NRC INSPECTION MANUAL

APOB

INSPECTION MANUAL CHAPTER 0308 ATTACHMENT 3 APPENDIX F

TECHNICAL BASIS
FIRE PROTECTION SIGNIFICANCE DETERMINATION PROCESS
(SUPPLEMENTAL GUIDANCE FOR IMPLEMENTING IMC 0609, APPENDIX F)
AT POWER OPERATIONS

Effective Date: January 1, 2025

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0308.03F-01 ENTRY CONDITIONS AND APPLICABILITY

SECY-99-007A (Reference 1) describes the need for a method of assigning a risk characterization to inspection findings. This risk characterization is necessary so that inspection findings can be aligned with risk-informed plant performance indicators during the plant performance assessment process. An attachment to the SECY describes in detail the staff's efforts for the risk characterization of inspection findings, which have a potential impact on operations at power, affecting the initiating event, mitigating systems, or barrier cornerstones associated with the reactor safety strategic performance area. This significance determination process (SDP), discussed in the SECY, focuses on risk-significant issues that could influence the determination of the change in core damage frequency (ΔCDF) at a nuclear power plant (NPP). In this context, risk significance is based on the ΔCDF acceptance guidelines in NRC Regulatory Guide (RG) 1.174 (Reference 2).

A performance issue that leads to an increase in CDF larger than 10^{-4}/ry is risk significant and therefore the highest risk category (red) is given to this frequency range (as shown in Table 1.1). Lower frequency ranges are allocated different colors (and hence risk significance categories) in one order of magnitude decrements. The Fire Protection SDP (Inspection Manual Chapter (IMC) 0609, Appendix F (Reference 3); referred to hereafter as "Appendix F") is based on changes in CDF, rather than changes in the large early release frequency (LERF). However, should an SDP performed for LERF indicate a more severe color than one for CDF, that color should take precedence.

Table 1.1 – Risk Significance Based on ΔLERF versus ΔCDF		
Frequency Range/ry*	SDP Based on ΔCDF	SDP Based on ΔLERF
$\geq 10^{-4}$	Red	Red
$\geq 10^{-5}$ and $< 10^{-4}$	Yellow	Red
$\geq 10^{-6}$ and $< 10^{-5}$	White	Yellow
$\geq 10^{-7}$ and $< 10^{-6}$	Green	White
$<10^{-7}$	Green	Green

*ry = reactor year

The Fire Protection SDP methodology consists of three phases:

- Phase 1: Characterization and initial screening of findings;
- Phase 2: Initial approximation and basis of risk significance; and
- Phase 3: Finalized determination and basis of risk significance.

The initial screening of findings in the Phase 1 process should lead to an identification of those findings that require Phase 2 or Phase 3 assessments. The fire modeling tools used to support the Phase 2 fire growth, damage time, detection, and suppression analysis are relatively simple correlation-based modeling approximations. These tools cannot handle all fire growth conditions accurately. Hence, an analysis that encounters complicated fire growth conditions is a potential candidate for a Phase 3 assessment. Moreover, a Phase 2 analysis generally does not account for the effects of human error and spurious operations. If needed, these effects are considered in Phase 3.

01.01 Entry Conditions

The entry conditions for the Fire Protection SDP are defined for inspection findings of degraded conditions associated with the plant fire protection program. The as-found degraded conditions are assumed to result from deficient licensee performance during full power operation of the plant (see IMC 0609, Appendix A (Reference 4)). This may involve findings associated with fire protection features, fire protection systems, post-fire safe shutdown (SSD) systems, procedures, and equipment, or any other aspect of the fire protection program.

Appendix F provides a simplified risk-informed methodology that estimates the increase in CDF associated with inspection findings of deficient licensee performance in assuring fire protection during full power operations. Guidance for assessing risk significance of fire protection issues during low power or shutdown operations are currently not addressed in this Appendix. If the inspection finding is not related to deficient performance, no SDP evaluation would be performed.

Nominally, each inspection finding is initially screened using the guidance in IMC 0612, Appendix B (Reference 5), to determine whether the finding is more than minor. If the finding is more than minor, IMC 0612 guidance directs the analyst to perform a Phase 1 SDP assessment. All inspection findings related to the fire protection program, except for fire brigade findings, are referred to Appendix F for further consideration.

A detailed Phase 3 analysis is recommended for any finding evaluated in Phase 2 as greater than Green. In addition, the Phase 2 analysis can be skipped and a Phase 3 analysis performed for a complex finding, based on the discretion of the inspector, risk analyst, and management. A complex finding is defined as:

a. A finding with a number of correlated (or dependent) findings of performance deficiencies[1]; or
b. A finding assessed in Phase 2 whose approximate risk significance appears to be driven by contentious assumptions and/or over-conservatism, or appears to be substantially affected by uncertainties associated with simplifying assumptions; or
c. A finding judged to be potentially risk significant that is not covered by the guidance provided in this Appendix (see Section 0308.03F-02).

01.02 Applicability

The Fire Protection SDP is designed to provide NRC analysts and management with a risk-informed tool for identifying potentially risk-significant issues that involve degradations in the plant fire protection program. All such findings are evaluated in terms of the impact of the degradation finding on the change in fire-induced CDF. The Fire Protection SDP also helps to

[1] Since the figure of merit for the SDP analysis is an increase in the average annual CDF, inspection findings are considered simultaneously in an analysis only when findings are due to a common cause. Otherwise, the coincidence of the findings would be considered a random occurrence, and each finding analyzed separately.

facilitate communication of the basis for significance between the NRC and regulated licensees. In addition, the SDP identifies findings that do not warrant further NRC engagement, due to very low risk significance, so that these findings are entered into the licensee's corrective action program.

0308.03F-02 LIMITS AND PRECAUTIONS

This document provides supporting guidance for implementation of Phase 1 and 2 analyses under the Fire Protection SDP as described in Appendix F. The actual analysis procedure is documented in Appendix F. This document is intended to serve as a supplemental resource to assist in implementation of, and to foster a greater understanding of, the Appendix F procedure. This document is considered a necessary companion to the procedure itself.

The Fire Protection SDP is a simplified tool that generally provides a slightly conservative, nominally order of magnitude assessment of the risk significance of inspection findings related to the fire protection program. The Fire Protection SDP is a tool that facilitates NRC analysts obtaining a risk-informed assessment of the significance of a finding.

The Fire Protection SDP approach has a number of inherent assumptions and limitations:

a. The Fire Protection SDP assesses the change in CDF, rather than LERF, as a measure of risk significance. The likelihood of early release of radioactive materials or long-term risk measures such as population dose (person-rem) and latent cancer fatalities are not addressed in this Appendix. Containment performance depends on the containment design, plant-specific attributes and features, which have considerable variability and are typically beyond the scope of this simplified fire risk analysis tool. If a finding increases the likelihood of otherwise low probability events that primarily impact LERF (such as fire-induced spurious opening of a containment isolation valve), the change in LERF may be the more appropriate risk metric. In this case, the SDP analysis should proceed directly to Phase 3.
b. The quantification approach and analysis methods used in this Fire Protection SDP are largely based on existing fire Probabilistic Risk Assessment (PRA) analysis methods. As such, the methods are also limited by the current state of the art in fire PRA methodology.
c. The Fire Protection SDP focuses on risks due to degraded conditions of the fire protection program during full power operation of an NPP. This tool does not address the potential risk significance of fire protection inspection findings in the context of other modes of plant operation (i.e., low power or shutdown).
d. The process strives to achieve order of magnitude estimates of risk significance. However, it is recognized that fire PRA methods in general retain considerable uncertainty. The Fire Protection SDP strives to minimize the occurrence of false-negative findings. In the process of simplifying existing fire PRA methods for the purposes of the Phase 2 Fire Protection SDP analysis, compromises in analysis complexity have been made. In general, these compromises have involved the application of quantification factors that may be somewhat conservative for specific applications. Hence, the objective of order of magnitude accuracy may not be uniformly achieved in the Fire Protection SDP Phase 2 analyses.

e. The Fire Protection SDP excludes findings associated with the performance of the onsite manual fire brigade or fire department. If the finding involves the fire brigade, Appendix F directs the NRC analyst to use IMC 0609, Appendix A (Reference 4).

f. The Fire Protection SDP Phase 2 quantitative screening method includes an approach for incorporating known issues about fire-induced circuit failure modes and effects into an SDP analysis. The SDP approach is mainly intended to support the assessment of known issues in the context of an individual fire area. However, the Phase 2 process may be appropriate for some issues involving multiple fire areas. In practice, an issue about given circuit failure modes and effects will likely impact the risk contribution arising from multiple fire areas. The SDP analysis approach, in theory, could be used to provide a screening estimate of the plant-wide risk significance of a particular circuit failure issue, if supported by a plant-wide search for relevant vulnerabilities (i.e., plant-wide routing information for all relevant cables and circuit, and an assessment of fire vulnerabilities for each relevant fire area). It is recommended that additional guidance be sought from a risk analyst in the conduct of such an analysis. A systematic plant-wide search and assessment effort is beyond the intended scope of Phase 2. In such cases, the SDP analysis can proceed directly to Phase 3.

g. The Fire Protection SDP Phase 2 quantitative screening method does not currently include explicit treatment of main control room (MCR) fires or fires leading to MCR abandonment (either due to fire in the MCR or due to fires in other fire areas that would impair the ability to control the reactor from the MCR). The Phase 2 process may be able to address such scenarios, but it is recommended that additional guidance be sought from a risk analyst in the conduct of such an analysis.

0308.03F-03 ABBREVIATIONS, SYMBOLS AND DEFINITIONS

03.01 Abbreviations

AF	Adjustment Factor
CCDP	Conditional Core Damage Probability
CDF	Core Damage Frequency
CM	Compensatory Measure
DF	Duration Factor
DID	Defense in Depth
EPRI	Electric Power Research Institute
FDS	Fire Damage State
FDTs	Fire Dynamics Tools
FIF	Fire Ignition Frequency
FIVE	Fire-Induced Vulnerability Evaluation
FLASH-CAT	Flame Spread over Horizontal Cable Trays
GDC	General Design Criterion
HEAF	High Energy Arcing Fault
HGL	Hot Gas Layer
HRR	Heat Release Rate
HRRPUA	Heat Release Rate per Unit Area
IMC	Inspection Manual Chapter
IPEEE	Individual Plant Examination for External Events
LER	Licensee Event Report
LERF	Large Early Release Frequency
MCC	Motor Control Center
MCR	Main Control Room
MQH	McCaffrey, Quintiere, and Harkleroad
NEI	Nuclear Energy Institute
NIST	National Institute of Standards and Technology
NPP	Nuclear Power Plant
NRC	Nuclear Regulatory Commission
NRR	NRC Office of Nuclear Reactor Regulation
NFPA	National Fire Protection Association
NSP	Non-Suppression Probability
PRA	Probabilistic Risk Assessment
PSM	Point Source Model
QTP	IEEE 383-Qualified Thermoplastic
RES	NRC Office of Nuclear Regulatory Research
RG	Regulatory Guide
RTI	Response time index
ry	Reactor Year (generally in the context of an event frequency)
SIS	Switchboard Wire
SDP	Significance Determination Process
SE	Sensitive Electronics
SF	Severity Factor
SSCs	Structures, Systems, and Components

SSD	Safe Shutdown
TER	Total Energy Release
TP	Thermoplastic
TS	Thermoset
ZOI	Zone of Influence

03.02 Mathematical Symbols

A	Parameter used in view factor calculation (Equation 22)
A_f	Fire area
A_T	Total area of the compartment enclosing surfaces minus A_v
A_v	Area of the ventilation opening
c_a	Specific heat capacity of air at ambient temperature (Equations 16 and 18)
c_p	Specific heat capacity of the interior wall lining (Equation 26)
C	Constant
D	Fire diameter
D_{eff}	Effective fire diameter
D_{max}	Fire diameter at peak HRR
E	Emissive power of the flame
E_{SE}	Integrated exposure for sensitive electronics
E_{TP}	Integrated exposure for thermoplastic cable targets
E_{TS}	Integrated exposure for thermoset cable targets
F	Cumulative gamma distribution of ignition source HRR
F_{dam}	Damage function
f_{high}	Transient or hot work fire frequency for area rated as high
f_{low}	Transient or hot work fire frequency for area rated as low
f_{medium}	Transient or hot work fire frequency for area rated as medium
$f_{plant\text{-}wide}$	Plant-wide transient or hot work fire frequency
$F_{t\text{-}f}$	View factor between a target and the flame
g	Acceleration of gravity
h	Parameter used in view factor calculation (Equation 22), vertical spacing between horizontal trays in a vertical stack (Equation 28)
h_c	Convection coefficient
h_T	Heat transfer coefficient
H	Ceiling height above the fire base
H_f	Flame height
H_v	Height of the ventilation opening
HRR_{peak}	Ignition source peak HRR
i	Index
I_{dam}	Damage integral
k	Thermal conductivity of the interior lining
$k\beta$	Flame absorption coefficient
L_n	Lateral extent of the initial fire in the n^{th} tray in a stack above the ignition source
m'	Cable mass per unit length
$\dot{m}''_{max}$	Maximum pool fire mass loss rate per unit area
n	Upper limit for index i
N	Number of fire scenarios evaluated for a given finding
n_d	Decay exponent
n_g	Growth exponent

n_{high}	Number of areas in the plant with high transient or hot work fire likelihood rating
n_{low}	Number of areas in the plant with low transient or hot work fire likelihood rating
n_{medium}	Number of areas in the plant with medium transient or hot work likelihood rating
$\dot{m}_c''$	Combustible cable mass per unit tray area
N	Number of cables per tray
NSP_{Fixed}	NSP assuming fixed fire suppression system activation
NSP_{Manual}	NSP assuming manual fire suppression only
$NSP_{Scenario}$	NSP for the scenario, which combines NSP_{Fixed} and NSP_{Manual} based on the event tree, and accounting for the fixed fire suppression failure probability
$\dot{q}''$	Incident heat flux at the target
$\dot{q}_r''$	Incident radiant heat flux or irradiance
$\dot{q}_{cr}''$	Damage or ignition threshold heat flux of the target
Q	Exposure
Q*	Froude number
$\dot{Q}$	HRR of the fire
$\dot{Q}_c$	Convective part of the HRR of the fire
$\dot{Q}_{min}$	Minimum HRR to create a damaging HGL
$\dot{Q}_{peak}$	Ignition source peak HRR
$\dot{Q}_{\Delta T=10°C}$	HRR needed to raise the ceiling jet temperature to 10°C above T_a
R	Radial distance between the target and the center of the ignition source (Equation 22), or radial distance from the center of the fire base to the detector (Equations 33, 34, 36, 38, 39), or sprinkler head (Equations 41-44, 46, 47)
S	Parameter used in view factor calculation (Equation 22)
t	Time
t_{act}	Smoke detector actuation time
t_{cj}	Lag time for the ceiling jet to travel to the detector
t_d	Decay time
t_{dam}	Time to damage
$t_{detection}$	Time to fire detection
TER	Total energy release
t_g	Growth time
t_p	Thermal penetration time (Equation 26), plateau time
t_{peak}	Time to peak HRR
t_{pl}	Lag time for the plume to rise to the ceiling
t_{resp}	Smoke detector response time
$t_{Suppression.}$	Time to fire suppression
$t_{\Delta T=10°C}$	Time for the ceiling jet temperature to reach 10°C above ambient
T	Temperature
T_a	Ambient air temperature
T_{act}	Sprinkler activation temperature
T_{cj}	Ceiling jet temperature
T_{cr}	Damage or ignition threshold temperature
T_g	HGL temperature
T_{ink}	Sprinkler link or bulb temperature
T_p	Plume centerline temperature
u_{cj}	Ceiling jet velocity
v_f	Flame spread rate
V_f	Liquid fuel volume
W	Cable tray width

WF	Weighting Factor - a factor that is used to apportion the plant-wide FIF for transient, hot work, and self-ignited cable fires to a specified fire area
Y_c	Char yield
Y_p	Plastic mass fraction
z	Elevation above the fire base
z_0	Elevation of the virtual origin of the point source plume
ZOI_{rad}	Radial ZOI
ZOI_{vert}	Vertical ZOI
α	Gamma HRR distribution shape parameter
β	Gamma HRR distribution rate (scale) parameter
δ	Fuel spill depth (Equation 5), thickness of the interior lining (Equation 26), or model bias
ΔCDF	Estimated change in CDF (a subscript indicate the specific analysis step during which the CDF change has been calculated and implies the level of detail incorporated into the change estimate)
$\Delta h_{c,eff}$	Effective heat of combustion
ΔH_v	Heat of combustion of the fuel volatiles
Δt	Electrical cable burning duration (Equation 30), time step (Equation 12)
Δt_{decay}	Duration of ignition source HRR decay period
Δt_{steady}	Duration of ignition source peak burning period
ΔT_g	HGL temperature rise above ambient, T_g - T_a
ε	Surface emissivity/absorptivity
ρ	Density of the interior lining
ρ_a	Density of ambient air at temperature T_a
σ	Model uncertainty (one standard deviation), Boltzmann radiation constant ($5.67037 \cdot 10^{-11}$ kW/m$^2 \cdot$K^4)
τ	Time
τ_{dam}	Time to damage
χ_r	Radiative fraction

03.03 Definitions

Alternative Shutdown (or Alternate Shutdown): The capability to safely shut down the reactor in the event of a fire using existing systems that have been rerouted, relocated, or modified. A distinction is made between shutdown outside the MCR that can be accomplished at a single location via a dedicated shutdown panel versus the need to travel to various locations around the plant to perform actions at various components themselves. The former typically gets credit in fire PRAs while the latter, if it does, suffers from higher human error probabilities than under non-fire conditions. See also: *Remote Shutdown*. (RG 1.189 (Reference 7))

Cable: In the context of fire PRA, the term cable refers to assemblies designed to conduct electrical current. Hence, a cable is an assembly of one (single-conductor cable) or more (multi-conductor cable) insulated electrical conductors (generally copper or aluminum) that may or may not be surrounded by an outer jacket. (This definition excludes fiber-optic type cables.) (NUREG/CR-6850, Vol. 2 (Reference 8))

Cable Failure: A condition whereby the affected (or failed) cable is no longer able to perform its intended function. (Reference 8)

Cable Failure Mode: The mode by which a wire or conductor fails. Three principle failure modes are defined: open circuit, ground fault (short-to-ground), and hot short. (Reference 8)

Ceiling Jet: Refers to the relatively rapid gas flow in a shallow layer beneath the ceiling surface that is driven by the buoyancy of hot combustion products. Ceiling jets form when a fire plume impinges under a ceiling and hot gases spread away. (Reference 8)

Circuit Analysis: The process of identifying cables and circuits that, if damaged by fire, could prevent a Fire PRA component from operating correctly. (Reference 8)

Circuit Failure Mode: The manner in which a conductor fault is manifested in the circuit. Circuit failure modes include loss of motive power, loss of control, loss of or false indication, open circuit conditions (e.g., a blown fuse or open circuit protective device), and spurious operation.

Compensatory Measure: Actions taken by a licensee to mitigate the potential impact of a known degradation of defense in depth (DID), in this case, in some element of the plant fire protection program.

Compartment: A fire compartment is a well-defined volume within the plant that is not necessarily bounded by rated fire barriers or complete physical barriers but that is expected to substantially contain the adverse effects of fires within the compartment. Fire compartments are defined for the purposes of fire PRA analysis, and generally represent a subset of a plant fire area.

Conditional Core Damage Probability (CCDP): The conditional core damage probability calculated by the fire PRA Model. This probability is conditional on a specific fire scenario in a fire compartment postulated as a result of a fire-induced initiating event and includes the likelihoods of the combinations of equipment failures (some may be directly induced by the fire itself) and operator failures that result in core damage. The CCDP for a given fire scenario times the frequency of the given fire scenario (see fire scenario definition below for the considerations that are captured within the context of a fire scenario) results in the Core Damage Frequency contribution for the given fire scenario. (Reference 8)

Core Damage Frequency (CDF): Expected number of core damage events per unit of time.

Damaging Hot Gas Layer (HGL): A hot gas layer (see definition of Hot Gas Layer) that is sufficiently high in temperature to damage fire PRA systems and equipment (see definition of Fire PRA Systems and Equipment) throughout the compartment.

Exposed Compartment: In the context of a multi-compartment, or room-to-room, fire scenario, the exposed compartment is that compartment to which the fire may spread. An unsuppressed fire in the exposing compartment may spread through a fire barrier to the exposed compartment. (See definition of Exposing Compartment.)

Exposing Compartment: In the context of a multi-compartment, or room-to-room, fire scenario, the exposing compartment is that compartment where the fire is initiated or ignited. An unsuppressed fire in the exposing compartment may spread through a fire barrier to the exposed compartment. (See definition of Exposed Fire Area.)

Fire Area: The portion of a building or plant that is separated from other areas by rated fire barriers adequate for the fire hazard. (Reference 7) The term fire area is used generically in

Appendix F and is not intended to exclude application of the guidance to findings pertaining to fire zones or compartments.

Fire Barrier: Components of construction (walls, floors, and their supports), including beams, joists, columns, penetration seals or closures, fire doors, and fire dampers that are rated by approving laboratories in hours of resistance to fire, that are used to prevent the spread of fire. (Reference 7)

Fire Brigade: A team of on-site plant personnel that have been qualified and equipped to perform manual fire suppression activities. (Reference 7)

Fire Damage (or Fire-Induced Damage): A structure, system or component that is no longer free of fire damage (see definition of Free of Fire Damage). That is, the structure, system, or component under consideration is no longer capable of performing its intended function without repair.

Fire Damage State (FDS): A discrete stage of fire growth and damage postulated in the development of Fire Protection SDP fire scenarios. Four fire damage states are defined as follows:

FDS0*:* Only the fire ignition source and initiating fuels are damaged by the fire. FDS0 is not analyzed in the Fire Protection SDP as a risk contributor even if the ignition source is also a target, such as an electrical enclosure that will yield a non-zero CCDP by itself.

FDS1: Fire damage occurs to components or cables protected by a degraded local fire barrier system (e.g., a degraded cable tray fire barrier wrap), or to unprotected components or cables located near the fire ignition source. This damage state also includes ignition of secondary combustibles (cable trays) near the fire ignition source.

FDS2: Widespread fire damage occurs to unprotected components or cables within the compartment of fire origin, to components or cables protected by a degraded local fire barrier system (e.g., a degraded cable tray fire barrier wrap), or to components or cables protected by a non-degraded one hour fire barrier due the development of a damaging hot gas layer (HGL).

FDS3: Fire damage extends to a compartment adjacent to the compartment of fire origin, in general, due to postulated fire spread through a degraded inter-compartment fire barrier element (e.g., wall, ceiling, floor, damper, door, penetration seal, etc.)

Fire Growth and Damage: The part of a fire scenario (see definition of *Fire Scenario*) that characterizes the potential for fires involving a particular fire ignition source (see definition of *Fire Ignition Source*) to ignite secondary combustible fuels, the subsequent spread of fire within and among any secondary combustible fuels, and the potential for fire-induced damage to fire PRA systems and equipment (see definition of Fire PRA Systems and Equipment).

Fire Hazard: The existence of conditions that involve the necessary elements to initiate and support combustion, including fixed or transient combustible materials, ignition sources (e.g., heat, sparks, open flames), and an oxygen environment. (Reference 7)

Fire Ignition Source: The part of a fire scenario (see definition of Fire Scenario) that defines the early physical characteristics of the fire itself including factors such as the ignition source, the initially ignited combustible material(s), and the characteristics of the fire involving those initial combustible materials (e.g., heat release rate, location, duration).

Fire PRA Systems and Equipment: Structures, systems, components, and cables (power, instrumentation and control) credited for plant shutdown in the context of a fire PRA. The fire PRA systems and equipment will typically include all of the fire SSD systems and equipment, other systems and equipment credited in the internal events PRA, and other systems and equipment subject to unique fire-induced failure modes (e.g., components susceptible to fire-induced spurious actuation).

Fire Protection Defense in Depth (DID): Achieving the required degree of reactor safety using administrative controls, fire protection systems and features, and SSD capability. It is aimed at preventing fires from starting, rapidly detecting and suppressing fires that occur, and protecting of the reactor's ability to safely shutdown if a fire is not promptly extinguished. (Reference 7)

Fire Protection Feature: Administrative controls, fire barriers, means of egress, industrial fire brigade personnel, and other features provided for fire protection purposes. (Reference 9)

Fire Protection Program: The integrated effort involving components, procedures, and personnel utilized in carrying out all activities of fire protection. It includes system and facility design, fire prevention, fire detection, annunciation, confinement, suppression, administrative controls, fire brigade organization, inspection and maintenance, training, quality assurance, and testing. (Reference 7)

Fire Protection Program Element: Any individual system, feature, provision, analysis, procedure, requirement, training program, or plant practice that is a part of the overall fire protection program. The term "fire protection program element" is used in this document as the most general reference to individual aspects of the overall fire protection program.

Fire Protection System: Fire detection, notification, and fire suppression systems designed, installed, and maintained in accordance with the applicable National Fire Protection Association (NFPA) codes and standards. (Reference 9)

Fire Scenario: A sequence of events that begins with the ignition of a fire that has the potential to upset normal plant operations and ends when the plant fails to achieve a safe and stable mode of plant operation, i.e., core damage occurs. A fire scenario is made up of a unique combination of elements: fire ignition source, fire growth and damage, fire suppression (assumed unsuccessful and termed "non-suppression"), a plant damage state, and a plant SSD response, also assumed to be unsuccessful (see related definitions). Occurrence of a plant damage state and failure to achieve SSD, resulting in core damage, comprise the CCDP. Changes in any one of these five elements implies the introduction or identification of a new fire scenario.

Fire Suppression: Control and extinguishing of fires (firefighting). Manual fire suppression is the use of hoses, portable extinguishers, or manually actuated fixed systems by plant personnel. Automatic fire suppression is the use of automatically actuated fixed systems such as water, Halon, or carbon dioxide systems. (Reference 7)

Fire Watch: Individuals responsible for providing additional (e.g., during hot work) or compensatory (e.g., for system impairments) coverage of plant activities or areas for the purposes of detecting fires or for identifying activities and conditions that present a potential fire hazard. The individuals should be trained in identifying conditions or activities that present potential fire hazards, as well as the use of fire extinguishers and the proper fire notification procedures. (Reference 7)

Free of Fire Damage: The structure, system, or component under consideration is capable of performing its intended function during and after the postulated fire, as needed, without repair. (Reference 7)

Heat Release Rate (HRR): The amount of heat generated by a burning object per unit time. It is usually expressed in kW. An HRR profile refers to the behavior of the heat release rate as a function of time (an HRR versus time plot). For example, a fire with a constant heat release rate has an intensity that does not change.

Heat Soak Method: A methodology to calculate the time to damage for generic cables exposed to a time-dependent plume temperature or radiant heat flux. (Appendix A in Reference 10)

High Energy Arcing Fault (HEAF): High energy electrical devices (i.e., switchgear, load centers, and bus bars/ducts 440V and above) are subject to a unique failure mode and unique fire characteristics referred to as a high energy arcing fault (HEAF). This fault mode leads to the rapid release of electrical energy in the form of heat, vaporized copper, and mechanical force. Faults of this type are also commonly referred to as high energy, energetic, or explosive electrical equipment faults or fires. Similar failure modes can occur in large oil-filled transformers. (Reference 8)

Hot Gas Layer (HGL): Refers to the volume under the ceiling of a fire enclosure where smoke accumulates and high gas temperatures are observed. It is the upper zone in a two-zone model formulation. (Reference 8)

Important to Safe Shutdown (SSD): Structures, systems, and components (SSCs) that support the ability to achieve and maintain the credited shutdown reactivity conditions (either hot or cold shutdown depending on the plant). This includes SSCs that support the long-term ability of the SSD equipment to perform its function, such as water supply tanks, HVAC systems, and small diversion paths. For the purposes of this SDP, equipment that is required for SSD is a subset of equipment important to SSD. Therefore, equipment that is important to SSD is not always required for SSD. See definitions of Safe Shutdown Systems and Equipment and Required for SSD. (Reference 7)

Ignition Source: Piece of equipment or activity that causes a fire. (Reference 8)

Ignition Source Weighting Factor: Fraction used to translate generic fire frequencies for a generic location or ignition source to a specific ignition source within the plant. (Reference 8)

Natural Ventilation: Gas flows into or out of the room induced by density differences between the fluids. In enclosure fires, density differences are observed between colder fresh air and hot smoke. (Reference 8)

Non-Degraded: A fire protection system or feature that has no findings of degradation pending against it. A non-degraded system or feature is considered fully functional.

Phases of a Significance Determination:

- Phase 1 - Characterization and Initial Screening of Findings: Precise characterization of the finding and an initial screening of very low significance findings for disposition by the licensee's corrective action program.
- Phase 2 - Initial Approximation and Basis of Risk Significance: Initial approximation of risk significance of the finding and development of the basis for this determination for those findings that filter through the Phase 1 screening process.
- Phase 3 - Finalized Determination and Basis of Risk Significance: Refinement of the risk significance estimation results from Phase 2 or performance of risk significance analysis outside of this guidance, by an NRC risk analyst. Any departure from the guidance provided in this document for Phase 1 or Phase 2 analysis constitutes a Phase 3 analysis and must be performed by an NRC risk analyst.

Post-Fire Safe Shutdown (SSD) Response: The part of a fire scenario that involves the plant response, including operator actions, to fire-induced damage to a specific and pre-determined set of plant components and systems. An analysis of the post-fire SSD response scenario typically involves identification of one or more relevant plant accident sequence initiating events, application of plant system modeling event trees and/or fault trees, the assessment of automatic plant responses, the assessment of component and system failure modes and effects (circuit analysis), and the analysis of operator responses and actions, all intended to achieve a safe and stable plant shutdown state, i.e., avoid core damage.

Qualified Cable: A cable that is certified for use in severe accident environmental conditions per the full suite of performance tests specified in IEEE-383, which includes a flame spread test. Cables using thermoset insulation are usually qualified to IEEE-383. In general, cables that pass IEEE-383 rating (i.e., IEEE-383 qualified) are thermoset cables. (Reference 11)

Raceway: An enclosed channel of metal or nonmetallic materials designed expressly for holding wires, cables, or bus bars, with additional functions as permitted by code. Raceways include, but are not limited to, rigid metal conduit, rigid nonmetallic conduit, intermediate metal conduit, liquid-tight flexible conduit, flexible metallic tubing, flexible metal conduit, electrical nonmetallic tubing, electrical metallic tubing, underfloor raceways, cellular concrete floor raceways, cellular metal floor raceways, surface raceways, wireways, and busways. (Reference 7)

Raceway Fire Barrier: Non-load-bearing partition type envelope system installed around electrical components and cabling that are rated by test laboratories in hours of fire resistance and are used to maintain SSD functions free of fire damage. (Reference 7)

Radiant Energy (Heat) Shield: A noncombustible or fire resistive barrier installed to provide separation protection of redundant cables, equipment, and associated non-safety circuits within containment. (Reference 7)

Required for Safe Shutdown (SSD): SSCs that are required to achieve and maintain the credited shutdown reactivity conditions (either hot or cold shutdown depending on the plant). This includes SSCs that directly support the short-term ability of the SSD equipment to perform its function, such as power supplies, instrumentation, and large diversion paths. For the purposes of this SDP, equipment that is required for SSD is a subset of equipment important to SSD. Therefore, any equipment that is required for SSD is also considered important to SSD. See definitions of Important to SSD and SSD Systems and Equipment. (Reference 7)

Remote Shutdown: The capability, including necessary instrumentation and controls, to safely shut down the reactor and maintain shutdown conditions from outside the MCR (see GDC 19). See also: Alternative Shutdown. (Reference 7)

Safe Shutdown (SSD) Systems and Equipment: Systems and equipment that perform functions needed to achieve and maintain SSD regardless of whether or not the system or equipment is part of the success path for SSD. See definitions of Important to SSD and Required for SSD. (Reference 7)

Screen to Green: If a finding satisfies established screening criteria, it is assigned a very low safety significance, or Green color rating, and the SDP analysis is complete. Phases 1 and 2 of the Fire Protection SDP both include various qualitative and quantitative screening checks where a finding may screen to Green.

Secondary Combustible: Any and all combustible materials that are separate and distinct from the initially ignited combustible material(s) associated with the fire ignition source scenario itself (see definition of Fire Ignition Source Scenario). Secondary combustibles may become involved in the fire if ignited. The ignition of secondary fuels implies a spreading fire has developed; i.e., the fire has spread beyond the fuels associated with the fire ignition source scenario.

Severity Factor (SF): The probability that fire ignition would include certain specific conditions that influence its rate of growth, level of energy emanated and duration (time to self-extinguishment) to levels at which target damage is generated. It can also be defined as the probability associated with a specific fire intensity. (Reference 8)

Split Fraction: A conditional probability value reflecting the likelihood that one specific outcome from a set of possible outcomes will be observed. Example: When there are two possible outcomes, a split fraction is used to represent the likelihood that each specific outcome will be observed. A common example in the Fire Protection SDP is fire intensity. Each fire ignition source is characterized by two fire intensity values. The lower value is assumed to represent 90 percent of all fires involving that fire ignition source, the higher value represents the remaining 10 percent of fires. This would be a 90/10 (or 0.9/0.1) split fraction between these two outcomes - the smaller fire versus the larger fire.

Spurious Operation: A circuit fault mode wherein an operational mode of the circuit is initiated (in full or in part) due to failure(s) in one or more components (including cables) of the circuit. (Reference 8)

Target: May refer to fire damage targets and/or ignition targets. A fire damage target is any item whose function can be adversely affected by the modeled fire. Typically, a fire damage target is a cable or equipment that belongs to the Fire PRA component list. An ignition target is any flammable or combustible material to which fire might spread. (Reference 8)

Thermoplastic (TP) versus Thermoset (TS): Of the materials available for use as cable insulation and jacketing, the broadest categories are TP and TS. TP materials melt when heated and solidify when cooled. TS materials do not melt but do begin to smolder and burn if sufficiently heated. In general, TS materials are more robust, with failure temperatures of approximately 350°C (662°F) or higher. TP materials typically have failure temperatures much lower than 218°C (425°F), where failure is typically associated with melting of the material. (Reference 11)

Total Energy Release (TER): The total amount of heat generated by a burning object between ignition and burnout. Mathematically it is equal to the area under the HRR profile (i.e., HRR versus time plot), and usually is expressed in MJ.

Transient Combustibles: Combustible materials temporarily stored in locations that are usually associated with (but not limited to) maintenance or modifications involving combustible and flammable liquids, wood and plastic products, waste, scrap, rags, or other combustibles resulting from the work activity. (Reference 8)

Unqualified Cable: A cable that has not been certified for use in severe accident environmental conditions per the full suite of performance tests specified in IEEE-383. In general, cables that do not pass IEEE 383 rating (i.e., non-IEEE qualified) are TP. (Reference 11)

Zone of Influence (ZOI): A volume surrounding an ignition source where all secondary combustibles and targets may be adversely affected by a fire initiated by the ignition source. (Reference 8).

04.01 Road Map

The Fire Protection SDP, as documented in Appendix F, involves a series of qualitative and quantitative analysis steps for estimating the risk significance of inspection findings related to licensee performance in meeting the objectives of the fire protection defense in depth (DID) elements. The fire protection DID elements are:

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

The Fire Protection SDP uses simplified fire probabilistic risk assessment (PRA) methods, tools, and approaches. The general philosophy of the Fire Protection SDP is to minimize the potential for false-negative findings, while avoiding undue conservatism. The duration (or exposure time) of the degraded conditions is considered at all stages of the analysis. Compensatory measures (CMs) that might offset (in part or in whole) the observed degradation are considered in Phase 2.

Phase 1 is a preliminary screening assessment intended to identify findings that can be quickly classified as Green and dispositioned into the licensee's corrective action program without further analysis. Findings that do not screen to Green in Phase 1 pass forward to Phase 2.

Phase 2 of the Fire Protection SDP is quantitative and involves several analysis steps. Each step introduces greater refinement and detail. Quantitative screening checks are made each time new or refined analysis detail has been developed. The various screening steps are summarized in Table 4.1.1. Section 04.02 describes these screening steps in more detail. Steps 2.1-2.3 are performed in sequence, while the analyst, in an attempt to reduce the level of effort in screening the finding to Green, may decide to perform Steps 2.4-2.7 in any order.

Table 4.1.1 – Summary of Quantification/Screening Steps.

Step	Refined or New Information Added
2.1	Screen based on final estimate of duration factor (DF), and bounding (area-wide) estimates of the remaining factors in the six-factor formula for change in core damage frequency (ΔCDF)
2.3	Identify credible fire scenarios and screen finding to Green if none are identified
2.4	Obtain final fire ignition frequency (FIF) for each fire scenario and update risk quantification
2.5	Obtain final conditional core damage probability (CCDP) for each fire scenario and update risk quantification
2.6	Obtain final severity factor (SF) for each fire scenario and update risk quantification
2.7	Obtain final non-suppression probability (NSP) for each fire scenario and update risk quantification

04.02 General Approach

04.02.01 Phase 1: Qualitative Screening Analysis

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

The Phase 1 analysis procedure is provided in IMC 0609 Appendix F. Phase 1 involves five analysis steps. A flow chart illustrating the Phase 1 process is provided in IMC 0609 Appendix F. The Phase 1 steps are summarized as follows:

- Step 1.1: Provide a statement of the fire inspection finding.
- Step 1.2: Assign one of the eight categories to the fire finding.
- Step 1.3: Assign a degradation rating based on the potential impact the degraded condition might have on the performance of the degraded fire protection program element. Screen the finding to Green if the degradation rating is low.
- Step 1.4: Answer the screening questions for the category determined in Step 1.2 to determine if the finding is very low risk significant (screen to Green).
- Step 1.5: Screen based on licensee fire PRA results.

04.02.02 Phase 2: Quantitative Analysis

A finding that does not meet the Phase 1 screening criteria is processed through Phase 2. Phase 2 involves a quantitative assessment of ∆CDF given a finding. There are seven analysis steps in Phase 2, as discussed further below. The Phase 2 process is illustrated in a flow chart provided in IMC 0609 Appendix F. Each step introduces new detail and/or refines previous analysis assumptions and results.

