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Methodology for Modeling Transient Fires in Nuclear Power Plant Fire Probabilistic Risk Assessment

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research
Washington, D.C. 20555-0001

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Technical Report, May 2020

U.S. Nuclear Regulatory Commission
Office of Nuclear Regulatory Research (RES)
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NOTE

ABSTRACT

The method for analyzing transient fires in NUREG/CR-6850 made use of the limited available data, and its application resulted in conservative estimates of transient fire risk. To counter the lack of available data, additional testing was performed based on the transient fire events observed in the Electric Power Research Institute fire events database. The results from the testing effort served as a primary input to develop more realistic data to analyze transient fire risk. This report develops new distributions of peak heat release rate, total energy release, and zones of influence for transient fires. Additionally, this report recommends input values for the detailed fire modeling of transient fires that include fire growth and decay parameters, yields of minor products of combustion, heat of combustion, and the physical size and effective elevation of the fire.

Keywords
Fire modeling
Fire probabilistic risk assessment
Heat release rate
Transient fires
Zone of influence

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EXECUTIVE SUMMARY

PRIMARY AUDIENCE: Fire probabilistic risk assessment (FPRA) engineers and fire protection engineers supporting the development and/or maintenance of FPRAs.

SECONDARY AUDIENCE: Fire protection engineers responsible for plant fire protection and control of transient fire hazards. Engineers, utility managers, and other stakeholders who review FPRAs and who interface with FPRA methods.

KEY RESEARCH QUESTION

How can nuclear power plant fire operating experience and experimental results be used to improve the FPRA methodology and data for transient fires?

RESEARCH OVERVIEW

This report is a joint collaboration between the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission Office of Nuclear Regulatory Research (NRC-RES) under a memorandum of understanding on fire research. The methods in this report were developed by a working group consisting of fire protection engineers and technical experts in experimental test programs, FPRA, operating experience, and fire modeling, representing both EPRI and the NRC. The working group met periodically to discuss the results and formalize the methods and data that are presented in this report.

This report combines experimental data on transient combustibles with operating experience to develop new probabilistic distributions for modeling transient fires in FPRA. Two sets of distributions have been developed. Each set consists of distributions of heat release rate (HRR), total energy release (TER), and zones of influence (ZOIs). The first is a set of generic parameters applicable for any at-power transient fire. The second is a set of parameters intended for use in locations subject to strict controls on the presence of transient combustibles.

In addition to the two sets of distributions, this report also develops input parameters for use in detailed fire modeling. These include fire growth and decay timing data, heat of combustion, fire Froude number, and yields of minor product of combustion.

KEY FINDINGS

- Multiple independent evaluations of operational experience were combined to create the distributions and input parameters in this report. Analysis of the independent evaluations does not show a significant sensitivity of the probability distributions with respect to the individual assessments.
- The peak HRR of a generic transient fire can be represented by a gamma distribution with a 98th percentile fire size of 278 kW and a 75th percentile fire size of 42 kW (see Table 4-1). At the 98th percentile, this is a 13% reduction from the 317 kW in NUREG/CR-6850 Volume II; however, at the 75th percentile, this is a 70% reduction in peak HRR from the 142 kW in NUREG/CR-6850 Volume II.

- The 98th percentile peak HRR of a transient fire in a transient combustible control location (TCCL) is 143 kW (see Table 4-4). This is a 55% reduction from the NUREG/CR-6850 Volume II value. At the 75th percentile, the peak HRR of 25 kW is an 83% reduction in peak HRR from the NUREG/CR-6850 Volume II value.
- The 98th percentile TER for a generic transient fire is 123 MJ. In the absence of secondary combustibles and in conjunction with the 278 kW peak HRR, this value is unlikely to result in hot gas layer capable of damaging electrical cables.
- The 98th percentile vertical (plume temperature) ZOI for thermoplastic cable is 1.78 m (5.8 ft). Combined with the effective fire elevation of 15 cm (6 in.) this gives a total ZOI of 1.93 m (6.3 ft) above the floor. Any cable trays above the height of a typical interior door, 2.13 m (7 ft), will screen. For transient sources in a corner, the same cable trays will screen at the 90th percentile.
- In detailed fire modeling, transient fires (both generic and TCCL) can be modeled with a heat of combustion of 25 MJ/kg, a fire Froude number (Q^*) of 0.54, a soot yield of 5.2%, a CO yield of 4.3%, and an effective elevation above the local floor of 15 cm. (6 in.). A summary of the input parameters for detailed fire modeling is found in Table 5-3.
- All transient fires (both generic and TCCL) can be modeled using a time-dependent HRR that combines a power law growth, a constant plateau, and a power law decay. The growth and decay exponents are fixed at 2.7 and 0.32, respectively. The growth time, plateau time, and decay times can be expressed as a function of the TER and peak HRR. Table 5-4 (for generic transient fires) and Table 5-10 (for TCCL transient fires) summarize the time for growth, steady state, and decay for various points along the respective HRR/TER distribution profiles.

