. During 2013 and 2014, independent review teams conducted targeted reviews of the effectiveness of fire protection programs (FPPs), with specific attention to program implementation, at 12 DOE nuclear facilities under the line management responsibility of different DOE operations or field offices, and corresponding DOE Headquarters program offices.

1.1 Report Scope

The EA targeted fire protection reviews included evaluation of key FPP elements within five broad fire protection safety review areas: program documentation and implementation; fire hazard analysis (FHA) and documented safety analysis (DSA) integration; engineered design features; technical safety requirements (TSR) surveillance and testing; and configuration management. The nuclear facilities identified for each review were selected based on the level of fire risk, using such indicators as the safety classification of fire protection systems. The sites and facilities reviewed, along with associated contractors, DOE site offices and DOE Headquarters program offices, are listed in Table 1 below. The term, DOE site office, is used generically in this report to refer also to DOE field office, DOE project office, and DOE operations office.

The FPP reviews focused on the adequacy of institutional FPP programs, their execution by the responsible site contractors, and the oversight provided by the respective DOE site offices. The program reviews at the facility level included verifying the adequacy of procedures, processes, and activities to ensure that the engineering and administrative controls for reducing the risks associated with fire were established and being maintained. The reviews were based on a sampling of data and were not intended to represent a full programmatic review of site FPPs. The review scope included the inspection criteria in CRAD 45-34, Rev. 1, *Fire Protection Inspection, Approach, and Lines of Inquiry*, which is based on the requirements of DOE Order 420.1B, *Facility Safety*, and DOE Order 226.1B, *Implementation of DOE Oversight Policy*. This CRAD was used to determine whether the FPPs, including policies, procedures, and engineered design features, had been implemented to meet DOE's objectives for minimizing the potential for a fire or related event that could cause unacceptable onsite or offsite release of hazardous or radiological material, property loss, or damage of critical process controls. The review took into consideration that a few DOE sites were contractually bound to DOE Order 420.1B, while other sites have implemented the new DOE Order 420.1C.

Table 1. Nuclear Facilities, DOE Program Offices, and DOE Site Offices in the Review

Review Site	Facilities Reviewed	Operating Contractor	DOE Headquarters Program Office	DOE Site Office
Pacific Northwest National Laboratory	Radiochemical Processing Laboratory	Battelle Memorial Institute (BMI)	Office of Science (SC)	Pacific Northwest Site Office
Los Alamos National Laboratory (LANL)	Technical Area 55 Plutonium Facility	Los Alamos National Security, LLC (LANS)	National Nuclear Security Administration (NNSA)	Los Alamos Field Office
Lawrence Livermore National Laboratory	B332 and High Explosive Application Facility	Lawrence Livermore National Security, LLC	NNSA	Livermore Field Office
Oak Ridge National Laboratory (ORNL)	Transuranic Waste Processing Center	Wastern Advantage, Inc.	Office of Environmental Management (EM)	Oak Ridge Environmental Management Site Office
Savannah River Site (SRS)	Salt Waste Processing Facility (SWPF)	Parsons Corporation	EM	SWPF Project Office of the Savannah River Operations Office
LANL	Weapons Engineering Tritium Facility	LANS	NNSA	Los Alamos Field Office
Idaho National Laboratory	Irradiated Materials Characterization Laboratory	Battelle Energy Alliance, LLC	Office of Nuclear Energy (NE)	Idaho Operations Office
Paducah Site	Depleted Uranium Hexafluoride Conversion Facility	Babcock & Wilcox Conversion Services	EM	Paducah Portsmouth Project Office
Idaho Site	Advanced Mixed Waste Treatment Project	Idaho Treatment Group, LLC	EM	Idaho Operations Office
ORNL	Irradiated Fuels Examination Laboratory Building 3525	UT-Battelle, LLC	SC	Oak Ridge Field Office
Y-12 National Security Complex	Buildings 9212 and 9204-2E	Consolidated Nuclear Security, LLC	NNSA	NNSA Production Office (NPO)
Pantex Plant	Buildings 12-84 (bay) and 12-98 (cell)	Consolidated Nuclear Security, LLC	NNSA	NPO

EA evaluated the implementation of FPPs for facilities by reviewing documents, such as the DOE contractor's FPP policies and procedures, the safety basis documents (DSA and TSRs), the FHA, and other documents that support and establish the performance criteria of the fire protection structures, systems, and components (SSCs). EA reviewed facility fire protection systems to confirm that they were appropriate for the facility fire scenarios identified in the FHA and the safety basis. EA conducted walkdowns of the relevant facility systems and structures and interviewed key personnel responsible for implementing the FPP, including fire protection engineers, safety basis engineers, and personnel from facility operations, site utilities maintenance, and fire departments. For nuclear facilities under construction, EA reviewed various aspects of the FPP, including installation of penetration seals; evaluation of the need to install fire protection material on heating, ventilation, and air conditioning ducts and structural steel; the adequacy of the FPP for construction operations; and implementation of any compensatory measures before commissioning of the fire systems.

In addition, EA reviewed reports of fire protection related occurrences at DOE sites during the last five years, which are in the DOE Occurrence Reporting and Processing System (ORPS) database. These ORPS reports provide a perspective for gauging the prevalence of the conditions and potential issues that EA identified during the targeted reviews.

1.2 Requirements and Guidance

The DOE requires that an FPP provide a level of fire protection consistent with the best protected class of industrial risks ("Highly Protected Risk" or "Improved Risk"). The hierarchy of requirements begins with the Federal requirement, 10 CFR 851, *Worker Safety and Health Program*, and cascades down to the specific DOE orders and standards: DOE Order 420.1B (or C, as applicable) and DOE Standard (STD)-1066-2012, *Fire Protection*.

DOE Order 420.1B (or C), in turn, requires that DOE contractor's fire protection and emergency services programs meet or exceed the applicable codes and standards of the National Fire Protection Association (NFPA). Sites are also required to meet the provisions of subsequent editions of the codes and standards to the extent that they are explicitly applicable to existing facilities or when an identified deficiency could pose an immediate risk to life safety or health. These standards are more specific in addressing design, installation, and inspection, testing, and maintenance (ITM) requirements for fire-related SSCs. For example, the ITM requirements are provided in NFPA-25, *Standard for the Inspection, Testing, and Maintenance of Water-Based Fire Protection Systems*; the FPP facility requirements are provided in NFPA-801, *Standard for Fire Protection for Facilities Handling Radioactive Materials*, and the requirements applicable to fire suppression systems (FSS) are provided in NFPA-13, *Standard for Installation of Sprinkler Systems.* Site contractors generally maintain fire water supply systems in accordance with NFPA codes and standards and/or American Water Works Association (AWWA) standards.

1.3 Report Organization

Section 2 provides a consolidated assessment based on the results from all the individual FPP reviews. The discussion is delineated as follows:

- Program documentation and implementation, including the processing of exemptions and equivalencies
- Integration of FHA and safety basis
- Engineered design features, including their technical bases and the reliability of infrastructure water supplies

- TSR surveillance and testing of safety systems
- DOE site office oversight of the fire protection functional area.