The quantification process parallels fire PRA practice. In a fire PRA, the fire-induced CDF is quantified as the product of the following four terms:

a. Fire Ignition Frequency (FIF) - the likelihood that a potentially challenging fire will occur in a specific location during a reactor operating year (ry).
b. Severity Factor (SF) - the likelihood that the heat release rate (HRR) of an ignition source is sufficient to cause damage to a target or cause ignition of a secondary combustible.
c. Fire Damage State (FDS) Non-Suppression Probability (NSP) - the likelihood that fire suppression efforts fail to suppress the fire before a pre-defined set of plant components/electrical cables are damaged by the fire.
d. Conditional Core Damage Probability (CCDP) - the likelihood that the fire-induced damage to plant components/electrical cables leads to core damage (post-fire SSD efforts fail to achieve safe and stable hot shutdown conditions).

In addition to these four fire PRA quantification factors, the SDP also includes the duration factor (DF) associated with a finding, and, if applicable, an FIF adjustment factor (AF). The value of the DF established in Step 2.1.1 is used in all Phase 2 quantification steps. If the finding category assigned in Step 1.2 is Fire Prevention and Administrative Controls, an increase of the FIF by up to a factor of 10 may be applicable to hot work and transient combustible fires. Guidance for determining the applicable AF is provided in Steps 2.4.2 and 2.4.3.

The procedure for a Phase 2 analysis is documented in IMC 0609 Appendix F. The Phase 2 analysis involves seven steps, each involving specific analysis sub-steps. The steps and sub-steps are summarized as follows:

Step 2.1 – Bounding Risk Quantification:
- Step 2.1.1: Estimate the DF to be used in all Phase 2 quantification steps.
- Step 2.1.2: Estimate bounding area-wide value of the FIF.
- Step 2.1.3: Estimate bounding value of the AF.
- Step 2.1.4: Estimate bounding value of the SF.
- Step 2.1.5: Estimate bounding value of the NSP.
- Step 2.1.6: Estimate bounding value of the CCDP.
- Step 2.1.7: Evaluate the effect of the finding category on the bounding risk quantification.
- Step 2.1.8: Estimate bounding value of ∆CDF.

Step 2.2 – Identifying Credible Fire Scenarios and Information Gathering:
- Step 2.2.1: Initial FDS assignment based on the finding category.
- Step 2.2.2: Information gathering for the analysis of credible fire scenarios.

Step 2.3 - Ignition Source Screening and Fire Scenario Refinement:
- Step 2.3.1: Characterize fire ignition sources in the fire area under evaluation.
- Step 2.3.2: Screen ignition sources that are not capable of causing damage to a target or causing ignition of a secondary combustible (FDS1).
- Step 2.3.3: Screen ignition sources that are not capable of causing a damaging HGL in the fire compartment under evaluation (FDS2).
- Step 2.3.4: Screen fire ignition sources that are not capable of causing a damaging HGL in an adjacent compartment separated by a degraded barrier from the fire compartment under evaluation (FDS3).
- Step 2.3.5: Screening Check - finding screens to Green if ALL fire ignition sources screened out (no credible fire scenario).

Step 2.4 – Final FIF Estimates for Unscreened Fire Ignition Sources:
- Step 2.4.1: Estimate nominal fire frequencies for each unscreened fire ignition source.
- Step 2.4.2: Increase hot work and/or transient fire frequencies if finding is against administrative controls.
- Step 2.4.3: Reduce hot work and/or transient fire frequencies if CMs will reduce likelihood of fire occurrence.
- Step 2.4.4: Critical Area Adjustment Factor
- Step 2.4.5: Perform a screening check using updated room fire frequency.

Step 2.5 – Final CCDP Estimates:
- Step 2.5.1: Determine damaged target set and corresponding CCDP for FDS1 scenarios.
- Step 2.5.2: Determine damaged target set and corresponding CCDP for FDS2 scenarios.
- Step 2.5.3: Determine damaged target set and corresponding CCDP for FDS3 scenarios.
- Step 2.5.4: Perform screening using updated CCDPs.

Step 2.6 – Final SF Estimates:

Step 2.6.1: Determine the SF for each unscreened ignition source.

Step 2.6.2: Perform screening using updated SFs.

Step 2.7 - Final NSP Estimates:

Step 2.7.1: Determine damage and ignition times.

Step 2.7.2: Estimate the time to fire detection.

Step 2.7.3: Estimate performance time for fixed fire suppression systems.

Step 2.7.4: Estimate fire suppression time for manual firefighting.

Step 2.7.4: Estimate NSP for each FDS fire scenario.

Step 2.7.5: Perform screening check using updated NSPs.

In order to optimize the efficiency of the analysis, Phase 2 includes six screening checks. These screening checks ensure that a low significance finding will screen to Green as soon as the information developed is sufficient to support such a determination. A screening check is made each time a refined estimate of any one of the four fire risk quantification factors identified above is developed (DF remains constant once set in Phase 2). If at any time the estimated CDF change meets the screening criteria, the finding is assigned a preliminary significance of Green and the analysis is considered complete. Subsequent steps need not be performed. The Phase 2 screening checks are summarized as follows:

a. Step 2.1 includes a screening check that is based on a bounding quantification of the ΔCDF based on initial area-wide factors. DF is determined as part of this step and the resulting value is also used in all subsequent Phase 2 quantification steps. The screening ΔCDF is calculated as follows:

$$\Delta\mathrm{CDF} \approx \mathrm{DF} \times \mathrm{FIF} \times \mathrm{AF} \times \mathrm{SF} \times \mathrm{NSP} \times \mathrm{CCDP} \qquad [1]$$

FIF is a bounding area-wide estimate for the type of fire area under evaluation and, at this point in the analysis, does not credit any potential adjustments (i.e., AF = 1). SF and NSP are also assumed equal to 1 in this step. CCDP is a bounding value that is obtained based on an assessment of the unavailability and independence of the designated SSD path for the area under evaluation. If multiple areas are affected by the finding, the bounding risk quantification is based on the sum of the changes in CDF for all affected areas.

b. Step 2.3 screens a finding to Green if <u>all</u> fire ignition sources screen out as non-spreading and non-damaging (no credible fire scenario).

c. Steps 2.4-2.7 each include a screening check that obtains a refined assessment of the ΔCDF based on best available estimates of the six terms for each fire scenario that needs to be considered in the evaluation of a given finding. The refined screening ΔCDF is calculated as follows:

$$\Delta\mathrm{CDF} \approx \mathrm{DF} \times \sum_{i=1}^{N}\left[\mathrm{FIF_i} \times \left(\prod \mathrm{AF}\right)_i \times \mathrm{SF_i} \times \mathrm{NSP_i} \times \mathrm{CCDP_i}\right] \qquad [2]$$

where:

N	=	Number of fire scenarios evaluated for a given finding;
DF	=	Duration factor;
$\mathrm{FIF_i}$	=	Fire frequency for the fire ignition source that started scenario i;

AF	=	Ignition source specific frequency adjustment factors;
SF_i	=	Severity factor for scenario i;
NSP_i	=	Non-suppression probability for scenario i;
$CCDP_i$	=	Conditional core damage probability for scenario i.

If the refined ΔCDF is less than 1E-6 at any time in Phase 2 of the SDP, the analysis is complete and the finding screens to Green. When all steps have been completed and the final ΔCDF is still 1E-6 or greater, a Phase 3 assessment is required to determine the final risk significance of the finding.

04.03 Analysis Procedures

The procedures for the Fire Protection SDP Phase 1 and Phase 2 analyses are provided in IMC 0609 Appendix F, including its associated attachments. These procedures are intended to serve as essentially stand-alone working application tools and guidance. The procedures include an expanded description of each analysis step and the supporting information required to complete each step. Attachments to the Appendix F procedures provide additional details and guidance required for completion of specific analysis steps. Worksheets for managing and documenting the analysis are also provided.

This document is intended to provide supplemental guidance to support implementation of the IMC 0609 Appendix F procedures. In particular, the information in Section 0308.03F-05 provides additional discussion intended to enhance the analyst's understanding of the procedures. Section 0308.03F-05 also includes a set of examples illustrating how to the use the tables and plots in IMC 0609 Appendix F Attachment 8. The text focuses on expanded discussions on the intent of each analysis step, and on the relationships between steps. Section 0308.03F-06 of this document provides basis discussions supporting each step in the analysis procedure.

04.04 Flexibility in Exercising the Analysis Procedures

04.04.01 Fire Protection Significance Determination Process Flexibility

As discussed in Section 04.02, the Fire Protection SDP uses simplified versions of fire PRA methods, tools, and approaches. Fire PRA is, by design, a flexible analysis process. PRA analysts exercise judgement and tailor their analysis process to suit specific applications. It is intended that the Fire Protection SDP retain this flexibility.

The analysis procedures involve a series of steps. The order of the steps, as written, should optimize the analysis of most fire protection findings. However, situations will arise where the as-written process flow path may not be the optimum path. In such cases, the procedures should be viewed with flexibility and adjustments to either the order of analysis steps, or to the analysis depth in a specific step may be considered. This is particularly valid for Steps 2.3 through 2.7.

Sections 0308.03F-05 and 0308.03F-06 provide additional information about the analysis process, its intent, and the inter-relationships between various steps. Section 0308.03F-05 provides additional explanatory material in the form of supplemental background and supporting information for each analysis task. Section 0308.03F-06 provides information on the underlying basis for the Fire Protection SDP approach. Reference to this information should support decision making with regard to process flexibility.

04.04.02 Flexibility Examples

This section provides examples where some adjustment of the analysis process may be appropriate. The examples are not exhaustive, but rather, are illustrative of the intent with regard to process flexibility. In general, flexibility may be exercised in the order of step performance and in the depth of a given step.

Specific step input assumptions should not be adjusted except as allowed by the guidance as written. That is, no adjustments should be made to assigned values for factors such as screening criteria, FIF, fire intensity profiles, SF, damage criteria, damage times, suppression times, suppression reliability, etc., unless the possibility of an adjustment to suit case-specific factors is called out in the procedures. Supplemental adjustments to input assumptions are deferred to Phase 3.

04.04.03 Early Completion of a Later Step

The order in which analysis steps are performed may be adjusted if early completion of a later step might result in a finding screening to Green with a reduced level of effort.

a. Example 1: In Step 2.1.6, a designated SSD path is identified but not credited. Step 2.4 provides refined fire frequencies for the ignition sources in the fire area under evaluation, and the screening ∆CDF for the finding determined in Step 2.4.4 is already at 9E-6. Hence, one additional order of magnitude in risk reduction would result in a Green color assignment. In this case, it may be more efficient to develop a refined CCDP value prior to the development and analysis of specific fire growth and damage scenarios (e.g., Steps 2.5.1-2.5.3). Note that in this example, Step 2.5 must be entered assuming fire damage consistent with the limiting, or most severe, unscreened FDS scenario. Should the analysis fail to demonstrate the anticipated risk reduction, the analysis can return to Step 2.5.1 for completion of the fire growth and damage analysis tasks.
b. Example 2: A finding impacts a fire area with a minimal set of fire ignition sources. Further, it is expected that the fire ignition sources will likely screen out as non-threatening such that no credible fire scenario will be developed for the fire area. In this case, it may be appropriate to first complete Worksheets 2.2.2b and 2.2.2c as described in Step 2.2.2, and then perform Step 2.3.2 to screen ignition sources that are not capable of causing damage to a target or ignition of a secondary combustible. If all ignition sources are screened out, the finding screens to Green and the analysis is complete. If some ignition sources are retained, perform Step 2.4 to determine the FIF for each of the unscreened ignition sources and return to Step 2.1 with the resulting refined area-wide FIF (sum of FIF for all unscreened ignition sources).

In performing a later step earlier in the analysis process, the analyst is essentially developing a more refined estimate for one of the fire risk quantification factors described in Section 04.02.02 earlier in the analysis process. The refined risk quantification factor is then folded into the CDF formulas <u>in place of</u> the corresponding, and less refined, value that would have been used had the earlier steps been completed in their normal order.

Care must be exercised to ensure that no “double counting” of the same risk quantification factor occurs. Replacing the nominal value with the refined value ensures that no double counting occurs.

In many cases, the nominal value for a factor that is being replaced by early completion of a later step may be an implied value of 1.0. For example, the term NSP does not appear in the risk quantification equations for Steps 2.1 through 2.6, assuming these steps are performed in sequence. Hence, the implied value of NSP is 1.0 for these steps; that is, Steps 2.1 through 2.6 assume that suppression efforts will fail to protect exposed components/electrical cables in a timely manner with a probability of 1.0. A specific value of NSP is not calculated until Step 2.7. (If the analyst senses that estimation of a lower NSP could be the determining factor in lowering the ΔCDF below the threshold for Green, (s)he should pursue Step 2.7 early in the process.)

04.04.04 Omission of Non-Productive Steps

Certain steps may not need to be performed if sufficient information has already been gathered to determine that no discernable risk reduction benefit will be gained.

> Example: Based on knowledge of the designated SSD path for a given fire area, a decision may be taken to not credit that path in the initial stages of analysis. In this case, Step 2.1 might not be formally conducted and the analysis might proceed directly to Step 2.2 using a screening CCDP value of 1.0.

04.04.05 Reducing Analysis Depth for a Given Step

The depth of analysis pursued in a given step may be reduced if additional depth is either not needed to conclude that the finding is Green, or if additional depth will not provide any discernible risk reduction benefit.

> Example: The fire area impacted by a finding has full coverage sprinkler protection that is not impacted by the finding. Step 2.7.1 has been completed, and the actuation time analysis in Step 2.7.3 reveals that the sprinklers will actuate at least 10 minutes prior to the estimated fire damage time, even for the individual fire scenario with the shortest damage time (from Step 2.7.1). Hence, the sprinklers will be given maximum credit in all scenarios for suppressing the fire prior to damage (98 percent based on general system reliability, see Table A7.1 in Attachment 7 to Appendix F).
>
> This result indicates that, at worst, a 0.02 NSP (1 – 0.98 = 0.02) can be applied to all scenarios reflecting credit only for the fixed suppression system. The added consideration of manual firefighting can only improve this value (reduce the NSP). Hence, crediting only the fixed suppression system would be conservative.

When combined with previous factors a NSP of 0.02 may be sufficient to conclude the finding is Green. In this case Step 2.7 can be completed without a formal analysis of sprinkler activation time for each individual fire scenario, and without an analysis of manual fire fighting for any fire scenarios (i.e., without completing Step 2.7.4). The finding can be screened to Green based on Step 2.7.5 using a bounding NSP value of 0.02.

0308.03F-05 SUPPORTING GUIDANCE AND EXPLANATORY MATERIAL

This section provides supporting guidance and additional explanation of the various steps in the Fire Protection SDP analysis procedure. The material includes additional discussion of the relationship between steps, PRA methods background information, and historical perspectives relating to the Fire Protection SDP analysis approach. The information in this section is not required for completion of an SDP Phase 1 or Phase 2 analysis; rather, it is intended to enhance the analyst's understanding of the analysis approach.

05.01 Phase 1 Analysis Supporting Information

05.01.01 Step 1.1: Provide Statement of Fire Inspection Finding

No supplemental guidance is provided regarding this step.

05.01.02 Step 1.2: Assign a Fire Finding Category

No supplemental guidance is provided regarding this step.

05.01.03 Step 1.3: Screen Low Degradation Deficiencies

No supplemental guidance is provided regarding this step.

05.01.04 Step 1.4: Qualitative Screening Questions for Eight Individual Categories

No supplemental guidance is provided regarding this step.

05.01.05 Step 1.5: Screen Based on Licensee Fire PRA Results

No supplemental guidance is provided regarding this step.

05.02 Phase 2 Analysis Supporting Information

05.02.01 Step 2.1: Bounding Risk Quantification

Rather than quantifying ∆CDF based on the sum of the risk contributions from all credible fire scenarios in the area under evaluation, Step 2.1 obtains a conservative estimate of ∆CDF based on bounding area-wide values for the PRA risk quantification terms discussed in Section 04.02.02. In fact, the screening check in this step considers only the DF, the fire area FIF, and the fire-induced CCDP. In the context of the six-term risk quantification framework discussed in Section 04.02.02, this screening step (1) does not account for the fact that some fires in the area under evaluation may not cause damage, and (2) gives no credit to fire suppression. In mathematical terms, SF and NSP are, in effect, both set to 1.0 in this step. In addition, the fire area fire frequency does not credit potential adjustments, i.e., AF = 1.0. DF is determined in Step 2.1.1 and remains at the same value in all subsequent Phase 2 quantification calculations. A bounding FIF is determined in Step 2.1.2 based on the functionality of the area under evaluation. A first-level estimate of the fire-induced CCDP is calculated in Step 2.1.6 based on the potential to credit the post-fire SSD path. All fire PRA risk quantification terms, except DF, will be refined in subsequent steps of the Phase 2 analysis.

05.02.01.01 Step 2.1.1: Estimate the Duration Factor

The DF value determined in this step is final. In other words, the same value is used in all Phase 2 risk quantification steps.

05.02.01.02 Step 2.1.2: Estimate Bounding Value of the Fire Ignition Frequency

The FIFs in Table 2.1.3 of Appendix F are used when transient combustibles or hot work fires are the only ignition sources that need to be considered, which includes findings in the Fire Prevention and Administrative Controls Category or when there are no other types of ignition sources present in fire area under evaluation. The area-wide FIFs in Table 2.1.2 of Appendix F are used if other ignition sources need to be considered.

05.02.01.03 Step 2.1.3: Estimate Bounding Value of Ignition Frequency Adjustment Factors

No supplemental guidance is provided regarding this step (AF is set to 1.0).

05.02.01.04 Step 2.1.4: Estimate Bounding Value of the Severity Factor

No supplemental guidance is provided regarding this step (SF is set to 1.0).

05.02.01.05 Step 2.1.5: Estimate Bounding Value of the Non-Suppression Probability

No supplemental guidance is provided regarding this step (NSP is set to 1.0).

05.02.01.06 Step 2.1.6: Estimate Bounding Conditional Core Damage Probability

A key aspect of fire PRA analysis approaches is to estimate the conditional probability (or likelihood) that fire-induced damage to plant components/electrical cables will lead to core damage, that is, the CCDP. Said another way, the PRA estimates the probability that given fire-induced damage, post-fire SSD efforts will fail to achieve safe and stable shutdown conditions.

The assessment of CCDP is done at two levels: Step 2.1.6 represents the first level of analysis; Step 2.5 represents the second level of analysis. In the first level of analysis, only the designated post-fire SSD path is credited. In the second level of analysis, all available means for achieving SSD are credited.

Step 2.1.6 involves the identification and assessment of the post-fire SSD path for the fire areas examined during an inspection. If the SSD path is independent of any FDS scenarios that might be developed as a part of the finding assessment, then it will be credited at a nominal level until Step 2.5 is performed. If the SSD path might be damaged given at least one possible FDS fire scenario that could be developed in subsequent steps, then credit for the SSD path will be deferred until Step 2.5 when specific fire damage scenarios have been defined. Credit for the SSD path is re-considered on a scenario-specific basis in Step 2.5.

The post-fire SSD path is documented in the licensee's fire protection program for each fire area in the plant. Step 2.1.6 can be completed based entirely on plant documentation.

Once the areas to be examined during the inspection have been identified, the following licensee documents should be requested and reviewed to support this step including:

a. The licensee's fire hazards analysis for the fire areas being evaluated.
b. The post-fire SSD analysis for the fire areas being evaluated.
c. The licensee's lists of required and associated circuits.
d. Post-Fire operating procedures applicable to the fire areas being assessed.
e. Documentation for any NRC approved deviations or exemptions relevant to the fire areas being assessed.

Identify the Designated Post-Fire SSD Path

Fire protection regulations require that licensees identify, analyze, and protect a designated post-fire SSD path that will remain free of fire damage given a fire impacting any single fire area in the plant. In Step 2.1.6, the analyst is first asked to identify this designated SSD path. This part of the step also involves gathering basic information to characterize this SSD path.

The SSD path should be documented in the licensee's post-fire SSD analysis. The designated post-fire SSD path may vary by plant location and should be identified for each fire area to be inspected.

As a part of the SSD path identification effort, the corresponding Appendix R Section III.G.2 compliance strategy should also be determined for plants that did not transition to NFPA 805. Section III.G.2 requires the separation and protection of the SSD pathways. If an exemption or exception to III.G.2 has been granted by the NRC for the fire area of interest, the exemption should also be carefully reviewed so that the separation or protection strategy is clearly understood prior to entry into the fire area.

The analyst should also obtain and review the corresponding procedures for execution of post-fire SSD. Particular note should be taken of any credited human actions, which, if important to the evaluation, are addressed in Phase 3. The location where these actions take place is important to the assessment of the independence of the identified SSD path, especially if the process includes any human actions that require entry into, or passage through, the fire area under analysis.

Finally, the functions and systems that are required to support the SSD path should be identified. The analyst should also review the corresponding circuit analysis results for the designated SSD path. This review may include an assessment of the completeness of the SSD required and associated circuit component lists. Again, this step may be completed prior to entry onto the plant site for the inspection. Note that findings against the post-fire SSD program may arise from these reviews.

Assess the Unavailability of the Identified SSD Path

In the second part of Step 2.1.6, a total unavailability factor is assigned to the post-fire SSD path. The value used is either 1.0 (no credit - assigned when the SSD path fails to meet the independence criteria), 0.1, or 0.01. The unavailability factors are based on the characteristics of the SSD path. The assessment criteria are described in Table 2.1.4 in Appendix F. In general, terms, the unavailability factor is based on the failure probability for the weakest link in the SSD path.

Assess the Independence of the Identified SSD Path

The intent of the third part of Step 2.1.6 is to determine if the designated SSD path is independent of all fire damage scenarios that might be developed in later steps of the analysis. If the SSD path might be damaged in one or more fire scenarios, then crediting the SSD path at this early stage of analysis could lead to false-negative findings.

It is, in fact, likely that the SSD path could be credited in some fire scenarios, even if it cannot be credited in all possible scenarios. However, at this stage of analysis, specific fire damage scenarios have not been defined. This does not take place until Step 2.4 has been completed. Hence, a conservative assessment of SSD path independence is necessary. Credit for the SSD path is reassessed in Step 2.5 once the specific fire damage scenarios have been defined.

05.02.01.07 Step 2.1.7: Effect of Finding Category

No supplemental guidance is provided regarding this step.

05.02.01.08 Step 2.1.8: Estimate Bounding Value of ∆CDF

No supplemental guidance is provided regarding this step.

05.02.02 Step 2.2: Identifying Credible Fire Scenarios and Information Gathering

05.02.02.01 Step 2.2.1: Initial FDS Assignment

The initial assignment of FDS scenarios is intended to focus the analysis on those fire scenarios that may change as a result of a finding.

> Example: If the finding is a degraded fire barrier element separating two fire areas (category: fire confinement) then only fire scenarios leading to the spread of fire between these two fire areas are relevant to the risk increase calculation. Any fire scenario that impacts only one fire area or the other will not change as a result of the observed fire barrier degradation.

The initial FDS assignment is broadly inclusive of potential fire scenarios.

05.02.02.02 Step 2.2.2: Information Gathering for the Analysis of Credible Fire Scenarios

Supplemental guidance supporting Step 2.2.2 is included as Attachment 3 to Appendix F.

The identification and counting of fire ignition sources is intended to include only those fire scenarios relevant to the calculation of risk increase. That is, if the risk contribution for a fire scenario is the same with or without the observed degradation, then the corresponding fire ignition source should not be counted in this step. Several specific cases where the scope of the fire ignition source counting exercise is sharply limited are discussed in Appendix F. Below are additional illustrative examples:

a. Example 1: The finding being evaluated is a partial-coverage sprinkler system installed where a full coverage system is required. As installed, the system provides adequate fire protection for those fire sources within the coverage zone, but not all of the fire sources in the fire area are within this coverage zone. Extending the coverage zone to the full fire area would not alter the risk contribution for fire sources already provided with adequate fire protection (i.e., those fire ignition sources within the existing coverage zone). Hence, the SDP Phase 2 analysis of risk increase should focus only on those fire sources outside the system's coverage zone.

b. Example 2: The finding being evaluated involves a violation of the combustible controls program. In this case, only transient fuel fires are relevant, and fixed fire ignition sources need not be evaluated. (A transient fire may still spread to fixed combustibles, but the only fire ignition source that needs to be considered is a transient fire.)
c. Example 3: The finding being evaluated involves a degraded raceway fire barrier - a small un-patched hole was left in the barrier after maintenance work. In this case, the SDP Phase 2 analysis only needs to consider those fire ignition sources that have the potential to threaten the cables within the degraded fire barrier. Because the hole is highly localized, a fire that might threaten the protected cables would generally need to be directly below the point of degradation. In this case, the Phase 2 analysis would focus primarily on growth and damage scenarios involving those fire ignition sources located directly below the point of degradation. A bounding assessment of the potential hot gas layer (HGL) effects for other fire ignition sources in the fire area would also be needed.

05.02.03 Step 2.3: Ignition Source Screening and Fire Scenario Refinement

05.02.03.01 Step 2.3.1: Characterize Fire Ignition Sources

Characterization of a fire ignition source means that the initial HRR profile (before fire spread to secondary combustibles) is set, and a specific location is assigned to the fire. Additional guidance to address these two aspects of ignition source characterization is provided below. In some cases, the Phase 2 analysis can be made more efficient by considering ignition sources of a particular type as a group. Additional guidance for grouping ignition sources and assigning their location is also provided below.

Assigning HRR Characteristics:

Attachment 5 to Appendix F provides the HRR profiles and related characteristics of the most common ignition sources. Guidance from either Regional or Headquarters fire protection staff should be sought when determining the HRR characteristics of ignition sources that are not provided in Attachment 5 to Appendix F, such as those of severe fires involving the main turbine generator set or hydrogen fires.

Grouping of Fire Ignition Sources:

In some applications, it is both more efficient and appropriate to group fire ignition sources. The most common example is electrical panels. It is quite common to encounter a "bank" of like electrical panels. In such a panel bank, each individual panel is essentially identical to its neighbors and will be assigned the same fire characteristics. In such cases, non-HEAF fires involving each individual panel may be represented by one (or more) fire ignition source scenario(s) that conservatively bound(s) the conditions of the entire panel bank. That is, fires involving all members of the group are treated using one (or more) representative bounding case(s). The FIF for the group is equal to the sum of the FIF for all sources in the group. For HEAF scenarios, switchgear are grouped in banks by default.

A group of like fire ignition sources may be treated, in effect, as a single fire ignition source scenario in subsequent analyses. Grouping is appropriate when all of the following criterial are met:

a. All of the individual fire ignition sources are of the same type and hence have the same HRR characteristics (e.g., a row of breaker panels). It may be possible to group ignition sources of different types provided each ignition source is assumed to have the most severe HRR characteristics of all sources in the group.
b. All of the individual fire ignition sources have a similar proximity to the nearest secondary combustible fuels and/or fire damage targets (e.g., a stack of cable trays running directly above a row of electrical panels). This means that a fire involving any one individual source will behave similarly to the other individual sources in the group with regard to fire growth, spread, and damage.
c. Each of the individual fire ignition sources will represent a roughly equivalent challenge to fire detection and suppression given that a fire does occur (e.g., none of the sources is located in an especially challenging location, or in a location with different levels of fire detection and/or suppression coverage, in comparison to other sources).

Grouping of ignition sources may still be appropriate even given some variation in the features noted in the above criteria if the group can be conservatively bounded by one or more representative cases. Again, judgement is required in making such decisions.

<u>Assigning a Location to Fire Ignition Sources:</u>

Fixed fire ignition sources are assigned to their actual physical location:

a. In plan view, the fire location for a fixed fire ignition source is the physical center of the fire ignition source itself, unless this choice is in obvious conflict with the likely location of a fire involving the source. However, the horizontal distance to the nearest edge of the ignition source is used to determine whether a target is within the radial ZOI.
b. The fire base for closed top electrical enclosures (i.e., enclosures without horizontal top vents or openings) is assumed to be at 1 ft. below the top of the enclosure as determined from a walkdown. For electrical enclosures not sealed at the top, the fire base is placed at the top of the enclosure. (Reference 12, FAQ 08-0043)
c. For electric motors sealed at the top, the fire base height is the elevation of the highest vent. (If the vent location is not known, assume the fire base height to be 1 ft. below the top of the motor, but not below the base of the motor housing.) For a motor not sealed at the top, the fire base height is at the top of the motor. (Reference 10)
d. The assumed fire base height for dry transformers sealed at the top and fully sealed dry transformers is 1 ft. below the top. For a dry transformer not sealed at the top, the fire base height is at the top of the transformer. Alternatively, for side-vented dry transformers, the analyst can locate the fire base at the uppermost vent. (Reference 12)
e. The default elevation of the fire base for transient combustibles is 0.5 ft. above the floor. (Reference 13)

In other cases, the choice of fire ignition source location is more complex. For example, choosing one or more representative locations (i.e., one or more representative fire ignition source scenarios) to represent a grouped set of ignition sources requires the application of judgement. Examples of these and other similar cases include:

a. Choosing one or more representative locations for a bank of electrical panels of the same general type.

b. Choosing the location for a transient fuel fire.
c. Choosing the location for a self-ignited cable fire.
d. Choosing the location for a transient oil spill fire.

In general, the location should be chosen so as to maximize the potential damage to targets when estimating the zone of influence (ZOI). The assignment of source location will drive aspects of the fire ignition source scenario screening process (Steps 2.3.2-2.3.4) and the fire damage time analysis for unscreened fire ignition source scenarios (Step 2.7.1).

For a grouped fire ignition source set, and for non-fixed fire ignition sources (transients, hot work, liquid fuel spills), the location chosen should conservatively bound the potential for fire spread and damage. This often means choosing the specific ignition source or location that is nearest secondary combustibles, or is nearest a thermal damage target. For radiant heat exposure, nearest means line of sight. For plume exposure, nearest means the first target directly above the source (directly above the source's physical "footprint").

a. Example 1: A fire area contains multiple fire ignition sources of a similar type; in this example, two rows of breaker panels located on opposite sides of the room. Proximity to secondary combustibles (e.g., overhead cables) and fire protection features, and coverage are all found to be similar regardless of which individual panel is considered. Cable locations are not well characterized (e.g., certain cables are known (or assumed) to be in the fire area but their specific locations within the area are not known). A single bounding location is used to represent all of the individual breaker panels and the fire is located within the individual electrical panel that is closest to secondary combustibles and/or damage targets.
b. Example 2: The physical situation is similar to Example 1, but in this case, there is detailed information on component and cable locations within the fire area. Consistent with an FDS1 type scenario, fires involving one row of the breaker panels may damage a Train A function, while fires involving the second row of breaker panels may damage a Train B function. Consistent with FDS2, fires involving any panel might damage both the Train A and B functions. In this case, at least three fire scenarios are developed, one representing each row of breaker panels for FDS1, and a third representing any panel fire leading to FDS2 level damage. Each scenario requires that a representative location be identified.

In the case of transients, the fire base is always assumed to be 0.5 ft. above the floor, unless specific conditions observed during an inspection suggest otherwise. The exact location of the fire may eventually prove critical to the fire spread and damage potential if, for example, there is a cable pinch point where multiple target cables cross. For the purposes of this screening step, it is only necessary to determine whether a transient fire in some plausible location might spread or cause damage. That is, if all combustible materials or targets are located well above the floor, then any floor level transient fire may not cause damage. In this case, transients screen out. However, if there is any location in the fire area where combustible materials or damage targets are low enough to be within the transient fire's damage zone, then the transients are retained. The analyst may use judgement to determine if a transient existing in such a location is plausible. If the identified location is not plausible, then the transients could still be screened out.

<u>05.02.03.02 Step 2.3.2: FDS1 Ignition Source Screening</u>

ZOI tables and plots have been pre-calculated for fixed and transient ignition sources and confined and unconfined oil fires. The results of these ZOI calculations are presented in table/plot set A of Attachment 8 to Appendix F.

The ZOI for fixed and transient ignition sources can be determined from Tables A.01 (for electrical enclosures) and A.02 (for transient and other fixed ignition sources) of Attachment 8 to Appendix F. In these tables, the ZOI is presented as a function of the 98th percentile of the peak HRR of the ignition source, which can be obtained from Tables A5.1 (for fixed ignition sources) and A5.2 (for transient ignition sources) in Attachment 5 to Appendix F. Tables A.01 and A.02 provide the vertical ZOI for two configurations; unobstructed open plume (also referred to as "free-burn"), and corner plume. The latter is applicable for fixed and transient ignition sources with edges that are at a distance of 2 ft. or less from the two intersecting walls of a corner. The former is applicable for fixed and transient ignition sources with edges that are at a distance of at least 2 ft. from the intersecting walls of a corner. Fixed and transient ignition sources within 2 ft. of a single wall are considered to be in the open. Consequently, the unobstructed open plume configuration would be used for a fixed ignition source that is within 2 ft. of one of the intersecting walls of a corner and close to but not within 2 ft. of the other intersecting wall.

The results of the ZOI calculations for confined oil pool fires are presented as a function of the diameter of the pool and the type of oil in Figures A.02-A.04 (vertical) and Figures A.05-A.07 (radial) of Attachment 8 to Appendix F. The results of the ZOI calculations for unconfined oil spill fires are presented as a function of the volume of the spill and the type of oil in Figures A.08-A.10 (vertical) and Figures A.11-A.13 (radial) of Attachment 8 to Appendix F. The table in Figure A.01 is used to determine the minimum spill volume that that is needed to cover a specified containment area. If the spill volume is less that the tabulated value, the fire is treated as an unconfined spill even though a containment of the specified size is present.

Two Fire Dynamics Tools (FDTs) from NUREG-1805 Supplement 1, Vol. 2 (Reference 14) were used in conjunction with heat soak method calculations to generate the vertical and radial ZOI values that are presented in table/plot set A of Attachment 8 to Appendix F. The two FDTs are identified below. The assumptions that were made in these calculations are discussed in Section 06.03.01. To automate the development of the tables and plots in Attachment 8 to Appendix F, the FDT calculations were implemented in a series of spreadsheets.

In the 2018 Fire Protection SDP, the analyst could use the aforementioned FDT spreadsheets supplied with Reference 14 to perform custom calculations as an alternative to using the pre-calculated ZOI tables and plots. However, because the heat soak method requires an iterative process to determine the ZOI, direct use of the FDT spreadsheets is no longer available as an alternative. It is recommended that additional guidance be sought from either the Regional or Headquarters staff if the analyst decides or needs to perform custom ZOI calculations.

Plume Centerline Temperature Correlation

The plume centerline temperature correlation described in Chapter 9 of Reference 11 was used in conjunction with heat soak method calculations to develop the vertical ZOI tables and plots in Attachment 8 to Appendix F. The following FDTs spreadsheet can be used to calculate the centerline temperature of a buoyant fire plume and the vertical ZOI:

09_Plume_Temperature_Calculations_Sup1.xls.

The plume correlation is dependent on the fire location, and in particular, must be adjusted for fires located adjacent to a wall or corner as follows:

a. For fires in an open area away from corners, the 98th percentile HRR and the characteristic dimension (effective diameter) of the ignition source are used in the plume temperature calculation directly.
b. For a fire located directly next to a corner, the 98th percentile HRR is multiplied by four and the characteristic dimension is multiplied by two in the plume temperature calculation. The basis for these adjustments is discussed in Section 06.03.01.02.

The 2013 version of Appendix F recommended that for a fire located directly next to a wall, the 98th percentile HRR be multiplied by two. Wall fire adjustments are not considered in the present Fire Protection SDP. For the purposes of the Phase 2 analysis, a fire is considered to be near a corner if it is within two feet of each of the two walls making up the corner.

Radiant Heat Flux Calculation

A modified version of the "Solid Flame Radiation Model" for estimating the radiant heat flux to a target described in Chapter 5 of Reference 11 was used in conjunction with heat soak method calculations to develop the radial ZOI tables and plots in Attachment 8 to Appendix F. The following FDTs spreadsheet can be used to calculate the radiant heat flux from the fire to a target and the radial ZOI:

05.1_Heat_Flux_Calculations_Wind_Free_Su1.xls (Click on Solid Flame 2 Tab).

05.02.03.03 Step 2.3.3: FDS2 Ignition Source Screening

Pre-calculated tables and plots have been developed that present the minimum HRR of a fire in a compartment that is required to create a damaging HGL as a function of the type of targets in and the physical dimensions (floor area and ceiling height) of the compartment. The results of these calculations are presented in table/plot set B of Attachment 8 to Appendix F. The tables and plots in set B are used to ensure that general heating of a room by a fire ignition source, in and of itself, cannot lead to component damage. Few fire sources will be of sufficient intensity, in and of themselves, to cause widespread damage in a room. Exceptions will be encountered given either a relatively small room and/or particularly challenging fire sources (e.g., oil-filled transformers or the turbine generator set).

The FDT from Reference 14 that was used to generate the HGL tables and plots in set A of Attachment 8 to Appendix F is described below. The assumptions that were made in the HGL calculations are discussed in Section 06.03.02. To automate the development of the HGL tables and plots in Attachment 8 to Appendix F, the FDT calculations were implemented in a series of spreadsheets.

The heat soak method has not been implemented in the present Fire Protection SDP for FDS2 and FDS3 scenarios. Consequently, as an alternative to using the pre-calculated HGL tables and plots, the analyst may choose to use the aforementioned FDT spreadsheet supplied with Reference 14 to perform custom calculations. This approach may also be useful to analyze cases for which the input parameters are outside the range considered in the development of the tables and plots. It is recommended that additional guidance be sought from either the Regional or Headquarters staff if the analyst decides or needs to perform custom FDT calculations.

Hot Gas Layer Temperature Analysis Correlation

The “Temperature-NV” correlation described in Chapter 2 of Reference 11 was used to develop the HGL tables and plots in Attachment 8 to Appendix F. The following FDTs spreadsheet can be used to calculate the HGL temperature for a fire with a specified HRR in a naturally vented compartment:

02.1_Temperature_NV_Sup1.xls.