WHY THIS MATTERS

The methods and data provided in NUREG/CR-6850 Volume II and NUREG/CR-6850 Supplement 1 resulted from an extensive effort to gather together the knowledge and best practices at that time for modeling fires in FPRAs. In some cases, the level of knowledge was not as mature as needed for supporting realism in FPRAs. For example, the aggregate results of multiple FPRAs showed that transient fires were consequential and high contributors to plant risk, which is a conclusion not wholly supported by operating experience. As a result, the FPRAs contain oversimplifications and assumptions that lean in the conservative direction. Over the years, the industry and the NRC have worked to perform testing on actual transient combustibles found in nuclear power plants and develop methods that are more realistic and representative of the operating experience with respect to fire. This report develops improved fire modeling methods that will improve the realism of modeling transient fires in FPRAs.

HOW TO APPLY RESULTS

This report provides new probabilistic distributions and detailed fire modeling input parameters for the modeling of transient fires in FPRAs. Distributions of ZOI enable the screening of targets without the need to separately calculate a ZOI through fire modeling. Detailed fire model input parameters on the fuel properties and fire growth and decay profiles can be used as direct replacement for values used in detailed fire models in current FPRAs and fire hazard analyses. This new set of model input data replaces the more limited set of data contained in NUREG/CR-6850 and NUREG/CR-6850 Supplement 1.

LEARNING AND ENGAGEMENT OPPORTUNITIES

Users of this report may be interested in FPRA training, which is sponsored jointly by EPRI and the U.S. NRC-RES. The two modules that may be of interest are Module III: Fire Analysis and Module V: Advanced Fire Modeling. The Fire Analysis course is geared toward PRA practitioners responsible for treating those aspects related to fire growth and damage assessment. This training covers the basics of plant partitioning, fire frequency analysis, and the development and analysis of fire scenarios from fire ignition to target impact and fire suppression. The Advanced Fire Modeling course covers fundamentals of fire science and guidance on the use of fire models to predict fire-generated conditions that may impact nuclear power plant safety functions.

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ACRONYMS

CFAST	Consolidated Model of Fire Growth and Smoke Transport
CH	challenging
CO	carbon monoxide
CSV	comma separated value
EDG	emergency diesel generator
EPRI	Electric Power Research Institute
FAQ	frequently asked question
FDS	Fire Dynamics Simulator
FDT^S	Fire Dynamics Tools
FEDB	fire events database
FPRA	fire probabilistic risk assessment
FR	fire resistant
GT	general transient
HGL	hot gas layer
HRR	heat release rate
HVAC	heating, ventilation, and air conditioning
KC	Kerite-FR cable
MCR	main control room
NC	non-challenging
NFPA	National Fire Protection Association
NPP	nuclear power plant
NRC	Nuclear Regulatory Commission
NSP	non-suppression probability
P-P	probability-probability
PAU	physical analysis unit
PC	potentially challenging
PPE	personal protective equipment
PRA	probabilistic risk assessment

RCP	reactor coolant pump
RES	NRC's Office of Nuclear Regulatory Research
RHR	residual heat removal
SE	sensitive electronics
SF	severity factor
SNL	Sandia National Laboratories
SRS	Savannah River Site
TCCL	transient combustible control location
TER	total energy release
TI	bulk cable/tray ignition
TISR	transient ignition source region
TISRF	transient ignition source region factor
TP	thermoplastic
TS	thermoset
WC	welding and cutting
WPI	Worcester Polytechnic Institute
ZOI	zone of influence