EA also addressed configuration management as defined and outlined in the CRAD referenced above. The issues that EA identified in this area, such as inconsistencies among system requirements, system performance criteria, system documentation, and physical configuration of systems, were related to concerns in other areas of the reviews and thus are discussed in connection with those concerns in Section 2. Section 3 of this report identifies a few best practices that EA noted during the targeted reviews. Appendix A provides recommended actions for consideration as potential improvements at all sites. Appendix B lists the EA participants in the targeted review.

2.0 OVERALL ASSESSMENT

2.1 Program Documentation and Implementation

Inspection Criteria: *A documented fire safety program exists as required by DOE Order 420.1B/C requirements and applicable standards, and is described in sufficient detail. The program includes fire-fighting operations, updated baseline needs assessment (BNA) of the fire protection emergency response organization, and processes to prioritize and monitor the assessment results until final resolution. The program further includes requirements for the use and storage of combustible, flammable, radioactive and hazardous materials that minimize the risk from fire, fire protection system impairments, smoking and hot work, safety operation of process equipment, and prevention measures to decrease the risk of fire. Formal assessments shall be completed and documented based on the monetary value of the facilities and the respective frequency. When applicable, any exemptions, equivalencies, and variances are documented with appropriate compensatory actions plans. (DOE Order 420.1B/C, DOE-STD-1066, and NFPA-801)*

Results. Most FPP description documents and associated procedures at the reviewed facilities were in accordance with DOE governing requirements. Most of the fire protection objectives of DOE Order 420.1B/C were met. Any deviations from established fire protection design criteria and recognized codes and standards were generally supported by approved equivalencies or exemptions. Further, most of the designated fire protection engineers were actively involved in completing or overseeing the necessary fire protection assessments, and were integrated into facility review and approval. During walkdowns with EA, facility managers typically demonstrated a high level of knowledge regarding the inherent fire risks and how they managed the tracking and correction of identified deficiencies.

However, EA identified several significant inadequacies and weaknesses in FPP description, FPP procedures, and implementation of the procedures at the reviewed facilities. The safety controls for reducing the risk associated with fire were established and implemented with varying levels of effectiveness. The numerous identified issues included inadequacies in documentation, training, and in the implementation of combustible controls, fire impairments for passive systems, equivalencies and exemptions, and pre-fire plans.

- **Program Description.** The FPP and associated policies and procedures at some facilities had significant inadequacies in the description of organizational and individual responsibilities. For example, at a few facilities, the descriptions did not address the specific responsibilities of the fire protection engineer or the system engineer, including such functions as coordination, auditing, and oversight responsibilities. At one facility, the fire protection program plan did not clearly specify the department responsible for surveillance and ITM of the fire water infrastructure. Consequently, the interface of the organization managing fire water supply with the fire protection engineer was not adequately established, and the technical requirements for performing maintenance on the fire water system had not been communicated or fully implemented. EA found that most of the issues in establishing clear roles and responsibilities were in areas with shared program responsibilities, such as coordination of FHA and DSA technical content between two organizational units, maintenance of the site's infrastructure water supply systems, and the interface between the DOE and contractor authority having jurisdiction (AHJ).

- **Inadequate Procedures.** EA observed some significant inadequacies in procedures, or the lack of appropriate fire protection provisions in the procedures. At one facility nearing completion of construction, the required procedure to identify overall project fire protection requirements was limited to new construction only. The procedure also omitted specific requirements for the buildings under construction, including which functional fire hydrants and standpipes the fire department could use in case of a fire. Procedural requirements that govern ignition source control were also deficient at some facilities. For example, at one facility, the controls for fuel receipt did not adequately and consistently define standoff distances, bonding and grounding, and other appropriate ignition source controls for dispensing fuel to motor vehicles. At another facility, the procedures that were intended to address emergency lighting systems did not include the annual functional test required by NFPA-101, *Life Safety Code*. EA also reviewed response procedures related to incidents involving identified hazards. At one facility, the response procedure for an identified postulated explosion event did not consider the results of the technical analysis detailing the potential effects of the blast or provide for training site personnel on how to respond.

- **Inadequate Implementation of Procedures.** EA identified inadequate implementation of fire protection procedures in key programmatic areas. For example:

  - **Combustible Controls.** In general, facilities struggled to communicate clear expectations on the allowed limits for transient combustibles and the need to develop effective methods, such as quantifying combustibles for buildings with TSR credited administrative controls. One facility did not implement the credited specific administrative control (SAC) for managing combustible controls, and allowed the storage of five 55-gallon drums of oil compromising the SAC.

  - **Impairments.** Contrary to some facilities' procedures for managing fire protection impairments, contractors did not track passive fire protection system deficiencies, such as fire barriers and fire dampers, and did not document the deficiencies as system impairments. In a few cases, they did not implement compensatory measures commensurate with the risk posed, or they placed insufficient priority on evaluation and implementation of the necessary compensatory measures and subsequent repair of the impairments.

  - **Equivalencies and Exemptions.** In some facilities where NFPA codes and standards required complete sprinkler protection, EA identified several areas that were unprotected and lacked an approved equivalency or exemption. One facility did not request an exemption from the requirements of the DOE order even though the maximum possible fire loss (MPFL) exceeded the limit ($150 million). The facility's FHA stated that installing a three-hour fire barrier was very expensive and would not significantly reduce the real risk, but the facility did not address the occupancy classification or the need to satisfy fire separation requirements that limit the MPFL. At two facilities, equivalencies had not been documented for areas lacking automatic sprinkler protection; both facilities implemented administrative controls and identified the deficiency but failed to initiate the appropriate equivalency to assure clarity in management approval of non-standard approaches. EA also found variability in the effectiveness of contractors' and DOE site offices' processes for approving equivalencies. In some cases, the DOE offices and their contractors did not formalize or adequately document the process to ensure that the level of non-compliance and the risk associated with fire was understood or would justify an equivalency.

- **Baseline Needs Assessment.** EA identified issues related to implementation of the DOE order requirements for the BNA. In one case, contrary to the facility's procedure, the conditions described in the BNA as not meeting the requirements were not processed as equivalencies, and the documented compensatory measures were not evaluated for effectiveness. The conclusions of the BNA, including, in some cases, non-compliances associated with response times and emergency medical service capabilities, were also not incorporated into the facility FHA. In addition, several BNAs had not been updated every three years as required by DOE Order 420.1B/C.

- **Training.** In a facility with manually operated FSSs, operator training was deficient. Also, the training on maintenance of systems that protected unoccupied areas, such as hot cells and gloveboxes, was deficient. At another facility, fire department personnel responsible for maintaining the site fire systems did not have the required training to perform corrective maintenance and were not aware of the applicable NFPA requirements.

- **Evaluation of Issues.** EA found deficiencies in the process for evaluating fire protection issues. Several facilities did not evaluate critical risk factors with a significant impact on event frequency and consequence, such as life safety, unacceptable program interruption, and potential damage to process control and safety systems, as part of prioritizing the more serious deficiencies for prompt corrective actions and appropriate compensatory measures. The DOE order requires the FPP to have such a process and to monitor the status of fire protection assessment findings, recommendations, and corrective actions until final resolution.