In most cases, the thermally thick correlation will apply. Additional guidance is provided within the electronic spreadsheet. Using the spreadsheet, the predicted HGL temperature will rise with increasing time. Screening should consider the temperature at 30 minutes. By this time, conditions will be approaching steady state, and the likelihood of fire suppression is relatively high for most scenarios. This is taken as a representative estimate of the HGL temperature likely to be observed during an extended fire involving the fire ignition source.

05.02.03.04 Step 2.3.4: FDS3 Ignition Source Screening

This screening step is only performed for findings in the Fire Confinement Category. The approach is similar to that in Step 2.3.3, except that the two compartments that are separated by a degraded barrier are combined into a larger virtual compartment. The floor area of the virtual compartment is equal to the sum of the floor areas of the compartments that are combined. The ceiling height of the new compartment can conservatively be assumed as the lower of the ceiling heights of the compartments that are combined. The latter may be overly conservative if the exposed compartment is significantly taller than the exposing compartment and comparable or larger in area. In this case, the analyst may consider determining whether any of the ignition source fires postulated in the exposing compartment would be capable of generating a damaging HGL in the exposed compartment. Ignition sources that only lead to fires with a maximum HRR that is insufficient to cause a damaging HGL can then be screened.

05.02.03.05 Step 2.3.5: Screening Check

No supplemental guidance is provided regarding this step.

05.02.04 Step 2.4: Final Fire Ignition Frequency Estimates

05.02.04.01 Step 2.4.1: Nominal Fire Frequency Estimation

FIFs for a range of ignition sources are tabulated in Attachment 4 to Appendix F. For most fire ignition sources, the fire frequency is provided on a per component basis. However, for non-qualified cables, transients, and hot work a relative ranking of fire areas as low, medium, or high is required. The guidance for assigning these rankings is provided in Attachment 4 to Appendix F. In addition, Table A4.1 in Attachment 4 to Appendix F gives plant-wide FIFs for battery chargers and junction boxes. Total plant-wide unit counts need to be obtained to determine the per unit frequencies for these ignition sources. Furthermore, the following ignition sources require a HEAF zone-wide unit count to determine the per unit FIF from the FIF provided in Table A4.1 in Attachment 4 to Appendix F:

- Load center HEAFs – requires an estimate of the total number of supply circuit breakers.
- Switchgear HEAFs – requires an estimate of the total number of switchgear banks in the HEAF fault zone (1 or 2) where the switchgear unit under analysis is located.

- Non-segregated bus duct HEAFs – requires an estimate of the number of non-segregated bus duct transition points, or the total length of non-segregated bus ducts in the bus duct HEAF fault zone (BDUAT or BDSAT versus BD1, BD2 or BDLV) where the non-segregated bus duct under analysis is located.

The location of the switchgear and non-segregated bus duct in the electrical distribution system of the plant in discussed in detail in Reference 15, and is summarized in Attachment 3 to Appendix F.

05.02.04.02 Step 2.4.2: Findings Based on Increase in Fire Frequency

High Degradation Findings Against the Combustible Controls Program

Recall that combustible control program findings are ranked as either high or low degradation (see Attachment 2 to Appendix F). Low degradation findings screen to Green in Phase 1. Hence, this step only applies to high degradation findings.

If the finding being evaluated involves a violation of the combustible controls program, then the fire frequency for transient fires may be increased to reflect an increased likelihood that improperly stored or inappropriate transient fuels might be ignited. Fire areas are ranked using a low/medium/high likelihood ranking scheme for transient fires as described in Attachment 4 to Appendix F.

The increase in fire frequency for a given fire area is reflected by increasing the likelihood ranking by one level from what would normally be assigned. Thus, an area that would normally be ranked as low becomes medium, and a medium area becomes high. For a fire area already ranked as high likelihood for transient fires, the base fire frequency is multiplied by 3. The rationale for the factor of 3 is provided in Section 06.02.04.02.

High Degradation Findings Against a Hot Work Fire Watch

If the finding is associated with hot work permitting and/or hot work fire watch provisions of the fire protection program, then Step 2.4.2 will increase the hot work fire frequency. Hot work findings are ranked as either high or low, and low degradation findings screen to Green in Phase 1. Hence, this step is only applied to high degradation hot work findings.

As with the transient fire case, fire areas are ranked as low/medium/high likelihood for hot work fires. A violation of hot work requirements in a fire area automatically results in a fire area being ranked as high likelihood for hot work fires.

However, the base fire frequency values for hot work fires already credit an effective hot work fire watch. A high degradation means that the fire suppression function of the fire watch is compromised. The fire event data show that at least 2 out of 3 hot work fires are suppressed promptly by the fire watch. This has been credited in the base fire frequency estimates. That is, the base fire frequency reflects only those fires where prompt suppression did not occur. If the fire watch is not functional for fire suppression purposes, then removal of this credit is appropriate.

For a high degradation of hot work administrative controls, the base hot work fire frequency for a high likelihood fire area is multiplied by a factor of 3. The rationale for the factor of 3 is provided in Section 06.02.04.02.

05.02.04.03 Step 2.4.3: Adjustment Factors for Compensatory Measures

The base fire frequency estimates include at least a nominal fire frequency for hot work and transient fires in all fire areas. In Step 2.4.1, the fire area must be ranked at least as low and hence is assigned some fire frequency. Step 2.4.3 credits administrative controls, which prevent the introduction of combustibles or performance of hot work in a fire area during normal plant operations or during the exposure time of the finding if the plant-specific conditions merit this adjustment.

The following criteria are used to credit measures that may reduce fire frequency:

a. If there is a combustible control system supported by frequent surveillance patrols (at least once per shift) that would preclude transients from a fire area, assign the low likelihood rating FIF for transient fires from Table A4.1 to the fire area and postulate the TCCL HRR profile in the analysis of transient fire scenarios. It is expected that a review of surveillance reports would be performed to identify any cases of improperly stored combustibles. If surveillance reports indicating improperly stored materials during the finding exposure period are found, then the unadjusted likelihood rating FIF is retained and a generic HRR profile is to be postulated.
b. If hot work is improbable in the fire area under review and it can be shown that no hot work has been performed in the area during the exposure period associated with the finding, the hot work fire frequency can be set to zero by applying an AF = 0.0. This could occur if hot work has been precluded by a compensatory measure, or if by normal practice hot work is explicitly prohibited during normal plant operations. It is expected that hot work permits would be reviewed to confirm that no hot work occurred.

Note that a zero fire frequency overall is not permitted for any location. The minimum fire frequency that can be assumed in a given location is 7.0E-6, which is the lowest per unit fire frequency in Table A4.1 of Attachment 4 to Appendix F. Consequently, the full credit for CMs cannot be taken in transient-free zones where no other ignition sources are present, for example.

05.02.04.04 Step 2.4.4: Critical Area Adjustment Factors

Transient Fire Critical Area Adjustment Factor

Transient combustibles can be postulated at any location in a fire area where temporary or permanent storage of transient fuel material is considered plausible. The corresponding floor space is referred to as the “plausible” floor area. The “critical” floor area for a specified transient fire scenario (i.e., a transient fire scenario with a specified target set) is a subset of the plausible floor area and is equal to the total floor area where ignition or damage is possible. The ratio of the critical to the plausible area is used to adjust (reduce) the transient FIF for the entire fire area to the FIF for the specified transient fire scenario.

Hot Work Fire Critical Area Adjustment Factor

A critical area AF can be postulated for hot work fires similar to that used for transient fires. The “plausible” floor area for a specific hot work fire scenario is the floor area where hot work, such as welding or cutting, is considered plausible. The “critical” floor area for a specified hot work fire scenario is the floor area where sparks from the hot work could ignite a fire in transient combustibles, exposed cables, insulation, or other combustibles. The ratio of the critical area to the plausible area is used to adjust (reduce) the hot work FIF for the entire fire area to the FIF for the specified hot work fire scenario.

05.02.04.05 Step 2.4.5: Screening Check

Recall that at this stage of the analysis, fire frequencies are available to characterize each unscreened fire ignition source scenario. If at this point Steps 2.5-2.7 have not been performed yet, the present screening check consists of updating the ΔCDF calculated in Step 2.1.8 with the refined area-wide FIF (sum of FIFs for all unscreened ignition sources). If any of Steps 2.5-2.7 have been completed, the present screening check can be based on the updated ΔCDF calculated according to Equation 2, instead of Equation 1.

05.02.05 Step 2.5: Final Conditional Core Damage Probability Estimates Determination

The purpose of Step 2.5 is to define the target set that will be damaged in the postulated FDS1, FDS2, and FDS3 scenarios initiated by the unscreened ignition sources as determined in Step 2.3 of the Fire Protection SDP. Guidance for the identification of targets and their damage and ignition criteria is provided in Attachment 6 to Appendix F. Once the damaged targets sets have been defined, the senior reactor analyst (SRA) can use the SPAR models to determine the corresponding CCDP for each fire scenario. At the discretion of the SRA, the CCDP obtained at this stage may account for effects due to human error and/or spurious operation. Typically, these effects are not considered in the Fire Protection SDP until Phase 3. Fire human reliability analysis guidelines are provided in NUREG-1921 (Reference 16). Spurious operation occurrence and duration exceedance probabilities are reported in NUREG/CR-7150, Vol. 2 (Reference 17).

05.02.05.01 Step 2.5.1: Determine Damaged Target Set and CCDP for FDS1 Scenarios

The default assumption in the Phase 2 analysis of FDS1 scenarios is that the entire target set within the ZOI of the ignition source is damaged at the time that the nearest and most vulnerable target is damaged. This may lead to overly conservative ΔCDF estimates if the CCDP of the damaged target set is dominated by a target that is at a much greater distance from the ignition source than the nearest and most vulnerable target. If this is the case, the analyst may choose to split the damaged target set for the scenario into two smaller sets. The first subset consists of targets that are relatively close to the ignition source and of low risk significance. The second subset consists of the more distant targets within the ZOI, but accounts for the bulk of the CCDP. The FDS1 scenario for the ignition source is essentially split into two FDS1 scenarios with different target sets. The first scenario will have a low CCDP, but a relatively high SF and NSP. The second scenario will have a high CCDP, but a lower SF and NSP.

05.02.05.02 Step 2.5.2: Determine Damaged Target Set and CCDP for FDS2 Scenarios

Usually, the analyst only needs to consider FDS2 scenarios for a single target type, i.e., either thermoset (TS) cables, thermoplastic (TP) cables, or exposed temperature-sensitive electronics. However, in some cases the analyst may decide to include FDS2 scenarios for multiple target types in the risk quantification. This would be the case, for example, if a relatively even mixture of TS and TP cables is present in the compartment, and the CCDP associated with the failure of each cable type is comparable.

05.02.05.03 Step 2.5.3: Determine Damaged Target Set and CCDP for FDS3 Scenarios

No supplemental guidance is provided regarding this step.

05.02.05.04 Step 2.5.4: Screening Check

No supplemental guidance is provided regarding this step.

05.02.06 Step 2.6: Final Fire Severity Factor Estimates

In the present Fire Protection SDP, the SF for fixed and transient ignition sources is determined based on the HRR required to cause damage to the nearest and most vulnerable target. If this target is located in the buoyant plume, the SF can be determined from table/plot set D in Attachment 8 to Appendix F as a function of the elevation of the nearest and most vulnerable target above the ignition source. An example of using the pre-calculated SF tables and plots in set D is presented in Section 05.03.04. If the nearest and most vulnerable target is not in the buoyant plume, but heated by radiation, the SF can be determined from table/plot set E in Attachment 8 to Appendix F. An example of using the pre-calculated SF tables and plots in set E is presented in Section 05.03.05. HEAFs and liquid fuel spill fires (confined and unconfined) are assigned an SF of 1.0.

05.02.07 Step 2.7: Final Non-Suppression Probability Estimates

The NSP for a specified fire scenario is a function of (1) the time available between start of the fire and failure of the critical component associated with the target set (usually cables) as determined by the plant response to the initiated accident scenario, (2) the time to damage of the target set for the scenario and (3) the time to suppression of the fire. The damage time for FDS1 scenarios is determined from table/plot set D for targets in the buoyant plume and from table/plot set E for targets heated by radiation. Examples to illustrate the use of these tables and plots are provided in Sections 05.03.04 and 05.03.05 for set D and E, respectively. The approach for determining the damage time for FDS2 scenarios involving secondary combustibles is illustrated in Section 05.03.03.02.

The determination of the fire suppression time also involves the analysis of the fire detection response. Fire detection is important in the SDP context because it triggers the manual response, whether by fire brigade or other personnel. All of the manual firefighting probability curves assume that fire detection has occurred. Hence, the total fire duration when following a manual suppression path is the sum of the detection time plus the manual suppression time. It is this total fire duration that is compared to the fire damage time to assess damage likelihood. Although the manual suppression time curves credit non-brigade response, for certain types or sizes of fires, it is not appropriate to credit suppression by plant personnel other than those specifically trained, i.e., the fire brigade.

With regard to fire detection, the analysis approach credits the dominant path to fire detection only. That is, while there are multiple paths to achieving fire detection, only one path needs to succeed. In practice, only the path that leads to the shortest fire detection time is credited. If there is a continuous fire watch, the detection time is zero. In other cases, a fixed fire detection system, if installed, will be assumed to be the predominant means of detection. Failing these two features, detection by general plant personnel is credited.

With regard to fire suppression, all fire areas are covered by the manual fire brigade, but many plant areas will also have fixed fire suppression systems. In general, if a fixed fire suppression system is in place and functional, it is presumed to be the first line of defense. If the fixed system fails on demand, then manual response, either by plant personnel or the fire brigade, is credited as a back-up means of fire suppression. If there is no fixed suppression present, or if the fire suppression system is highly degraded, manual response is credited as the primary means of fire suppression.

Supplemental guidance supporting the specific tasks under Steps 2.7.2-2.7.5 is included as Attachment 7 to Appendix F.

05.03 Attachment 8: Tables and Plots Supporting the Phase 2 Risk Quantification

Attachment 8 to Appendix F consists of a collection of tables and plots that are used in support of a Phase 2 assessment. Various FDTs from Reference 14 were used to generate the data that are presented in the tables and plots. To automate the process the FDT calculations were implemented in a series of spreadsheets. The assumptions and background for these calculations are discussed in Section 06.03. Eight sets of plots and tables were developed. The use of each set is illustrated below by means of examples.

05.03.01 Table/Plot Set A: Vertical and Radial Zone of Influence

Table/plot set A provides the vertical and radial ZOI for fixed and transient ignition sources, and for confined liquid fuel pool fires and unconfined liquid fuel spill fires. It is used to screen ignition sources that cannot cause damage to components or cables in the fire area and that are not capable of causing fire to spread to secondary combustibles (Step 2.3.2 in Appendix F), and to identify the damaged target set for a specified FDS1 scenario (Step 2.5.1 in Appendix F).

05.03.01.01 Example 1

The nearest target to a motor control center (MCC) is a TP cable located 2.7 ft. above the top of the enclosure. The MCC is at 6 ft. from the nearest corner. Determine whether the MCC can be screened.

Solution

Because an MCC is a closed electrical enclosure, the base of an MCC fire is placed 1 ft. below the top of the enclosure (see Section 05.02.03.01, “Assigning a Location to Fire Ignition Sources,” item b in the first lettered list). Therefore, the target is located at 3.7 ft. above the fire base. The MCC can be screened if the TP cable target is outside the 98th percentile HRR vertical ZOI. Table A.01 of Attachment 8 to Appendix F indicates that a TP cable target exposed in the plume of a 98th percentile HRR MCC free-burn fire is equal to 5.82 ft., as duplicated in Figure 5.2.1 below. Since the vertical ZOI (5.82 ft.) is greater than the vertical distance between the base of the ignition source fire and the TP cable target (3.7 ft.), the MCC fire is capable of damaging the target and therefore cannot be screened.

Electrical Enclosures		98% HRR (kW)	Vertical ZOI (ft)				Horizontal ZOI (ft)		
			Open Fire		Corner Fire				
			TP	TS	TP	TS	TP	TS	SE
Group 1 Switchgear & Load Centers	Closed	170	6.48	5.24	10.93	8.72	1.65	0.79	3.43
Group 2 MCCs & Battery Chargers	Closed	130	5.82	4.70	9.81	7.82	1.40	0.65	2.96
Group 3 Power Inverters	Closed	200	6.92	5.59	11.66	9.30	1.81	0.89	3.74
Group 4a Large [>50 ft^3]	Closed	400	9.13	7.38	15.39	12.28	2.71	1.43	5.42
	Open	1000	13.17	10.65	22.20	17.71	4.55	2.58	8.81
Group 4b Medium [≤50 ft^3 and >12 ft^3]	Closed	200	6.92	5.59	11.66	9.30	1.81	0.89	3.74
	Open	325	8.40	6.79	14.16	11.30	2.40	1.24	4.85
Group 4c Small [≤12 ft^3)]	All	45	3.81	3.08	6.43	5.12	0.73	0.28	1.66

Figure 5.2.1 – Finding the Vertical ZOI for an MCC and TP Cable Target.

05.03.01.02 Example 2

Determine whether a generic transient fire is capable of igniting TS cables in a cable tray that is located 7 ft. above the top of the transient combustible.

Solution

The generic transient fire is capable of spreading to the TS cables if the tray is in its vertical ZOI. The base of a transient fire is at the top of the transient combustible, which by default is located 0.5 ft. above the floor. Consequently, the TS cable target is at 6.5 ft. above the generic transient fire base. The vertical ZOI for a transient fire can be determined from Table A.02 of Attachment 8 to Appendix F, which is duplicated in Figure 5.2.2 below. Since the elevation of the cable tray above the top of the generic transient combustible (6.5 ft.) exceeds the vertical ZOI (4.87 ft. from Figure 5.2.2), a generic transient fire more than 2 ft. away from a corner would not be capable of spreading to the cable tray. However, a transient fire within 2 ft. of a corner could ignite the cables because the tray is within its vertical ZOI (7.85 ft. from Figure 5.2.2).

Other Ignition Sources	98% HRR (kW)	Vertical ZOI (ft)				Horizontal ZOI (ft)		
		Open Fire		Corner Fire				
		TP	TS	TP	TS	TP	TS	SE
Class A Motors [>5 hp and ≤30 hp]	15	2.39	2.01	4.01	3.33	0.24	0.03	0.87
Class B Motors [>30 hp and ≤100 hp]	37	3.38	2.82	5.64	4.67	0.50	0.04	1.44
Class C Motors [>5 hp and ≤30 hp]	100	4.91	4.08	8.16	6.72	1.00	0.29	2.47
Class A Dry Transformers [>45 kVA and ≤75 kVA]	30	3.32	2.77	5.62	4.65	0.11	0.03	1.26
Class B Dry Transformers [>75 kVA and ≤750 kVA]	70	4.49	3.71	7.55	6.19	0.83	0.26	1.98
Class C Dry Transformers [>750 kVA]	130	5.43	4.43	9.02	7.28	1.23	0.53	2.76
Generic Transient Combustibles	278	5.81	4.87	9.62	7.85	1.23	0.45	4.39
TCCL Transient Combustibles	143	4.40	2.64	7.19	4.58	0.76	0.22	3.08

Figure 5.2.2 – Tabulated Vertical ZOI for a Generic Transient and TS Cable Target.

05.03.01.03 Example 3

The nearest target to a closed large electrical enclosure is a TP cable tray located at a radial distance of 1.75 ft. from the edge of the enclosure. There are no components or cables located directly above the enclosure. Determine whether the enclosure can be screened.

Solution

The radial ZOI for a closed large electrical enclosure can be determined from Table A.01 of Attachment 8 to Appendix F, which is duplicated in Figure 5.2.3. Since the radial ZOI (2.71 ft.) is greater than the horizontal distance of the cable target (1.75 ft.), the enclosure cannot be screened.

Electrical Enclosures		98% HRR (kW)	Vertical ZOI (ft)				Horizontal ZOI (ft)		
			Open Fire		Corner Fire				
			TP	TS	TP	TS	TP	TS	SE
Group 1 Switchgear & Load Centers	Closed	170	6.48	5.24	10.93	8.72	1.65	0.79	3.43
Group 2 MCCs & Battery Chargers	Closed	130	5.82	4.70	9.81	7.82	1.40	0.65	2.96
Group 3 Power Inverters	Closed	200	6.92	5.59	11.66	9.30	1.81	0.89	3.74
Group 4a Large [>50 ft^3]	Closed	400	9.13	7.38	15.39	12.28	2.71	1.43	5.42
	Open	1000	13.17	10.65	22.20	17.71	4.55	2.58	8.81
Group 4b Medium [≤50 ft^3 and >12 ft^3]	Closed	200	6.92	5.59	11.66	9.30	1.81	0.89	3.74
	Open	325	8.40	6.79	14.16	11.30	2.40	1.24	4.85
Group 4c Small [≤12 ft^3)]	All	45	3.81	3.08	6.43	5.12	0.73	0.28	1.66

Figure 5.2.3 – Radial ZOI for a Closed Large Enclosure and TP Cable Target.

05.03.01.04 Example 4

An oil-filled transformer contains 100 gal of mineral oil and is located in a 4 × 4 ft. containment pan that can hold 40 percent of the oil. Determine whether an oil spill fire is capable of damaging a TS cable target that is located above the transformer at 16 ft. above the floor.

Solution

Two scenarios need to be considered. In the first scenario 10 percent (or 10 gal) of the mineral oil is assumed to spill. Since the containment pan is designed to hold more than this amount of mineral oil, ignition of the oil will result in a confined pool fire. The effective diameter of this noncircular pool fire follows from:

$$D_{eff} = \sqrt{\frac{4A_f}{\pi}} = \sqrt{\frac{4 \times 4 \times 4}{\pi}} = 4.5 \text{ ft.} \quad [3]$$

Consequently, the vertical ZOI for the first scenario, as determined from Figure A.03 of Attachment 8 to Appendix F, is 13 ft. (see Figure 5.2.4 below). The vertical ZOI (13 ft.) of the oil fire is below 16 ft., and the confined pool fire is therefore not capable of causing damage to the cable target and can be screened. Furthermore, Table A5.5 in Attachment 5 to Appendix F indicates the burning rate is 0.743 gal/min and it will therefore take 10/0.743 ≈ 13.5 min to consume the 10 gal of fuel.

D (ft.)	HRR (kW)	Vertical ZOI (ft.)	
		TS Target	TP Target
1.0	25.4	2.3	3.1
1.5	81.4	3.7	5.1
2.0	183	5.3	7.2
2.5	341	6.8	9.2
3.0	562	8.4	11.3
3.5	851	9.9	13.4
4.0	1213	11.5	15.5
4.5	1650	13.0	17.6
5.0	2165	14.5	19.6
5.5	2759	16.0	21.6
6.0	3432	17.4	23.6
7.0	5017	20.3	27.4
8.0	6917	23.0	31.2
9.0	9128	25.7	34.8
10.0	11640	28.2	38.2

D (ft.)	HRR (kW)	Vertical ZOI (ft.)	
		TS Target	TP Target
11	14448	30.7	41.6
12	17544	33.0	44.8
13	20921	35.3	48.0
14	24574	37.5	51.0
15	28498	39.7	54.0
16	32689	41.7	56.9
17	37145	43.8	59.7
18	41862	45.7	62.4
19	46839	47.7	65.1
20	52075	49.5	67.8
21	57570	51.4	70.4
22	63322	53.2	72.9
23	69332	55.0	75.4
24	75600	56.7	77.9
25	82126	58.4	80.3

Figure 5.2.4 – Vertical ZOI for Confined Lube and Mineral Oil Pool Fires.

The fact that an oil spill is collected in a containment area does not always lead to a confined pool fire. If the amount of oil that is spilled exceeds the capacity of the containment area, an unconfined spill fire will result. Figure A.01 of Attachment 8 to Appendix F gives the minimum volume of a liquid fuel spill to cover a containment area as a function of the diameter of the area. This figure indicates that, for this example, between 0.5 and 1.0 gal are needed to cover the containment area below the transformer with a 2-mm thick layer (minimum thickness to sustain flame spread over the fuel surface; see Figure 6.2.2 and related discussion). Since a 10-gal spill is postulated in the first scenario, it is appropriate to assume a confined pool fire.

In the second scenario 100 percent (or 100 gal) of the mineral oil is assumed to spill. Since the containment pan can only hold 40 gal, the pan will overflow. It is conservative to ignore the containment pan and assume that following ignition, an unconfined 100 gal spill fire will result outside the containment area. The vertical ZOI of unconfined mineral oil spill fires can be determined from Figure A.09 of Attachment 8 to Appendix F. The maximum spill volume in this figure is 30 gal, but the table and graph in the figure indicate that the vertical ZOI for a 30-gal spill is well above 16 ft. (approximately 58 ft as shown in Figure 5.2.5). Moreover, the table and graph in Figure A.09 of Attachment 8 indicate that, for this example, an unconfined pool fire of between 1 and 2 gal would be sufficient to result in an uncontained pool fire that would damage the target. Therefore, a spill only 1 to 2 gal in excess of the containment size is sufficient to damage the TS cable target.

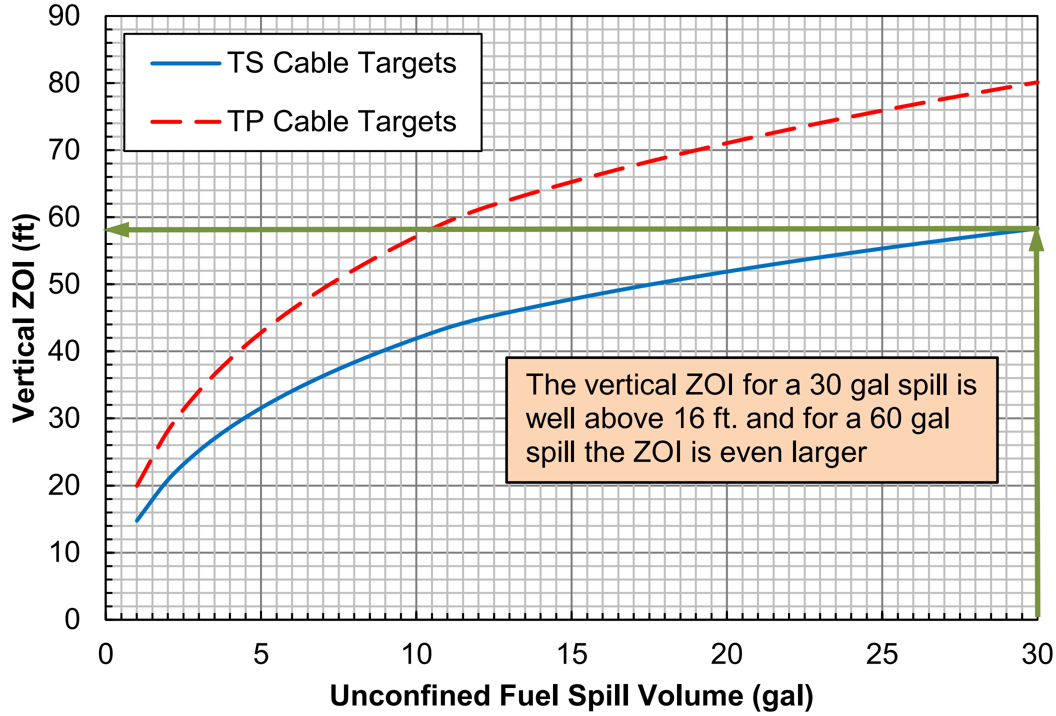

Figure 5.2.5 – Vertical ZOI of Unconfined Lube and Mineral Oil Spill Fires.

05.03.02 Table/Plot Set B: Minimum HRR to Create a Damaging HGL

Table/plot set B provides the minimum HRR that is needed to create damaging HGL conditions for a range of compartment sizes and different target types. It is used to screen ignition sources that are not capable of generating a damaging HGL (Step 2.3.3 in Appendix F), and to identify ignition sources and fire scenarios involving secondary combustibles that can cause development of a damaging HGL in the fire area(s) under evaluation (Steps 2.5.2 and 2.5.3 in Appendix F).

05.03.02.01 Example 1

Determine whether the confined spill fire scenario in Example 4 in Section 05.03.01 will lead to the development of a HGL that can damage TS cable targets in a compartment with a floor area of 2400 ft^2 and a ceiling height of 15 ft.

Solution

The minimum HRR required to create a damaging HGL for TS targets in a specified compartment can be determined from Figure B.01 of Attachment 8 in Appendix F. The minimum HRR required to do so for a compartment with floor area of 2400 ft^2 and ceiling height of 15 ft. is approximately 2670 kW, as shown in Figure 5.2.6 below. Table A5.5 in Attachment 5 to Appendix F indicates that the HRR of a 4.5 ft. diameter confined mineral oil spill fire is 1650 kW. It can therefore be concluded that a 10-gal spill fire will not lead to the development of a damaging HGL since its HRR is lower than the HRR required to create a damaging HGL.

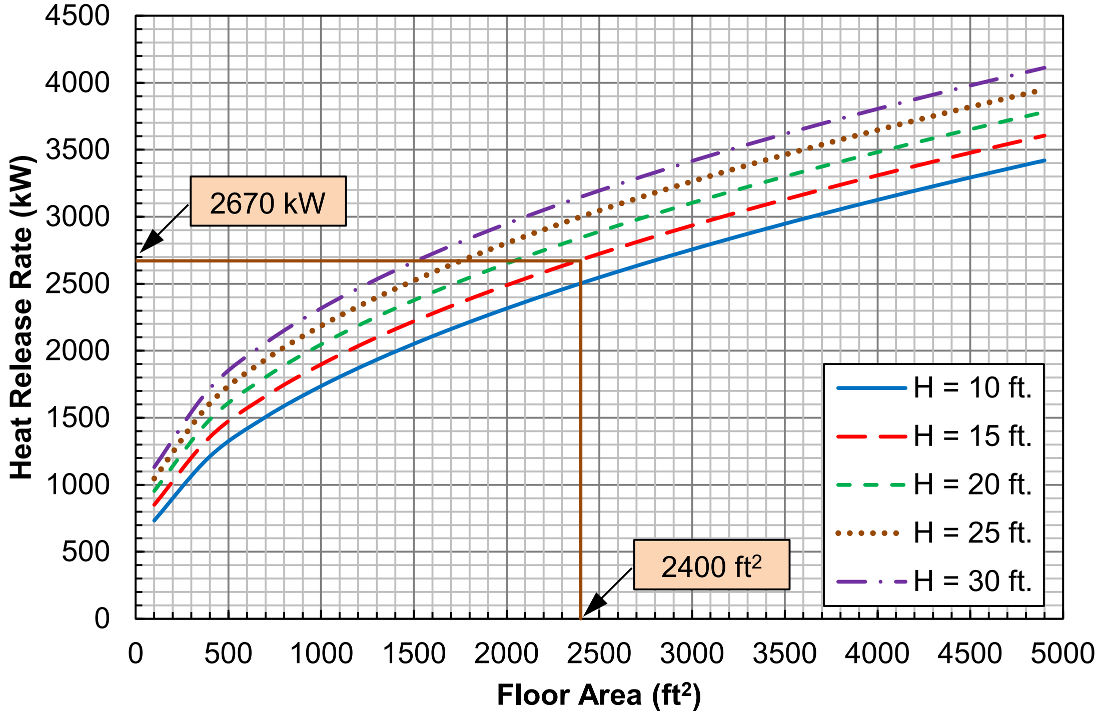

Figure 5.2.6 – Minimum HRR Required to Create a Damaging HGL for TS Targets in a Compartment with a Floor Area of 2400 ft^2 and Ceiling Height of 15 ft.

05.03.02.02 Example 2

Determine the minimum HRR to create a damaging HGL for TS and TP cable targets in a 38 ft. wide and 50 ft. long compartment with a ceiling height of 20 ft.

Solution

The floor area of the compartment is 38 × 50 = 1900 ft^2. The minimum HRR required to create a damaging HGL for TS targets in this compartment is 2599 kW, which can be determined from Figure B.01 of Attachment 8 in Appendix F (see Figure 5.2.7). The minimum HRR for TP targets is 1176 kW based on the table in Figure B.02 of Attachment 8 in Appendix F. The minimum HRRs can also be determined from the graphs, but the tabulated values are more precise in this case.

Floor Area (ft^2)	Minimum HRR to Create Damaging Hot Gas Layer Conditions (kW)				
	H = 10 ft.	H = 15 ft.	H = 20 ft.	H = 25 ft.	H = 30 ft.
100	734	851	954	1047	1132
400	1212	1356	1487	1607	1719
700	1505	1661	1803	1934	2058
1000	1737	1898	2047	2186	2317
1300	1934	2100	2254	2398	2534
1600	2108	2277	2435	2583	2724
1900	2266	2438	2599	2751	2894
2200	2412	2586	2750	2904	3050
2500	2547	2724	2889	3046	3195
2800	2675	2853	3020	3179	3330
3100	2796	2975	3144	3305	3458
3400	2910	3091	3262	3424	3579
3700	3020	3202	3374	3538	3694
4000	3126	3308	3482	3647	3804
4300	3227	3411	3585	3751	3910
4600	3325	3510	3685	3852	4013
4900	3420	3605	3781	3950	4111

Figure 5.2.7 – Minimum HRR Required Creating a Damaging HGL for TS Targets in a Compartment with a Floor Area of 1900 ft2 and Ceiling Height of 20 ft.

05.03.03 Table/Plot Set C: HRR Profiles of Fires Involving Cable Trays

Table/plot set C provides the combined HRR of an ignition source and a vertical stack of between one and seven horizontal cable trays as a function of time for various ignition source-cable tray configurations. This set is used in conjunction with table/plot set B to determine if and when a fire scenario involving secondary combustibles will cause a damaging HGL in the fire area (Steps 2.5.2 and 2.5.3 in Appendix F).

05.03.03.01 Example 1

Determine if the HRR of a switchgear fire involving a vertical stack of seven 1.5 ft. wide horizontal trays filled with TS cables is sufficient to create a damaging HGL for TS cable targets in a compartment with a floor area of 1900 ft^2 and a ceiling height of 20 ft.

Solution

From Example 2 in Section 05.03.02 we know that the minimum HRR required to create a damaging HGL for TS targets in the specified compartment is 2599 kW. Figure C.19.b in Attachment 8 to Appendix F indicates that the HRR of the switchgear/cable tray fire is less than 1300 kW over a 40-minute period and is therefore not capable of creating a damaging HGL for TS targets in the specified compartment.

05.03.03.02 Example 2

Assume in the previous example that an inspector identified a significant amount of TP cables in the trays and elsewhere in the compartment. Determine if the HRR of the switchgear/cable tray fire is sufficient to create a damaging HGL for TP cable targets in the specified compartment. If so, determine the time at which the HGL reaches the damage threshold. (When there is more than some very minimal amount of TP cables present in a tray of mixed cable types, the thresholds for damage of TP cables should be assumed.)

Solution

From Example 2 in Section 05.03.02 we know that the minimum HRR required to create a damaging HGL for TP targets in the specified compartment is 1176 kW. Since the cable trays contain a significant amount of TP cables we need to use Figure C.19.c in Attachment 8 to Appendix F to determine the HRR of the switchgear/cable tray fire. This figure indicates that the HRR of the fire reaches 1176 kW between 13 and 14 minutes, as shown in Figure 5.2.8 below. In an analysis, one would conservatively assume 13 minutes. Alternatively, one could determine a more precise value from Figure C.19.a and use 13.5 minutes based on interpolation between the tabulated HRRs at 13 and 14 minutes (1012 and 1301 kW, respectively). Either way, there is clearly the potential for generating a damaging HGL in this example.

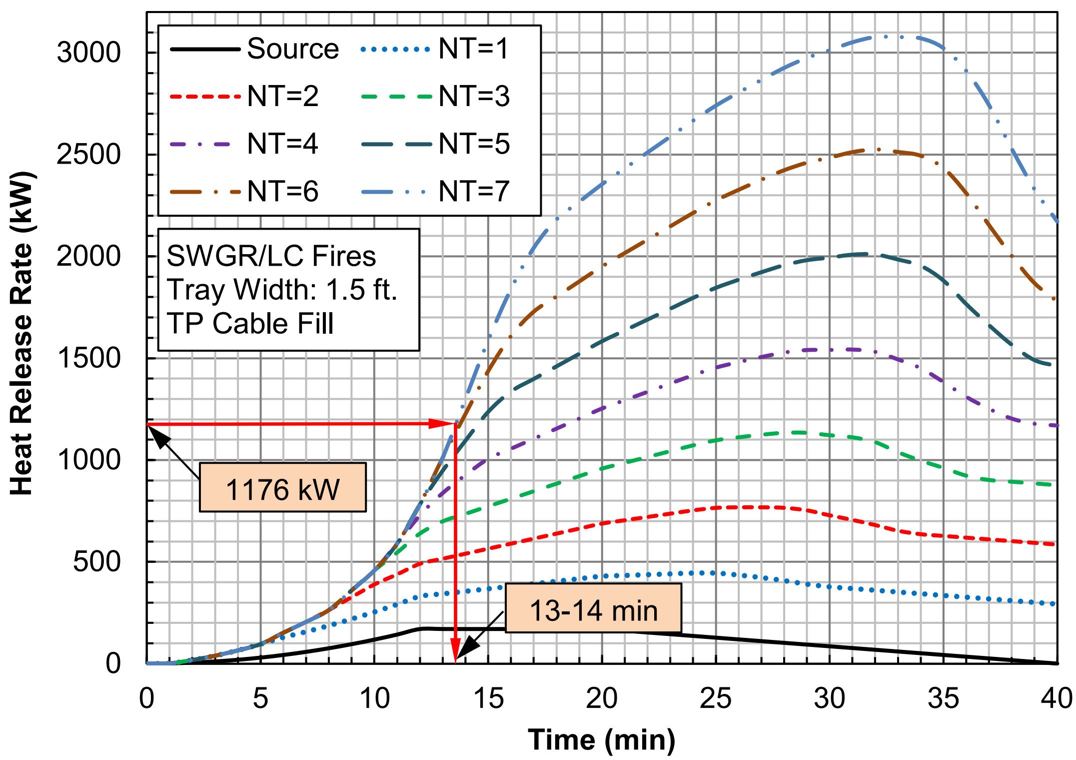

Figure 5.2.8 – HRR of a Switchgear Fire Involving a Vertical Stack of 1.5 ft. Wide Horizontal Cable Trays Filled with TP Cables.