1 INTRODUCTION

1.1 Background

In 2005, the Electric Power Research Institute (EPRI) and the U.S. Nuclear Regulatory Commission's (NRC's) Office of Nuclear Regulatory Research (RES) issued a joint technical report titled *EPRI/NRC-RES Fire PRA Methodology for Nuclear Power Facilities* (EPRI 1011989, NUREG/CR-6850) [1]. This report documented methods, tools, and data for conducting a fire probabilistic risk assessment (FPRA) for a commercial nuclear power plant (NPP) application. Following this publication, many utilities developed FPRAs using the guidance in NUREG/CR-6850 to support risk-informed applications, including the transition to the performance-based fire protection licensing basis, National Fire Protection Association (NFPA) 805. The results obtained from the FPRA models have suggested specific elements in the fire scenario analysis where improved methods and/or guidance could reduce conservatism and increase realism in the risk estimates. Consequently, during the past 15 years, FPRA research covering the areas of fire ignition frequencies (for example, NUREG-2169 [2]), fire modeling (for example, NUREG-2178 [3, 4] and NUREG/CR-7010 [5, 6]), human reliability analysis (NUREG-1921 [7]), and spurious operations (for example, NUREG/CR-7150 [8]) have been published and made available to the industry.

The previously mentioned reports have resulted in improved realism for electrical cabinet fires, cable tray fires, electric motor fires, and dry transformer fires, which cover all of the ignition sources covered in Appendix G of NUREG/CR-6850 except for transient combustibles. The research in this report addresses that gap in recent research on improved realism.

This report consolidates existing methods on the modeling of transient fires; provides new probabilistic distributions for peak heat release rate (HRR), total energy release (TER)[1], and zones of influence (ZOIs) for various types of targets and provides a method for the detailed modeling of transient fires including fire growth and decay, yields of minor combustion products, and the physical size and location of the fire. The distributions and data developed in this report are intended for use in at-power FPRA applications. For low-power FPRA applications, the distributions and detailed fire modeling data developed in this report would be applicable for transient fire locations where the combustible load does not change due to storage of materials or maintenance activities during low-power operations.

[1] Note that TER is referred to as *total heat released* in applicable ASTM standards for oxygen consumption calorimetry.

1.2 Technical Approach

The research documented in this report was developed by a working group that included members of both the regulator and the nuclear power industry. The working group members, along with their affiliations, are as follows:

- Jason Floyd, Jensen Hughes
- Brian Metzger, NRC-NRR
- Nicholas Melly, NRC-RES
- Mark Schairer, Engineering, Planning, and Management, Inc.
- Denis Shumaker, Public Service Electric & Gas
- David Stroup, NRC-RES

The project consisted of two phases. The first phase was an extensive set of experiments that measured the HRR and other fire characteristics of transient fires [9]. The test report contains details on all of the fuel packages that were tested; the test protocol, including selection of fuel packages and selection of ignition sources; the methods used to process the collected test data; and the collected and derived data including HRR, fire diameter, ZOIs, fire growth and decay parameters, and the combustion properties of the fuel packages. The second phase, documented in this report, created a combined data set of data collected in the first phase with data from previous experimental programs, developed a methodology for weighting the combined data set based on industry experience with transient fires, and used the weighted combined data set to create improved probabilistic distributions for use in modeling transient fires in FPRA. Additionally, this report presents detailed guidance for modeling the time dependence and defining the combustion characteristics of transient fires.

Additional support was obtained in the weighting of test data from the following individuals:

- Joelle DeJoseph, Jensen Hughes
- Orelvis Gonzalez, Jensen Hughes
- Victor Ontiveros, Jensen Hughes

1.3 Report Organization

The report is organized as follows:

- Section 2 provides a review of prior work related to transient fires. Section 2.1 is a review of prior FPRA guidance related to transient fires. Where this report provides updated data or methods, it is noted in the summary for that item. Section 2.2 is a review of prior testing of transient fuel packages and the applicability of that testing for the distributions and input data developed in Sections 4 and 5.
- Section 3 covers the technical approach for developing the new distributions and related input data for modeling, including the definition of a transient combustible control location (TCCL).
- Section 4 develops and presents two sets of probabilistic distributions for peak HRR, TER, and ZOIs. The two sets are a generic distribution applicable to all areas of a plant and a distribution intended for a TCCL.

- Section 5 develops and presents new input data for performing detailed fire modeling for transient fires. This includes defining physical parameters of the fire such as the diameter, heat of combustion, and product yield data. It also includes experimentally derived correlations that link the distributions of peak HRR and TER to the growth, steady-state, and decay stages of a transient combustible fire.
- Section 6 covers potential sources of uncertainty.
- Section 7 covers the extent to which the application of the new data and distributions can be combined with existing FPRAs using the prior distributions and modeling parameters
- Section 8 summarizes the results of this study.