- **Pre-fire Plan Weaknesses.** EA identified several weaknesses in the pre-fire plans at some facilities. In most cases, these plans did not fully meet the facility's own requirements (e.g. its procedure for pre-fire plan development). In these cases, pre-fire plans did not reflect the physical conditions in the facility or did not contain all the specified information for supporting the safe and efficient response of the facility's fire department. For example, one facility's pre-incident plan lacked information on fire walls, controls for fire water runoff, and locations of hazardous materials including compressed gas storage. At another facility, the pre-fire plan omitted the locations of fire walls, fire alarm panels, fire detection systems, and locations of flammable liquid storage cabinets. At this facility, a recent emergency highlighted the importance of pre-fire plan information in providing a safe and efficient response; the fire department did not look at the fire alarm control panel that would have identified the specific device and location of the alarm inside the facility and thus would have reduced both the overall response time and the risk to the first responders. Also, at one facility nearing completion of construction, the pre-fire plan did not show the current configuration of the fire hydrants and fire department connections to ensure a prompt and effective response by the site's emergency services.

Overall, although most FPPs were adequately documented, EA identified numerous programmatic weaknesses with respect to implementation. In some cases, key personnel responsibilities were not established, particularly when they were shared among different organizations. In other cases, the procedures and their implementation for key programs, such as managing fire impairments for passive systems, developing pre-fire plans, documenting and processing equivalencies, and controlling combustibles, were inadequate to fully address the risk of fire. EA identified these areas of program deficiencies at several DOE sites, and they represent a significant complex-wide concern. **See Appendix A, Recommended Actions.**

2.2 FHA and DSA Integration

Inspection Criteria. *A comprehensive and accurate FHA has been prepared and maintained for each nuclear facility. Fire and related safety hazards have been identified and evaluated in conjunction with the documented safety analysis. FHA conclusions are incorporated into the nuclear facility safety authorization basis documents, and demonstrate the adequacy of controls provided to eliminate, limit, or mitigate identified fire hazards. The safety basis documents are fully consistent with the FHA. The process for maintaining the controls is defined. (DOE Order 420.1B/C and DOE-STD-1066)*

Results. For most of the reviewed facilities, FHAs comprehensively and qualitatively described facility operations, identified the fire hazards, assessed the risk from fire within individual fire areas in the facility, concisely described building construction, and identified fire rated area separations. However, EA identified several deficiencies in the development and use of FHAs across the complex, as further described in the following paragraphs.

FHA Programmatic Issues. EA identified some inconsistencies and omissions in FHA documents and processes. Some facility FHAs did not identify the applicable standards or certain key supporting documents and information, specifically the list of applicable codes of record, consistent with the recommendations of NFPA-801 and DOE-STD-1066. In some instances, they did not document codes of record dates to ensure facility-specific compliance, to facilitate design modifications to facility SSCs, and to ensure that ITM was properly performed. Further, in some cases, the FHA did not provide references to documents that formed the basis for statements in the FHA, such as the design documents describing safety SSCs and their performance. One facility FHA did not incorporate the BNA conclusions, including non-compliances associated with response times and emergency medical service capabilities, in accordance with FPP requirements.

In some cases, the heat release rate (HRR) analyses of various fire scenarios were either not performed or not referenced in the facility FHA. In several cases, the methodology and empirical estimates were presented in the FHA without any formal analysis specific to the facility hazard being evaluated, taking into account the unique facility structural characteristics and nearby building materials.

The MPFL estimation was deficient in several FHAs. One facility did not include the basis for the valuation of certain processing and support equipment areas, the monetary threshold of which would dictate the need for redundant fire protection systems. In a few other cases, the MPFL did not consider the cost of lost time (although it considered mission interruption costs), costs for reestablishing operations, or environmental cleanup costs. Additional examples of significant deficiencies in MPFL estimation arising out of inadequate integration with the facility DSA include:

- The FHA at one facility had several omissions and weaknesses. It did not provide or refer to HRR analyses for a fire related to a fuel spill accident scenario; did not adequately evaluate the fire water supply distribution system, describing the known deficiencies that affect system reliability; and did not identify the means for handling potentially contaminated fire water runoff as required by NFPA-801. It was also deficient in estimating the MPFL.

- Another facility FHA did not describe some important features of the water supply system (e.g., operational interface with water supply systems of other facilities) and had not evaluated the water supply capacity relative to potential demands. It also did not address the system’s ability to meet the two-hour fire flow demand mentioned in the DSA. The sprinkler flow and pressure demands specified in the FHA also differed from those documented in the system design description, and the pertinent analytical bases were unavailable. Moreover, the FHA did not document all known fire protection deficiencies and did not adequately describe the fire protection related deficiencies noted in existing, approved equivalencies.

- One FHA did not classify the facility in accordance with either the International Building Code or NFPA-101, *Life Safety Code*, and did not identify requirements, including fire separation, limitations on flammable liquids, means of egress, and fire extinguishing systems unique to the applicable building classification.

Postulated Accidents. EA identified some significant omissions, inconsistencies, and deficiencies in the integration of accidents analyzed in the FHA with the facility's safety basis. For example:

- At one facility, contrary to the guidance in the DOE implementation guide for DOE Order 420.1, the damage potential associated with the design basis fire scenario defined and discussed in the facility's DSA was not considered in the determination of the MPFL. In this case, the FHA analysis postulated the design basis fire in a different room from the DSA and assumed a different combustible loading. A similar issue at another facility was that the FHA documented the MPFL based on a fire event in the hot cell, while the DSA's design basis accident analysis included a glovebox fire as part of this event; the damage potential of the glovebox fire was not determined or considered in the FHA.

- At one facility, the FHA considered fires associated with a transport vehicle in the facility's operating gallery and the shipping bay and assumed a specific quantity of gasoline or diesel fuel that could be involved. However, neither the facility's DSA nor its combustible loading program procedure specifically addressed any limits on the quantity of fuel discussed in the FHA. Further, there were no formal safety basis HRR analyses for the fuel spill accident scenarios.

- At another facility nearing construction completion, the FHA did not identify or evaluate the fire-related safety controls identified in the preliminary safety basis documents, including ignition source, flammability, and combustibility controls.

- In a few instances, the FHA and/or DSA had other types of omissions and inconsistencies. For example, at one facility, the documents did not accurately reflect the facility's insufficient capability to contain contaminated fire water runoff from the high efficiency particulate air (HEPA) filter deluge system, and there was no agreement on the worst-case fire water runoff scenario. Another facility's FHA documented inadequate containment of contaminated fire water runoff but provided no approved exemption or equivalency for this condition. At yet another facility, the support systems relied upon for the safety significant FSS to perform its safety function, including electrical power for heat tracing and heaters, were not discussed in either the FHA or the facility DSA. Likewise, these support systems were not classified for safety, commensurate with the safety system being supported.