05.03.04 Table/Plot Set D: Severity Factor and Damage Time vs. Vertical Target Distance

To develop table/plot set D, calculations were performed to determine the highest elevation and corresponding time at which a target will be damaged, or a secondary combustible will ignite when exposed in the plume of an ignition source with a HRR profile that corresponds to a specified SF. Each table and plot provides the elevations and damage times corresponding to SFs ranging from 0.02 to 0.75 for one of the fixed or transient ignition sources listed in Attachment 5 to Appendix F, located either in the open or in a corner. Table/plot set D is used in Appendix F to conservatively estimate the SF for a target or secondary combustible located within the vertical ZOI based on its elevation above the ignition source (Step 2.6.1), and to determine the corresponding damage or ignition time (needed to calculate the NSP in Step 2.7.1).

05.03.04.01 Example 1

Determine the SF and corresponding damage time for the ignition source and nearest target of Example 1 in Section 05.03.01.

Solution

The ignition source of Example 1 in Section 05.03.01 is an MCC (closed group 2 electrical enclosure) and the nearest target is a TP cable located 3.7 ft. above the fire base. The SF in this case can be determined through interpolation between the SF values at elevations of 3.77 ft. and 3.59 ft. given in the table in Figure D.10 of Attachment 8 in Appendix F (see Figure 5.2.9 below). That is, the SF at a ZOI of 3.7 ft. is equal to 0.30+(0.35-0.30)×(3.70-3.77)/(3.59-3.77) = 0.319. Alternatively, to avoid having to interpolate, a conservative SF value of 0.35 could be assumed. Since the damage times for a ZOI of 3.77 ft and 3.59 ft. are identical, as shown in Figure 5.2.9, the damage time for a ZOI of 3.7 ft. is the same (1521 s).

SF	HRR (kW)	Vertical Open Fire				Vertical Corner Fire			
		TP		TS		TP		TS	
		ZOI (ft)	t_{dam} (s)	ZOI (ft)	t_{dam} (s)	ZOI (ft)	t_{dam} (s)	ZOI (ft)	t_{dam} (s)
0.02	130	5.82	1521	4.70	1193	9.81	1527	7.82	1189
0.05	101	5.27	1521	4.26	1193	8.88	1527	7.08	1189
0.10	79.4	4.78	1521	3.86	1193	8.06	1527	6.43	1189
0.15	66.4	4.45	1521	3.60	1193	7.50	1527	5.98	1189
0.20	57.2	4.19	1521	3.39	1193	7.07	1527	5.64	1189
0.25	49.9	3.97	1521	3.21	1193	6.69	1527	5.34	1189
0.30	44.0	3.77	1521	3.05	1193	6.36	1527	5.07	1189
0.35	38.9	3.59	1521	2.90	1193	6.05	1527	4.83	1189
0.40	34.4	3.42	1521	2.76	1193	5.77	1527	4.60	1189
0.45	30.4	3.26	1521	2.63	1193	5.49	1527	4.38	1189
0.50	26.8	3.10	1521	2.50	1193	5.22	1527	4.16	1189
0.55	23.5	2.94	1521	2.38	1193	4.96	1527	3.95	1189
0.60	20.5	2.78	1521	2.25	1193	4.69	1527	3.74	1189
0.65	17.7	2.62	1521	2.12	1193	4.42	1527	3.52	1189
0.70	15.0	2.45	1521	1.98	1193	4.14	1527	3.30	1189
0.75	12.4	2.28	1521	1.84	1193	3.8	1527	3.06	1189

Figure 5.2.9 – SF and Damage Time for a TP Target 3.7 ft. above an MCC.

05.03.05 Table/Plot Set E: Severity Factor and Damage Time vs. Radial Target Distance

To develop table/plot set E, calculations were performed to determine the longest radial distance at which a target will be damaged, or a secondary combustible will ignite when exposed to the radiant heat flux from an ignition source with a HRR profile that corresponds to a specified SF. Each table and plot provides the radial distances corresponding to SFs ranging from 0.02 to 0.75 for one of the fixed or transient ignition sources listed in Attachment 5 to Appendix F. Table/plot set E is used to conservatively estimate the SF for a target or secondary combustible located within the radial ZOI based on its distance from the ignition source (Step 2.6.1), and to determine the corresponding damage or ignition time (needed to calculate the NSP in Step 2.7.1).

05.03.05.01 Example 1

Determine the SF for the ignition source and nearest radial target of Example 3 in Section 05.03.01.

Solution

The ignition source in Example 3 in Section 05.03.01 is a closed large electrical enclosure (group 4a) and the nearest radial target is a TP cable located 1.75 ft. from the source. The SF in this case is determined through interpolation between the SF values at distances of 1.82 ft. and 1.56 ft. given in Figure E.12 of Attachment 8 in Appendix F (see Figure 5.2.10 below). That is, the SF at a ZOI of 1.75 ft. is equal to 0.10+(0.15-0.10)×(1.75-1.82)/(1.56-1.56) = 0.113. The corresponding damage time determined from interpolation is equal to 1497 s. Alternatively, to avoid having to interpolate, conservative values could be assumed for SF and damage time of 0.15 and 1497 s, respectively.

SF	HRR (kW)	Horizontal					
		TP		TS		SE	
		ZOI (ft)	t_{dam} (s)	ZOI (ft)	t_{dam} (s)	ZOI (ft)	t_{dam} (s)
0.02	400	2.71	1505	1.43	1474	5.42	720
0.05	285	2.23	1502	1.14	1468	4.53	720
0.10	202	1.82	1500	0.90	1463	3.76	720
0.15	155	1.56	1497	0.74	1459	3.26	720
0.20	124	1.36	1495	0.63	1455	2.88	720
0.25	100	1.20	1493	0.54	1451	2.57	720
0.30	81.6	1.06	1491	0.46	1447	2.30	720
0.35	66.7	0.94	1489	0.39	1443	2.06	720
0.40	54.3	0.83	1487	0.33	1438	1.84	720
0.45	44.0	0.72	1484	0.28	1434	1.64	720
0.50	35.3	0.63	1481	0.23	1428	1.45	720
0.55	27.9	0.54	1478	0.19	1421	1.27	720
0.60	21.6	0.46	1475	0.15	1414	1.10	720
0.65	16.3	0.38	1470	0.11	1406	0.94	720
0.70	11.9	0.30	1465	0.08	1396	0.78	719
0.75	8.23	0.24	1461	0.05	1379	0.63	719

Figure 5.2.10 – SF for a TP Target at 1.75 ft. from a Closed Large Enclosure.

05.03.06 Table/Plot Set F: Detector Actuation and Sprinkler Activation Times

Table/Plot set F consists of three subsets of tables:

a. Tables to determine smoke detector actuation time as a function of the ceiling height above the fire and the radial distance between the detector and the fire (Step 2.7.2).
b. Tables to determine sprinkler activation time for fixed and transient ignition source fires as a function of the ceiling height above the fire and the radial distance between the sprinkler head and the fire (Step 2.7.3).
c. Tables to determine sprinkler activation time for fires with an unknown HRR profile as a function of the ceiling height above the fire and the radial distance between the sprinkler head and the fire (Step 2.7.3).

Table/Plot set F is used to determine the actuation time of a detector and the activation time of a sprinkler system based on the ceiling height above the fire and the radial distance from the detector or sprinkler head to the fire. These times are used in the fire detection and fixed fire suppression analyses (Steps 2.7.2 and 2.7.3, respectively).

05.03.06.01 Example 1

Assume the compartment that contains the MCC of Example 1 in Section 05.03.01 is protected by a halon system. Determine whether the halon system is likely to extinguish the fire before the nearest target above the ignition source is damaged. The ceiling height is 7 ft. above the top of the electrical enclosure (or 8 ft. above the base of the ignition source fire) and the radial distance to the nearest detector is 5 ft.

Solution

The ignition source in Example 1 in Section 05.03.01 is an MCC and the nearest target is a TP cable located 3.7 ft. above the base of the ignition source fire. The MCC is not located in a corner. In Example 1 of Section 05.03.04, it was determined that the TP cable target fails in 1521 s, and that the SF corresponding to the lowest peak HRR required to cause damage is approximately 0.319.

The time to the start of suppression is equal to the sum of the actuation time of the smoke detector that generates the demand signal for the suppression system, and the halon discharge delay time. The detector actuation time, in turn, is the sum of the time for the HRR from the MCC fire to reach the minimum HRR required to actuate the detector, and the time for the plume and ceiling jet to travel to the detector.

To determine the detector actuation time, we first need to determine the minimum HRR to actuate the detector. The minimum HRR in this case is 15 kW, as shown in Figure F.01 of Attachment 8 to Appendix F (see Figure 5.2.11 below). The time for the HRR from the MCC fire to reach 15 kW can then be estimated from the HRR growth profiles shown in Figures F.15 (for SF ranging from 0.02 to 0.35) and F.16 (for SF ranging 0.4 to 0.75) in Attachment 8 to Appendix F. As mentioned earlier, in Example 1 of Section 05.03.04, it was determined that the SF corresponding to the lowest peak HRR required to cause damage to the target is approximately 0.319. Figure F.15 in Attachment 8 to Appendix F can be used to determine the time needed for reach a HRR of 15 kW, $t_{15\,kW}$, for SF values ranging from 0.02 to 0.35. For SF equal to 0.30 and 0.35, the corresponding $t_{15\,kW}$ is equal to 421 s and 447 s, respectively, as shown in Figure 5.2.12 (which is a duplicate of Figure F.15 in Attachment 8 to Appendix F). Consequently, $t_{15\,kW}$ for SF = 0.319 can be estimated from linear interpolation as follows: $t_{15\,kW} \approx 421 + (447 - 421) \times (0.319 - 0.30) / (0.35 - 0.30) = 431$ s. Alternatively, to avoid having to interpolate, a conservative (longer) estimate for $t_{15\,kW}$ of 447 s can be obtained by assuming SF = 0.35.

The plume and ceiling jet lag time can be determined from Figure F.29 of Attachment 8 to Appendix F. The lag time for this example is 7 s, as shown in Figure 5.2.13 below. The detector actuation time is therefore estimated at 431 + 7 = 438 s. To that, we need to add the discharge delay time, which is typically between 30 and 120 s. Hence, the time to the start of suppression is expected to be between 468 and 558 s. Given a time to target damage of 1521 s and assuming a discharge delay time of 120 s, the time to damage minus the time to start of suppression is 963 s. Based on Table A7.3 in Attachment 7 to Appendix F, because the difference is greater than 10 min or 600 s, the NSP for the halon system is limited by its random failure probability, which is 0.05. Therefore, it is very likely that the halon system will extinguish the MCC fire before the target is damaged. The inspector should determine the discharge delay time to confirm this.

H (ft.)	Minimum HRR for Detector Actuation in kW as a Function of Radial Distance R in ft.															
	R=0	R=1	R=2	R=3	R=4	R=5	R=6	R=7	R=8	R=9	R=10	R=11	R=12	R=13	R=14	R=15
5	2	2	3	5	6	8	9	11	12	14	15	16	18	19	21	22
6	3	3	4	6	8	10	12	14	16	18	20	22	23	25	27	29
7	4	4	5	8	10	13	15	17	20	22	25	27	29	32	34	37
8	5	5	6	9	12	15	18	21	24	27	30	33	36	39	42	45
9	6	6	8	11	15	18	22	25	29	32	36	39	43	46	50	53
10	8	8	9	13	17	21	25	29	33	37	42	46	50	54	58	62
11	10	10	10	15	19	24	29	34	38	43	48	53	57	62	67	72
12	12	12	12	17	22	28	33	38	44	49	55	60	65	71	76	82
13	15	15	15	19	25	31	37	43	49	55	61	68	74	80	86	92
14	18	18	18	21	28	35	41	48	55	62	69	75	82	89	96	103
15	21	21	21	23	31	38	46	53	61	68	76	84	91	99	106	114
16	24	24	24	25	34	42	50	59	67	75	84	92	100	109	117	125
17	28	28	28	28	37	46	55	64	73	82	92	101	110	119	128	137
18	33	33	33	33	40	50	60	70	80	90	100	110	120	130	139	149
19	37	37	37	37	44	54	65	76	87	97	108	119	130	140	151	162
20	42	42	42	42	47	59	70	82	94	105	117	128	140	152	163	175
21	48	48	48	48	51	63	76	88	101	113	126	138	151	163	176	188
22	53	53	53	53	54	68	81	94	108	121	135	148	161	175	188	202
23	60	60	60	60	60	72	87	101	115	130	144	158	173	187	201	216
24	66	66	66	66	66	77	92	107	123	138	153	169	184	199	214	230
25	73	73	73	73	73	82	98	114	130	147	163	179	195	212	228	244
26	81	81	81	81	81	87	104	121	138	156	173	190	207	225	242	259
27	89	89	89	89	89	92	110	128	146	165	183	201	219	238	256	274
28	97	97	97	97	97	97	116	135	155	174	193	212	232	251	270	289
29	106	106	106	106	106	106	122	143	163	183	203	224	244	264	285	305
30	116	116	116	116	116	116	129	150	171	193	214	235	257	278	300	321

Figure 5.2.11 – Minimum HRR for Detector Actuation.

Heat Release Rate Profiles for Group 2 Electrical Enclosures															
SF=0.02		SF=0.05		SF=0.10		SF=0.15		SF=0.20		SF=0.25		SF=0.30		SF=0.35	
Time (s)	HRR (kW)	Time (s)	HRR (kW)	Time (s)	HRR (kW)	Time (s)	HRR (kW)	Time (s)	HRR (kW)	Time (s)	HRR (kW)	Time (s)	HRR (kW)	Time (s)	HRR (kW)
89	2	101	2	114	2	114	2	135	2	144	2	154	2	163	2
109	3	124	3	140	3	140	3	165	3	176	3	188	3	200	3
126	4	143	4	162	4	162	4	190	4	204	4	217	4	231	4
141	5	160	5	181	5	181	5	213	5	228	5	243	5	258	5
155	6	175	6	198	6	198	6	233	6	250	6	266	6	283	6
167	7	189	7	214	7	214	7	252	7	270	7	287	7	306	7
179	8	202	8	229	8	229	8	269	8	288	8	307	8	327	8
190	9	215	9	242	9	242	9	286	9	306	9	326	9	346	9
200	10	226	10	256	10	256	10	301	10	322	10	343	10	365	10
210	11	237	11	268	11	268	11	316	11	338	11	360	11	383	11
228	13	258	13	280	12	280	12	330	12	353	12	376	12	400	12
245	15	277	15	291	13	291	13	343	13	367	13	392	13	416	13
261	17	295	17	302	14	302	14	356	14	381	14	406	14	432	14
275	19	312	19	313	15	313	15	369	15	395	15	421	15	447	15
290	21	328	21	323	16	323	16	381	16	408	16	434	16	462	16
303	23	343	23	343	18	333	17	393	17	420	17	448	17	476	17
316	25	358	25	361	20	343	18	404	18	432	18	461	18	490	18
328	27	372	27	379	22	352	19	415	19	444	19	473	19	503	19
340	29	385	29	396	24	361	20	426	20	456	20	486	20	517	20
357	32	405	32	412	26	370	21	436	21	467	21	498	21	529	21
374	35	423	35	428	28	388	23	447	22	478	22	509	22	542	22
390	38	441	38	443	30	404	25	457	23	489	23	521	23	554	23
405	41	458	41	457	32	420	27	466	24	499	24	532	24	566	24
419	44	475	44	471	34	435	29	476	25	509	25	543	25	577	25
433	47	491	47	485	36	450	31	486	26	549	29	554	26	589	26
447	50	506	50	505	39	464	33	504	28	558	30	564	27	600	27
460	53	521	53	524	42	478	35	522	30	567	31	575	28	611	28
473	56	536	56	542	45	492	37	539	32	576	32	585	29	622	29
490	60	554	60	554	47	505	39	555	34	585	33	595	30	633	30
506	64	573	64	572	50	518	41	571	36	594	34	605	31	643	31
517	67	590	68	588	53	530	43	587	38	603	35	614	32	653	32
532	71	607	72	605	56	542	45	602	40	611	36	624	33	663	33
547	75	624	76	621	59	554	47	617	42	620	37	633	34	673	34
562	79	640	80	636	62	566	49	632	44	628	38	642	35	683	35
576	83	656	84	652	65	583	52	646	46	644	40	652	36	693	36
589	87	671	88	666	68	599	55	660	48	660	42	661	37	703	37
603	91	686	92	681	71	616	58	673	50	676	44	669	38	712	38
616	95	701	96	695	74	631	61	687	52	691	46	678	39	720	39
632	100	716	100	709	77	647	64	700	54	706	48	687	40		
648	105	733	105	723	80	662	67	713	56	720	50	695	41		
663	110	751	110	741	84	676	70	725	58	735	52	704	42		
678	115	767	115	758	88	691	73	744	61	749	54	712	43		
692	120	784	120	775	92	705	76	762	64	762	56	720	44		
707	125	800	125	792	96	718	79	779	67	776	58				
720	130	720	101	720	79	720	79	720	57	720	50				

Figure 5.2.12 – HRR Growth Profile for Group 2 Electrical Enclosures and SF = 0.02 to 0.35.

H (ft.)	Sum of Plume & Ceiling Jet Lag Times and Detector Response Time in s															
	R=0	R=1	R=2	R=3	R=4	R=5	R=6	R=7	R=8	R=9	R=10	R=11	R=12	R=13	R=14	R=15
5	5	6	6	7	7	8	8	9	9	10	10	11	11	12	12	13
6	5	5	6	6	7	7	8	8	9	9	9	10	10	11	11	12
7	5	5	6	6	7	7	7	8	8	8	9	9	9	10	10	11
8	5	5	6	6	6	7	7	7	8	8	8	9	9	9	10	10
9	5	5	6	6	6	6	7	7	7	8	8	8	8	9	9	9
10	5	5	5	6	6	6	6	7	7	7	8	8	8	8	9	9
11	5	5	5	6	6	6	6	7	7	7	7	7	8	8	8	8
12	5	5	5	6	6	6	6	6	7	7	7	7	7	8	8	8
13	5	5	5	6	6	6	6	6	6	7	7	7	7	7	8	8
14	5	5	5	6	6	6	6	6	6	7	7	7	7	7	7	8
15	5	5	5	5	6	6	6	6	6	6	7	7	7	7	7	7
16	5	5	5	5	6	6	6	6	6	6	6	7	7	7	7	7
17	5	5	5	5	6	6	6	6	6	6	6	7	7	7	7	7
18	5	5	5	5	6	6	6	6	6	6	6	6	7	7	7	7
19	5	5	5	5	6	6	6	6	6	6	6	6	6	7	7	7
20	5	5	5	5	6	6	6	6	6	6	6	6	6	7	7	7
21	5	5	5	5	6	6	6	6	6	6	6	6	6	6	7	7
22	5	5	5	5	6	6	6	6	6	6	6	6	6	6	7	7
23	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	7
24	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	7
25	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6
26	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6
27	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6
28	5	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6
29	5	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6
30	5	5	5	6	6	6	6	6	6	6	6	6	6	6	6	6

Figure 5.2.13 – Determination of Plume and Ceiling Jet Lag Time.

05.03.06.02 Example 2

Determine whether a generic transient fire is capable of activating a wet pipe sprinkler system. The distance between the top of the transient (which is assumed to be 0.5 ft. above the floor) and the ceiling is 10 ft. and the nearest sprinkler head is 4 ft. from the fire.

Solution

Whether the wet pipe sprinkler system will activate or not depends on the severity factor. Figure F.37 of Attachment 8 to Appendix F indicates that for SF = 0.02 (98th percentile HRR profile) the sprinkler will activate in 380 s, as shown in Figure 5.2.14 below (which is a duplicate of Figure F.37 in Attachment 8 to Appendix F). However, the same figure also shows that the generic transient HRR profile for SF = 0.05 will be too low to activate the sprinkler.

H	Sprinkler Activation Time in Seconds (Generic Transients, SF=0.02)															
(ft.)	R=0	R=1	R=2	R=3	R=4	R=5	R=6	R=7	R=8	R=9	R=10	R=11	R=12	R=13	R=14	R=15
5	168	177	225	258	284	307	327	347	373	448	NA	NA	NA	NA	NA	NA
6	189	191	238	273	301	325	350	392	NA	NA	NA	NA	NA	NA	NA	NA
7	209	209	250	287	317	345	396	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	229	229	261	300	332	372	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	249	249	272	313	350	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	268	268	282	324	380	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11	286	286	292	337	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12	305	305	307	352	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
13	323	323	324	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
14	345	345	345	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
15	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

H	Sprinkler Activation Time in Seconds (Generic Transients, SF=0.05)															
(ft.)	R=0	R=1	R=2	R=3	R=4	R=5	R=6	R=7	R=8	R=9	R=10	R=11	R=12	R=13	R=14	R=15
5	179	189	239	275	303	335	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	202	204	253	291	325	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	224	224	267	307	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	245	245	279	325	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	266	266	290	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	286	286	302	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11	307	307	314	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

H	Sprinkler Activation Time in Seconds (Generic Transients, SF=0.10)															
(ft.)	R=0	R=1	R=2	R=3	R=4	R=5	R=6	R=7	R=8	R=9	R=10	R=11	R=12	R=13	R=14	R=15
5	189	199	252	294	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	213	215	268	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	236	236	283	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	259	259	313	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	282	282	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
10	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

H	Sprinkler Activation Time in Seconds (Generic Transients, SF=0.15)															
(ft.)	R=0	R=1	R=2	R=3	R=4	R=5	R=6	R=7	R=8	R=9	R=10	R=11	R=12	R=13	R=14	R=15
5	194	205	265	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	220	222	345	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	244	244	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
8	299	299	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
9	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

H	Sprinkler Activation Time in Seconds (Generic Transients, SF=0.20)															
(ft.)	R=0	R=1	R=2	R=3	R=4	R=5	R=6	R=7	R=8	R=9	R=10	R=11	R=12	R=13	R=14	R=15
5	198	209	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	224	226	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
7	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

H	Sprinkler Activation Time in Seconds (Generic Transients, SF=0.25)															
(ft.)	R=0	R=1	R=2	R=3	R=4	R=5	R=6	R=7	R=8	R=9	R=10	R=11	R=12	R=13	R=14	R=15
5	197	214	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Figure 5.2.14 – Sprinkler Activation Time for Generic Transient Fire.

0308.03F-06 BASIS

06.01 Phase 1 Analysis Basis

06.01.01 Step 1.1: Provide Statement of Fire Protection Finding

A clear description of the fire finding is necessary to ensure that it is assigned to the appropriate category.

06.01.02 Step 1.2: Assign a Fire Finding Category

The finding categories are assigned primarily as a tool for guiding aspects of the analysis. The finding categories map directly to the fire protection DID elements. Certain steps in the analysis are only relevant to specific types of findings, and other steps are skipped for specific types of findings.

06.01.03 Step 1.3: Low Degradation Deficiencies

Assignment of a Degradation Rating

Degradation ratings are defined in a context explicitly consistent with the fire PRA approach and the overall objective of the SDP as a risk-informed analysis tool. The generic definitions are explicitly tied to the level of credit that will be given to a degraded fire protection program element in the subsequent PRA-based analyses. All case specific degradation ratings have been established consistent with the generic definitions of High and Low Degradation as discussed in Attachment 2 to Appendix F. Specific bases for the degradation ratings assigned to specific types of findings are discussed in the subsections that follow.

Fire Prevention and Administrative Controls Programs

Fire prevention and administrative controls program degradations focus on issues related to hot work fire watches and combustible materials controls.

Hot work fire watch degradations rated as high focus on those issues that might render hot work fire watches ineffective at promptly suppressing hot work fires. The available experience demonstrates that a hot work fire watch is an effective means of mitigating hot work fires. At least 2 out of 3 hot work fires in the fire event database used to generate NSAC-178 (Reference 18) were promptly suppressed through actions of the fire watch. Degradations to the hot work fire watch fire suppression capability will be taken as indicative of a high degradation and the fire frequency will be increased accordingly.

The items identified as low degradation are primarily related to the hot work fire watch function as a fire detection and suppression mechanism, or relate to documentation and training issues associated with the hot work activities.

In the case of transient fuels control programs, a similar approach is taken. That is, the focus is placed on degradations that could lead to a substantial increase in fire frequencies. In this case, there are no industry-wide standards against which to weigh a given situation. Each licensee sets its own requirements for administrative controls. Hence, the licensee's performance must be weighed against their requirements.

Fixed Fire Detection & Suppression Degradation

The degradation ratings for fixed fire detection and suppression systems are intended to reflect the general functionality of the system in light of the noted degradation. Many minor deviations from the code of record are possible that would not substantially degrade the system performance. These types of degradations are assigned to the low category.

The high degradation category is reserved primarily for those degradations that render the system ineffective. This implies that the system will not be credited in the risk quantification.

Significant degradations that could either delay the systems actuation, render the system less effective in fighting one or more fire scenarios in the fire area, or adversely impact system reliability are also considered high. However, the expectation is that even given the degradation, the system should function with some substantial degree of reliability and effectiveness. The system can therefore be partially credited in the risk quantification.

Fire Barrier Degradation

The fire barrier degradation rating is tied to the expected performance time of the degraded barrier in terms of its fire resistance or its ability to prevent failure or ignition of the SSD-credited equipment protected by the barrier. Indeed, this is how the degradations are reflected in risk quantification. The examples are taken from the experience of field inspectors, NRC headquarters staff, research, and the plants themselves.

SSD Findings

The SSD finding degradation levels are intended to align with the generic definitions. However, in this context the interpretation focuses somewhat more sharply on 'reliability' issues. For example, a fire suppression system can be compared to a code of record and deviations can be readily identified. SSD provisions rarely have such a definitive yardstick against which they can be measured. SSD findings are more likely to hinge on qualitative factors. For example, issues likely to arise could include the adequacy of post-fire SSD procedures, the reliability of a proposed SSD path, unavailability of required functions, likelihood of spurious equipment operations, etc. The criteria, as written, reflect the qualitative nature of these findings. It is expected that considerable judgement on the part of the practitioner will be required to properly assess SSD findings.

Low Degradation Deficiency Screening Check

The first question in the qualitative screening check asks if a low degradation rating was assigned to the finding. By design, the definition of low degradation implies that the performance and/or reliability of the fire protection feature is minimally impacted by the noted degradation finding. Hence, the feature would be given essentially full credit in the PRA-based analysis. In this case, the risk change is essentially zero, and the finding should be screened to Green. Question 1.3.1-A accomplishes this action.

06.01.04 Step 1.4: Qualitative Screening Questions

Step 1.4 consists of a series of questions that are used to determine whether the finding can be screened to Green without the need to perform a quantitative analysis. The basis for each of the qualitative screening questions, which are specific to the finding category assigned in Step 1.2, is discussed below.

06.01.04.01 Step 1.4.1: Fire Prevention and Administrative Controls

Basis for 1.4.1-A Question: Fire prevention or administrative controls deficiencies that can result in larger fires than originally postulated (such as transient combustibles found in combustible free areas) may exacerbate the likelihood or severity of fire scenarios for the area. Fire watch deficiencies may result in delays in detecting the fire, affecting the probability of non-suppression for the fire. If the finding does not create a more likely or severe fire scenario than was already analyzed, or otherwise adversely impact the SSD strategy for the area, the finding can be screened to Green because the risk impact is low.

Basis for 1.4.1-B Question: Fire prevention or administrative controls deficiencies can increase the adverse impact of fire scenarios for an area. Fully functional fixed fire suppression systems quickly and reliably suppress fires or prevent them from spreading. If an area is protected by a fixed fire suppression system that is capable of handling the identified deficiency (such as increased transient combustibles), the risk associated with the deficiency is low because the fixed fire suppression system will quickly stop fire progression.

06.01.04.02 Step 1.4.2: Fixed Fire Protection Systems

Basis for 1.4.2-A Question: The purpose of this question is to screen findings that do not adversely affect the ability of the fire suppression system to protect the targets. The inspector should evaluate the location of targets in the area in relation to the degradation in the suppression system, and the location and type of combustibles in the area. For example, a finding related to a broken or blocked sprinkler head that is on the opposite side of the room from the target can be screened to Green if the remaining sprinkler heads would be sufficient to protect the target. However, a large combustible source in the area, such as an oil reservoir, would require additional evaluation in Phase 2.

06.01.04.03 Step 1.4.3: Fire Water Supply

Basis for 1.4.3-A Question: Fire water systems are generally designed to provide adequate water supply for fixed sprinkler or large deluge systems protecting equipment that may not be important to safety or SSD. The water supply required to suppress fires in equipment important to SSD prior to adversely affecting this SSD capability may be much less than the full capacity of the system. The location of equipment important to SSD varies by plant. The most limiting location onsite that protects equipment important to SSD depends on factors such as the elevation of the equipment, type of combustibles in the area, method of suppression, and the flow required for suppression. The inspector should consider whether the fire water system degradation would affect the ability to get adequate water supply to protect equipment important to SSD in the most limiting location and for the most severe fire. If a fire water supply finding does not screen to Green in this step, the finding may affect multiple fire areas. In this case, the evaluation can proceed directly to Phase 3. If the finding is limited to a few areas, the evaluation can proceed using Phase 2.

06.01.04.04 Step 1.4.4: Fire Confinement

Basis for 1.4.4-A Question: The purpose of this question is to screen findings that do not affect the ability of the fire barrier system to protect the targets. The inspector should evaluate the location of targets in the area in relation to the degraded fire barrier system, and the location and type of combustibles in the area. For example, a finding related to a moderately degraded fire barrier can be screened to Green if the combustible loading in the area of concern is consistent with that analyzed in the approved fire protection program, including not only amount but also location. However, a large combustible source in the area, such as an oil reservoir, or combustibles or targets adjacent to the degraded barrier would require additional evaluation in Phase 2.

Basis for 1.4.4-B Question: An automatic water-based suppression system is designed to suppress a fire in the compartment in which the fire originates. In addition, the automatic fire suppression system would likely actuate and limit fire damage if the fire were to spread to the compartment from an adjacent compartment due to a fire barrier deficiency.

Basis for 1.4.4-C Question: In most cases these types of findings are considered low degradation and would have been screened to Green in a prior step. However, if not previously screened, then they are screened here.

Basis for 1.4.4-D Question: Closed fire doors provide adequate separation for most fire areas. However, fire doors that enclose fire areas with gaseous suppression systems are credited to ensure the proper concentration of suppression agent is maintained and therefore require additional evaluation in Phase 2. In addition, areas protected by gaseous suppression are generally risk-significant areas that require additional evaluation in Phase 2.

Basis for 1.4.4-E Question: If the exposing and exposed fire compartments contain the same set of targets, any increase in risk associated with the fire spreading from one zone to the other should be minimal if potential targets in the exposed zone have already been compromised by the exposing fire. However, if the fire spreading to another fire zone would impact SSD equipment not already compromised, additional evaluation is required in Phase 2.

Basis for 1.4.4-F Question: The inspector should consider the location of the degraded fire confinement element, the locations of any ignition sources and targets in the vicinity of the deficiency, the location of combustibles in the affected compartments, and the ability of the suppression system or fire brigade to extinguish the fire. Cable tray fires through a horizontal barrier progress slowly, such that the fire spread is not expected to impact the adjacent compartment before the fire brigade is able to respond. However, ceiling fire barrier deficiencies would transport flames/hot gases to the compartment above the fire much faster and should be evaluated further in Phase 2.

06.01.04.05 Step 1.4.5: Manual Fire Fighting

Basis for 1.4.5-A Question: Standard-sized fire extinguishers provide limited suppression value in comparison to fire hoses or fixed fire suppression systems. Possible exceptions are fire extinguishers used for hot work fire watches for an active ignition source or special large-capacity fire extinguishers for specific fire hazards.

Basis for 1.4.5-B Question: Irregularities in pre-fire plan information should not significantly impact fire brigade performance unless they can adversely impact the brigade's actions.

Basis for 1.4.5-C Question: Fixed fire suppression systems are much more likely to quickly suppress a fire than the fire brigade. Therefore, a manual firefighting deficiency would not significantly impact risk for a room with a fixed fire suppression system.

Basis for 1.4.5-D Question: Fire areas may have several hose stations nearby that can be used for manual firefighting. Some fire brigades carry additional hoses and equipment with them that can be used in place of the degraded equipment. Some plants stage additional firefighting equipment around the site for easy access. If alternative manual firefighting equipment is available to suppress the fire, the impact of the degraded hose station on risk is small. However, the alternative methods must be readily available and simple to execute such that SSD equipment is not adversely affected.

06.01.04.06 Step 1.4.6: Localized Cable or Component Protection

Basis for 1.4.6-A Question: Fire wraps extend the amount of time it takes for fire to damage the targets they protect. Fixed fire suppression systems quickly and reliably suppress fires or prevent them from spreading. If the target is protected by a fixed fire suppression system, the risk associated with low to moderate fire wrap degradations is low because the fixed fire suppression system will quickly stop fire progression. Highly degraded or non-functional fire wraps should be evaluated in Phase 2.

Basis for 1.4.6-B Question: In contrast to the previous, this question is intended to screen findings associated with degraded fire wraps to Green if the degradation is minor enough that the fire brigade, rather than a fixed fire suppression system, could suppress the fire before the target is damaged. The inspector should consider the extent of the damage to the wrap, location of the degradation, fire brigade response time, and ease of suppression. For example, a finding related to a 3-hour fire wrap that has been degraded to only provide 1 hour of protection can be screened to Green if the area has automatic detection, and the fire brigade would be able to reach and suppress the postulated fire within 1 hour.

06.01.04.07 Step 1.4.7: Post-Fire SSD

Basis for 1.4.7-A Question: If operators have adequate alternate lighting readily available to perform necessary manual actions, the actions remain feasible and the impact on risk is minimal.

Basis for 1.4.7-B Question: In general, the inspector should not have a finding in this category related to equipment that is not important to the credited SSD path. However, the equipment may not be required for SSD. Equipment that is important to SSD but not required for SSD affects SSD later in the fire scenario, after efforts to suppress the fire would have been taken. Therefore, this equipment is less risk significant, and the finding can be screened to Green.

Basis for 1.4.7-C Question: This question is intended to screen findings to Green that are only related to the ability to achieve cold shutdown (for Appendix R plants) or an extended safe and stable condition (for NFPA 805 plants), such that there is no degradation in the ability of the plant to reach hot shutdown/hot standby.

06.01.04.08 Step 1.4.8: Main Control Room (MCR) Fires

NOTE: This section only applies if there is no equipment greater than or equal to 440V in the MCR.

Basis for 1.4.8-A Question: From NUREG-2169 (Reference 19), the fire frequency in the Main Control Board is 0.005/ry. From Appendix L of NUREG/CR-6850 (Reference 8), Figure L-1 indicates that the product of severity factor and NSP depends solely on the distance between "targets" as located on the Main Control Board. For a bounding fire scenario where the fire frequency is 0.005/ry (which cannot be subdivided among individual panels) and the CCDP = 1, it requires the product of severity factor and NSP to be < (1.0E-6/ry)/(0.005/ry) = 2E-4 for screening at this step. Attaining such a low value (2E-4) is only possible if the cables in the Main Control Board are "qualified" and the targets on the Main Control Board are at least 2.5 m apart (see Figure L-1).

Basis for 1.4.8-B Question: For electrical enclosure fires, the original Fire Protection SDP assumed a "per-enclosure" fire frequency of 5.5E-5/ry based on the NUREG/CR-6850 (Reference 8) plant-wide FIF for electrical enclosures of 0.045/ry. This suggests an average of about 800 electrical enclosures per plant ([0.045/ry]/[5.5E-5/ry] ≈ 800). Reference 19 re-estimated the plant-wide electrical enclosure fire frequency as 0.030/ry, a 33 percent reduction, which would reduce the "per-enclosure" fire frequency to approximately (0.67)(5.5E-5/ry) ≈ 4E-5/ry. To achieve no greater than a 1E-6/ry CDF with spurious operations in two non-adjacent, non-Main Control Board electrical enclosures, the product of the inter-cable spurious operations cannot exceed (1E-6/ry)/(4E-5/ry) = 0.025. From Reference 17, the maximum probability of an inter-cable spurious operation is 0.025 for grounded AC cables with thermoplastic insulation (see Table 4-1). Therefore, the probability of two independent inter-cable spurious operations will be < 0.025, which is the case for two non-adjacent, non-Main Control Board electrical enclosures.

Basis for 1.4.8-C Question: As discussed in the basis for 1.4.8-A, the Main Control Board fire frequency is 0.005/ry, which requires a multiplicative factor of 2E-4 or less to *a priori* reduce the potential CDF to < 1E-6/ry. If no credit for suppression is given and a bounding CCDP = 1 is assumed, this CDF will reduce to an annual probability of <1E-6 only if the duration of the deficiency is no more than (1E-6/ry)(8760 hr/ry)/(0.005/ry) = 1.8 hr. Thus, rounding down to the nearest integer, a duration of 1 hr or less cannot lead to an annual probability of core damage of at least 1E-6.

06.01.05 Step 1.5: Screen Based on Licensee Fire PRA Results

Many NPPs in the U.S. have transitioned to a risk-informed performance-based fire protection program in accordance with NFPA 805 (Reference 9) via 10CFR50.48(c). For these and other plants with a fire PRA, the results of the licensee's PRA-based risk evaluation can serve as the basis for screening a finding to Green, provided a SRA reviews and approves.

06.02.01 Step 2.1: Bounding Risk Quantification

Entry into Step 2.1 implies that the finding was assigned a greater than low degradation rating (low degradation findings Screen to Green in Step 1.3). Hence, one element of the fire protection program will receive either no credit or credit that has been substantially degraded in subsequent analysis steps. On this basis, a quantitative screening check is performed based on the product of DF and conservative estimates of area FIF and CCDP.

06.02.01.01 Step 2.1.1: Estimate the Duration Factor

The DF converts the actual time over which the performance deficiency existed (up to a maximum of one year) to a fraction of a year (maximum value of 1.0). Previously, only three DFs were used: 0.01 (for durations of 3 days or less), 0.1 (for durations from 3 to 30 days), and 1 (for durations from one month to the maximum of one year).

06.02.01.02 Step 2.1.2: Estimate Bounding Value of the Fire Ignition Frequency

The generic FIFs used in Step 2.1.2 are based on a review of past fire PRA practice and insights gained from evaluations of fire event data. Generic fire area designations from these studies, and the corresponding fire event frequency estimates, were compiled. The values recommended for use in the Fire Protection SDP were based on a primarily conservative interpretation of the cited values. The sources considered are:

a. Typical Individual Plant Examination for External Events (IPEEE) practice as documented in the EPRI Fire-Induced Vulnerability Evaluation (FIVE) method (EPRI TR-100370) and the Fire PRA Implementation Guide (EPRI TR-105928);
b. NRC staff evaluations as documented in RES/OERAB/S02-01 (Jan. 2002);
c. The reactor safety studies documented in NUREG-1150;
d. The Risk Methodology Integration and Evaluation Program (RMIEP) analysis of the LaSalle Nuclear Power Station (NUREG/CR-4832); and
e. The Diablo Canyon NPP Fire Risk Analysis.

In general, the sources were consistent at least on the approximate order of magnitude associated with fire area-specific FIF values. The variation between one analysis and another was generally no more than a factor of 4 and was often less. In the case of the most significant variation, a review revealed that the value reported in one specific analysis included application of a fire severity factor. The Fire Protection SDP explicitly applies fire severity factors, and so this particular source was discounted.

Given the general agreement between the studies, the frequencies in Tables 2.1.2 and 2.1.3 of Appendix F represent aggregate, primarily conservative values based on the specific sources reviewed. The frequencies in these tables are identical to those in Table 1.4-2 in the 2004 version of Appendix F, except for the FIFs in the MCR and fires due to welding and cutting. The latter are based on values in the FIVE method.

06.02.01.03 Step 2.1.3: Estimate Bounding Value of Ignition Frequency Adjustment Factors

The bounding FIFs in Tables 2.1.2 account for any applicable adjustments. Consequently, the AF can be set equal to 1.0 in the Step 2.1 risk quantification, 06.02.01.04 Step 2.1.4: Estimate Bounding Value of the Severity Factor

The SF of an ignition source is a function of (1) its HRR characteristics, geometry, and location, and (2) the distance from the fire source to the nearest and most vulnerable target and (3) the damage and/or ignition characteristics of that target. This information is largely unknown at this stage and will not be gathered until Phase 2 has progressed to Step 2.2.2. Consequently, an SF that bounds all fire scenarios in the area(s) under evaluation cannot be determined, and the SF is conservatively set equal to 1.0 in the Step 2.1 risk quantification.

06.02.01.05 Step 2.1.5: Estimate Bounding Value of the Non-Suppression Probability

The NSP for a specific fire scenario is a function of the difference between the time until damage of the target set for the scenario, assuming no suppression, reaches the threshold for which mitigation of core damage cannot be achieved and the time to suppression of the fire. The information that is needed to determine these times is largely unknown at this stage and will not be gathered until Phase 2 has progressed to Step 2.2.2. Consequently, an NSP that bounds all fire scenarios in the area(s) under evaluation cannot be determined; therefore, the NSP is conservatively set equal to 1.0 in the Step 2.1 risk quantification.

06.02.01.06 Step 2.1.6: Estimate Bounding Conditional Core Damage Probability

Identify the Designated Post-Fire SSD Path

For each fire area in the plant, the licensee is required by the NRC fire protection regulations to establish a post-fire SSD path that will remain free of fire damage given the fire-induced failure of all unprotected cables and components within the fire area. In Step 2.1.6, the analyst is simply asked to identify this SSD path for the fire area under analysis.

Assess the Unavailability of the Identified SSD Path

The unavailability factors used for the mitigating system failure probabilities in the screening CCDP calculation are consistent with the SPAR models used for determining Phase 2 CCDP values.

Assess the Independence of the Identified SSD Path

The independence assessment is based primarily on the Appendix R, III.G.1 and III.G.2, compliance strategy for achieving physical protection of the designated post-fire SSD path. At this stage of the analysis, specific fire scenarios have not been developed or screened. Hence, a very stringent basis for independence of the designated post-fire SSD path is established.

The SSD path will be credited given one of four III.G.1 and III.G.2,.2 compliance strategies as outlined in Table 2.1.5 of Appendix F (see Step 2.1.6). The credit is based on the following bounding assessments of the likelihood that each of these compliance strategies might fail given a fire in the area:

a. Separation by fire area: Fire area boundaries as applied in the regulatory complex will generally have a minimum fire resistance rating of 2 hours, and often are rated at 3 hours. Other factors to be considered include the actual location of the fire (it would need to occur near, or spread to, the barrier element to be challenged), and the potential for a fire to actually become substantially threatening to the fire barrier (not all fires in the database had the potential to grow to such challenging proportions). Furthermore, the fire must also fail the redundant train of SSD equipment once the barrier is breached. Given these factors, a likely conservative assessment is that not more than 1 in 1000 fires (0.001) will result in breaching of a fire barrier and failure of redundant SSD equipment in an adjacent fire area. It is worth noting that in all the years of experience for the U.S. nuclear power industry, only one fire (Brown's Ferry, 1975) has resulted in breaching of an inter-area fire barrier element, and in that case, the barrier element was not complete. The most optimistic random failure probability estimate allowed in crediting the SSD path in this step is 0.01.

b. Separation by a 3-hour rated localized fire barrier: The argument for this case is similar to that presented above for an inter-area fire barrier.
c. Separation of more than 20 ft. plus automatic fire detection and suppression coverage for the fire area: The argument for this case is similar to that presented below for separation by a 1-hour barrier plus automatic detection and suppression.
d. Separation by a 1-hour barrier plus automatic detection and suppression: For this case three features are of particular importance: passive protection by the 1-hour barrier; active protection by the automatic fire suppression system; and active protection by the fire brigade with a high probability of early fire detection. If additional credit is taken for the fixed fire suppression system, in a non-degraded condition, activation of the fire suppression system should achieve fire control and prevent breaching of the localized fire barrier. Nominal failure probabilities for water-based fixed suppression systems are about 0.02. Given the fact that the vast majority of fires are suppressed well within an hour, the most optimistic assessment allowed is 0.01.

Other protection schemes will not be credited at this stage of the analysis. For example, if the protection scheme involves spatial separation, HGL or radiant heating effects might cause failure of the redundant train, i.e., should fire suppression fail or given a high-intensity fire exposure source. At this stage of the analysis, (Step 2.1) fire scenarios have not been developed to a sufficient level of detail to assess the likelihood that such effects will be observed given a fire in the area. Hence, credit for survival of the SSD path will be deferred pending further refinement of specific fire scenarios.

06.02.01.07 Step 2.1.7: Effect of Finding Category

The finding category affects the fire scenarios that need to be considered in the risk quantification. Since no fire scenarios are defined at this stage, only two of the eight finding categories affect the Step 2.1 bounding risk quantification:

a. For findings in the Fire Prevention and Administrative Controls Category, the fire frequencies in Table 2.1.3 are used instead of Table 2.1.2.
b. For findings in the Fire Confinement Category, all areas separated by the degraded barrier need to be included in the risk quantification.

06.02.01.08 Step 2.1.8: Estimate Bounding Value of ∆CDF

The quantitative screening in this step involves the determination of a bounding estimate of the ∆CDF for the area(s) under evaluation based on estimates of three factors in the risk quantification, i.e., DF, FIF, and CCDP. The remaining factors are assumed to equal to 1.0. It is unlikely that a finding will be screened to Green in this step, but the bounding risk quantification should give the analyst an indication of the likelihood that the finding can be screened to Green in Phase 2 and provide guidance on how this can be accomplished most efficiently.

06.02.02 Step 2.2: Identifying Credible Fire Scenarios and Information Gathering

A fire scenario starts with an ignition source and may lead to damage of one or several PRA targets in the area(s) under evaluation. In this step, information is collected for the ignition sources in the area(s) under evaluation that have the potential of starting a fire that contributes to the ΔCDF, and for the targets that could be damaged in fires that are initiated by these ignition sources. Some fire scenarios involve secondary combustibles, and information for those is collected in this step as well. The ignition source, secondary combustible, and target data collected in this step define the fire scenarios that are considered credible at this stage, and that may need to be included in the final risk quantification for the area(s) under evaluation. The list of credible fire scenarios is refined in future steps.

06.02.02.01 Step 2.2.1: Initial FDS Assignment

The initial FDS assignment of Step 2.2.1 is broadly inclusive of potential risk scenarios. The selection of FDSs applicable to a given finding is limited only by the nature of the finding itself. That is, an FDS need not be considered if and only if the finding itself inherently implies that any scenario corresponding to that particular FDS would be unaffected by the finding.

The first exclusion involves findings against fire confinement. Fire confinement refers to those fire barrier elements that segregate one fire area from an adjacent fire area. These inter-compartment fire barriers will only be relevant to the analysis of inter-compartment fire scenarios. i.e., the FDS3 scenarios. Any fire scenario that remains confined within the fire area of fire origin (i.e., any FDS1 or FDS2 scenario) would be unaffected by a finding associated with fire confinement. Therefore, the risk change for FDS1 and FDS2 scenarios is by definition zero and need not be analyzed. Hence, Step 2.2.1 requires that only the FDS3 scenarios be considered in the risk quantification.

The only other exclusion from the initial FDS assignment is the exclusion of FDS3 scenarios for findings in categories other than "Fire Confinement." This is because the probability of a fire propagating to an adjacent compartment through an undegraded barrier is very low (between 1.2E-03 and 7.4E-3 depending on the type of barrier, see Table 11-3 in NUREG/CR-6850 [Reference 8]).

06.02.02.02 Step 2.2.2: Information Gathering for the Analysis of Credible Fire Scenarios

Step 2.2.2 and several worksheets (Attachment 1, Worksheets 2.2.2a, 2.2.2b, 2.2.2c and 2.2.2d) are included in Appendix F to streamline the collection of information needed to perform the Phase 2 analysis.

Gathering Information for Ignition Sources in the Area(s) Under Evaluation

The analyst first needs to identify and count all ignition sources in the area(s) under evaluation that have the potential of starting a fire that contributes to the ΔCDF, and assign each ignition source to the appropriate fire ignition source type bin in Table A4.1 of Attachment 4 to Appendix F. Electrical enclosures ≥ 440 V are assigned to two bins for non-HEAF and HEAF scenarios, respectively. In addition, each electrical enclosure is further assigned to one of the HRR bins in Table A5.1 in Attachment 5 to Appendix F. Ignition source counting instructions are provided in Attachment 4 to Appendix F, and are based on the guidance in the following documents.

a. NUREG/CR-6850 (Reference 8), Section 6.5.6: Fixed Fire Ignition Source Counts;
b. FAQ 06-0016: Ignition Source Counting for Electrical Cabinets (Reference 20);
c. FAQ 06-0018: Ignition Source Counting for Main Control Board (Reference 21);
d. FAQ 07-0031: Miscellaneous Fire Ignition Frequency Binning Issues (Reference 22);
e. FAQ 12-0064: Hot Work/Transient Fire Frequency Influence Factors (Reference 23);
f. NUREG-2262: High Energy Arcing Fault Frequency and Consequence Modeling (Reference 15), updates previous counting guidance for HEAFs in switchgear, load centers in FAQ 06-0017 (Reference 24) and for bus duct HEAFs in FAQ 07-0035 (Reference 25).

For each ignition source, the analyst also needs to determine whether the ignition source is in an open area away from any corner (free-burning), or near a corner. For the purposes of the Phase 2 analysis, a fire is considered to be near a corner if within two feet of each of the two intersecting walls making up the corner.

<u>Gathering Information for Targets in the Area(s) Under Evaluation</u>

As a minimum, at this stage the analyst is asked to identify the nearest fire ignition and damage targets without regard to the specific importance of these targets in a PRA context. For example, the nearest damage target may not be a safety-related damage target, and its loss may have no measurable risk impact. However, by screening fire ignition sources based on the nearest targets in Step 2.3.2, optimistic screening results are precluded. Additional consideration is given to the identification and behavior of scenario-specific targets to the extent allowed by the available cable and component routing information in later steps of the analysis.

It is anticipated that the fire and ignition targets will generally be electrical cables. Electrical cables typically represent the most vulnerable element of major plant components. For example, the mechanical portions of a large pump are relatively invulnerable to fire-induced damage due to their shear mass and the lack of specifically vulnerable parts. However, the power cable that supplies power to the pump motor, and/or the control cables that control operation of the pump are typically exposed, and are known to be vulnerable to fire-induced failure. Hence, the SDP focus on cables is both appropriate and consistent with common PRA practice.

It is anticipated that some specific applications might involve thermal damage targets that are more fragile than the cables. An example would be solid-state signal conditioning or control switching equipment (temperature-sensitive electronics). Provisions for such cases have been allowed in the guidance. However, the guidance also specifies that given a fire in an electrical panel, including a control panel, that all of the components in that panel be assumed to fail. Hence, it is likely that most SDP analyses will continue to focus on electrical cables as both the ignition and damage targets.

Additional guidance for the identification of targets and their ignition and damage criteria is provided in Attachment 4 to Appendix F. The bases for the damage and ignition thresholds in this Appendix are as follows:

a. TS and TP Cable Targets: Damage and ignition criteria for TS and TP cable targets are given in NUREG/CR-6850 (Reference 8), Appendix H, Table H-1.
b. Kerite Cable Targets:
    1. FAQ 08-0053, Revision 1 (Reference 26) recommends a damage threshold of 247°C (477°F) for Kerite-FR cable targets. Consequently, assuming the TP damage thresholds for Kerite-FR cable targets is conservative.

    2. Reference 26 further recommends using damage thresholds from NUREG/CR-7102 (Reference 27) for Kerite FR-II, FR-III, and HT cable targets. Assuming the TS damage thresholds for Kerite FR-II, FR-III, and HT cable targets is also conservative, since the lowest failure temperature reported in Table 8-3 of Reference 27 for the Penlight tests performed on these Kerite cable varieties is 367°C (693°F).
    3. The TS ignition thresholds are assumed for Kerite cable based on the fact that all varieties are IEEE 383 qualified.

c. Cables in Metal Conduit: The treatment in terms of damage and ignition of cables in metal conduit is based on the guidance in NUREG/CR-6850 (Reference 8), Section 8.5.1.2.

d. Cables Coated with an FR Coating: The treatment in terms of damage and ignition of cables coated with an FR coating is based on the guidance in NUREG/CR-6850 (Reference 8), Section 8.5.1.2.

e. Cable Trays with Solid Bottoms: In the 2018 Fire Protection SDP, the treatment in terms of damage and ignition of TS cables in cable trays with solid bottoms is based on the guidance in NUREG/CR-6850 (Reference 8), Appendix Q, Section Q.2.2. The treatment in terms of damage and ignition of TP cables in cable trays with solid bottoms was based on test data in Table V of NUREG/CR-0381 (Reference 28). Since the present version now uses the heat soak method to determine the ZOI of cable targets, a longer delay can be assumed if the method predicts a damage or ignition time that exceeds 20 or 4 min for TS and TP cables, respectively. The treatment in terms of ignition and flame spread of cables in fully enclosed cable trays and trays with solid bottoms and ceramic fiber blanket covering the tray contents was used by several licensees that transitioned to NFPA 805 and accepted by NRC staff.

f. Mixed Cable Insulation/Jacket Type Configurations: Mixed cable insulation/jacket type configurations are treated conservatively, i.e., they are assigned TP damage and ignition thresholds if either the jacket, the insulation, or both are TP.

g. Temperature Sensitive Electronics:
    1. The treatment in terms of damage to exposed sensitive electronics is based on the guidance in NUREG/CR-6850 (Reference 8), Appendix H, Section H.2.
    2. The treatment in terms of damage to temperature sensitive electronics in an enclosure is based on the guidance in FAQ 13-0004 (Reference 29), which recommends assuming TS damage thresholds provided
        (a) The component is not mounted on the surface of the enclosure (front or back wall/door) where it would be directly exposed to the convective and/or radiant energy of an exposure fire.
        (b) The presence of louvers or other typical ventilation means does not invalidate the guidance provided in the FAQ.

h. Other Targets: The treatment in terms of damage and ignition of targets other than electrical cables and temperature-sensitive electronics is based on the guidance in NUREG/CR-6850 (Reference 8), Appendix H, Section H.2.

i. Targets in Equipment Vulnerable to HEAFs: NUREG-2262 (Reference 15) specifies the ZOI for HEAFs in switchgear, load centers and non-segregated bus ducts as a function of the fragility of the target (TS or TP cable), and for bus duct HEAFs also as a function of the fragility of the bus duct material (steel or aluminum. Target fragilities for equipment vulnerable to HEAFs are provided in NRC RIL 2022-01 (Reference 30).

06.02.03 Step 2.3: Ignition Source Screening and Fire Scenario Refinement

06.02.03.01 Step 2.3.1: Characterize Fire Ignition Sources

For each ignition source identified in Step 2.2.2, a HRR profile and nominal location are assigned. The HRR profiles for various ignition sources can be found in Attachment 5 to Appendix F. The basis for these profiles is discussed below.

HRR Profile of Fixed Ignition Sources

The HRR profile of a fixed or transient ignition source consists of three stages and is defined by six parameters as shown in Equation 5.1 of Attachment 5 to Appendix F. The first parameter is the maximum HRR, denoted as HRR_{peak} or $\dot{Q}_{peak}$. The remaining parameters are as follows:

a. Growth Time, t_g: The time during which the HRR increases from 0 kW to reach HRR_{peak} as an exponential function of time.
b. Growth Exponent, n_g: The exponent in the function that describes the exponential growth of the HRR from 0 kW to HRR_{peak} between t = 0 min and $t = t_g$.
c. Plateau Time, t_p: The time after the growth period during which the HRR remains steady at HRR_{peak}.
d. Decay Time, t_d: The time during which the HRR decreases from HRR_{peak} to 0 kW as an exponential function of time.
e. Decay Exponent, n_d: The exponent in the function that describes the exponential decay of the HRR from HRR_{peak} to 0 kW between $t = t_g + t_p$ to $t = t_g + t_p + t_d$.

The 98th percentile peak HRRs for fixed and transient ignition sources that are used in the Fire Protection SDP to determine the ignition source ZOI for screening purposes are given in Tables A5.1 and A5.3 of Attachment 5 to Appendix F, respectively. The remaining HRR profile parameters for the fixed and transient ignition sources are given in Tables A5.2 and A5.4 of Attachment 5 to Appendix F, respectively. Figure 6.2.1 below shows a generic version of the HRR profile for electrical enclosures. HRR_{peak} is a function of the type of the electrical enclosure (switchgear, MCC, etc.) but the remaining profile parameters are the same for all electrical enclosures, i.e., t_g = 12 min, n_g = 2, t_p = 8 min, t_d = 19 min and n_g = 1).

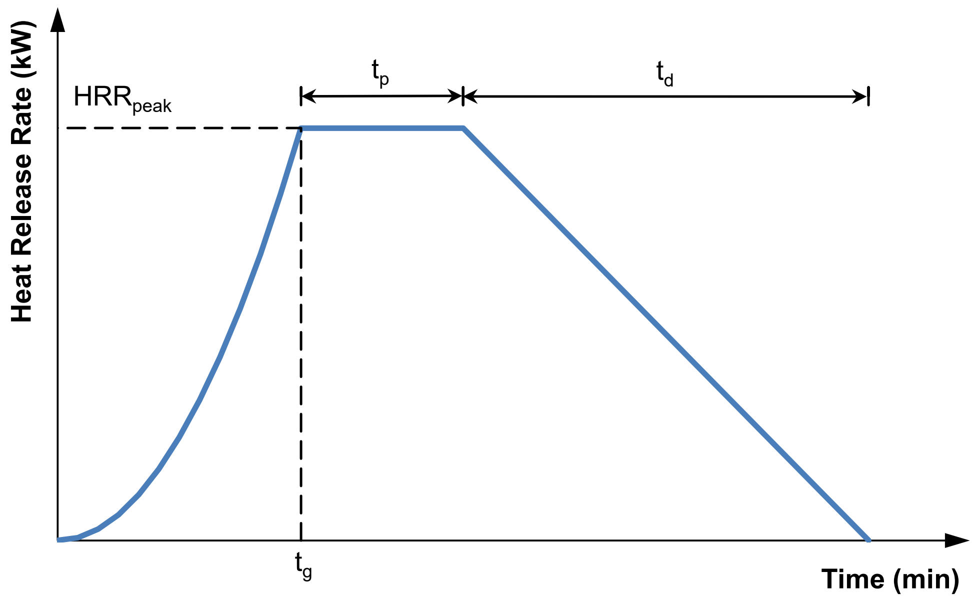

Figure 6.2.1 – HRR Profile of Electrical Enclosures.

The fixed ignition sources listed in Table A5.1 of Attachment 5 to Appendix F consist of three classes of electric motors and three classes of dry transformers defined in NUREG-2178, Vol. 2 (Reference 10), and selected electrical enclosures defined in NUREG-2178, Vol. 1 (Reference 31). Table 6.2.1 provides a list of all electrical enclosures for which HRR distributions were developed and reported in Reference 31.

Table 6.2.1 – Electrical Enclosures from Reference 31.			
Enclosure Group	Configuration	Fuel Type*	Fuel Loading
Switchgear & Load Centers	Closed	TS/QTP/SIS	NA
	Closed	TP	NA
MCCs & Battery Chargers	Closed	TS/QTP/SIS	NA
	Closed	TP	NA
Power Inverters	Closed	TS/QTP/SIS	NA
	Closed	TP	NA
Large Enclosures V>1.42 m^3 V>50 ft^3	Closed	TS/QTP/SIS	Default
	Closed	TP	Default
	Open	TS/QTP/SIS	Default
	Open	TP	Default
	Closed	TS/QTP/SIS	Low
	Closed	TP	Low
	Open	TS/QTP/SIS	Low
	Open	TP	Low
	Closed	TS/QTP/SIS	Very Low
	Closed	TP	Very Low
	Open	TS/QTP/SIS	Very Low
	Open	TP	Very Low
Medium Enclosures 0.34 m^3<V≤1.42 m^3 12 ft^3<V≤50 ft^3	Closed	TS/QTP/SIS	Default
	Closed	TP	Default
	Open	TS/QTP/SIS	Default
	Open	TP	Default
	Closed	TS/QTP/SIS	Low
	Closed	TP	Low
	Open	TS/QTP/SIS	Low
	Open	TP	Low
	Closed	TS/QTP/SIS	Very Low
	Closed	TP	Very Low
	Open	TS/QTP/SIS	Very Low
	Open	TP	Very Low
Small Enclosures	NA	All	Default

* TS=Thermoset, QTP=Qualified TP, SIS=Switchboard Wire, TP=Thermoplastic

The subset of electrical enclosures retained in the Fire Protection SDP (non-shaded cells in Table 6.2.1) is based on the conservative assumption that they have TP cable contents and default fuel loading. Focusing on this subset of electrical enclosures significantly reduces the number of tables and plots for sets C through F in Attachment 8 to Appendix F. The reduction makes the use of the plots and tables in Attachment 8 to Appendix F more manageable, and is further justified by the fact that it is often very difficult to ascertain the fuel type and loading of electrical enclosures, and that a Phase 2 assessment is intended to be conservative.

The basis for the HRR profile parameters of fixed ignition sources in Tables A5.1 and A5.2 of Attachment 5 to Appendix F is provided below:

a. Electric Motors: The HRR gamma distribution parameters and corresponding 75th and 98th percentile HHRs for Class A, Class B and Class C electric motors in Table A5.1 of Attachment 5 to Appendix F are based on the values reported in NUREG-2178, Vol. 2 (Reference 10), Table 8-1. The HRR profile parameters for electric motors in Table A5.2 of Attachment 5 to Appendix F are based on the guidance in NUREG-2178, Vol. 2 (Reference 10), Section 8.3.1.
b. Dry Transformers: The HRR gamma distribution parameters and corresponding 75th and 98th percentile HHRs for Class A, Class B and Class C dry transformers in Table A5.1 of Attachment 5 to Appendix F are based on the values reported in NUREG-2178, Vol. 2 (Reference 10, Table 8-2. The HRR profile parameters for electric motors in Table A5.2 of Attachment 5 to Appendix F are based on the guidance in NUREG-2178, Vol. 2 (Reference 10), Section 8.3.2.
c. Electrical Enclosures: The HRR gamma distribution parameters and corresponding 75th and 98th percentile HHRs for the electrical enclosures in Table A5.1 of Attachment 5 to Appendix F are based on the values reported in NUREG-2178, Vol. 1 (Reference 31), Table 7-1. However, the distribution parameters reported in the NUREG have limited precision (the shape factor α is rounded to one decimal place, and the rate factor β is reported as an integer). The distribution parameter values in Table A5.1 are more precise and result in 75th and 98th percentile HRR values that are an exact match to the corresponding HRRs reported in Table 7-1 of the NUREG. The HRR profile parameters for electrical enclosures in Table A5.2 of Attachment 5 to Appendix F are based on the guidance in NUREG/CR-6850 (Reference 8), Section G.3.1.

HRR Profile of HEAFs in Electrical Enclosures

The HRR profile of HEAFs in electrical enclosures is identical to that for non-HEAF fires, except that t_g = 0 min. This is based on the guidance in NUREG-2262 (Reference 15), Section 10.2.1 for HEAFs in load centers and Sections 10.2.2 and 10.2.3 for switchgear in Zone 1 and Zone 2, respectively.

HRR Profile for Propagating Electrical Enclosure Fires

The screening conditions, time to propagate to adjacent enclosure(s) and the resulting HRR profile for a propagating electrical enclosure fire are based on the guidance in NUREG-2178, Vol. 2 (Reference 10), Sections 4.2 (screening) and 4.5 (enclosure to enclosure fire spread).

HRR Profile of Transient Combustible Fires

The HRR and TER (Total Energy Release) gamma distribution parameters and corresponding 75th and 98th percentile HHRs for transient combustible fires in Table A5.3 of Attachment 5 to Appendix F are based on the values reported in NUREG-2233 (Reference 13), Table 8-1 for generic transients and Table 8-2 for transient combustible control location (TCCL) transients. The HRR profile parameters for transient combustible fires in Table A5.4 of Attachment 5 to Appendix F are based on the values reported in NUREG-2178, Vol. 2 (Reference 10), Table 8-3 for generic transients and Table 8-4 for TCCL transients. The profile timing parameters (t_g, t_p and t_d) vary as a function of the TER and are calculated using Equations 5-2 through 5-6 in the NUREG.

HRR Profile of Oil Fires

The HRR of oil fires is assumed to reach peak HRR immediately following ignition and is considered to burn at peak rate until all fuel is consumed. The HRR of oil fires depends on whether the spill is confined (i.e., captured in a pan or diked area) or unconfined.

HRR of Confined Liquid Fuel Pool Fires

For confined liquid fuel pool fires the area is known and the HRR can be estimated from Babrauskas' correlation for the burning rate of pool fires as a function of the size of the pool and properties of the fuel (Equation 3-8 in Reference 11):

$$\dot{Q} = \dot{m}''_{max} \Delta h_{c,eff} A_f \left(1 - e^{-k\beta D}\right) \quad [4]$$

where

$\dot{Q}$	=	HRR (kW)
$\dot{m}''_{max}$	=	maximum mass loss rate per unit area ($g/m^2 \cdot s$)
$\Delta h_{c,eff}$	=	effective heat of combustion (kJ/g)
A_f	=	area of the pool fire (m^2)
$k\beta$	=	absorption coefficient (m^{-1})
D	=	diameter of the pool fire (m)

Table 6.2.2 gives the properties for liquid fuels commonly used in NPPs. Only those fuels are explicitly considered in Phase 2 of the Fire Protection SDP update.

Table 6.2.2 – Liquid Fuel Properties for Equation 4.

Fuel	Density (kg/m3)	$\dot{m}''_{max}$ (g/m2·s)	Δhc,eff (kJ/g)	kβ (m-1)
Diesel Fuel	970	35	39.7	1.7
Fuel Oil, Heavy	970	35	39.7	1.7
Lube Oil	760	39	46.4	0.7
Mineral Oil	760	39	46.4	0.7
Silicone Fluid	980	5	28.1	1.0

The properties for heavy fuel oil, mineral oil, and silicone fluid are taken from Table 3-2 in NUREG-1805 (Reference 11). Based on generic physical properties and flammability data in the literature, diesel fuel and lube oil are conservatively assumed to have the same properties as heavy fuel oil and mineral oil, respectively.

HRR of Unconfined Liquid Fuel Spill Fires

The maximum area of an unconfined liquid fuel spill can be estimated with the method recommended in NUREG/CR-6850 (Reference 8), Appendix G, Section G.4. This method was originally developed by Gottuk and White as described in the Society of Fire Protection Engineers (SFPE) Handbook (Reference 33). The method assumes that the maximum area of an unconfined spill is equal to 1.4 m^2/ℓ (57 ft^2/gal) if the total volume of fuel spilled is 95 ℓ (25 gal) or less, and equal to 0.36 m^2/ℓ (15 ft^2/gal) if the total volume of fuel spilled is greater than 95 ℓ (25 gal). Note that the spill areas per unit volume in Reference 8 are actually incorrect. The correct values are given on the NUREG/CR-6850 errata sheet (Reference 34).

The maximum spill area estimate can be used in conjunction with Equation 4 to obtain a conservative value of the HRR of an unconfined liquid fuel spill fire. However, the discontinuity in the maximum spill area estimates at 95 ℓ (25 gal) leads to inconsistencies in the calculated HRRs. For example, the HRR for a spill of 76 ℓ (20 gal) diesel fuel is approximately 2.6 times the HRR for a 113 ℓ (30 gal) spill. To address this problem, the fuel spill depth is calculated from the spill volume according to the following equation:

$$\delta = 0.52 \ln(V_f) + 0.04 \qquad [5]$$

where,

δ	=	fuel spill depth (mm)
V_f	=	fuel volume (ℓ)

The relationship between δ and V_f in Equation 5 is based on the curve for JP-4 fuel in Figure 2-15.1 of Reference 33 (duplicated in Figure 6.2.2 below). Based on the data collected by Gottuk and White, Equation 5 appears to provide conservative estimates of δ (small fuel depth) and A_f (large spill area) for unconfined liquid hydrocarbon fuel spills.

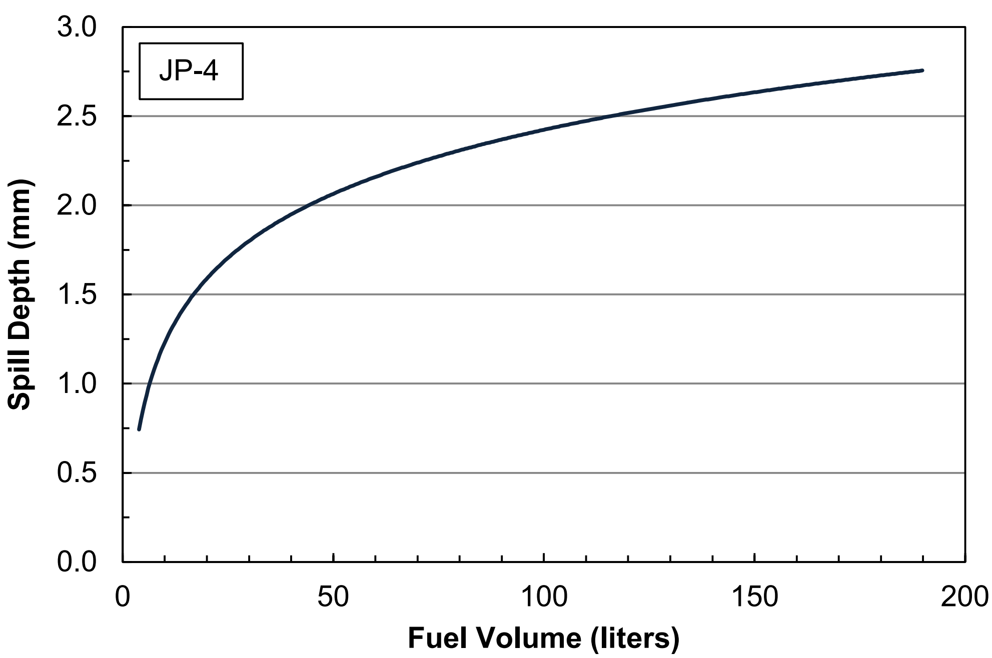

Figure 6.2.2 – Spill Depth as a Function of Fuel Volume for Unconfined JP-4 Spills. (Source: Figure 2-15.1 in Reference 33)

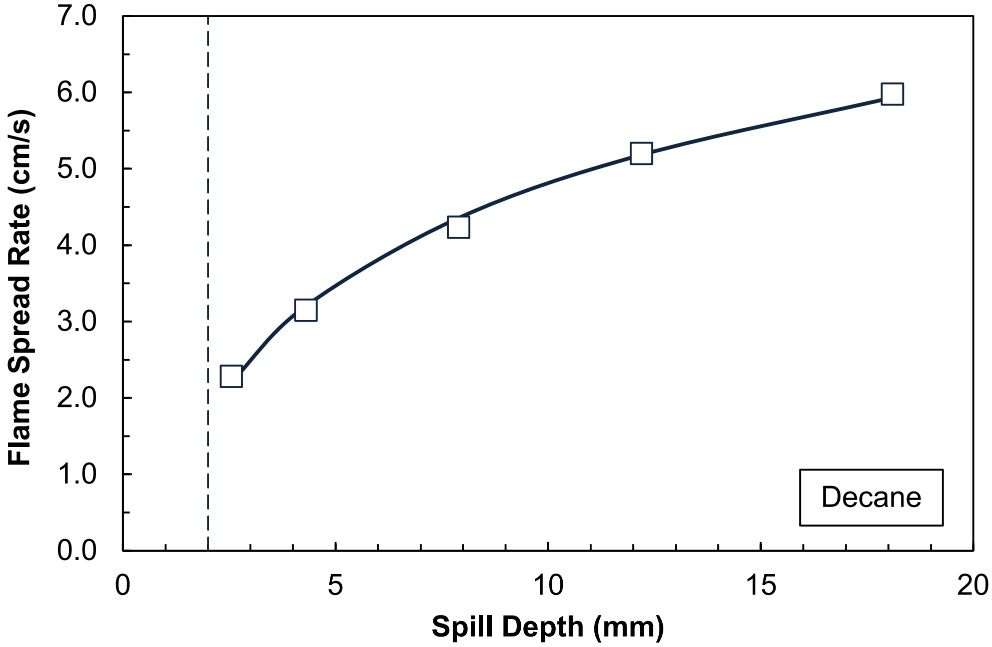

Figure 6.2.3 – Flame Spread Rate versus Spill Depth for an Unconfined Decane Spill.
(Source: Figure 2-15.7 in Reference 33)

In addition, literature data for decane (a hydrocarbon fuel) cited in Reference 33 indicate that flames do not spread away from the ignition source in liquid pools that are 2 mm or less deep, as shown in Figure 6.2.3. Consequently, in the development of the ZOI tables and plots for unconfined pool fires in Attachment 8 to Appendix F, δ = 2 mm was assumed for spill volumes of 43 ℓ (11.5 gal) or less. Applying the 2 mm limit to the fuels listed in Table 6.2.2 can be justified on the basis that the flash point of decane (46°C or 115 °F, determined according to the test method in Reference 35 is lower than the lowest flash point for the liquid fuels listed in the table (52°C or 126°F for diesel fuel), which implies that flames spread more easily over the surface of a decane fuel spill than over the surface of a spill of any of the fuels for which ZOI tables were developed.

HRR of Horizontal Cable Tray Fires

The HRR profiles of vertical stacks of horizontal cable trays in table/plot set C of Attachment 8 to Appendix F were calculated based on the FLASH-CAT (Flame Spread over Horizontal Cable Trays) model described in NUREG/CR-7010, Vol. 1 (Reference 36), Chapter 9. The assumptions that were made in these calculations are discussed in the section that describes the basis for table/plot set C in Attachment 8 to Appendix F.

HRR of Vertical Cable Tray Fires

The HRR of a vertical cable tray is equal to the exposed area of the tray times the HRR per unit area (HRRPUA) of the cables in the tray. The latter is the default HRRPUA value for the appropriate cable type (TS or TP as recommended in Reference 36, Chapter 9).

06.02.03.02 Step 2.3.2: FDS1 Ignition Source Screening

The approach defined for the screening of fire ignition sources is based on practices that are recommended in NUREG/CR-6850 (Reference 8) and NUREG-2178, Vol. 2. The ZOI tables and plots in Attachment 8 to Appendix F (table/plot set A) cover the two modes of fire damage that are considered in fire modeling of FDS1 scenarios. The correlations used in development of the ZOI tables and plots to estimate fire plume temperatures and radiant heating effects are well-established handbook correlations. However, the 2018 Fire Protection SDP assumed that damage or ignition is instantaneous when the plume temperature at a vertical target or the incident radiant heat flux to a horizontal target reaches the applicable damage/ignition threshold. The present Fire Protection SDP accounts for the fact that it takes some time to heat a cable target to failure after the surrounding plume temperature or incident radiant heat flux has reached (or even exceeds) the failure threshold. The approach to calculate the time to damage or ignition of a cable target exposed to a time-dependent plume temperature or radiant heat flux is referred to as the "heat soak method". The method is described in NUREG-2178, Vol.2 (Reference 10), Appendix A. Additional discussion of the method can be found in NUREG-2232 (Reference 37), Section 5.6.

The damage/ignition thresholds values used to establish cable damage and ignition temperatures are bounding values representative of the weakest members of the two major cable groups. The values used (400°F and 625°F) reflect commonly applied screening values for the damage thresholds for minimum damage/ignition thresholds for thermoplastic and thermoset cables respectively.