Overall, although most of the FHAs that EA reviewed had the required attributes, EA identified several instances of deficiencies with the FHA and the facility safety basis documents. In particular, certain specific design basis or other postulated accident scenarios that were evaluated in the DSA were not considered in the FHA, or vice versa. Additionally, most FHAs lacked sufficient rigor and completeness in the determination of the MPFL and in some cases only qualitatively referred to HRR analyses related to the facility-specific fire hazards. The importance of proper coordination and integration between FHAs and safety bases is highlighted by the relatively large fraction (roughly half) of fire protection related occurrences that involve safety basis considerations. EA's review of occurrences at DOE sites indicates that these typically involve a failure to recognize or properly analyze a fire hazard (and thus, for example, controls were not developed); inadequate safety basis level controls (including potential inadequacies in safety analyses); failure to properly flow down safety requirements into work documents and practices;

and failure to follow established controls and requirements at the working level. **See Appendix A, Recommended Actions.**

2.3 Engineering Design Features

Inspection Criteria. *The safety authorization basis is consistent with the fire hazards analysis and demonstrates the adequacy of controls provided by the fire protection systems to eliminate, limit, or mitigate identified hazards; specifies the technical, functional, and performance requirements for the systems; and translates these into design calculations and procedures, as appropriate. Items and processes are designed using sound engineering and scientific principles, and appropriate codes and standards; and the items are designed, installed, tested, and maintained to assure they can satisfy the credited safety functions under the appropriately analyzed accident conditions. Further, a configuration management program, including formal change control and work control processes, is used to integrate and maintain consistency among system requirements and performance criteria, system documentation, and physical configuration of the systems within the scope of the fire protection program. (DOE Order 420.1B/C, DOE-STD-1066, NFPA-13, and NFPA-25)*

Results. The safety basis documents generally identified and adequately described the safety functional requirements of the fire protection systems and the essential supporting systems. The facility risks associated with fire were well defined, and appropriate controls were identified. These risks and controls were adequately documented in the technical baseline documents, including the FHA. The FSS safety design and functional requirements, performance criteria, and appropriate consensus standards were described and referenced. With some exceptions, the configuration management at various facilities generally provided adequate processes to establish, document, and control the facility design requirements and the facility baseline.

Further, in several cases, the reviewed fire protection systems were adequately designed, installed, tested, and maintained to ensure that they could perform the required safety functions. For the most part, the FSSs at the reviewed facilities were in conformance with NFPA-13 and had the appropriate discharge spray density, sufficient water supply, and appropriate sprinkler spatial layout to fulfill the safety function. ITM of the systems was in accordance with NFPA-25 and ensured the availability and reliability of the FSSs. Surveillances of the fire water isolation valves generally verified that there was an open and unobstructed water flow path to the sprinkler system. The sprinkler system design accounted for the pressure drop in the piping, fittings, and sprinklers.

However, at most of the reviewed sites, EA also identified significant concerns and deficiencies with respect to fire protection safety controls, which may be broadly categorized as follows:

- Inadequacies in safety classification of systems required to ensure timely and adequate response of the fire protection system
- Weaknesses in technical bases for the FSS
- Inadequacies in the design and testing of fire suppression and water supply systems, including issues related to performance degradation, design, and age-degradation
- Other weaknesses in implementation of fire protection design requirements
- Inadequacies in controlled documentation.

These concerns and deficiencies are discussed in detail below, with examples.

Safety Classification. At one facility, operator response to a seismic event (for manual isolation of non-seismically qualified buildings) was not controlled as an SAC, even though these actions could influence the performance of the facility's FSS safety function (e.g., timely identification of locations, timeliness of response, and periodic drills to confirm timeliness of response). In the case of a seismically induced fire, the water flow could be diverted from the facility due to an open flow path to non-seismically qualified buildings and an inherent pipe failure of the non-seismic piping, and there would be insufficient water in the fire water storage tank.

At three facilities, EA found inadequate safety classification of electric power to provide freeze protection for a safety fire protection system. At one of these facilities, the electric heater in the hot box enclosure, which was required for freeze protection of a 4-inch backflow preventer and piping that supplied the safety significant FSS, was non-safety, even though it was required to ensure that the safety FSS could perform its designated function during freeze conditions. The standards (DOE-STD-3009, DOE-STD-1189, and DOE-STD-1021) and industry best practice provide that any SSC needed to ensure the availability of safety SSCs shall be likewise classified for safety. The inadequate safety classification of the freeze protection heater and the consequent absence of an appropriate TSR cannot ensure a surveillance frequency sufficient to protect system operation. At the other facilities, the safety sprinkler piping in two riser rooms had electric heaters for freeze protection. However, the electric heat tracing and the riser room electric heaters were provided with non-safety electric power, and there was no analysis or other technical basis for periodic temperature verification, such as through an appropriately defined and implemented SAC, to protect the operation of the safety system.

Technical Bases for the FSS. At several facilities, EA identified some significant issues, inaccuracies, and other deficiencies in design basis hydraulic calculations, including incorrect methodology, errors, and non-conservative assumptions, which compromised the performance of FSS as required by their safety bases.

At one facility, several technical analyses relied on to establish and confirm system TSR performance criteria contained inaccuracies, were not conservative, and did not meet the DOE expectations for a safety class system. The problems included: (a) an as-built piping configuration that consisted of a fire riser size reduction, which was not accounted for in hydraulic calculation, and for which no unreviewed safety question determination was performed; (b) incorrect elevation of water source; (c) incorrect flow rate for a riser; and (d) inadequate analytical basis for the adequacy of combustion and dilution air intake louvers in fire water pump houses (an NFPA-54 requirement).

Similarly, at another facility, EA identified anomalies and non-conservative inputs in the technical basis calculation intended to demonstrate the required hydraulic performance capabilities of the safety class wet pipe sprinkler systems. The errors included incorrect friction loss coefficients, incorrect pipe material and internal diameter, missing inline components in models, and pipe run length variations. At the same facility, two other calculations related to determining the fire protection water demand (water pressure at the riser) did not consider the frictional and dynamic losses through the water supply system. Further, significant design information important to establishing the system design basis and configuration control was missing or had not been identified.

At two facilities, the FSS engineered design features did not provide sufficient water pressure margin at the most remote sprinkler head in conformance to DOE-STD-1066. Reduction in margin was a potential critical concern because of other facility supply diversions. Moreover, inadequate supply pressure could compromise the ability to achieve the required performance of the sprinkler system.

At one facility, the calculation that supported the approval of an equivalency request for a non-compliant water delivery time did not match the existing field performance conditions of the facility's FSS. Since the approval of the equivalency, the most recent dry pipe valve testing showed that water flow delivery times for five risers had degraded and exceeded the maximum approved value by significant margins, nearly doubling for three of the risers. Thus, the inputs to the basis-for-acceptance calculation supporting the equivalency were non-conservative, and neither the documentation nor the FHA had been revised.

At a facility nearing the completion of construction, the design of a safety deluge sprinkler system protecting process equipment critical to the mission, as well as the supporting design analysis for its operation, did not consider the most demanding hydraulic scenario.

Other technical basis weaknesses potentially affecting fire suppression at some of the reviewed facilities included incomplete design analyses for a safety sprinkler system; lack of an analysis to demonstrate the full range of fire system flow and pressure demands (e.g., with the test pump operating) for a design basis accident; and unverifiable hydrant flow test data used in a bounding design basis calculation.

Design and Testing of Fire Suppression and Water Supply Systems. In reviewing the safety FSS and the infrastructure water supply systems, EA identified many significant issues related to the performance capability of the systems, the adequacy of their designs, the physical condition of water supply systems, and the quality of associated controlled documentation. A subset of these issues was specifically related to the TSR related performance testing of safety FSS, as discussed in Section 2.4. The rest are discussed below.

- **Performance Degradation.** EA found several examples of conditions that could degrade the performance or reliability of the water supply systems. One facility did not have a looped underground water main for the fire water supply, instead using a single 10-inch supply line from the area's remote storage tanks. This arrangement was contrary to DOE-STD-1066, which specifies a looped grid type water distribution system providing two-way flow with sectional valves arranged to provide alternate water flow paths to any point in the system, to fulfill the requirement of a reliable water supply.

  Another facility lacked the required water supply system to support emergency services response during the construction phase of the project. The underground fire water supply system was not adequately installed and integrated with the standpipe system in accordance with NFPA-241, potentially compromising the site fire department's ability to protect the facility's occupants and physical assets in the event of a fire.

  At some facilities, the ITM of water supply components was not in accordance with NFPA standards. For example, at one facility, certain underground sectional control valves and post indicating valves were not being tested such that each sectional control valve is operated annually through its full range and returned to its normal position, as required by NFPA-25. Without this testing, there is insufficient assurance that the normally open sectional control valves could be closed if necessary to facilitate isolation of water branch mains for routine or emergency maintenance and to verify effective system control to service areas.

  At another facility, auxiliary valves for fire hydrants were not being inspected or tested, and the frequency of flushing hydrants had been reduced. The reduction of ITM was not always coordinated and sufficiently evaluated from a nuclear facility perspective to ensure that a reliable supply of water for safety related fire protection can be maintained. Another example at a different facility was omission of the five-year internal inspection of piping for obstructions required by NFPA-25 for a safety FSS.

  At a facility under construction, the performance of a pump required for water supply to the area had degraded, but the declaration of impairment was inordinately delayed. Also at this facility, a flow test supporting the hydraulic analysis for a FSS in an operational warehouse had not been performed within the five-year time interval specified in NFPA-25.

- **Design Inadequacies.** EA also identified instances where the FSS and/or supporting equipment were not adequately designed or installed, so the system might not be fully reliable in performing its safety functions. For example:

    - At one facility, the FSS could be damaged in a design basis event, and therefore potentially unavailable, because its design and installation did not account for potential collapse of the ceiling hoist system and the consequent damage to the FSS during a seismic event.

    - At another facility, several FSS seismic vulnerabilities, as defined by NFPA-13, were identified. These included inadequate clearances in pipe penetrations for several risers; lack of flexible couplings at floor penetrations or at upgraded risers; and inadequate (non-seismic) support for sprinkler piping in the basement.

    - At one facility, a design deficiency led to some sections of water supply piping being undersized, resulting in high velocities and consequently higher pressure losses.

    - A bridge crane located at the ceiling level represented a potential obstruction to the existing overhead sprinkler system. This installation had not been formally evaluated for sprinkler obstructions.

- **Age-Degradation of Water Supply Systems.** EA identified potentially significant degraded conditions and configuration of fire water supplies at some of the facilities, as further discussed below. The numerous fire protection related occurrences of underground infrastructure water supply events and issues throughout the DOE complex corroborate the concern about the reliability of these systems in supporting credited safety fire protection systems.

    - The review of a legacy water supply system at a site serving multiple nuclear facilities determined that the system did not meet the requirement for an adequate and reliable water supply for fire suppression. The system was aged and constructed largely of cast iron piping, and several major breaks had occurred; however, the site had no documented plans to replace the aged piping with piping material that is less susceptible to pipe breaks due to water pressure surges and seasonal ground movement. The primary fire water diesel pump had been derated from its design output to approximately 20% below the manufacturer's pump performance curve based on its performance history, with no compensatory measures or system impairment in place. Additionally, a fire water tank associated with the same water supply system was impaired due to unacceptable interior corrosion and had been taken out of service. At two other sites, also with multiple nuclear facilities, although much of the legacy cast-iron piping in the main water supply systems had been replaced, the vulnerabilities due to aged interface piping to the several facilities served by the system still remain. These sites have already experienced significant pipe breaks or leaks in the recent past. The cast-iron pipe excavated from a break in the lateral pipe feeding to a facility at one of these sites showed severe signs of external corrosion and pitting.

    - At another facility, the water supply system was not in a condition to reliably provide an adequate water supply to the facility's fire protection system. The underground piping of the supply system was aged cast iron piping, and the general material condition was poor. The facility's limited replacements and repairs of the aged underground piping were largely reactive after discovering problems, rather than proactive based on planned inspections. The ITM for pumps and valves was not routinely performed to the requirements of NFPA or AWWA standards; rather it was ad hoc, based on vendor recommendations and as deemed necessary by operations staff.

- o At a different facility, issues involving the condition of the underground fire water distribution system were not sufficiently analyzed to determine whether they compromised the requirement for an adequate and reliable water supply system. The facility's last annual fire protection self-assessment report documented the issues relating to aging components; however, correcting the issues would necessitate replacing certain valves and portions of the underground piping network. The report concluded, without any supporting technical evaluations, that the replacement project would be too costly and that there was insufficient justification to pursue this project.

Other Aspects of Fire Protection Design Implementation. EA identified various design or installation related deficiencies not directly related to fire water supply in the implementation of fire protection requirements at the reviewed facilities. For example:

- Inconsistencies between the inspection and test program for passive fire barrier penetrations and the applicable engineering specifications and manufacturer requirements provided in the construction work package.

- Inadequate curbing or controlled drainage holdup to contain potentially contaminated water discharged from the suppression system to the environment (per DOE Order 420.1B/C, DOE-STD-1066, and NFPA-801, Section 5.10), possibly allowing exposure of emergency responders and emergency equipment to contaminated water. This concern was identified at several facilities, where the fire water containment systems did not have sufficient volume to prevent a release of significant quantities of contaminated fire-fighting water into the environment in the event of a large fire.

- Fire alarm notification devices that were not designed for use in radiation areas.

Inadequacies in Controlled Documentation. At one facility, the various inconsistencies, omissions, and outdated information in the facility's configuration management plan were such that the integrity of the safety basis and safety controls could be compromised. These issues included incorrect cross-references, incomplete guidance on changes to technical baseline drawings, and obsolete or missing references. Moreover, considerable original design basis information for the facility, including that for the FSS, was unavailable.