The ignition temperatures of TS and TP cable targets have been assumed equal to the damage temperature based on NRC-sponsored testing from the late 1980's (NUREG/CR-5546 (Reference 38)) which showed piloted ignition concurrent with failure of an energized electrical cable. Kerite-FR cable targets are conservatively assumed to have the same damage threshold as TP cables, while other types of Kerite cable targets are assigned thermoset damage thresholds. This is based on test data reported in NUREG/CR-7102 (Reference 27). All Kerite cable varieties are IEEE 383-qualified and are therefore assumed to have the same ignition temperature as TS cable targets. For the SDP, piloted ignition conditions are assumed without explicit analysis of the flame zone location or extent in order to simplify the analysis. This may be a source of some modest conservatism for some cases.

06.02.03.03 Step 2.3.3: FDS2 Ignition Source Screening

This step screens ignition sources that do not release heat at a sufficient rate to cause the development of a damaging HGL in the compartment under evaluation. The minimum HRR required to cause damage to all targets of a specific type (FDS2) in a compartment of a specified size can be determined from table/plot set B in Attachment 8 to Appendix F. The tables and plots in this set were developed using a well-established handbook correlation, referred to as the method of McCaffrey, Quintiere, and Harkleroad or MQH method (see Chapter 2 in Reference 11). Note that the heat soak method has not been implemented for FDS2 scenarios in the present Fire Protection SDP.

06.02.03.04 Step 2.3.4: FDS3 Ignition Source Screening

This step is only performed for findings in the Fire Confinement Category. It is similar to the previous step, and screens ignition sources in each of the compartments separated by the degraded barrier that do not release heat at a sufficient rate to cause the development of a damaging HGL in the adjacent compartment. Note that the heat soak method has not been implemented for FDS3 scenarios in the present Fire Protection SDP.

06.02.03.05 Step 2.3.5: Screening Check

The screening check in Step 2.3 only screens a finding in a category other than the Fire Confinement Category to Green if the analyst is unable to identify a fire ignition source with a potential to ignite the nearest secondary combustible material or damage the single most vulnerable thermal damage target. This indicates that there are no fire ignition sources in the fire area, including hot work and transient fires, capable of creating a credible fire scenario. This is taken as a very strong indication of low fire risk based on a demonstrated lack of fire hazards. In addition, a finding in the Fire Confinement Category is screened to Green if none of the ignition sources in the separated compartments is capable of igniting a secondary combustible and all screen out in Step 2.3.4.

06.02.04 Step 2.4: Final Fire Ignition Frequency Estimates

06.02.04.01 Step 2.4.1: Nominal Fire Frequency Estimation

In many ways FIF is estimated in exactly the same manner used in most current fire PRAs. The most significant extension applied in the SDP is the use of component or fire ignition source specific FIFs for nearly all sources (a few sources require the analyst to estimate the total plant-wide or HEAF fault zone-wide unit count). Implementation of this approach did require significant simplification to the application process. The major difference for the Fire Protection SDP is that, with a few exceptions, the analyst is not asked to count fire sources throughout the plant, only those in the fire area under analysis. In other PRA analysis methods, it is assumed that the analyst will have a complete count of fire ignition sources throughout the plant. Hence, the generic plant-wide FIF is partitioned to individual components based on the plant-specific total component count. In the SDP, generic or representative component counts are applied, and the generic plant-wide FIF is partitioned to individual components based on these generic component count values.

The resulting component-specific FIF are provided in Table A4.1 of Attachment 4 to Appendix F. Table 6.2.3 illustrates the process for obtaining these frequencies. A description of the columns in this table follows.

Table 6.2.3 – Calculation of Component-Specific Fire Ignition Frequencies Based on Plant-Wide Fire Ignition Frequency and Generic Component Counts.							
Generic Ignition Source	NUREG-2169 Bin(s)	Plant-wide FIF (/ry)	Plant- or Zone-wide Count (average)	Counting Unit	Fire Type	Weighting Factor	FIF per Counting Unit (/ry)
Self-Ignited Cables – Thermoplastic:							
Cables – Low Loading	12	7.0E-04	~1% of total fire frequency		Cable	0.01	7.0E-06
Cables – Medium Loading			~25% of total fire frequency			0.25	1.8E-04
Cables – High Loading			~74% of total fire frequency			0.74	5.2E-04
Electrical Enclosures (non-HEAF):							
Electrical Enclosures	15	3.0E-02	750	# distinct vertical sections	Electrical	1.00	4.0E-05
Main Control Board	4	2.05E-03	1	# control rooms per unit	Electrical	1.00	2.05E-03
Electric Motors:							
Electric Motors	14	5.4E-03	4	# motors	Electrical	1.00	1.4E-03
Generators:							
Diesel Generators	8	7.8E-03	2	# diesel generators	Electrical	0.16	6.2E-04
					Oil	0.84	3.3E-03
					Total	1.0	3.9E-03
Gas Turbine Generators		3.1E-02	2	# gas turbine generator sets	Oil	1.00	1.6E-02
RPS MG Sets	22	2.3E-03	3	# RPS MG sets	Electrical	1.00	7.7E-04
High Energy Arcing Faults:							
Zone 3 Load Centers (≤1000 V)	16.a	5.3E-04	TBD	# supply circuit breakers	HEAF	1.00	TBD
Zone 1 Switchgear (>1000 V)	16.b	1.7E-03	TBD	# switchgear banks	HEAF	1.00	TBD
Zone 1 Switchgear (>1000 V)	16.b	2.8E-04	TBD	# switchgear banks	HEAF	1.00	TBD
Zone BDUAT & BDSAT NSBD	16.1-1	2.6E-03	TBD	# non-segregated bus transitions	HEAF	1.00	TBD
Zone BD1, BD2 & BDLV NSBD	16.1-2	9.0E-04	TBD	# non-segregated bus transitions	HEAF	1.00	TBD
Iso-Phase Bus Ducts	16.2	1.0E-03	2	# iso-phase bus duct ends	HEAF	1.00	5.0E-04
Hot Work Transient Fires:							
Hot Work – Low	3, 6, 24, 36	1.4E-02	10	# low fire areas	Transient	0.025	3.5E-05
Hot Work – Medium			30	# moderate fire areas	Transient	0.225	1.1E-04
Hot Work – High			10	# high fire areas	Transient	0.750	1.1E-03
Hydrogen Sources:							
H_2 Recombiner (BWR)	20	5.8E-03	3	# H_2 recombiners	Hydrogen	1.00	1.9E-03
H_2 Storage Tanks	17	4.9E-03	1	# H_2 tanks	Hydrogen	1.00	4.9E-03
Misc. Hydrogen Fires	19	4.8E-03	3	# fire areas with charged piping	Hydrogen	1.00	1.6E-03

Table 6.2.3 (Continued) – Calculation of Component-Specific Fire Ignition Frequencies Based on Plant-Wide Fire Ignition Frequency and Generic Component Counts.							
Generic Ignition Source	NUREG-2169 Bin(s)	Plant-wide FIF(/ry)	Plant-wide Count (average)	Counting Unit	Fire Type	Weighting Factor	FIF per Counting Unit (/ry)
Main Turbine Generator Set:							
T/G Exciter Fire	33	8.4E-04	2	# exciters	Electrical	1.00	4.2E-04
T/G Oil Fires	35	5.5E-03	5	# lube oil systems	Oil	1.00	1.1E-03
T/G Hydrogen Fires	34	4.1E-03	3	# Hydrogen systems	Hydrogen	1.00	1.4E-03
Miscellaneous Components:							
Air Compressors	9	4.7E-03	10	# air compressors	Electrical	0.62	2.9E-04
					Oil	0.38	1.8E-04
Battery Banks	1	3.9E-04	4	# interconnected battery sets	Electrical	1.00	9.8E-05
Boiler Heating Units	30	1.1E-03	1	# boilers	Oil	1.00	1.1E-03
Electric Dryers	13	3.7E-03	3	# dryers	Transient	1.00	1.2E-03
Ventilation Subsystems	26	1.6E-02	150	# major ventilation systems	El. or Oil	1.00	1.1E-04
Pumps:							
Reactor Coolant Pump (PWR)	2	N/A	N/A	# reactor coolant pumps	Electrical	0.14	1.9E-04
Reactor Feed Pump (BWR)					Oil	0.86	1.2E-03
Main Feedwater Pumps	32	N/A	N/A	# main feedwater pumps	Electrical	0.11	4.8E-04
					Oil	0.89	3.9E-03
Other Pumps	21	2.7E-02	90	# other pumps	Electrical	0.54	1.6E-04
					Oil	0.46	1.4E-04
Transformers:							
Outdoor/Yard	27, 28, 29	1.7E-02	6	# outdoor transformers	El./Oil	1.00	2.8E-03
Indoor Dry and Oil-Filled	23	9.6E-03	60	# indoor dry transformers	Electrical	1.00	1.6E-04
				# indoor oil-filled transformers	Oil	1.00	1.6E-04
Transient Fuels:							
Transients – Low	3, 7, 25, 37	1.9E-02	10	# low fire areas	Transient	0.025	4.7E-05
Transients – Medium			30	# moderate fire areas	Transient	0.225	1.4E-04
Transients – High			10	# high fire areas	Transient	0.750	1.4E-03
Ignition Sources Requiring Total Plant Unit Count Estimates:							
Battery Chargers	10	1.1E-03	TBD	# battery chargers	Electrical	1.00	TBD
Hot Work Cable Fires	5, 11, 33	1.4E-03	TBD	Consult with regional/HQ staff	Transient	TBD	TBD
Junction Boxes	18	3.6E-03	TBD	# junction boxes	Electrical	1.00	TBD

a. Generic Ignition Source - Each ignition source in the plant is mapped to a generic ignition source. The first column in Table 6.2.3 lists all generic ignition sources that may need to be considered in a Phase 2 Fire Protection SDP assessment.
b. NUREG-2169 Bin(s) - The fire ignition sources used in fire PRAs are divided into groups called bins that represent location, causal, and mechanistic factors deemed important to depict frequencies of initiating fire scenarios at different plants. The generic bin definitions, plant operating mode applicability, and associated frequencies used in fire PRAs were originally developed and provided in NUREG/CR-6850 (Reference 8). Most generic ignition sources are in a single bin, but some are assigned to multiple bins. The second column in Table 6.2.3 lists the applicable bin(s) for the corresponding generic ignition source in the first column. NUREG-2262 (Reference 15) subdivides bin 16.1 into two smaller bins depending on the HEAF fault zone where the non-segregated bus duct being analyzed is located.
c. Plant-wide FIF - To obtain the total plant-wide FIF for a generic ignition source, the FIFs are summed for all bins to which the ignition source is assigned. Note that 56 percent of the frequency for bin 3 contributes to the plant-wide FIF for transient fires caused by hot work, while the remaining 44 percent contributes to the plant-wide FIF of transient fires. The 0.44/0.56 split fractions are specified in NUREG/CR-6850 (Reference 8), Section 6.3.1, Table 6-1. The fire frequencies for each bin are taken from NUREG-2169 (Reference 19), Section 4.2, Table 4-6, which is based on the U.S. NPP fire event experience through 2009.
d. Plant-wide Count - This column lists the assumed generic component counts for a “typical” plant. The basis for these estimates is as follows:
    1. The average count of electrical enclosures that are subjected to HEAFs is based on experience from the NFPA 805 transition process.
    2. According to Section 7.2.1.2 of Reference 25, there is a maximum of one iso-phase bus duct per unit. Consequently, there are only two locations (the ends) where a HEAF can occur.
    3. The 2013 Fire Protection SDP specifies an average plant-wide count of six battery banks. However, several plants have two battery rooms with two battery banks each. Hence, the plant-wide battery bank count was changed to four, which increases the per component frequency and is therefore more conservative.
    4. The frequency for PWR reactor coolant pumps is specified per pump with a 0.14/0.86 electrical/oil fire split fraction per Table 6-1 in NUREG/CR-6850 (Reference 8), Section 6.3.1. There is no bin specifically for BWR reactor feed pumps, but these pumps are of a similar nature and therefore combined with PWR reactor coolant pumps for the purpose of estimating fire frequency. The weighting factors for main feedwater pumps and other pumps are also based on split fractions in NUREG/CR-6850 (Reference 8), Section 6.3.1, Table 6-1. The frequency for main feedwater pumps is also specified per unit. The plant-wide count for other pumps is the same as in the 2013 Fire Protection SDP.
    5. Plant-wide unit counts need to be estimated for load center HEAFs (electrical enclosures ≤ 1000 V), battery chargers, hot work cable fires, and junction boxes. HEAF fault zone unit counts need to be estimated for switchgear HEAFs (enclosures >1000 V) and non-segregated bus duct HEAFs.
    6. The plant-wide unit counts for the remaining generic ignition sources are based on the plant-wide unit counts specified in the 2013 Fire Protection SDP. These generic component counts were generated using information for several plants. The EPRI Fire PRA Implementation Guide provided counts for seven plants based on work performed during the IPEEE analyses. The Nuclear Energy Institute (NEI) provided counting information for four additional plants as a part of their efforts to support and

comment on this revision of the process guidance. These results contained substantial plant to plant variability in some categories. Discussions with individuals knowledgeable of the counting process revealed that much of the variability was due to differences of interpretation of the EPRI IPEEE guidance. An individual plant volunteered to provide component counts using the SDP guidance directly. These counts were relied upon heavily in establishing the final generic count values.

e. Counting Unit - Briefly describes how the counting units are defined.
f. Fire Type - Identifies the fire type(s) each ignition source can generate.
g. Weighting Factor - The weighting factors for self-ignited cable fires are self-explanatory. The weighting factors for hot work transient fires and transient fires are discussed in a separate subsection below. Air compressors and pumps can lead to electrical or oil fires depending on what drives the device, and the weighting factors for the two types of fires are based on the corresponding split fractions in NUREG/CR-6850 (Reference 8), Section 6.3.1, Table 6-1. All diesel generators can initiate both electrical and oil fires. A weighting factor of 1.0 is used if the fire type is unknown.
h. FIF per Counting Unit - For most ignition sources the FIF per counting unit for each fire type is equal to the plant-wide FIF divided by the plant-wide unit count and multiplied by the weighting factor. Exceptions are self-ignited cables, for which the total unit count is incorporated into the weighting factors, and specific types of pumps, for which per component FIFs are specified.

<u>Weighting Factors for Transient Fires</u>

Estimating the frequency of transient fires for a given fire area involves the process of fire frequency partitioning, i.e., the process of apportioning the plant-wide FIF to individual fire areas or fire scenarios. For fires involving transient fuels (e.g., trash, general materials storage of solids or liquids, maintenance materials, materials staged in anticipation of maintenance activities) the partitioning process is based on four assumptions.

a. Assumption 1: The plant-wide FIF for transient fires is approximately 1.9E-2/ry. This value is derived from analysis of the fire event database updated in 2009 (Reference 19).
b. Assumption 2: Each fire area will be assigned a relative transient fire likelihood rating. Three likelihood ratings will be used (Low, Medium, and High). Guidance for assigning a likelihood rating to a given fire area is provided below.
c. Assumption 3: On a fire area by fire area basis, the relative likelihood of a transient fire occurring in a “medium” fire area is three times the likelihood of a fire occurring in a “low” fire area ($f_{med} = 3 \times f_{low}$). In the same manner, the likelihood of a transient fire in a “high” fire area is ten times the likelihood of a fire occurring in a “medium” fire area ($f_{high} = 10 \times f_{med} = 30 \times f_{low}$).
d. Assumption 4: A typical plant would have a total of approximately 10 fire areas that would be designated “low”, 30 fire areas designated “medium”, and 10 fire areas designated “high”.

Using these assumptions, the FIF for any given fire area can be established based on the assignment of a “low”, “medium”, or “high” rating. Using the relative FIF ratios, and the assumed number of fire areas in each category, the plant-wide FIF is reconstructed based on the following simple equation:

$$\mathrm{f_{plant-wide} = n_{low} \times f_{low} + n_{med} \times f_{med} + n_{high} \times f_{high}} \quad [6a]$$

or

$$f_{plant-wide} = 10 \times f_{low} + 30 \times 3 \times f_{low} + 10 \times 30 \times f_{low} = 300 \times f_{low} \qquad [6b]$$

where $f_{plant\text{-}wide}$ = 1.9E-2/ry (per assumption 1); f_{low}, f_{medium}, and f_{high} are the FIF for a fire area rated as low, medium, and high, respectively (unknown), and 'n' represents the number of fire areas in each likelihood category (n_{low} = 10, n_{med} = 30, and n_{high} = 10 per assumption 4). Solving this equation for f_{low} and recognizing assumption 3 yields the following (rounding to two significant figures):

Table 6.2.4 – Transient Fire Frequency. (per Fire Area)	
Low	f_{low} = 4.7 E-5 /ry
Medium	f_{med} = 1.4 E-4 /ry
High	f_{high} = 1.4 E-3 /ry

Weighting Factors for Hot Work Fires

The estimation of hot work FIF parallels the treatment of transients as described above. Using the same approach as documented above, the plant-wide FIF is partitioned (assigned) to specific fire areas. The nominal plant-wide FIF for hot work fires is estimated at 1.4E-2/ry (Reference 19). The fire area-specific FIF is based on the hot work fire likelihood rating based on the following table.

Table 6.2.5 – Hot Work Fire Ignition Frequency. (per Fire Area)	
Low	f_{low} = 3.5 E-5 /ry
Medium	f_{med} = 1.1 E-4 /ry
High	f_{high} = 1.1 E-3 /ry

Note that the hot work FIF cited here exclude fires promptly suppressed by a hot work fire watch. That is, these FIFs values include full credit for prompt suppression by an effective hot work fire watch.

06.02.04.02 Step 2.4.2: Findings Based on Increase in Fire Frequency

Certain types of findings are quantified, in whole or in part, based on an increase in FIF. In particular, this approach is applied to findings related to hot work permitting and fire watch programs, and to findings against the plant fire prevention programs and the transient combustible controls programs in particular.

Hot Work Fire Ignition Frequency

The factors affecting hot work were primarily based on the requirements of NFPA 51B "Fire Prevention During Welding, Cutting, and Other Hot Work," 2014, and the description of events as provided in Appendix B to the code "Significant Hot Work Incidents." Most of the degradations had to do with fire watch deficiencies based on the fact that the fire watch provides both early detection and early suppression of the incipient fire.

Deficiencies such as failure to implement a fire watch in positions to observe all areas of vulnerability, failure to implement a fire watch at all, or not having a proper or functional fire extinguisher were considered high degradations. A method of recovery from not having a functional fire extinguisher is to be within 30 ft. of a properly identified functional fire extinguisher of the proper type and size for the potential fire. If such conditions exist, the deficiency may be considered a low degradation. The 30 ft. criterion is the maximum allowable distance to a small extinguisher for Class B fire hazards from NFPA 10 “Portable Fire Extinguishers.” A wet standpipe and hose station was considered as being equivalent to the fire extinguisher during an iteration of this document, however, because the operation of the hose can be more complex and time consuming than operation of a portable extinguisher and requires special training, the wet standpipe and hose station was excluded as a method of recovery.

Another deficiency that should be considered a high degradation is failure by the licensee or fire watch to maintain personnel safety conditions during hot work operations. Although such failures do not remove the fire watch as a means of detection and suppression, the probability of a fast-growing fire which could challenge the effectiveness of the fire extinguisher increases. Low degradation deficiencies were considered to be deficiencies observed by reviews of training records or interviews of fire watches. These are considered low because in an actual situation, it is likely that other members of the hot work crew would have the knowledge to compensate. The nominal hot work fire frequency values reported in the SDP frequency analysis tables excluded fire events that were promptly suppressed by the fire watch. A high degradation will be factored into the risk analysis by “removing” this prompt suppression credit. This is reflected by multiplying to nominal fire frequency by a factor of 3. The multiplication factor is based engineering judgement.

Transient Combustible Fire Ignition Frequency

Findings for which degradations may impact the transient combustible FIF will be based on the requirements in the plant’s written policies regarding transient combustible storage. Items of interest in regard to transient combustible FIF are considered to be relatively low flashpoint flammable and combustible liquids, self-igniting combustibles, evidence of smoking in a non-smoking area, and unapproved heaters or heat sources. The relatively low flashpoint flammable and combustible liquids are those liquids with flashpoints below 200°F and include Class I liquids (flashpoint 73°F - 100°F), Class II liquids (flashpoint 100°F - 140°F), and Class IIIA liquids (140°F - 200°F). The selection of 200°F was based on limiting flammable/combustible liquids to those liquids that could result in a flash fire because of their proximity to a heat or ignition source. Combustible liquids with flashpoints over 200°F are more likely to require actual contact or close proximity to an ignition source similar to ordinary solid combustibles. In addition, the “low flashpoint” liquids have to be in unapproved containers and unattended to qualify as a high degradation. Low flashpoint liquids above the amount specified in the plant’s storage policies but in approved containers will be considered a low degradation and will not affect the transient combustible FIF. However, such a finding may increase combustible loading assumptions for fire modeling.

Other findings that would result in high degradations are self-igniting combustibles in unapproved containers that are not being attended; evidence of smoking materials in a non-smoking area; and unapproved heaters and heat sources. All high degradations findings will increase the transient FIF for the fire area in which they are found by a factor of 3. The multiplication factor is based on engineering judgement.

Another type of finding that may be associated with transient combustibles is discovering combustibles outside of approved locations or inside unapproved locations. However, if such findings do not involve combustible liquids with flashpoints under 200°F, they should be treated under combustible loading considerations and/or by adding to the continuity of combustibles.

All of the possible degradations discussed above will have a dependence on the plant's combustible control procedures. In that these procedures vary from plant to plant, it must be assumed that the level of safety provided by adherence to the procedures also varies. This will require the consideration of the plant's combustible control program and potential CMs in the determination of the baseline transient combustible FIF for different areas of the plant.

06.02.04.03 Step 2.4.3: Credit for Compensatory Measures

The purpose of Step 2.4.3 is to account for certain types of CMs that will act to reduce FIF. In most cases, CMs are credited with reducing the frequency of transient fuel fires. The only example of CMs that reduce the FIF are administrative controls that prevent combustibles or hot work.

Under these circumstances, assign the low likelihood rating FIF for transient fires from Table A4.1 to the fire area and postulate the TCCL HRR profile in the analysis of transient fire scenarios. It is expected that the practitioner will ensure that, during the exposure time of the finding, transient combustibles were not present in order to reduce the transient combustible FIF.

Note that hot work fire prevention measures are not treated as CMs. Rather, these measures are assumed to be required. The base FIF for hot work fires has already credited prompt suppression by the hot work fire watch. Hence, no further reductions in hot work fire frequency are warranted. However, the hot work FIF may be reduced to zero using an AF = 0.0 if the area is not subject to hot work. This should be verified by ensuring there is no equipment in the area that would be subject to hot work and by verifying that no hot work permits were issued for the area under review.

06.02.04.04 Step 2.4.4: Critical Area Adjustment Factors

The purpose of this step is to determine the AF used to further apportion the transient and/or hot work FIF for a fire area to the FIF for a specified fire scenario and corresponding target set. The AF accounts for the fact that, to have the potential of causing damage to the specified target set, transient combustibles must be located within or hot work performed within a subset (referred to as the "critical" floor area) of the total floor space of the fire area (referred to as the "plausible" floor area). The AF is equal to the critical floor area divided by the plausible floor area and is a measure of the probability that a fire will occur in a specific location within the fire area where it can cause damage to the target set for the fire scenario under evaluation.

06.02.04.05 Step 2.4.5: Screening Check

The SDP approach assigns a FIF to each individual fire ignition source. The total FIF for a fire area is the sum of the frequencies for the individual sources in the area. This approach makes it quite simple for the analyst to obtain a refined estimate of the room FIF, or the FIF of a specific fire ignition source scenario. This approach is broadly consistent with the approaches being applied in fire PRAs.

If none of the Steps 2.5-2.7 has been performed at this stage, the general approach to the screening check in Step 2.4 is the same as that applied in Step 2.1.8 as discussed earlier. In Step 2.1.8, the fire frequency applied was the full fire area fire frequency as conservatively determined in Step 2.1.2. The refinement of this frequency in Step 2.4 means that one aspect of potential risk reduction–the observation that not all fires are potentially challenging to nuclear safety–has been explicitly credited.

06.02.05 Step 2.5: Final Conditional Core Damage Probability Estimates Determination

06.02.05.01 Step 2.5.1: Determine Damaged Target Set and CCDP for FDS1 Scenarios

In Step 2.2.2, the analyst identified all ignition sources in the area under evaluation, and for each of these sources determined the targets that could potentially be damaged and secondary combustibles that could potentially be ignited. The location of these damage and ignition targets was recorded on form 2.2.2b (for fixed ignition sources and oil fires) and 2.2.2c (for transient combustibles). This information was then used in Step 2.3.2 to screen ignition sources that are not capable of initiating an FDS1 scenario. In Step 2.5.1 the information recorded on forms 2.2.2b and 2.2.2c is further used to determine the damaged target set for each of the unscreened ignition sources in Step 2.3.2. The damaged target set consists of the collection of targets that are located within the ZOI of the ignition source.

06.02.05.02 Step 2.5.2: Determine Damaged Target Set and CCDP for FDS2 Scenarios

The damaged target set for FDS2 scenarios consists of all targets of a specific type in the area under evaluation. A fire growth scenario may lead to FDS2 if, and only if, at least one of the following conditions is true:

a. The ignition source that started the fire releases heat at a sufficient rate to cause the development of a damaging HGL in the area under evaluation.
b. The ignition source that started the fire is capable of igniting a secondary combustible that, in combination with the HRR of the ignition source, releases heat at a sufficient rate to cause the development of a damaging HGL in the area under evaluation.

Any ignition sources that are not screened in Step 2.3.3 meet the first condition. Typically, the only ignition sources that are not screened in Step 2.3.3 are oil fires. For those, an additional analysis to determine whether the fire may involve secondary combustibles is not necessary.

If all ignition sources are screened out in Step 2.3.3, the analyst first needs to determine for each ignition source whether it is capable of igniting a secondary combustible. This can easily be done based on the information recorded on form 2.2.2b (for fixed ignition sources and oil fires) and form 2.2.2c (for transient combustibles). If the ignition source is capable of igniting a secondary combustible, the analyst further needs to determine whether the HRR of the ignition source in combination with the HRR of the secondary combustible can at one time be sufficient to cause the development of a damaging HGL. Form 2.2.2d is used for this purpose. The minimum HRR required for the development of a damaging HGL in the area under evaluation was determined in Step 2.3.3. The most common secondary combustible is a vertical stack of horizontal cable trays. The HRR profiles of various ignition source-cable tray configurations are provided in Attachment 8 to Appendix F (table/plot set C). The use of the tables and plots in this set is illustrated by example in Section 05.03.03.

06.02.05.03 Step 2.5.3: Determine Damaged Target Set and CCDP for FDS3 Scenarios

The analysis in this step is similar to that in the previous step. The damaged target set for FDS3 scenarios consists of all targets of a specific type in the adjacent (or exposed) area, i.e., the area that is separated from the fire area (or exposing area) by the degraded barrier. A fire growth scenario may lead to FDS3 if, and only if, at least one of the following conditions is true:

a. The ignition source that started the fire releases heat at a sufficient rate to cause the development of a damaging HGL in the exposed area.
b. The ignition source that started the fire is capable of igniting a secondary combustible that, in combination with the HRR of the ignition source, releases heat at a sufficient rate to cause the development of a damaging HGL in the exposed area.

Ignition sources that are not screened in Step 2.3.4 meet the first condition. Typically, the only ignition sources that are not screened in Step 2.3.4 are oil fires. For those, an additional analysis to determine whether the fire may involve secondary combustibles is not necessary.

If all ignition sources are screened out in Step 2.3.4, the analyst first needs to determine for each ignition source whether it is capable of igniting a secondary combustible. This can be done based on the information recorded on form 2.2.2b (for fixed ignition sources and oil fires) and form 2.2.2c (for transient combustibles). The analyst further needs to determine whether the HRR of the ignition source in combination with the HRR of the secondary combustible can be sufficient to cause the development of a damaging HGL in the exposed area. Form 2.2.2d is used for this purpose. The HRR profiles in Attachment 8 to Appendix F (table/plot set C) can be used to determine whether a specified combination of an ignition source and vertical stack of horizontal cable trays is capable of reaching the minimum HRR required for the development of a damaging HGL in the exposed area determined in Step 2.3.4.

06.02.05.04 Step 2.5.4: Screening Check

The final result of Steps 2.5.1 through 2.5.3 is a list of fire scenarios and corresponding damaged target sets that need to be included in the risk quantification. Based on the damaged target set information, the SRA can determine the CCDP for each scenario. The analyst then uses these CCDPs together with the most recent estimates of the other factors in Equation 1 to obtain an updated value for the ΔCDF. If this updated value is less than 1E-6, the finding screens to Green.

06.02.06 Step 2.6: Final Fire Severity Factor Estimates

06.02.06.01 Step 2.6.1: Determine Severity Factors

Phase 2 of the Fire Protection SDP does not involve a step to determine the SF for HEAFs and oil fires because it specifies the SF for the ignition source types and HRRs that need to be considered in a Phase 2 analysis. The SF for HEAFs is equal to 1.0. For oil fires, two scenarios need to be considered. The first scenario assumes that 100 percent of the available amount of oil has spilled. The SF for this scenario is 0.02. The SF for the second scenario, which assumes a 10 percent spill, is 0.98 (Reference 8). For confined oil fires, it is not necessary to evaluate the two scenarios if the containment volume is large enough to hold 100 percent of the oil that can be spilled. Consequently, Step 2.6.1 in Appendix F only determines the SF for scenarios initiated by fixed or transient ignition sources.

The SF for an FDS1 scenario is defined in Reference 8, Appendix E as the probability that the HRR of the ignition source that started the fire is sufficient to cause damage to the nearest and most vulnerable target in the damaged target set for the FDS1 scenario under consideration. It is determined from the HRR distribution for the ignition source as illustrated in Figure 6.2.4. The area under the HRR distribution curve is equal to 1. The SF is the area under the curve to the right of HRR_{min}. The latter, in this case, is equal to the minimum HRR to cause damage to the nearest and most vulnerable target. Table/plot sets D and E in Attachment 8 to Appendix F can be used to determine the SF as a function of vertical or radial distance from the ignition source to the nearest and most vulnerable target, respectively. Examples in Sections 05.03.04 and 05.03.05 illustrate how these tables and plots can be used.

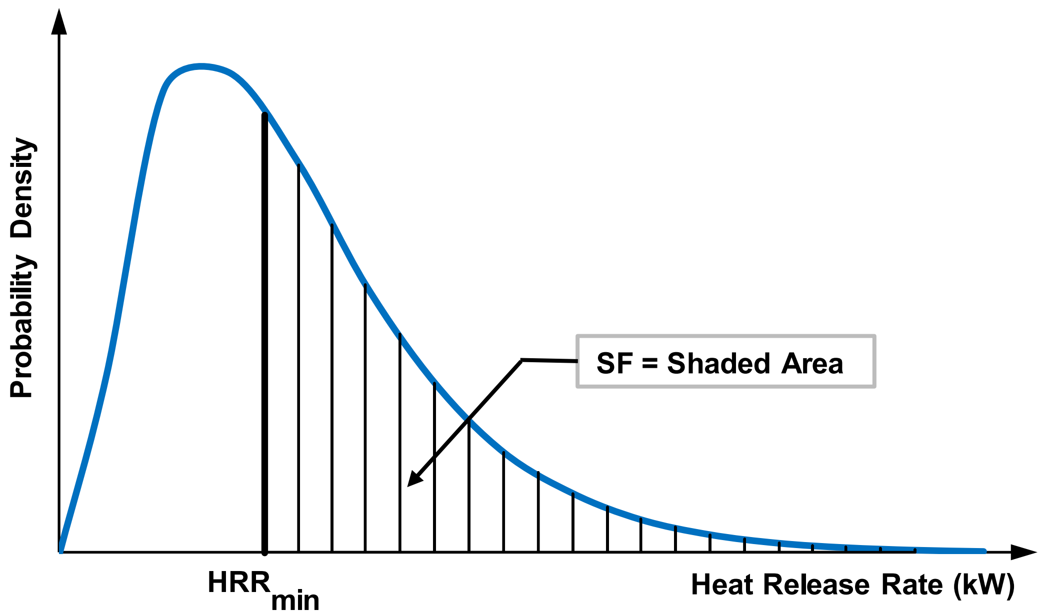

Figure 6.2.4 – Determination of the Severity Factor

For FDS2 and FDS3 scenarios, there are two possibilities:

a. For FDS2 and FDS3 scenarios that do not involve secondary combustibles, at some time during the growth phase the ignition source must release heat at a sufficient rate to cause the development of a damaging HGL. In this case, the SF is still determined as illustrated in Figure 6.2.3, except that HRR_{min} is now equal to the minimum HRR needed to cause the development of a HGL in the compartment of fire origin (for FDS2 scenarios) or in the exposed compartment (for FDS3 scenarios. Typically, only severe oil fires are capable of generating a damaging HGL, and the SF for oil fire scenarios is specified as discussed above.
b. For FDS2 and FDS3 scenarios that involve secondary combustibles, the SF is the probability that the HRR of the ignition source is sufficient to ignite the secondary combustible. Consequently, the SF for these scenarios is determined using the same approach as for FDS1 scenarios. HRR_{min}, in this case, is equal to the minimum HRR to cause ignition of the nearest and most vulnerable target.

06.02.06.02 Step 2.6.2: Screening Check

The SFs determined in Step 2.6.1 together with the most recent estimates of the other factors in Equation 1 are used to obtain an updated value for the ΔCDF. If this updated value is less than 1E-6, the finding screens to Green.

06.02.07 Step 2.7: Final Non-Suppression Probability Estimates

Additional guidance for the fire NSP analysis performed in this step is provided in Attachment 7 to Appendix F.

06.02.07.01 Step 2.7.1: Determine Damage and Ignition Times

For FDS1 scenarios, damage occurs when the HRR of the ignition source is sufficient to cause damage to the nearest and most vulnerable target. The heat soak method is used to determine the time when this occurs (or whether it will occur at all) for a specified HRR profile. Table/plot sets D and E in Attachment 8 to Appendix F can be used to determine the damage time for FDS1 scenarios as a function of vertical or radial distance from the ignition source to the nearest and most vulnerable target, respectively. Examples in Sections 05.03.04 and 05.03.05 illustrate how these tables and plots can be used.

Since the heat soak method is not implemented for FDS2 and FDS3 scenarios, damage is assumed to occur instantaneously when the HGL temperature reaches the damage threshold for the targets in the compartment. Consequently, the time to damage is equal to the time from ignition until the ignition source releases heat at a sufficient rate to create a damaging HGL in the compartment. As mentioned before, in a typical compartment only severe oil fires are capable of releasing heat at a sufficient rate to cause damage to all targets in the compartment without the involvement of secondary combustibles. For these fires, it is assumed that the targets are damaged in one minute.

FDS2 and FDS3 scenarios typically involve secondary combustibles. The most common secondary combustible is a vertical stack of horizontal cable trays. The HRR profiles of various ignition source-cable tray configurations are provided in Attachment 8 to Appendix F (table/plot set C). The tables and plots in this set can be used to determine when the combined HRR of the ignition source and secondary combustible exceeds the minimum HRR to create a damaging HGL determined in Step 2.3.3 (for FDS2 scenarios) or in Step 2.3.4 (for FDS3 scenarios). This process is illustrated by example in Section 05.03.03.

06.02.07.02 Step 2.7.2: Fire Detection

It is important to note that fire detection time plays only one role in the Fire Protection SDP analysis; namely, it is a benchmark time from the point of fire ignition to triggering of the human response to the fire event. In this context, fire detection by any one of several paths is possible. The SDP approach is to credit just one of the available paths - that which is most likely to succeed first. In most cases, this will be detection by a fixed detection system, if available. The other paths are considered should there be no fixed detection system or the fixed detection system is found to be highly degraded (i.e., essentially non-functional).

Detection by a Continuous Fire Watch

A continuous fire watch is given substantial credit for prompt detection unless conditions specific to the fire watch warrant otherwise. It is well established in the literature that humans are highly effective as fire detectors (based primarily on the human sense of smell).

Detection by a Roving Fire Watch

A roving fire watch is expected to detect a fire if one is in existence at the time they enter the fire area. The mean time to response is used, which corresponds to one-half the period between patrols.

Detection by a Fixed Detection System

The correlation applied in the development of the tables in Attachment 8 to Appendix F that is used in the detection time analysis is a well-established handbook correlation referred to as the method of Alpert (Chapter 11 in Reference 11). For further information, the reader is referred to pertinent parts of the next subsection, which discusses the basis for the tables and plots in Attachment 8 to Appendix F.

Detection by General Plant Personnel

The time to detection by plant personnel depends on the circumstances and is estimated by the analyst except if the area is continuously manned, in which case the fire is assumed to be detected in 5 minutes.

06.02.07.03 Step 2.7.3: Fixed Fire Suppression Analysis

The correlation applied in the development of the tables in Attachment 8 to Appendix F that is used in the activation time analysis for fixed fire suppression systems is very similar to the method of Alpert to estimate smoke detector response and is described in Chapter 10 of Reference 11. For further information, the reader is referred to pertinent parts of the next subsection, which discusses the basis for the tables and plots in Attachment 8 to Appendix F.

06.02.07.04 Step 2.7.4: Plant Personnel and Manual Fire Brigade

The manual NSP curves used in Step 2.7.4 to determine NSP_{manual} are those recommended in Reference 19, except for the NSP curves for HEAFs and control room fires, which are taken from References 15 and 10, respectively. The approach applied in the analysis of manual firefighting response, using historical evidence, is a well-established and accepted approach in general fire PRA practice. Specific considerations relevant to this particular approach are the following:

a. Fire suppression by a hot work fire watch is a unique case. Historical evidence shows that hot work fire watches are effective at providing prompt suppression of most fires. This observation has been credited in the FIF statistics - fires suppressed promptly by a hot work fire watch have not been included in the base FIF. Hence, no additional credit for hot work fire watches is given in this step. (Note that a degraded hot work fire watch finding is reflected by an increase in FIF for the same reason.)
b. Roving fire watches are not credited for fire suppression in the Phase 2 analysis. Roving fire watches are credited for effecting fire detection (see Step 2.7.2).

c. The final line of defense for fire suppression of any fire is the plant fire brigade. The fire brigade response is assessed based on historical evidence from past fires.