EA also identified some implementation problems in change control, work control, and document control that may reflect basic weaknesses in configuration control. For example, various source documents at a facility provided different values for the same input parameter (vault volume) for a calculation supporting the safety basis. Also, the allowable combustible loading specified in a work package did not meet the limiting condition for operation in the TSR. Further, the facility had no formal process for tracking interrelationships between documents to ensure that when technical basis documents are changed, the impacts of those changes on both predecessor and successor documents are properly assessed and those documents modified as necessary. Thus, for example, there was no review to verify that the revisions of a particular hydraulic calculation were taken into account in the technical basis document supporting a TSR.

EA observed several instances of discrepant information, including inconsistencies among safety basis and supporting technical documents, which indicated weaknesses in configuration control. For example:

- Differing information on pipe sizing, reservoir volumes, and the location and numbers of pipes and valves on various system drawings used by internal services and organizations that depend on the water supply system.

- Disparity between the deluge water flow and pressure determined in the hydraulic analysis and the water flow indicated on the HEPA filter deluge system drawing.

- Failure to identify safety-significant components or to correctly describe their safety functions in engineering design documents, including the drawings and system descriptions.

Overall, several of the reviewed fire protection systems were adequately designed, installed, tested and maintained, and in compliance with applicable requirements and standards, to ensure that they can perform the required safety functions. However, at several sites, EA identified significant concerns that limit confidence in certain fire suppression water supply systems' reliability in supporting safety functions, or that compromised their reliability and performance. These concerns include aged, vulnerable infrastructure water supplies, often because of inadequate ITM and because installed cast iron piping is more susceptible to failure than ductile iron or other more suitable piping material. EA also identified a few instances of inadequate safety classification of equipment associated with safety fire protection controls, reducing assurance in a timely and adequate response of the fire protection systems. In some cases, the technical basis design analyses for establishing performance criteria were inadequate, including analyses that contained unverified assumptions. Additionally, EA identified significant configuration management deficiencies in some facilities' controlled documents.

Occurrence Reports of performance degradation of safety fire protection systems at DOE sites may reflect the fire protection water supply deficiencies discussed above. Aging facilities experience increasing corrosion, degradation, and possible failure of SSCs (which are often recognized as "legacy issues"), and inadequate periodic ITM of fire protection systems could prevent early detection and correction of problems. Occurrence data from DOE facilities reveals many water supply line breaks and leaks within the past few years. In some cases, timely compensatory measures were implemented, but sometimes these events resulted in performance degradation of safety related fire protection systems and interruption of facility mission. For example, at one facility, the water level in a storage tank could not be maintained as required by the TSR for the facility's safety class FSS, so the system was declared inoperable; it was later discovered that an underground pipe failure under the facility was depleting the storage tank water inventory. Another recent reported occurrence involved a circumferential break in a facility's underground water supply line, installed about 50 years ago, that also caused the facility FSS to be declared inoperable. At a different facility, the flooding of entire first floor to varying degrees was directly attributed to "aged (circa 1940s), corroded, cast iron pipe that failed along a 3-ft lateral crack. The main component of corrosion acted on the outside of the pipe. It is likely that the damp natural environment facilitated corrosion, and that this condition was exacerbated when one or more leaks occurred sometime in the past." The facility is near other higher-risk facilities with similar piping material and configuration. **See Appendix A, Recommended Actions.**

2.4 TSR Surveillance and Testing

Criteria. *Surveillance and testing of the safety FSS demonstrates that the system is capable of accomplishing its safety functions and continues to meet applicable system requirements and performance criteria. The acceptance criteria for the surveillance tests confirm that key operating parameters for the overall system and its major components remain within the safety basis and conform to applicable standards. Instrumentation and test equipment for the system are adequately calibrated and maintained. (DOE Order 420.1B/C, DOE-STD-1066, and NFPA-25)*

Results. For most facilities, TSR fire protection safety system surveillance testing confirmed that key operating parameters for the system and its components remained within the safety basis, that the systems were capable of accomplishing their safety functions, and that the performance of credited controls was in accordance with applicable system requirements, standards, and performance criteria. In most cases, applicable ITM provisions of NFPA were appropriately integrated into the facility TSR surveillance testing procedures, and the TSRs were developed such that FSS systems and components credited to perform a safety function were tested and inspected on an acceptable periodic basis. The reviewed facilities generally had adequate fire suppression and detection capabilities, supporting procedures, and the necessary inspection, surveillance, testing, and maintenance to ensure functionality. The maintenance and testing of the systems typically involved the qualified fire protection engineer.

However, EA identified several instances of inadequacies in the implementation of fire protection surveillance testing requirements at various DOE sites, including several that could affect water supply to the safety FSS. The inadequacies were primarily in the implementation of the surveillance test requirements, or they were related to inadequate technical safety basis for the surveillance procedures and for the acceptance criteria for surveillance test results.

Implementation of TSR Surveillance Testing. The following are examples of inadequacies in surveillance test implementation observed at several facilities:

- Some facilities did not properly implement surveillance testing to ensure the adequate capacity and performance of fire water supply systems. At one facility, contrary to the requirements of NFPA-25, the test procedure for the annual fire pump test had no acceptance criteria, did not prescribe the test and data evaluation methodology, and did not include pump field acceptance test curves. At several facilities, the annual diesel pump test pressure and flow data was not normalized to the pump manufacturer’s certified acceptance curve at the rated rotational speed, as prescribed by NFPA-25, and in some cases, the acceptance criteria for pump flow and developed pressure were inadequate and did not meet vendor data. Additionally, there was no evidence that test data was reviewed by a fire protection engineer. At a different facility, a compensatory measure provided in a fire water pump impairment permit had not been demonstrated to provide adequate water flow and pressure, as required by the facility’s hydraulic analysis and provisions of NFPA-25.

- At one facility, the TSR SAC surveillance frequency required the facility operations personnel to verify acceptable room temperature in a fire pump house every 24 hours during cold weather, a non-conservative approach in some situations. An analysis to establish the basis for this frequency determined that it would take 16 hours for the fire pump house and the water in the piping in the room to drop to 32 degrees F if the room electric heater failed. These results indicated a need for more frequent operator rounds than specified in the SAC. Further, the analysis itself was non-conservative because it was based on reaching the freezing temperature for 8-inch piping, while the smaller size piping in the room presented a more limiting condition that was not evaluated.

- At one facility, there was no valve alignment procedure to ensure an unobstructed flow path from water supply tanks to the safety FSS.

- At many facilities, certain routine NFPA-required inspection and maintenance activities were made part of the TSR surveillance testing requirement procedure, thereby introducing the potential for preconditioning the SSC and not demonstrating its safety function in an as-found condition. (Preconditioning is defined here as maintenance activities performed before surveillance testing, which may adversely affect the validity of surveillance test results. An SSC safety function is required to be demonstrated in an as-found condition.) In the identified cases, no process was in place to prevent preconditioning prior to TSR testing. As an example, for a dry pipe riser valve actuation test that in part demonstrated that water flowed at the inspector’s test valve in the required time, the TSR procedure required the main drain valve to be opened to flush sediment from the system before the dry pipe valve actuation test. Although opening the main drain valve to remove sediment is an appropriate routine maintenance activity consistent with NFPA-25, it is considered as preconditioning the nuclear safety system from the standpoint of demonstrating its safety functionality, and does not constitute performing the surveillance test in an as-found condition.

Technical Bases for Surveillance Testing. EA also identified several instances where the technical basis for surveillance testing was inadequate. For example:

- The TSR surveillance related to a dry pipe system at one facility involved checking the pressure gauges on the FSS risers upstream of the dry pipe valve to verify that water supply pressure was adequate. The procedure required the dry pipe sprinkler system be absent of water and pressurized with air to prevent freezing during cold weather conditions, but the facility allowed small amounts of water to accumulate, since the basis for this surveillance stated that small amounts of water infiltration into the dry pipe would not render the system inoperable. Operators periodically drained the small amounts of water from the dry pipe system. However, the TSR basis for this surveillance provided no justification for allowing small amounts of water and provided no quantitative limits on the amount of water allowed to accumulate. The amount of frozen water in the dry pipe system that could render it unable to perform its safety function was not evaluated.

- At one facility, EA identified a number of concerns associated with various TSR surveillance requirements, including a flawed analytical methodology to determine the basis for verifying the static pressure at the facility's water supply riser; the lack of a technical basis for testing and verifying the gauge pressure at a hydrant; the lack of measurable criteria and documented comparison to previous tests for indicating obstructions during main drain testing; and the lack of a provision for verifying a freeze-free water delivery system.

- The TSR for an automatic wet pipe sprinkler safety system at one facility required the static pressure at the base of the sprinkler system riser to be equal to or greater than 65 psig to define its operability; however, neither an adequate technical basis nor a sufficiently analyzed indication of system operability was available for the established pressure limits. Based on the last flow testing performed, the sprinkler system could have inadequate pressure if a loop sectional control valve was closed. The system could not meet the DOE-STD-1066 requirement that hydraulically designed sprinkler systems be designed for a supply pressure of at least 10 percent, but not less than 10 psi, below the water supply curve. (The pressure margin is intended to accommodate minor system modifications or degradation of the water supply and sprinkler systems over time.) EA concluded that the facility needed to revise the hydraulic calculations using the latest flow test results.

- A limiting condition for operation action defined in one facility's TSR required that a fire watch be completed once every 12 hours if the facility's FSS was declared inoperable. However, this fire watch frequency does not provide a level of protection similar to an installed automatic fire detection system, and the facility did not perform an evaluation to establish a conservative basis for the frequency.

Overall, EA observed that the operability of fire protection safety systems generally was well integrated with the facility TSR surveillance testing procedures, and that the TSRs generally showed that safety FSS systems and components were tested and inspected on an acceptable schedule. However, inadequacies were identified in the implementation of fire protection surveillance testing requirements at various DOE facilities, including several that could adversely affect water supply to the safety FSS. The inadequacies were generally in the execution of the TSR surveillance testing procedures, or were related to inadequate surveillance test procedures and acceptance criteria. In many cases, TSR surveillance testing was performed along with other NFPA-required periodic maintenance and inspection activities that in themselves were not required to demonstrate acceptable performance of the SSC safety functional requirement, but that could bias and compromise the validity of the test results. **See Appendix A, Recommended Actions.**

2.5 DOE Site Office Oversight

Criteria. *DOE field element line management has established and implemented oversight processes that evaluate contractor and DOE programs and management systems for effectiveness of performance, including compliance with requirements. These processes are tailored to the hazards at the site, giving additional emphasis to potentially high consequence activities. DOE field element staff are adequately trained and qualified to perform assigned oversight activities. (DOE Orders 226.1B, 360.1C, and 426.1)*

Results. EA reviewed selected DOE site offices' oversight of their contractors' implementation of FPPs and fire hazard controls. The oversight approach varied from site to site but was generally accomplished through a combination of planned independent assessments; joint assessments with the responsible DOE contractor; reviews of pertinent aspects of the facility safety basis documents, especially as part of vital safety system assessments; and routine oversight by the fire protection engineer, the safety system oversight engineer, and the Facility Representative. The periodic and routine oversight included verifying implementation of hazard controls in administrative and operating procedures and work control documents.

The reviewed site offices generally had documented procedures and processes governing oversight of the implementation of applicable fire protection requirements, codes, and standards at their nuclear facilities. However, one site office affected by a recent reorganization and the loss of fire protection expertise had significant weaknesses in its FPP implementation.

Some DOE site office assessments were competently performed by knowledgeable personnel using appropriate review criteria. The assessment team members were technically qualified, and they demonstrated familiarity with their facilities, specifically the fire suppression and water supply systems. In a few cases, the assessment scope was very well defined and included follow-up on prior assessment findings and reviews of the implementation of safety basis conditions of approval. The assessments included appropriate performance-based elements, such as walkdowns of portions of assessed systems and components, reviews of as-built drawings, interviews of engineering and operations personnel, review of surveillance test results, and review of any design modification packages and associated unreviewed safety question determinations.

Further, the few DOE site offices that conducted well planned and executed assessments with competent personnel also appropriately characterized and documented their findings and other observations. One site office documented a number of important observations, including a need for the site's water master plan to evaluate the underground system piping due to its age; the development of an emergency water system impairment recovery plan in the event of pipe breaks; and the development of a water isolation valve exercise program for exercising all critical isolation valves in the water system within a specified time period. However, this DOE site office, like some other offices performing such assessments, did not require a formal response and documented corrective actions from the contractor to address the findings and observations.

Although some DOE site offices provided effective oversight of their contractors' FPPs, many of the offices did not conduct assessments with sufficient depth and thus were unable to expose the significant vulnerabilities identified during the EA reviews summarized in this report. Often in these cases, the site office's assessment was relatively limited in scope, the facility-specific fire protection expertise was inadequate, or there was insufficient independence in performing the required assessments.

The scope of some site office assessments did not include a rigorous follow-up review of the areas of weakness and the corrective actions taken for significant issues identified by prior assessments. In particular, several offices did not specifically address issues involving the external infrastructure interfaces with the facility's fire protection suppression water supply or alarm systems.

The site office assessments often did not include rigorous reviews of the technical bases for verifying the adequacy of tests and surveillances, such as supporting analysis and assumptions. The assessments also did not always ensure that the fire hazard controls identified and analyzed in the DSAs were consistent with those derived from the accident scenarios in the FHAs and that their safety classification was correct.

EA also identified some weaknesses in interactions of the DOE site office with the responsible contractor, and in the evaluation of the contractor's execution of the FPP. For example, there were cases where the site office did not require formal deliverables in response to issues identified by its assessments. Further, in some instances, the site office did not establish clear expectations for integrating the DOE fire protection engineering staff into its independent contractor performance evaluation activities.

Overall, for the DOE site offices that were reviewed, processes for oversight of FPP implementation were generally in place and combined a variety of oversight activities. A few offices conducted very effective assessments and adequately followed up on the identified issues. However, many site offices had weaknesses in their oversight of fire protection, primarily due to the inadequate scope and technical rigor of their assessments, and a lack of formality in defining expectations for resolving the identified issues and following up on corrective actions. **See Appendix A, Recommended Actions.**

3.0 BEST PRACTICES

EA identified the following best practices that could also be valuable at other DOE sites.