Historically, most fires have been suppressed by plant personnel including especially the plant fire brigade. Hence, a large base of historical data exists upon which this analysis is based. In practice, this historical evidence also includes fires suppressed by other members of the plant staff (e.g., security or maintenance personnel who happen upon a fire and effect successful suppression). The approach to analysis is well documented in the literature.

06.02.07.05 Step 2.7.5: Determine Non-Suppression Probabilities

NSP_{Fixed}

For cases where the predicted time to fire suppression (fixed suppression system activation) is close to the threshold when mitigation of core damage cannot be achieved, we assume that damage will occur. Due to uncertainty in the FDTs that were used to develop the tables and plots in Attachment 8 to Appendix F, meaningful credit is not given for the fire suppression system until the delta between suppression and damage time is significant.

Note that in practice, the equation that combines the fixed and manual fire suppression credits ensures that the maximum credit for wet pipe water systems is 0.98, reflecting the general reliability of such systems. For CO_2 systems and for other types of fixed fire suppression, the maximum credit applied is 0.96 and 0.95, respectively. These types of systems require an electrical actuation circuit that has a probability of failure in addition to the failure of the mechanical system (Reference 39).

NSP_{Manual}

See basis discussion for Step 2.7.4 above.

$NSP_{Scenario}$

The roll-up of manual and fixed suppression credits is based on a direct application of event tree/fault tree analysis approaches. The failure probability values assumed for fixed fire suppression systems (0.02, 0.04 or 0.05 per demand) is based on the guidance in NUREG/CR-6850 (Reference 8), Appendix P, Section P.1.3.

06.02.07.06 Step 2.7.6: Screening Check

The NSPs determined in Step 2.7.5 together with the most recent estimates of the other factors in Equation 1 are used to obtain an updated value for the ΔCDF. If this updated value is less than 1E-6, the finding screens to Green.

06.03 Attachment 8: Tables and Plots Supporting the Phase 2 Risk Quantification

This section provides the basis and assumptions for the tables and plots that support the risk quantification in Phase 2 of the Fire Protection SDP. The tables and plots are compiled in Attachment 8 to Appendix F. The following table/plot sets have been developed:

a. Set A: Vertical and Radial ZOI;
b. Set B: Minimum HRR to Create a Damaging HGL;

c. Set C: HRR Profiles of Fires Involving Cable Trays for Different Ignition Sources;
d. Set D: Severity Factor and Damage Time versus Vertical Target Distance;
e. Set E: Severity Factor and Damage Time versus Radial Target Distance;
f. Set F: Detector Actuation and Sprinkler Activation Times.

Subsequent subsections describe the basis and assumptions for the calculations that were performed to generate each table/plot set.

06.03.01 Table/Plot Set A: Vertical and Radial ZOI

Table/plot set A provides the vertical and radial ZOI for fixed and transient ignition sources, confined liquid fuel pool fires and unconfined liquid fuel spill fires. It is used in the Fire Protection SDP to screen ignition sources that cannot cause damage to components or cables in the fire area, that are not capable of causing fire to spread to secondary combustibles (Step 2.3.2), and to identify the potentially damaged target set for given FDS1 scenarios (Step 2.5.1).

06.03.01.01 Heat Soak Method

The 2018 Fire Protection SDP assumed that damage or ignition is instantaneous when the plume temperature at a vertical target or the incident radiant heat flux to a horizontal target reaches the applicable damage/ignition threshold. The present Fire Protection SDP accounts for the fact that it takes some time to heat a cable target to failure after the surrounding plume temperature or incident radiant heat flux has reached (or even exceeds) the failure threshold. The approach used to calculate the time to damage or ignition of a cable target exposed to a time-dependent plume temperature or radiant heat flux is referred to as the heat soak method.

The heat soak method was implemented in Microsoft Excel® VBA® macro workbooks that were developed to update the tables and plots in Attachment 8 to IMC 0609, Appendix F (hereafter referred to as "SDP VBA macros"). A summary of the method and its implementation for various target types (thermoset cables, thermoplastic cables, and sensitive electronics) and the two thermal exposure conditions (plume temperature and radiant heat flux) is provided below. Verification of the SDP VBA macros (the process to verify that the macros produce the correct result for a variety of test cases) is briefly discussed next.

Temperature Exposure of Cable Targets

The heat soak method for gas temperature exposure is based on the assumption that the damage integral, I_{dam}, defined by the following equation, is equal to one.

$$I_{dam}(t) = \int_0^t F_{dam}\big(T(\tau)\big)\, d\tau \equiv \int_0^t \frac{1}{\tau_{dam}\big(T(\tau)\big)} d\tau \qquad [7]$$

and

$$I_{dam}(t_{dam}) = \int_0^{t_{dam}} F_{dam}\big(T(\tau)\big)\, d\tau = \int_0^{t_{dam}} \frac{1}{\tau_{dam}\big(T(\tau)\big)} d\tau \equiv 1 \qquad [8]$$

where

I_{dam}	=	Damage integral (–)
t	=	Time (s)

F_{dam}	=	Damage function (s^{-1})
t_{dam}	=	Time to damage (s)
$\tau_{dam}(T(\tau))$	=	Time to damage for constant exposure to $T(\tau)$ (s)

$\tau_{dam}(T(\tau))$ is obtained from Table 6.3.1 for TS cables and $T(\tau) \geq 330°C$, and from Table 6.3.2 for TP cables and $T(\tau) \geq 206°C$. The corresponding values of $F_{dam}(T(\tau))$ are given in the right-most column of Tables 6.3.1 and 6.3.2. Tables 6.3.1 and 6.3.2 were developed from Tables H-5 and H-6 from NUREG/CR-6850, respectively.

Table 6.3.1 – TS Failure Time-Temperature Relationship (NUREG/CR-6850, Table H-5)

Exposure Temperature, T		Time to Failure, t_{dam} (min)	F_{dam}** (1/s)
°C	°F*		
330 ≤ T < 335	625 ≤ T < 635	28	0.000595
335 ≤ T < 340	635 ≤ T < 644	24	0.000694
340 ≤ T < 345	644 ≤ T < 653	20	0.000833
345 ≤ T < 350	653 ≤ T < 662	16	0.001042
350 ≤ T < 360	662 ≤ T < 680	13	0.001282
360 ≤ T < 370	680 ≤ T < 698	10	0.001667
370 ≤ T < 380	698 ≤ T < 716	9	0.001852
380 ≤ T < 390	716 ≤ T < 734	8	0.002083
390 ≤ T < 400	734 ≤ T < 752	7	0.002381
400 ≤ T < 410	752 ≤ T < 770	6	0.002778
410 ≤ T < 430	770 ≤ T < 806	5	0.003333
430 ≤ T < 450	806 ≤ T < 842	4	0.004167
450 ≤ T < 470	842 ≤ T < 878	3	0.005556
470 ≤ T < 490	878 ≤ T < 914	2	0.008333
T ≥ 490	T ≥ 914	1	0.016667

* Converted from °C, except 330°C, i.e., slightly different from Table H-5
** Damage calculated, not from Table H-5

Table 6.3.2 – TP Failure Time-Temperature Relationship (NUREG/CR-6850, Table H-6)

Exposure Temperature, T		Time to Failure, t_{dam} (min)	F_{dam}** (1/s)
°C	°F*		
205 ≤ T < 220	400 ≤ T < 428	30	0.000556
220 ≤ T < 230	428 ≤ T < 446	25	0.000667
230 ≤ T < 245	446 ≤ T < 473	20	0.000833
245 ≤ T < 260	473 ≤ T < 500	15	0.001111
260 ≤ T < 275	500 ≤ T < 527	10	0.001667
275 ≤ T < 290	527 ≤ T < 554	8	0.002083
290 ≤ T < 300	554 ≤ T < 573	7	0.002381
300 ≤ T < 315	573 ≤ T < 600	6	0.002778
315 ≤ T < 330	600 ≤ T < 627	5	0.003333
330 ≤ T < 345	627 ≤ T < 654	4	0.004167
345 ≤ T < 355	654 ≤ T < 663	3	0.005556
355 ≤ T < 370	663 ≤ T < 698	2	0.008333
T ≥ 370	T ≥ 698	1	0.016667

* Converted from °C, except 205°C, i.e., slightly different from Table H-6
** Damage function calculated, not from Table H-6

At temperatures between ambient (25°C) and the damage threshold (330°C for TS cable and 205°C for TP cable), damage is assumed to accrue based on the integrated exposure to the cable. The exposure, Q(T), is defined as

$$Q(T) = \sigma(T^4 - T_a^4) + h_c(T - T_a) \qquad [9]$$

where

Q	=	Exposure (kW/m²)
σ	=	Boltzmann constant ($5.67037 \cdot 10^{-11}$ kW/$m^2 \cdot K^4$)
T	=	Surrounding gas temperature (K)
T_a	=	Ambient temperature (assumed 25°C or 298.15 K)
h_c	=	Convection coefficient (assumed 0.05 kW/$m^2 \cdot$K)

According to Table 6.3.1, a TS cable needs to be exposed to a gas temperature of 330°C for 28 min (or 1680 s) for damage to occur. The integrated exposure at that time, E_{TS}, is given by

$$E_{TS} = 1680[\sigma(603.15^4 - 298.15^4) + 0.05(603.15 - 298.15)] = 37475 \text{ kJ/m}^2 \qquad [10]$$

Similarly, the integrated exposure at failure for a TP cable exposed to a gas temperature of 205°C, E_{TP}, is given by

$$E_{TP} = 1800[\sigma(478.15^4 - 298.15^4) + 0.05(478.15 - 298.15)] = 20729 \text{ kJ/m}^2 \qquad [11]$$

At T values below the damage threshold, the damage function is given by $Q(T)/E_{TS}$ and $Q(T)/E_{TP}$ for TS and TP cable targets, respectively.

With T specified every time step, Δt, the damage integral is estimated from

$$I_{dam}(t = n\Delta t) \approx \sum_{i=1}^{n} \Delta t \, [F_{dam}(T_i) + F_{dam}(T_{i-1})]/2 \qquad [12]$$

Finally, to avoid that a cable exposed for a very long time to a temperature slightly above ambient will be predicted to fail, in addition to I_{dam} = 1, the heat soak method also requires that the cable exposure (i.e., plume temperature) be over the threshold exposure (330 °C for TS cable and 205 °C for TP cable) when I_{dam} = 1.

Heat Flux Exposure of Cable Targets

In this case, for heat fluxes at or above the damage threshold (11 kW/m² or 6 kW/m² for TS and TP cable, respectively), the damage time is determined from interpolation in Table 6.3.3 (TS cable) or Table 6.3.4 (TP cable). Tables 6.3.3 and 6.3.4 were developed from Tables H-7 and H-8 in NUREG/CR-6850, respectively. I_{dam} is calculated from Equation 13:

$$I_{dam}(t) = \int_0^t F_{dam}\big(\dot{q}''(\tau)\big)\, d\tau \equiv \int_0^t \frac{1}{\tau_{dam}\big(\dot{q}''(\tau)\big)} d\tau \qquad [13]$$

where

$\dot{q}''$	=	Incident radiant heat flux (kW/m²)

$\tau_{dam}(\dot{q}"(\tau))$ = Time to damage for constant exposure to $\dot{q}"(\tau)$ (s)

$\tau_{dam}(\dot{q}"(\tau))$ is obtained from Table 6.3.3 for TS cable and $\dot{q}"(\tau) \geq 11$ kW/m^2, and from Table 6.3.4 for TP cable and $\dot{q}"(\tau) \geq 6$ kW/m^2. The corresponding values of $F_{dam}(T(\tau))$ are given in the right-most column of Tables 6.3.3 and 6.3.4.

Table 6.3.3 – TS Failure Time-Heat Flux Relationship (NUREG/CR-6850, Table H-7)			
External Heat Flux, $\dot{q}_e^"$		Time to Failure, t_{dam} (min)	F_{dam}* (1/s)
BTU/ft²·s	kW/m²		
<1.0	<11	No Damage	
1.0	11	19	0.000877
1.2	14	12	0.001389
1.4	16	6	0.002778
1.6	18	1	0.016667
≥ 1.75	≥ 20	1	0.016667

* Damage function calculated, not from Table H-7

Table 6.3.4 – TP Failure Time-Heat Flux Relationship (NUREG/CR-6850, Table H-8)			
External Heat Flux, $\dot{q}_e^"$		Time to Failure, t_{dam} (min)	F_{dam}* (1/s)
BTU/ft²·s	kW/m²		
<0.5	<6	No Damage	
0.5	6	19	0.000877
0.7	8	10	0.001667
0.9	10	6	0.002778
1.0	11	4	0.004167
1.25	14	2	0.008333
≥ 1.4	≥ 16	1	0.016667

* Damage function calculated, not from Table H-8

It is important to note the difference between the temperature tables (Tables 6.3.1 and 6.3.2) and the heat flux tables (Tables 6.3.3 and 6.3.4). The first two tables give the damage times for constant exposure at gas temperatures within specified ranges or intervals. Tables 6.3.3 and 6.3.4 provide the damage times for constant exposure at specified incident radiant heat fluxes. Consequently, the time to damage for constant exposure at a heat flux between the heat fluxes listed in Table 6.3.3 or 6.3.4 should be determined from interpolation between tabulated values. However, for the radial ZOI calculations the heat flux tables were used in the same way as the temperature tables (i.e., without interpolation but assuming the damage function is constant between the heat fluxes at which the damage times are reported in Tables 6.3.3 and 6.3.4).

For heat fluxes below the damage threshold, F_{dam} is determined in a similar way as for temperature exposure. In this case the heat flux is divided by E_{TS} for TS cable or by E_{TP} for TP cable, where, from Table 6.3.3, E_{TS} is equal to 11 [kW/m^2] × 19 [min] × 60 [s/min] = 12540 kJ/m^2 and, from Table 6.3.4, E_{TP} is equal to 6 [kW/m^2] × 19 [min] × 60 [s/min] = 6840 kJ/m^2.

Exposure of Sensitive Electronics

For sensitive electronics that are directly exposed at a temperature at or above the damage threshold, F_{dam} = 1/60. For temperature exposure below the 65°C threshold, the approach to determine F_{dam} is the same as for cables, except that E_{SE} for temperature exposure is given by

$$E_{SE} = 60[\sigma(338.15^4 - 298.15^4) + 0.05(338.15 - 298.15)] = 152.6\ \mathrm{kJ/m^2} \quad [14]$$

For radiant heat exposure, E_{SE}, is given by

$$E_{SE} = 60 \times\ 3 = 180.0\ \mathrm{kJ/m^2} \quad [15]$$

Verification of Macro Workbooks Developed to Perform the Heat Soak Method Calculations

As in Appendix A of NUREG-2178, Vol. 2 (Reference 10), the following three sets of verification exercises were conducted for the SDP VBA macros that were developed to perform the heat soak method calculations:

1. Reproduce Tables H-5 through H-8 in NUREG/CR-6850, Vol. 2 (Reference 8).
2. Demonstrate that the approach does not fail cables at low exposure.
3. Demonstrate that the approach yields the expected value for a time-dependent exposure.

Identical results were obtained as presented in Appendix A of NUREG-2178, Vol. 2.

06.03.01.02 Vertical ZOI

Heskestad's Plume Centerline Temperature Correlation

Heskestad's plume centerline temperature correlation is described in Chapter 9 of Reference 11 and is used to determine the vertical ZOI of an ignition source, i.e., the maximum distance above the ignition source within which a secondary combustible can be ignited or a target can be damaged. The correlation is based on temperature data from liquid pool fire experiments but can also be applied to solid combustible fires (or gaseous fuel fires for that matter). A schematic is shown in Figure 6.3.1. This figure also defines the radial ZOI, which will be discussed in a later section.

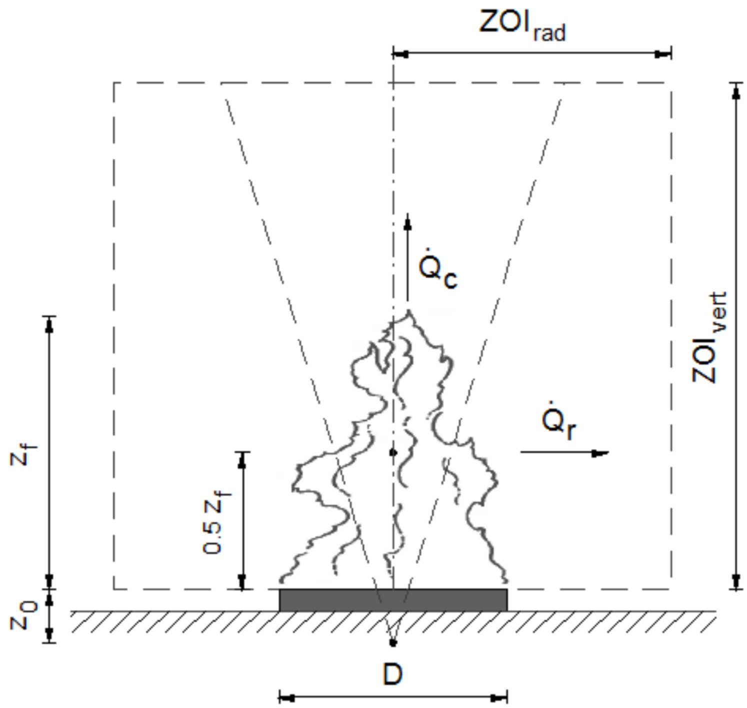

Figure 6.3.1 – Schematic of the Vertical and Radial ZOI

Heskestad's correlation is based on the assumption that the plume originates at a virtual point source, which may be located above or below the actual fire base depending on the HRR, $\dot{Q}$, and the physical size of the fire. The equations are as follows:

$$T_p(z) = T_a + C\left(\frac{273.15 + T_a}{g c_a^2 \rho_a^2}\right)^{1/3} \dot{Q}_c^{2/3}(z - z_0)^{-5/3} \qquad [16]$$

with

$$z_0 = 0.083\dot{Q}^{2/5} - 1.02\ D \qquad [17]$$

where

T_p	=	plume centerline temperature (°C)
z	=	elevation above the fire base (m)
T_a	=	ambient air temperature (°C)
C	=	constant
g	=	acceleration of gravity (9.81 m^2/s)
c_a	=	specific heat capacity of ambient air (kJ/kg·°C)
ρ_a	=	density of ambient air at temperature T_a (kg/m^3)
$\dot{Q}_c$	=	convective part of the HRR of the fire (kW)
z_0	=	elevation of the virtual origin of the point source plume (m)
$\dot{Q}$	=	HRR of the fire (kW)
D	=	fire diameter (m)

The constant, C, is dimensionless and equal to 9.1 for an unobstructed plume.

The convective part of the HRR can also be written as $\dot{Q}_c = \chi_c \dot{Q}$, where χ_c is the convective fraction of the fire HRR, which is typically of the order of 0.70. For noncircular fires with an area A_f, an equivalent effective diameter is used, which is calculated as shown in Equation 3.

Approach to Determine the Vertical ZOI

In the 2018 Fire Protection SDP, the vertical ZOI was determined as the height above the fire base where the plume centerline temperature is equal to the damage threshold temperature of a target. Damage thresholds for cable targets and sensitive electronics and ignition thresholds for cable targets are given in Attachment 6 to Appendix F. In the present SDP the approach to determine the vertical ZOI for a specified ignition source HRR profile (the 98th percentile HRR profile is used for screening purposes) is more complicated because damage or ignition is no longer assumed to be instantaneous when the plume temperature at the target reaches the damage threshold of the target. The approach to determine the ZOI for a specified HRR profile used in the development of the ZOI tables and plots in Attachment 8 to Appendix F is based on the bisection method, which is a numerical method to solve non-linear equations or sets of non-linear equations. The approach involved the following iterative process:

1. First determine the lower and upper limits for the ZOI. Zero was chosen as the lower limit. The ZOI based on the assumption that damage or ignition is instantaneous (i.e., the ZOI determined using the approach in the 2018 SDP) was used as the upper limit.
2. Use Equations 16 and 17 to calculate the plume temperature profile at a target that is located at an elevation halfway between the lower and upper ZOI limits.
3. Use the heat soak method to determine whether a target would be damaged when exposed to the plume temperature profile calculated in step 2.
4. If it is determined in step 3 that the target would be damaged, use the elevation of the target in step 3 as the lower ZOI limit in subsequent calculations. If the result of step 3 indicates that the target would not be damaged, use the elevation of the target in step 3 as the upper ZOI limit in subsequent calculations.
5. Repeat steps 2-5 if the difference between the ZOI limits exceeds 1 mm. If the difference between the lower and upper limit is 1 mm or less, the iterative process is completed. The final lower limit is the best estimate of the vertical ZOI to within 1 mm.

Assumptions for the Development of the Vertical ZOI Tables and Plots

This subsection provides a detailed discussion of the assumptions that were made and the input parameter values and ranges that were used in the development of the vertical ZOI tables and plots.

a. Ambient air properties: It is assumed that T_a = 25°C (77°F). This is the default value in FDT 9. The corresponding air properties are c_p = 1.005 kJ/kg·K and ρ_a = 1.18 kg/m^3.
b. Convective part of the HRR, $\dot{Q}_c$: The convective part of the HRR is equal to $\chi_c \dot{Q}$, where χ_c is the convective fraction, and $\dot{Q}$ is the HRR. A convective fraction of 0.70 is assumed, which is representative of transient fires and conservative for cable fires. This is the default value in FDT 9.
c. HRR, $\dot{Q}$: Ignition source screening for fixed and transient ignition sources is based on the 98th percentile of the peak HRR, as recommended in the following NUREGs:

    i. Electrical Enclosures: Table 7-1 in NUREG-2178, Vol. 1 (Reference 31).

ii. Motors: Table 8-1 in NUREG-2178, Vol. 2 (Reference 10)
iii. Dry Transformers: Table 8-2 in NUREG-2178, Vol. 2 (Reference 10)
iv. Generic Transients: Table 8-1 in NUREG-2233 (Reference 13)
v. TCCL Transients: Table 8-2 in NUREG-2233 (Reference 13)

The HRR profile parameters were obtained from the following sources:

i. Electrical Enclosures: Section G.3.1 of NUREG/CR-6850 (Reference 8)
ii. Motors: Section 8.3.1 in NUREG-2178, Vol. 2 (Reference 10)
iii. Dry Transformers: Section 8.3.2 in NUREG-2178, Vol. 2 (Reference 10)
iv. Generic Transients: Table 8-3 in NUREG-2233 (Reference 13)
v. TCCL Transients: Table 8-4 in NUREG-2233 (Reference 13)

Tables and plots were created that provide the vertical ZOI for the 16 HRR profiles. Tables and plots were also developed that show the vertical ZOI as a function of fire diameter for confined pool fires involving the liquid fuels in Table 6.2.2 above. Similar tables and plots were developed for unconfined spill fires that show the vertical ZOI as a function of the volume of the fuel spill. The HRRs of pool fires and unconfined oil spill fires were calculated from Equation 4.

d. Fire diameter, D: Reference 31 recommends using the area of the top surface of an electrical enclosure to determine the fire diameter, except if that leads to a Froude number (Q^*) that is outside the validated range in NUREG-1824, Supplement 1 (Reference 40). The Froude number is a measure of the relative importance of inertial to buoyancy forces and is defined as follows:

$$Q^* \equiv \frac{\dot{Q}}{c_a \rho_a (273.15 + T_a)\sqrt{g} D^{5/2}} \qquad [18]$$

The Froude number of solid combustible and liquid pool fires is typically of the order of one. The validated Q^* range for Heskestad's plume centerline temperature correlation reported in Reference 40 is $0.2 \le Q^* \le 9.1$. Table 6.3.5 gives the calculated minimum and maximum fire diameters (D_{min} and D_{max}) corresponding to the upper and lower limit, respectively, of the validated range for the 98th percentile HRRs of electrical enclosures. Table 6.3.5 also provides the diameter for $Q^* = 1$ ($D_{Q^*=1}$).

The recommendation in Reference 31 to determine the fire diameter based on the area of the top surface of electrical enclosures complicates the development of generic vertical ZOI tables and plots, since it adds another independent variable. Some licensees transitioning to NFPA 805 via 10 CFR 50.48(c) addressed this problem by assuming a fixed Froude number of one. The same assumption was made in the development of pertinent ZOI tables and plots for the Fire Protection SDP update, since it leads to reasonably conservative (i.e., small) fire diameters, as shown in Table 6.3.5.

Table 6.3.5 – Fire Diameter as a Function of HRR for Selected Q* Numbers.						
HRR (kW)	Q* = 9.1		Q* = 0.2		Q* =1.0	
	D_{min} (m)	D_{min} (ft.)	D_{max} (m)	D_{max} (ft.)	$D_{Q^*=1}$ (m)	$D_{Q^*=1}$ (ft.)
15	0.07	0.24	0.34	1.11	0.18	0.59
45	0.11	0.38	0.53	1.73	0.28	0.91
130	0.18	0.57	0.81	2.64	0.42	1.39
170	0.19	0.64	0.90	2.94	0.47	1.55
200	0.21	0.68	0.96	3.14	0.50	1.65
325	0.25	0.83	1.16	3.82	0.61	2.00
400	0.27	0.90	1.26	4.15	0.66	2.18
700	0.34	1.13	1.58	5.19	0.83	2.72
1000	0.40	1.30	1.82	5.98	0.96	3.14

For motors and dry transformers, the diameter is determined based on the applicable Froude number, Q*, in NUREG-2178 Vol. 2 (provided in Table 6.3.6). Note that for motors and dry transformers, Q* is higher for the vertical ZOI calculations than for the horizontal ZOI calculations. For transient combustibles the diameter is calculated based on the Froude number for transients specified in NUREG-2233 (Q* = 0.54). The process to determine the diameter as a function of time involves two steps. In the first step, the maximum diameter was determined during the peak burning period from the peak HRR and the Froude number for the ignition source. In the second step, the maximum diameter was used to calculate the HRRPUA during the peak burning period and the diameter at time t during the growth and decay stages was then determined from the HRR at time t based on the assumption the HRRPUA is constant for the entire profile.

Table 6.3.6 – Q* Numbers for Motors and Dry Transformers.		
Ignition Source	Vertical ZOI Q*	Radial ZOI Q*
Class A Motors	0.95	0.36
Class B Motors	0.81	0.29
Class C Motors	0.67	0.24
Class A Dry Transformers	1.65	0.14
Class B Dry Transformers	1.11	0.12
Class C Dry Transformers	0.64	0.11

e. Fire elevation (z = 0): Heskestad's correlation (Equations 16 and 17) is used to estimate the plume centerline temperature at a specified location above the fire base. To apply the vertical ZOI tables and plots that will be generated using this equation, the analyst will need to decide on the elevation of the fire base. The present Fire Protection SDP provides the following guidance:
   1. For closed top electrical enclosures (i.e., enclosures without horizontal top vents or openings), the fire base is placed at 1 ft. below the top of the enclosure as determined from a walkdown. For electrical enclosures not sealed at the top, the fire base is placed at the top of the enclosure.
   2. For motors and dry transformers, the fire base is determined from a walkdown following the pertinent guidance provided in NUREG-2178, Vol. 2.
   3. For transients a height 0.5 ft. is recommended.
   4. Confined liquid pool fires and unconfined liquid spill fires are placed on the floor.

Fire Location Effects

A fire located in a corner entrains less air than the same fire (same HRR, same fire diameter, etc.) in the open. As a result, the plume centerline temperature at a specified elevation above the fire base is expected to be higher for the corner location than for the open location. The Fire Protection SDP accounts for fire location effects on the vertical ZOI by quadrupling the HRR and the fire area for corner fires. Quadrupling the fire area is accomplished by replacing D in Equations 16 and 17 with 2D. This adjustment is based on the "image" method, which is illustrated in Figure 6.3.2. The method essentially determines the vertical ZOI based on the plume centerline temperature for an axisymmetric fire that has the same ratio of plume circumference (or area for air entrainment) to HRR as the wall or corner fire. However, the "image" method is conservative because it neglects the heat losses from the flame and plume to the walls. This is (partly) offset by heat losses to the walls, which cools the plume down. The present Fire Protection SDP no longer applies a location factor for wall fires based on the recommendations in NUREG-2178, Vol. 2 (Reference 10).

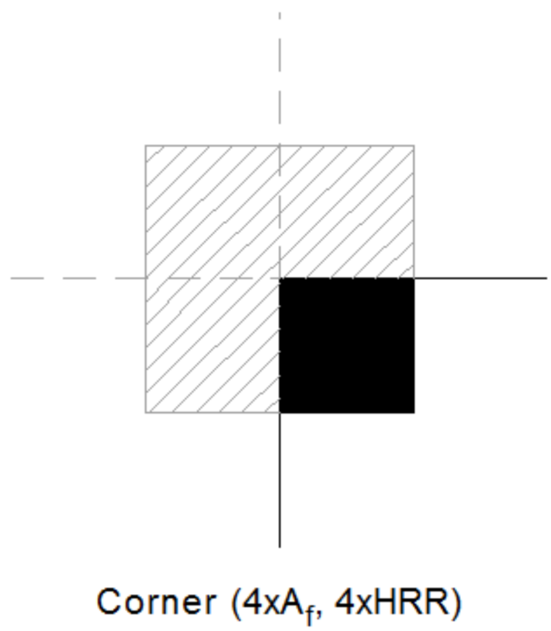

Figure 6.3.2 – Schematic of the "Image" Method for Corner Fires.

Obstructed Electrical Enclosure Fire Plumes

In addition to the development of new HRR distributions for electrical enclosures, Reference 31 also describes the results of a NIST Fire Dynamics Simulator study to assess the effect of an obstruction above an electronic enclosure on the plume temperature. The study suggests that obstructions reduce the plume temperature rise by 38 percent, provided the enclosure top plate is in the upper half of the compartment and the total area of all openings in the top plate does not exceed 5 percent of the area of the plate. The effect of an obstructed plume can be accounted for in the vertical ZOI calculations by reducing C in Equation 16 by 38 percent, i.e., by changing C from 9.1 to 5.64. The obstructed plume temperature correction is not considered in Phase 2 of the present Fire Protection SDP.

Plume-HGL Interaction

A plume that penetrates into the HGL will entrain gases at a temperature higher than T_a. Heskestad's plume centerline temperature correlation is still valid, but at heights above the HGL interface the HGL temperature, T_{HGL}, must be used instead of T_a. This expands the vertical ZOI if it is located above the HGL interface. The analyst may choose to account for the effect by extending the vertical ZOI to the ceiling if it is within a third of the compartment height from the ceiling.

Bias Adjustment

Reference 40 indicates that Heskestad's plume centerline temperature correlation (Equations 16 and 17) has a bias (δ) and standard deviation (σ) of 0.84 and 0.33, respectively. This means that, on average, the correlation underestimates the plume centerline temperature rise above ambient by 16 percent. However, this bias was not accounted for in the present Fire Protection SDP because it was not used in the vertical ZOI calculations reported in NUREG-2233 (Reference 13).

Verification

The Excel workbooks that were developed to calculate the vertical ZOIs were verified by comparing the tabulated ZOI values for selected cases with the ZOIs for transient fires reported in NUREG-2233 (Reference 13) and with the results of hand calculations for a Class C motors and Class B dry transformers in a spreadsheet provided by NRC.

06.03.01.03 Radial ZOI

The radial ZOI for a specific type of target is determined as the horizontal distance from the edge of the ignition source within which the incident heat flux is sufficient to cause damage to a target of the specified type or cause ignition of a secondary combustible of the specified type. Heat flux damage thresholds for different types of targets (cables and sensitive electronics) are given in Attachment 6 to Appendix F.

The 2018 Fire Protection SDP assumed that damage or ignition is instantaneous when the incident radiant heat flux to a horizontal target reaches the applicable damage/ignition threshold. The present Fire Protection SDP accounts for the fact that it takes some time to heat a cable target to failure after the incident radiant heat flux has reached (or even exceeds) the failure threshold. The approach to calculate the time to damage or ignition of a cable target exposed to a time-dependent radiant heat flux is referred to as the heat soak method and is described in Section 06.03.01.01.

In the 2018 Fire Protection SDP, the Point Source Model (PSM) was used to calculate the incident radiant heat flux from an ignition source fire to a target. The radial ZOIs in the present Fire Protection SDP were calculated with an adjusted version of the Solid Flame Radiation Model (SFM), which is shown in NUREG-2178, Vol. 2 (Reference 10) to provide more realistic heat flux predictions for small fires. The solid flame model is described in Chapter 5 of NUREG-1805 (Reference 11) and in Chapter 66 of the 5th edition of the SFPE handbook (Reference 41).

Adjusted Solid Flame Radiation Model

The solid flame radiation model approximates the flame as an opaque cylinder as shown in Figures 6.3.3 and 6.3.4. The incident radiant heat flux to an (infinitesimally) small vertical target at the same level as the base of flame (see Figure 6.3.3) is given by

$$\dot{q}_r'' = F_{t-f}E \qquad [19]$$

where

$\dot{q}_r''$ = Incident radiant heat flux or irradiance (kW/m²)
$F_{t\text{-}f}$ = View factor between the target and the flame
E = Emissive power of the flame (kW/m²)

The flame height of the fire, H_f, is determined using Heskestad's correlation given by

$$H_f = 0.235\dot{Q}^{2/5} - 1.02D \qquad [20]$$

Where H_f is the flame height in m, $\dot{Q}$ is the heat release rate of the fire in kW, and D is the fire diameter in m.

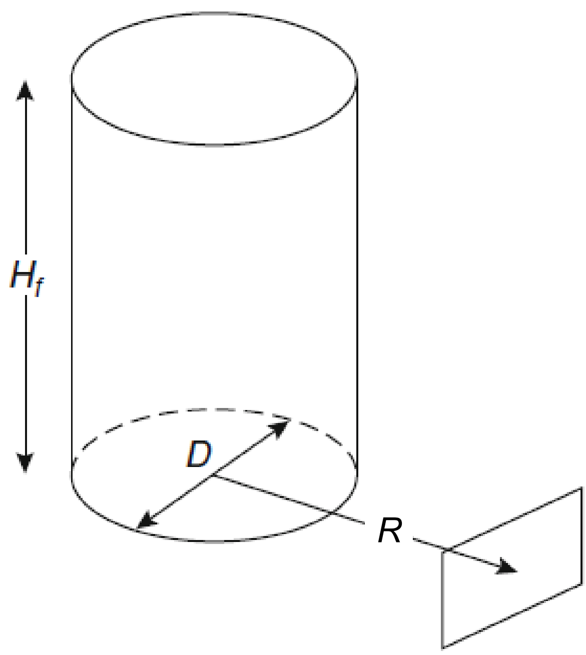

Figure 6.3.3 – Solid Flame Model for a Vertical Target at the Level of the Flame Base

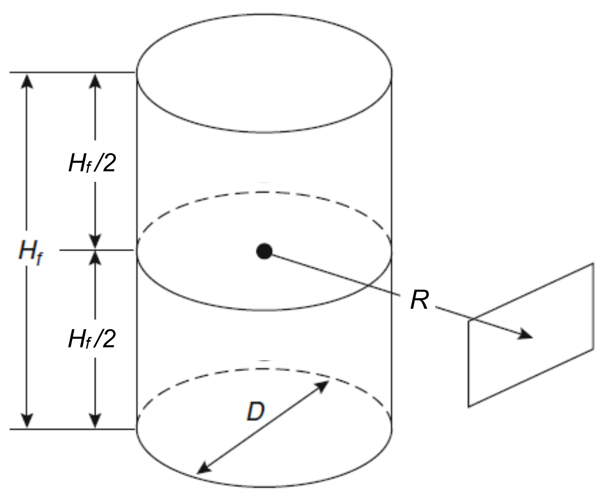

Figure 6.3.4 – Solid Flame Model for a Vertical Target Elevated at Half the Flame Height

For noncircular fires, the effective diameter will be defined as the diameter of a circular fire with an area equal to the actual area:

$$D = \sqrt{\frac{4}{\pi}A_f} \qquad [21]$$

where A_f is the surface area of the noncircular fire in m^2.

The view factor between a vertical target and the flame, as shown in Figure 6.3.3, can be calculated from the following equation:

$$F_{t-f} = \frac{1}{\pi S}\tan^{-1}\left(\frac{h}{\sqrt{S^2-1}}\right) - \frac{h}{\pi S}\tan^{-1}\sqrt{\frac{S-1}{S+1}} + \frac{Ah}{\pi S\sqrt{A^2-1}}\tan^{-1}\sqrt{\frac{(A+1)(S-1)}{(A-1)(S+1)}} \quad [22]$$

$$\text{with } A = \frac{h^2+S^2+1}{2S}, S = \frac{2R}{D}, \text{and } h = \frac{2H_f}{D}$$

where R = Distance between the target and the center of the cylinder (m).

However, the highest value for the view factor, $F_{t\text{-}f,max}$, is obtained for a vertical target at an elevation equal to half the flame height (see Figure 6.3.4). Consequently, $F_{t\text{-}f,max}$ is calculated from

$$F_{t-f,max} = 2F_{t-f}\left(D, \frac{H_f}{2}, R\right) \quad [23]$$

where $F_{t\text{-}f}$ is calculated from Equation 22 with $h = H_f/D$.

The emissive power is specified in NUREG-1805 (Reference 11) and the SFPE handbook (Reference 41) as $E = 58 \times 10^{-0.00823D}$ with E in kW/m² and D in m. However, in NUREG-2178 Vol. 2 (Reference 10) it was determined that this equation leads to artificially high heat fluxes for typical NPP ignition sources. To address this problem, the following adjustment was made to the equation for estimating the emissive power:

$$E = \text{Min}\left(58 \times 10^{-0.00823D}, \frac{\chi_r \dot{Q}}{\pi D H_f}\right) \quad [24]$$

where χ_r is the radiative fraction of the heat release rate of the fire (default value is 0.3).