3.1 Method for Verifying Accuracy and Completeness of Pre-fire Plans

The Oak Ridge National Laboratory Fire Department uses a method for verifying the accuracy and completeness of building pre-fire plans and the locations of facility fire protection equipment to be tested and inspected. This method, which involves the use of an iPad to view the plans while performing ITM, promotes efficiency in locating equipment being tested when confirming the accuracy of the fire safety building features documented in the pre-fire plan.

3.2 Fire Protection Assessment Deficiency Rating System

At the Oak Ridge National Laboratory, one contractor's (UT-Battelle) Fire Protection Engineering uses a tool that serves as a procedure for assigning a rating to a given deficiency based on its severity and probability. The Fire Protection Deficiency Rating Matrix helps the user identify the appropriate priority using specific categories for deficiencies: imminent, code non-compliance (serious), code noncompliance (moderate), code non-compliant (less serious), and non-serious technical. Each of these priority categories has representative examples to assist the fire protection engineer in determining the rating. This tool also facilitates the approval process between the contractor and the DOE site office for non-compliant conditions, especially for minor deficiencies that would not necessitate an equivalency or exemption.

3.3 Worker Safety and Health Considerations in Fire Protection

The Idaho National Laboratory FPP performed a management assessment to review the implementation of 10 CFR 851 requirements for worker safety and health as they pertain to fire protection, and to ensure that the operating contractor, Battelle Energy Alliance, maintains comprehensive, written fire protection criteria or procedures. The assessment is commendable in giving due recognition to the relevance of worker safety and health in fire protection.

Appendix A
Recommended Actions

The recommended actions discussed below are based on lessons learned during the EA reviews. While the underlying deficiencies and weaknesses do not necessarily apply to all of the sites, and many sites may have developed and implemented actions for the issues identified at their sites, EA's recommended actions are intended to provide additional insights for potential improvements at all sites. Consequently, DOE organizations and site contractors should evaluate the applicability of the following recommended actions to their respective facilities, and consider their use as appropriate in accordance with site-specific program objectives.

DOE Headquarters Office of Environment, Health, Safety and Security

Evaluate current guidance to identify potential enhancements/clarifications to prevent recurrence of the weaknesses and cross-cutting issues identified in this report. Some areas for consideration include:

- The scope of fire protection assessments as it pertains to the site infrastructure relied upon for fire protection
- Reconciliation of the Department's nuclear safety practices with NFPA code requirements for testing and the potential for preconditioning of equipment
- Alignment of DSAs and FHAs
- Operability criteria for safety-class and safety-significant fire protection components
- Use of exemptions, exceptions, impairments, compensatory measures, and metrics for fire protection programs, systems, and equipment.

Program Offices, Including the National Nuclear Security Administration

Establish actions to ensure identification, risk-based prioritization, and correction of vulnerabilities in systems and equipment relied upon to prevent and/or mitigate fires at nuclear facilities. Specific actions to consider include:

- Conduct extent-of-condition reviews with a particular focus on determining the risks associated with water systems supplying nuclear facility fire suppression systems.
- Use periodic, high-level rollup reporting on the status of site fire protection systems to identify significant vulnerabilities (or lack thereof), risks and actions to ensure that management is informed, and program-wide prioritization of major infrastructure upgrades.
- Develop program guidance designed to ensure a consistent level of quality in fire protection assessments.

DOE Site Offices

Improve oversight of contractor FPPs to ensure understanding and assessments of performance and equipment conditions sufficient to inform management of risks and performance and to prioritize and fund corrective actions. Specific actions to consider include:

- As a learning opportunity, discuss the results of this report with management and staff to solicit specific recommendations for improvement.
- In conjunction with site contractors, perform reviews to determine the condition and reliability of support systems relied upon for fire protection of nuclear facilities.

- During routine assessments, increase the emphasis on determining the condition of and interfaces among the infrastructure and systems that safety-significant fire protection systems rely on to implement their intended function.
- Strengthen the integration of reviews of FHAs and DSAs to ensure alignment.
- Include lines of inquiry in fire protection assessments for the areas of weakness identified in this report.
- In coordination with site contractor organizations, assess the proficiency of site fire departments in executing emergency response functions to ensure their state of readiness with respect to the requirements of DOE Order 151.1C and NFPA 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments.*
- Evaluate the Federal staff's ability to assess and monitor fire protection programs, systems, and equipment. As needed, increase the use of subject matter experts through sharing of resources.
- Ensure that contractors have adequate measures (e.g., impairments, deferred ITM, exemptions and equivalencies, and corrective actions) to ensure the reliability and availability of fire protection systems and equipment. Monitor those measures.
- Evaluate the current risks and vulnerabilities associated with aging equipment, and establish prioritized plans for upgrades and replacements.

Site Contractors

Ensure that FPP performance and equipment conditions are adequately assessed and understood to inform management of risks and performance and to prioritize and fund corrective actions. Specific actions to consider include:

- As a learning opportunity, discuss the results of this report with management and staff to solicit specific recommendations for improvement.
- Perform technical analyses and assessments to determine the condition and reliability of support systems relied upon for fire protection of nuclear facilities. Include technical evaluations and analyses and document the results in the site's System Health and Wellness Plan.
- During routine assessments, increase the emphasis on determining the condition of and interfaces among the infrastructure and systems that safety-significant fire protection systems rely on to implement their intended function.
- Strengthen the integration of reviews of FHAs and DSAs to ensure alignment.
- Strengthen/include lines of inquiry in fire protection assessments for the areas of weakness identified in this report, such as:
    - Roles, responsibilities, and interfaces
    - Pre-fire plans
    - Alignment between FHAs and DSAs
    - Management of impairments
    - Control of combustibles
    - Equivalencies and exemptions
    - MPFL estimates for all nuclear hazard category 2 and 3 facilities (to ensure proper classification of FSS and adequate fire area separation).
- Assess the proficiency of site fire departments in executing emergency response functions to ensure their state of readiness with respect to the requirements of DOE Order 151.1C and NFPA 1710.
- Evaluate metrics (e.g., impairments, deferred ITM, exemptions and equivalencies, and

corrective actions) to ensure that they provide meaningful information on the reliability and availability of fire protection systems and equipment.
- Evaluate the current risks and vulnerabilities associated with aging equipment, and establish prioritized plans for upgrades and replacements.

Enhance the existing processes for FHA and DSA development. Specific actions to consider include:

- Describe the expectations and process for integrating the FHA conclusions with the facility DSA.
- Reinforce the requirement that any system necessary to support the credited functions of a safety system should be likewise classified for safety.
- Reinforce the need for an approved technical basis for the functional and performance criteria of all fire safety SSCs and surveillance acceptance criteria.
- Reinforce the importance of coordination between the fire protection engineer, the system engineer, and the safety analyst.
- Develop and implement an approach to reconcile TSR and NFPA testing requirements, including a reduced potential for preconditioning of equipment.

Appendix B
Supplemental Information

Office of Enterprise Assessments

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