<u>Approach to Determine the Radial ZOI</u>

In the 2018 Fire Protection SDP, the radial ZOI was determined as the horizontal distance from the edge of the ignition source, where the incident radiant heat flux is equal to the damage threshold heat flux of a target. Damage thresholds for cable targets and sensitive electronics and ignition thresholds for cable targets are given in Attachment 6 to Appendix F. In the present SDP the approach to determine the radial ZOI for a specified ignition source HRR profile (the 98th percentile HRR profile to determine the vertical ZOI for screening purposes) is more complicated because damage or ignition is no longer assumed to be instantaneous when the incident heat flux to the target reaches the damage threshold for the target. The approach to determine the radial ZOI for a specified HRR profile that was used in the development of the ZOI tables and plots in Attachment 8 to Appendix F is based on the bisection method, which is a numerical method to solve non-linear equations or sets of non-linear equations. The approach involved the following iterative process:

1. First determine the lower and upper limits for the ZOI. One cm from the edge of the fire was chosen as the lower limit. A large distance of 5 m was used as the upper limit.

2. Use Equation 19 in conjunction with Equations 23 and 24 to calculate the incident radiant heat flux profile at a target that is located at a distance halfway between the lower and upper ZOI limits.
3. Use the heat soak method to determine whether a target would be damaged when exposed to the incident heat flux profile calculated in step 2.
4. If it is determined in step 3 that the target would be damaged, use the distance of the target in step 3 as the lower ZOI limit in subsequent calculations. If the result of step 3 indicates that the target would not be damaged, use the distance of the target in step 3 as the upper ZOI limit in subsequent calculations.
5. Repeat steps 2-5 if the difference between the ZOI limits exceeds 1 mm. If the difference between the lower and upper limit is 1 mm or less, the iterative process is completed. The final lower limit is the best estimate of the radial ZOI to within 1 mm.

Fire Location Effects

It is assumed that the SFM calculations are not affected by the location of the fire, and radial ZOI tables and plots for corner fires were therefore not developed.

Ceiling Jet Temperature

When a thermal plume reaches the ceiling, it turns into a ceiling jet. Theoretically, it is possible that the damage threshold will be reached in the ceiling jet at a distance beyond ZOI_{rad} based on radiation. From experience with the NFPA 805 transition process demonstrates that this is very unlikely for cable targets because (1) the ceiling jet temperature can only exceed the damage threshold if the plume centerline temperature at the ceiling is substantially above the threshold, and (2) only targets close to the ceiling (within 10 percent of the distance between the floor and ceiling according to Appendix F in Reference 8) are potentially affected. The ceiling jet ZOI_{rad} is more likely to dominate for sensitive electronics, but those are usually not located close to the ceiling.

Bias Adjustment

Reference 40 indicates that the unadjusted SFM (Equations 19 and 23 with E equal to $58 \cdot 10^{-0.00823D}$ kW/m^2) has a δ and σ of 1.17 and 0.44, respectively. However, the bias for the adjusted model is unknown and expected to be smaller. Consequently, the adjusted SFM calculations to determine the radial ZOI were not adjusted for model bias.

Verification

The Excel workbooks that were developed to calculate the radial ZOIs were verified by comparing the tabulated ZOI values for a Class C motors and Class B dry transformers with the results of hand calculations for the same ignition sources in a spreadsheet provided by the NRC.

06.03.01.04 High Energy Arcing Faults

HEAFs can be generated in 440 V and above switchgear enclosures, load centers and segregated bus bars or ducts. A discussion of the electrical distribution system in NPPs and guidance for determining the ZOI of HEAFs is provided in Attachment 3 to Appendix F.

06.03.02 Table/Plot Set B: Minimum HRR to Create a Damaging HGL

Table/plot set B provides the minimum HRR that is needed to create damaging HGL conditions for a range of compartment sizes and different target types. It is used in Appendix F to screen specific liquid pool and spill fire scenarios (Steps 2.3.3 and 2.3.4), and to identify scenarios involving secondary combustibles that can cause a damaging HGL in the fire area (step 2.5.2).

Method of McCaffrey, Quintiere and Harkleroad for Estimating HGL Temperature

The method of McCaffrey, Quintiere, and Harkleroad (MQH) was developed to estimate the HGL in a naturally vented compartment. The model is described in detail in Chapter 2 of Reference 11 and consists of the following equations:

$$\Delta T_g(t) = 6.85\left[\frac{\dot{Q}(t)^2}{\left(A_v\sqrt{H_v}\right)\left(A_T h_T(t)\right)}\right]^{1/3} \qquad [25]$$

with

$$h_T = \begin{cases} \sqrt{\dfrac{k\rho c_p}{t}} & \text{for } t < t_p \\ \dfrac{k}{\delta} & \text{for } t \geq t_p \end{cases} \quad \text{and } t_p \equiv \left(\frac{\rho c_p}{k}\right)\left(\frac{\delta}{2}\right)^2 \qquad [26]$$

where

ΔT_g	=	HGL temperature rise above ambient, T_g - T_a (°C)
T_g	=	HGL temperature (°C)
T_a	=	ambient temperature (°C)
t	=	time (s)
$\dot{Q}$	=	HRR of the fire (kW)
A_v	=	area of the ventilation opening (m^2)
H_v	=	height of the ventilation opening (m)
A_T	=	total area of the compartment enclosing surfaces minus A_v (m^2)
h_T	=	heat transfer coefficient (kW/m^2)
k	=	thermal conductivity of the interior lining (kW/m·°C)
ρ	=	density of the interior lining (kg/m^3)
c_p	=	specific heat capacity of the interior lining (kJ/kg·°C)
δ	=	thickness of the interior lining (m)
t_p	=	thermal penetration time (s)

The minimum HRR to create a HGL can be calculated for targets with a damage threshold temperature T_{cr} by setting ΔT_g equal to $T_{cr} - T_a$, and rearranging Equation 25 as follows:

$$\dot{Q}_{min} = \sqrt{\left[\frac{T_{cr} - T_a}{6.85}\right]^3 \left(A_v\sqrt{H_v}\right)[A_T h_T]} \qquad [27]$$

where

$\dot{Q}_{min}$ = minimum HRR to create a damaging HGL (kW)
T_{cr} = damage threshold temperature from Table 8 (°C)

Equation 27 was used to develop the tables and plots that show the minimum HRR to create a damaging HGL for TS and TP cable targets and for sensitive electronics as a function of the floor area and ceiling height of the compartment.

Assumptions for the Development of the HGL Tables and Plots

This subsection provides a discussion of the assumptions that were made and the input parameter values and ranges that were used in the development of the HGL tables and plots.

a. An important assumption is that the compartment has openings that are large enough to allow sufficient ventilation to support the fire, which justifies the use of the MQH method over the other methods that are described in Chapter 2 of Reference 11. In addition, the opening is assumed to be a standard 0.9 m (3 ft.) wide, 2.1 m (7 ft.) high open doorway. Several plants transitioning to NFPA 805 made the same assumptions, and the NRC review of the license amendment request (LAR) submitted by these plants concluded that these assumptions and the exclusive use of the MQH method are acceptable.
b. The ambient air temperature, T_a, is assumed to be 25°C (77°F).
c. The minimum HRR to create damaging HGL conditions was calculated for floor areas ranging from 9 to 455 m^2 (100 to 4900 ft^2), and ceiling heights between 3 and 9 m (10 and 30 ft.) It is unlikely that a HGL can develop in a compartment with a floor area and ceiling height outside those ranges.
d. The compartment boundaries (floor, walls, and ceiling) are assumed to be constructed of concrete with thermal properties taken from Table 2-3 in Reference 11 (k = 0.0016 kW/m·°C, ρ = 2400 kg/m^3, and c_p = 0.75 kJ/kg·°C), and a thickness of 0.3 m (1 ft.).
e. The heat transfer coefficient, h_T, in Equation 27 is determined from Equation 26 for t = 1800 s. This is conservative because h_T decreases as a function of t when t < t_p, and the minimum HRR to cause a damaging HGL is usually reached before 30 minutes have elapsed.

Fire Location Effects

The HGL temperature calculated according to Equations 25 and 26 is not affected by the location of the fire. For example, using the “image” method to calculate the HGL temperature in a corner fire, one would increase the HRR and area of the fire, the total area of the compartment enclosing surfaces, and the width of the ventilation opening by a factor of four. That would increase the numerator and the denominator of the term in brackets in Equation 25 by the same amount. Consequently, there was no need to develop HGL tables and plots specifically for wall and corner fires.

Bias Adjustment

Reference 40 indicates that the MQH method (Equations 25 and 26) has a δ and σ of 1.17 and 0.15, respectively. This means that, on average, the model overestimates the HGL temperature by 17 percent. Assuming a normal distribution, the δ and σ also imply that the probability of overestimating the HGL temperature is approximately 0.84. In other words, there is a 16 percent chance that the MQH correlation will underestimate the actual temperature. Consequently, the calculations to determine the minimum HRR to create a HGL were not adjusted for model bias.

Verification and Validation

The Excel workbooks that were developed were verified by comparing the tabulated HRR values for selected cases with the results of manual and/or FDT calculations. Validation involved demonstrating that the MQH correlation was used with normalized parameter values within the validated range in Reference 40 or justifying the use of the MQH correlation with normalized parameters outside the validated range.

06.03.03 Table/Plot Set C: HRR Profiles of Fires Involving Cable Trays

Table/plot set C provides the combined HRR of an ignition source and a vertical stack of between one and seven horizontal cable trays as a function of time for various ignition source/cable tray configurations. This set is used in Steps 2.5.2, 2.5.3 and 2.7.1 in conjunction with table/plot set B to determine if and when a fire scenario involving secondary combustibles will cause a damaging HGL in the fire area.

Model to Estimate Fire Propagation in a Vertical Stack of Horizontal Cable Trays

A relatively simple model was used to estimate the growth and spread of a fire within a vertical stack of horizontal cable trays located above an ignition source. The method is consistent with the model described in Appendix R of NUREG/CR-6850 (Reference 8), and similar to the FLASH-CAT model described in Chapter 9 of Reference 36. A schematic of the ignition source/cable tray configuration is shown in Figure 6.3.5, below. The main features and assumptions of the model are as follows:

a. The lowest tray in the stack is conservatively assumed to ignite in one minute, which is consistent with the approach of several plants transitioning to NFPA 805. The model in Appendix R of NUREG/CR-6850 (Reference 8) assumes that the bottom tray ignites when the plume temperature at the tray reaches the ignition threshold of the cables in the tray. This approach is not suitable for the development of generic tables and plots because the ignition time (i.e., the time when the cable trays start contributing to the HRR of the fire) would be a function of the distance between the fire base and the lowest tray, which depends on the actual configuration in the plant. The FLASH-CAT model assumes a fixed ignition time of five minutes, which may be non-conservative if the tray is very close to the ignition source. Therefore, this assumption has not been retained.

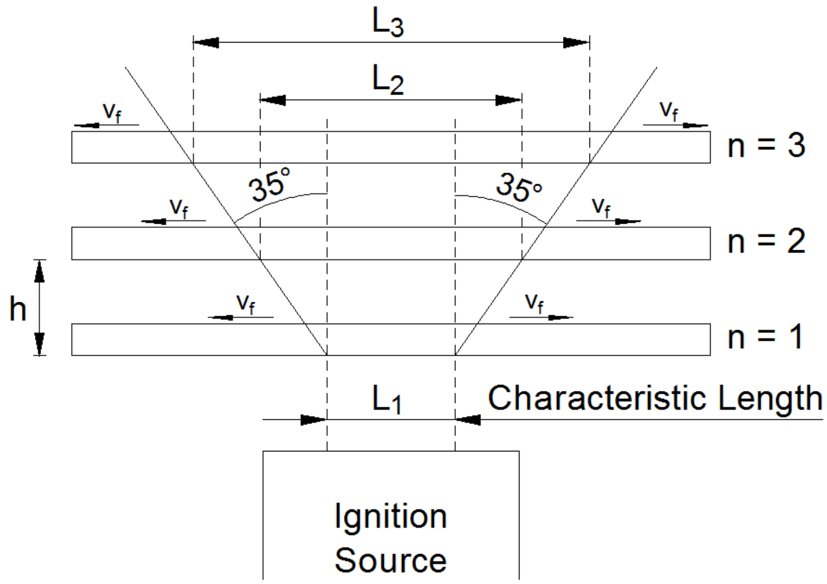

Figure 6.3.5 – Configuration for Modeling of Fire Propagation in a Stack of Cable Trays

b. Following ignition, a HRRPUA of 150 kW/m^2 is assumed if the bottom tray contains TS (or Kerite) cables. If the cables in the lowest tray are TP, a HRRPUA of 250 kW/m^2 is used. The assumed HRRPUA values are the generic values for TS and TP cables recommended in Chapter 9 of Reference 36.
c. For fixed and transient ignition sources, the lateral extent of burning cable in the lowest tray before the onset of lateral spread (L_1) is equal to the diameter of the 98th percentile ignition source fire ($D_{Q^*=1}$ in Table 6.3.5). For example, if the ignition source was a generic transient fire, for which the 98th percentile of the peak HRR is 278 kW, the assumed diameter would be 0.73 m (2.4 ft.) for Q^* = 0.54. L_1 is assumed to be equal to 0.5 m (1.65 ft.) when the ignition source is a confined liquid pool fire or an unconfined liquid spill fire.
d. Following ignition, the fire in the first tray spreads laterally at a rate of 0.3 mm/s for TS (or Kerite) cable and 0.9 mm/s for TP cable. This is consistent with the flame spread rates for TS and TS cables recommended in Appendix R of NUREG/CR-6850 (Reference 8).
e. The fire in the second tray ignites 4 minutes after ignition of the first tray. The fire in the third tray ignites 3 minutes after ignition of the second tray. The fire in the fourth tray ignites 2 minutes after ignition of the third tray. Trays above the fourth ignite 1 minute after ignition of the tray directly below it. The lateral extent of the initial fire in the second and subsequent trays (L_2, L_3, etc.) is widened from the initial lateral extent of the fire in the tray directly below it (L_1, L_2, etc.) based on empirical observations (35° spread angle, see Figure 6.2.7) as expressed by the following equation:

$$\mathrm{L_{n+1}} = \mathrm{L_n} + 2[\mathrm{h}\tan(35°)] \qquad [28]$$

The ignition timing for trays two through seven and the approach to determine the lateral extent of the initial fire in each tray are identical to the timing and approach used in the cable tray fire propagation model described in Appendix R of NUREG/CR-6850 (Reference 8). The burning and spread rates for the cables in the second tray and subsequent trays are the same as for the cables in the first tray.

f. Local burnout of the fire occurs when the cable plastic is consumed. The time to burnout is therefore calculated as follows. First, determine the combustible mass per unit area of tray:

$$m_c'' = \frac{N\, Y_p\, (1 - Y_c)\, m'}{W} \quad [29]$$

where

$\dot{m}_c''$ = Combustible cable mass per unit tray area (kg/m^2)
N = Number of cables per tray
Y_p = Plastic mass fraction (kg/kg)
Y_c = Char yield (kg/kg)
m' = Cable mass per unit length (kg/m)
W = Cable tray width (m)

The model assumes that the HRR per unit area ramps linearly to its average value over a time period of Δt/6, remains steady for a time period of 2Δt/3, and then decreases linearly to zero over a time period of Δt/6. The burnout time is therefore calculated as follows:

$$\Delta t = \frac{6 m_c'' \Delta H_v}{5\ \mathrm{HRRPUA}} \quad [30]$$

where

ΔH_v = Heat of combustion of the fuel volatiles (kJ/kg)
HRRPUA = Cable HRR per unit area (kW/m^2)

Additional Assumptions for the Development of Table/Plot Set C

This subsection provides a discussion of additional assumptions that were made and the input parameter values and ranges that were used in the development of table/plot set C.

a. The HRR as a function of time for an ignition source in combination with a vertical stack of cable trays was calculated at 1-minute intervals for the following ignition source-cable tray configurations:
   1. Ignition source-cable tray HRR tables and plots were developed for all ignition sources listed in Table A5.1 of Attachment 5 to Appendix F.
   2. In addition, HRR tables and plots were developed for cable tray fires without an ignition source. These tables and plots can be used to determine the HRR of cable trays fires that are ignited by a confined liquid fuel pool fire or an unconfined liquid fuel spill fire by adding the HRR of the confined liquid fuel pool fire or unconfined liquid fuel spill fire. The HRRs of confined liquid fuel pool fires and unconfined liquid fuel spill fires are tabulated in table/plot set A.
   3. HRR tables and plots were developed for cable trays widths of 0.46 and 0.91 m (1.5 and 3 ft.) The calculated HRR values for 0.46 m (1.5 ft.) wide trays can be used for 0.3 m and 0.61 m (1 ft. and 2 ft.) wide trays. The calculated HRR values for 0.91 m (3.0 ft.) wide trays can be used for single trays and multiple trays side-by-side with a total width greater than 0.61 m (2 ft.)

4. The trays were assumed to be 7.2 m (24 ft.) long and ignited at the center to ensure that it would take at least 1 hour for the flame to spread to the end of the trays.
5. The assumed spacing between trays was 0.3 m (1 ft.)
6. HRR tables and plots were developed for stacks of one through seven trays filled with TS and TP cables. The HRR tables and plots for TS cables can also be used for Kerite cables.

b. The table/plot set C HRRs for TS cables were calculated assuming 75 percent of the trays are filled with cables that have the characteristics of cable #16 in Reference 36 (also referred to as cable #13 in Section 8.2.6, Section 8.2.7, and Table 8-1 of this NUREG). This cable was chosen because, of all the TS cables that were tested, it results in the highest amount of active polymer in the trays. The tables and plots for TP cables were developed in the assumption that 75 percent of the trays are filled with cables that have the characteristics of cable #701 in Reference 36, which was the only true TP cable that was tested. The input parameters for the cable tray fire propagation model calculations are given in Table 6.3.7.

Table 6.3.7 – Input Parameters for the Cable Tray Fire Propagation Model		
Input Parameter	TS Cable	TP Cable
Number of cables per ft. tray width	44	44
Plastic mass fraction, Y_p (kg/kg)	0.48	0.42
Char yield, Y_c (kg/kg)	0.25	0
Mass per unit length, m' (kg/m)	0.671	0.366
Heat of combustion of fuel volatiles, ΔH_v (kJ/kg)	16000	16000
Cable HRRPUA (kW/m^2)	150	250
Flame spread rate, v_f (mm/s)	0.3	0.9

Applying Table/Plot Set C for Mixed Trays

For trays with a mix of TS and TP cables, the model input parameters for the cables with the highest HRRPUA shall be used, except when these cables account for 5 percent or less of the total cable mass (this is based on the recommendation for treating mixed trays in Reference 36). For example, a HRRPUA of 250 kW/m^2 shall be used for a tray filled with a mix consisting of 90 percent TS and 10 percent TP cables, but 150 kW/m^2 shall be used for a mix consisting of 95 percent TS and 5 percent TP cables.

Bias Adjustment

Reference 40 does not provide guidance on how to account for the bias in the FLASH-CAT model HRR predictions. However, the comparisons between FLASH-CAT model predictions and experimental HRR data in Figures 9-3 through 9-12 of Reference 36 show that the model slightly to significantly over-predicts the HRR for the majority of the tests. This indicates that the FLASH-CAT model is very likely to have a δ greater than one. Since the model that was used to develop the tables and plots in set C is essentially identical to the FLASH-CAT model (the only difference is the ignition time of the lowest tray, which is 1 minute instead of 5 minutes in the FLASH-CAT model), ignoring the bias leads to conservative HRR predictions.

Verification and Validation

The Excel workbooks that were used to develop the tables and plots in set C were verified by duplicating the FLASH-CAT HRR curves for tests MT-6, MT-7, and MT-8 in Figures 9-4 and 9-5 of Reference 36. Tests MT-6 and MT-8 were selected because they involved a stack of four trays filled with cable #16 and cable #701. Test MT-7 was included because it involved a stack of seven trays filled with cable #16. Figures 9-4 through 9-12 in Reference 36 provide the validation basis for the FLASH-CAT model. Since the models are essentially identical, the same figures also provide the validation basis for the cable tray fire propagation model that was used to develop the tables and plots in set C.

06.03.04 Table/Plot Set D: Severity Factor and Damage Time vs. Vertical Target Distance

To develop table/plot set D, calculations were performed to determine the highest elevation and corresponding time at which a target will be damaged or a secondary combustible will ignite when exposed in the plume of the ignition source with a HRR profile corresponds to a specified SF. Each table and plot provides the elevations and damage times corresponding to SFs ranging from 0.02 to 0.75 for one of the fixed or transient ignition sources listed in Attachment 5 to Appendix F, located either in the open or in a corner. Table/plot set D is used in Appendix F to conservatively estimate the SF for a target or secondary combustible located within the vertical ZOI based on its elevation above the ignition source (Step 2.6.1), and to determine the corresponding damage or ignition time (needed to calculate the NSP in Step 2.7.1).

The development of table/plot set D involved the following two steps:

a. For each ignition source listed in Table A5.1 of Attachment 5 to Appendix F, the peak HRRs were calculated that correspond to SFs of 0.02, 0.05, 0.10, 0.15, 0.20, 0.25, 0.30, 0.35, 0.40, 0.45, 0.50, 0.55, 0.60, 0.65, 0.70, and 0.75 based on the cumulative gamma probability distribution of the HRR for the ignition source:

$$\mathrm{HRR}_{\mathrm{peak}} = \mathrm{F}(1 - \mathrm{SF}; \alpha, \beta) \qquad [31]$$

where

HRR_{peak} = HRR that corresponds to a specified SF (kW)
F = inverse gamma distribution of the HRR for the ignition source
α = gamma distribution shape parameter
β = gamma distribution rate (scale) parameter

b. The approach to determine the vertical ZOI for a specified HRR profile described in Section 06.03.01.02 was then used to calculate the vertical ZOI and corresponding damage time for each of the SF values.

06.03.05 Table/Plot Set E: Severity Factor and Damage Time vs. Radial Target Distance

To develop table/plot set E, calculations were performed to determine the longest radial distance at which a target will be damaged or a secondary combustible will ignite when exposed to the radiant heat flux from an ignition source with a HRR profile that corresponds to a specified SF. Each table and plot provides the radial distances corresponding to SFs ranging from 0.02 to 0.75 for one of the fixed or transient ignition sources listed in Attachment 5 to Appendix F. Table/plot set E is used to conservatively estimate the SF for a target or secondary combustible located within the radial ZOI based on its distance from the ignition source (Step 2.6.1), and to determine the corresponding damage or ignition time (needed to calculate the NSP in Step 2.7.1). The development of table/plot set E involved the same steps as for table/plot set D; except that the approach to determine the radial ZOI for a specified HRR profile described in Section 06.03.01.03 was used to calculate the radial ZOI and corresponding damage time for each of the SF values.

06.03.06 Table/Plot Set F: Detector Actuation and Sprinkler Activation Times

Table/Plots set F consists of three subsets of tables:

a. Tables to determine smoke detector actuation time.
b. Tables to determine sprinkler activation time for fixed and transient ignition source fires.
c. Tables to determine sprinkler activation time for fires with an unknown HRR profile.

The methodology that was used and the assumptions that were made for the development of the three subsets are discussed below.

Smoke Detector Actuation Times

Chapter 11 in Reference 11 describes three methods for estimating smoke detector response as a function of ceiling height, H, and radial distance to the detector, R:

a. The method of Alpert estimates the response time of a smoke detector in a steady fire (i.e., a fire with constant HRR), assuming that a smoke detector can be modeled as a heat detector with a low response time index (RTI) and activation temperature (T_{act}) (Reference 42). Furthermore, the method assumes that a smoke detector actuates when the ceiling jet temperature at the detector is 10°C above ambient. The temperature criterion is based on experimental data and an analysis presented in Reference 43. This method was used in the development of the tables in Attachment 8 to determine smoke detector actuation time.
b. The method of Mowrer estimates smoke detector response time in a quasi-steady fire as the sum of two lag times; the time for the fire plume to rise to the ceiling, and the time for the ceiling jet to travel to the detector.
c. The method of Milke (Reference 44) estimates smoke detector response time based on an analysis of smoke detector actuation times in a series of full-scale fire experiments described in NUREG/CR-4681 (Reference 45) and NUREG/CR-5384 (Reference 46). Of the three methods, this method nearly always results in the longest response time. This is because in the tests, the smoke detectors actuated during the fire growth stage and their actuation time therefore includes the delay for the HRR to become large enough to cause detector actuation.

In the Phase 2 analysis of the Fire Protection SDP, the following equation is used to calculate the actuation time of a smoke detector:

$$t_{act} = t_{\Delta T=10°C} + t_{pl} + t_{cj} + t_{resp} \qquad [32]$$

where

t_{act}	=	smoke detector actuation time (s)
$t_{\Delta T=10°C}$	=	time for the ceiling jet temperature to reach 10°C above ambient (s)
t_{pl}	=	lag time for the plume to rise to the ceiling (s)
t_{cj}	=	lag time for the ceiling jet to travel to the detector (s)
t_{resp}	=	smoke detector response time (s)

The HRR needed to raise the ceiling jet temperature to 10°C above ambient, $\dot{Q}_{\Delta T=10°C}$, can be calculated from Equations 11-2 and 11-3 in Chapter 11 of Reference 11:

$$\text{Eq. } 11-2: \quad T_{cj} - T_a = \frac{16.9\,\dot{Q}^{2/3}}{H^{5/3}} \quad \therefore\ \dot{Q}_{\Delta T=10°C} = 0.455\,H^{5/2}\ \left(\text{for } \frac{R}{H} \leq 0.18\right) \qquad [33]$$

and

$$\text{Eq. } 11-3: \quad T_{cj} - T_a = \frac{5.38\left(\frac{\dot{Q}}{R}\right)^{2/3}}{H} \quad \therefore\ \dot{Q}_{\Delta T=10°C} = 2.534\,R\,H^{3/2}\ \left(\text{for } \frac{R}{H} > 0.18\right) \qquad [34]$$

where

T_{cj}	=	ceiling jet temperature (°C)
R	=	radial distance from the center of the fire base to the detector (m)
H	=	ceiling height above the fire base (m)
$\dot{Q}_{\Delta T=10°C}$	=	HRR needed to raise the ceiling jet temperature to 10°C above T_a (kW)

A smoke detector will never actuate if the peak HRR (HRR_{peak}) of the fire is lower than $\dot{Q}_{\Delta T=10°C}$. If HRR_{peak} is higher, the time for the ceiling jet temperature to reach 10°C above ambient, $t_{\Delta T=10°C}$, is equal to the time for the HRR of the fire to reach $\dot{Q}_{\Delta T=10°C}$. Figures F.01 and F.02 in table/plot set F in Attachment 8 to Appendix F give the minimum HRR_{peak} needed for a smoke detector to actuate, as a function of H and R. If $HRR_{peak} \geq \dot{Q}_{\Delta T=10°C}$, $t_{\Delta T=10°C}$ can be determined as follows:

For fires that only involve one of the ignition sources listed in Tables A5.1 or A5.3 of Attachment 5 to Appendix F, except for dry transformers, $t_{\Delta T=10°C}$ can be determined from the initial growth stage of the HRR profile. Figures F.03-F.28 in table/plot set F provides tabulated HRRs at specified times for each of these ignition sources and selected values for the severity factor. These figures can be used to determine $t_{\Delta T=10°C}$ as the shortest time at which the HRR of the ignition source is equal to or exceeds $\dot{Q}_{\Delta T=10°C}$.

a. For confined liquid fuel pool fires and unconfined liquid fuel spill fires with a HRR that is equal to or exceeds $\dot{Q}_{\Delta T=10°C}$, $t_{\Delta T=10°C}$ can assumed to be zero.
b. For fires that involve secondary combustibles, the tables and plots in set C can be used to determine the time when the HRR reaches $\dot{Q}_{\Delta T=10°C}$.

The lag time for the plume to rise to the ceiling, t_{pl}, and the lag time for the ceiling jet to travel to the detector, t_{cj}, can be determined from Equations 11-7 and 11-8 in Chapter 11 of Reference 11:

$$\text{Eq. } 11-7: \quad t_{pl} = \frac{0.67\, H^{4/3}}{\dot{Q}^{1/3}} \qquad [35]$$

and

$$\text{Eq. } 11-8: \quad t_{cj} = \frac{R^{11/6}}{1.2\, \dot{Q}^{1/3}\, H^{1/2}} \qquad [36]$$

Finally, the response time of the detector follows from Equations 11-1, 11-4, and 11-5 in Chapter 11 of Reference 11:

$$\text{Eq. } 11-1: \quad t_{resp} = \frac{RTI}{\sqrt{u_{cj}}} \ln\left(\frac{T_{cj} - T_a}{T_{cj} - T_{act}}\right) = \frac{3.466}{\sqrt{u_{cj}}} \qquad [37]$$

with

$$\text{Eq. } 11-4: \quad u_{cj} = 0.96 \left(\frac{\dot{Q}}{H}\right)^{1/3} \left(\text{for } \frac{R}{H} \leq 0.18\right) \qquad [38]$$

and

$$\text{Eq. } 11-5: \quad u_{cj} = \frac{0.195\, \dot{Q}^{1/3} H^{1/2}}{R^{5/6}} \left(\text{for } \frac{R}{H} > 0.18\right) \qquad [39]$$

where

RTI	=	response time index ($m^{0.5} \cdot s^{0.5}$)
u_{cj}	=	ceiling jet velocity (m/s)
T_{act}	=	activation temperature (°C)

Figures F.29 and F.30 in table/plot set F provide the sum of the plume and ceiling jet lag times and the detector response time for $\dot{Q} = \dot{Q}_{\Delta T=10°C}$ as a function of H and R. To develop these tables it was assumed that RTI = 5 $(m \cdot s)^{0.5}$ and $T_{act} = T_a + 5°C = 30°C$. The assumed RTI and T_{act} values are identical to those that are used in the sample FDT 11 calculations in Reference 11.

Sprinkler Activation Times for Fixed and Transient Ignition Source Fires

Chapter 10 in Reference 11 describes only one method for estimating sprinkler activation time, t_{act}, as a function of ceiling height, H, and radial distance to the sprinkler head, R. It is very similar to the method of Alpert to estimate smoke detector response discussed above, and like that method, applies to steady fires. The equations are duplicated below:

$$\text{Eq. } 10-2: \quad t_{act} = \frac{RTI}{\sqrt{u_{cj}}} \ln\left(\frac{T_{cj} - T_a}{T_{cj} - T_{act}}\right)$$ [40]

$$\text{Eq. } 10-3: \quad T_{cj} - T_a = \frac{16.9\,\dot{Q}^{2/3}}{H^{5/3}} \quad \left(\text{for } \frac{R}{H} \le 0.18\right)$$ [41]

$$\text{Eq. } 10-4: \quad T_{cj} - T_a = \frac{5.38\left(\frac{\dot{Q}}{R}\right)^{2/3}}{H} \quad \left(\text{for } \frac{R}{H} > 0.18\right)$$ [42]

$$\text{Eq. } 10-5: \quad u_{cj} = 0.96\left(\frac{\dot{Q}}{H}\right)^{1/3} \quad \left(\text{for } \frac{R}{H} \le 0.18\right)$$ [43]

and

$$\text{Eq. } 10-6: \quad u_{cj} = \frac{0.195\,\dot{Q}^{1/3} H^{1/2}}{R^{5/6}} \quad \left(\text{for } \frac{R}{H} > 0.18\right)$$ [44]

Actual fires are not steady and, strictly speaking, Equations 40-44 do not apply. A modified version of Alpert's method, referred to as DETACT-QS, was therefore used to calculate sprinkler activation time for each of the ignition sources listed in Tables A5.1 and A5.3 of Attachment 5 to Appendix F as a function of H and R. The results of these calculations are presented in Figures F.31 through F.61 of table/plot set F. The modified method was originally developed at NIST, and is described and validated in Reference 47. The equations are as follows:

$$\frac{dT_{link}(t)}{dt} = \frac{\sqrt{u_{cj}(t)}\left(T_{cj}(t) - T_{link}(t)\right)}{RTI}$$ [45]

with

$$T_{cj}(t) = \begin{cases} T_a + \dfrac{16.9\,\dot{Q}(t)^{2/3}}{H^{5/3}} & \text{for } \dfrac{R}{H} \le 0.18 \\ T_a + \dfrac{5.38\left(\frac{\dot{Q}(t)}{R}\right)^{2/3}}{H} & \text{for } \dfrac{R}{H} > 0.18 \end{cases}$$ [46]

and

$$u_{cj}(t) = \begin{cases} 0.96\left(\frac{\dot{Q}(t)}{H}\right)^{1/3} & \text{for } \frac{R}{H} \leq 0.13 \\ \frac{0.195\,\dot{Q}(t)^{1/3}H^{1/2}}{R^{5/6}} & \text{for } \frac{R}{H} > 0.13 \end{cases} \qquad [47]$$

where

T_{ink}	=	sprinkler link or bulb temperature (°C)
t	=	time (s)

Equation 45 was integrated numerically for a range of H and R values to determine how T_{link} increases as a function of time for each of the ignition sources listed in Tables A5.1 and A5.3 of Attachment 5 to Appendix F. The HRR profile, $\dot{Q}(t)$, for these ignition sources is expressed in Equation 5-1 of Attachment 5 to Appendix F, and the profile for a specific ignition source is defined by the corresponding parameters given in Tables A5.2 and A5.4 of Attachment 5 to Appendix F. Sprinkler activation is assumed to occur when T_{link} is equal to the activation temperature, T_{act}. For the calculations, the sprinklers were assumed to have an activation temperature of 74°C (165°F) and an RTI of 130 $(m{\cdot}s)^{0.5}$. These values were used in the fire modeling supporting the LAR of several plants transitioning to NFPA 805. The results of the sprinkler activation time calculated for all fixed and transient ignition sources as a function of ceiling height above the fire base and radial distance between the sprinkler and the fire, with SF ranging from 0.02 to as high as 0.70 are given in Figures F.31 through F.61 of Attachment 8 to Appendix F. Once the sprinkler activation time is determined, the plume and ceiling jet lag times (calculated according to Equations 35 and 36, respectively, with $\dot{Q}$ equal to the HRR at the time of sprinkler activation) need to be added, although these times are usually very small (a few seconds).

<u>Sprinkler Activation Times for Fires without Known HRR Profile</u>

Creating a concise set of tables with generic sprinkler activation times that cover the entire range of potential HRR profiles is a very difficult task. The tables that are currently available in set F (Figures F.62-F.67) allow the analyst to obtain a conservative estimate of the sprinkler activation time for fires that involve secondary combustibles.

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END

Attachment 1: Revision History for IMC 0308, Attachment 3, Appendix F

Commitment Tracking Number	Accession Number Issue Date Change Notice	Description of Change	Description of Training Required and Completion Date	Comment Resolution and Closed Feedback Form Accession Number (Pre-Decisional, Non-Public)
	ML041700302 05/28/04 CN 04-016	Initial issue to provide the supporting technical "basis" for IMC 0609, App F.		
	ML050700153 02/28/05 CN 05-007	Revised to correct typographical errors; change all references from 50th and 95th to 75th and 98th percentile, respectively, for expected and high confidence fire intensity values; add additional applicable correlations from NUREG-1805; remove bullet on moderate degradation against the fire prevention or administrative control program on page 48 (not applicable in current process); correct the base fire frequency for non-qualified cables, medium loading in Table A9.3 on page 59; expand Table A9.6 and A9.7 to provide a better breakout of time to failure using temperature ranges.		

Commitment Tracking Number	Accession Number Issue Date Change Notice	Description of Change	Description of Training Required and Completion Date	Comment Resolution and Closed Feedback Form Accession Number (Pre-Decisional, Non-Public)
	ML17144A273 DRAFT CN 17-XXX	Major revision to reflect revision of IMC 0609 Appendix F, including all of its attachments, to update the analysis methods for consistency with the guidance in NUREG/CR-6850 and superseding guidance in NFPA 805 FAQs, NUREG-2169, NUREG-2178, and NUREG/CR-7010. Revisions to Phase 1 include: (a) revision of the screening questions based on inspector feedback, (b) re-ordering of the steps, (c) removal of the initial quantitative screening, (d) addition of main control room fire questions, and (e) removal of fire brigade screening questions. Revisions to Phase 2 include: (a) removal of need to use the Fire Dynamics Tools (FDTs) Spreadsheets, (b) addition of tables and plots for determining zone of influence, hot gas layer, heat release rates for fires involving cable trays, severity factor, damage times, and detector and sprinkler activation times in lieu of using the FDTs, (c) re-organization of the process, (d) removal of moderate degradation rating screening criteria, (e) removal of 75th percentile fire analysis, and (f) update of the ignition source heat release rates, fire ignition frequencies, and manual fire suppression curves. This update includes closure of ROP feedback forms 0308.03F-1741 and 1916. CA Note sent 7/18/17 for information only, ML17191A681. Issued 10/11/17 as a draft publicly available document to allow for public comments.	November 2017	ML17145A084 0308.03F-1741 ML18093A045 0308.03F-1916 ML18093A046
	ML18087A416 05/02/18 CN 18-010	Re-issued with new accession number in order to issue as an official revision after receipt of public comments.	November 2017	ML17145A084 0308.03F-1741 0308.03F-1916

Commitment Tracking Number	Accession Number Issue Date Change Notice	Description of Change	Description of Training Required and Completion Date	Comment Resolution and Closed Feedback Form Accession Number (Pre-Decisional, Non-Public)
	ML24150A361 09/05/24 CN 24-024	This revision includes updating IMC 0609 Appendix F, its associated attachments, and the basis document to incorporate updated guidance for modeling transient fires per NUREG-2233, high energy arching faults per NUREG-2262, and electrical enclosure, electric motor, dry transformer and main control room fires per NUREG-2178 Volume 2. This revision also implements the heat soak method in the HRR and ZOI calculations.	N/A	ML24155A255