2
REVIEW OF PRIOR TRANSIENT FIRE WORK

This section provides a review of prior work on modeling transient fires in fire probabilistic risk assessments (FPRAs) and prior testing of transient fuel packages.

2.1 Frequently Asked Questions, NUREGs, and EPRI Research

In the review of prior work that follows, it is noted in each section whether the data developed in this report are an improvement over existing data. Note that the contents of Sections 4 and 5 show that conservatisms result from the application of the methods and data summarized in this section; therefore, the continued use of this prior work in FPRA is not a concern from a conservatism point of view. For existing FPRAs, a discussion on how an analyst may choose to apply the new distributions and data is presented in Section 7.

2.1.1 NUREG/CR-6850 Volume 2

NUREG/CR-6850 Volume 2 [1] provides guidance related to modeling the effects of transient fires. This includes ignition source weighting for transient fires, target screening, the peak heat release rate (HRR) distribution for transient fires, and determining the severity factor (SF) while accounting for non-suppression probability (NSP).

In the fire ignition frequencies (Task 6) discussion in NUREG/CR-6850 [1], a method is provided to apportion the transient fire frequencies over fire compartments in a nuclear power plant (NPP). The approach uses a relative ranking scheme that accounts for the variance in maintenance, occupancy, and storage that occur among different fire compartments. The ignition frequency for a specific ignition source, IS, in compartment J, $\lambda_{IS,J}$, is given by:

$$\boldsymbol{\lambda_{IS,J} = \lambda_{IS} W_L W_{IS,J,L}} \qquad \textbf{Eq. 2-1}$$

where λ_{IS} is the plant level fire ignition frequency for the ignition source (for example, values from NUREG-2169 [2]) appropriate for location L, W_L is the weighting factor for location L, and $W_{IS,J,L}$ is the weighting factor reflecting the quantity of ignition source in compartment J of location L. Note that transient ignition frequencies are mapped to four location bins for general transients and three location bins for transients due to hot work.

The location weighting factor, W_L, is tabulated in Table 6-2 of NUREG/CR-6850. W_L accounts for differences in plant construction where one or more plant locations might be shared by multiple units. This report does not change the application of Table 6-2 for determining W_L.

The NUREG/CR-6850 method for determining $W_{IS,J,L}$ was later clarified in frequently asked question (FAQ) 12-0064 R1 [10] and FAQ 14-0007 [11], covered in Sections 2.1.2 and 2.1.4. This report does not change the application of FAQ 12-0064 or FAQ 14-0007 as improved methods over those presented in NUREG/CR-6850.

In the scoping fire modeling (Task 8) discussion in NUREG/CR-6850, targets can be screened if an ignition source does not damage the target at the 98th percentile HRR for that ignition source type. This method was applied when defining the 98th percentile screening zones of influence (ZOIs) provided in Section 4.1 of this report.

In the detailed fire modeling (Task 11) discussion in NUREG/CR-6850, the compartment-based frequency may be further subdivided by assigning a scenario ignition frequency, $\lambda_{scenario}$, to subsets of the floor area. As a simple example, consider a large room with only a single target, no fixed ignition sources, and no secondary combustibles that could cause a damaging hot gas layer (HGL). Only transient fires located so that the target is within the transient fire scenario ZOI would damage the target. All other transient fire locations would not damage the target. The room could be partitioned to assign part of the transient fire frequency to the area of the ZOI and the remainder of the frequency to the remainder of the room. This apportionment is done based on the floor area fraction as shown:

$$\boldsymbol{\lambda}_{\mathbf{scenario}} = \boldsymbol{\lambda}_{\mathbf{IS,J}} \times \frac{\mathbf{n}_{\mathbf{A,scenario}}}{\mathbf{n}_{\mathbf{A,J}}} \qquad \textbf{Eq. 2-2}$$

where n_A is the floor area. This process was further refined in FAQ 14-0007.

The peak HRR distribution is defined in NUREG/CR-6850 Appendix G as a gamma distribution with a 75th percentile HRR of 142 kW and 98th percentile HRR of 317 kW. This distribution is defined with gamma parameters of α = 1.8 (shape parameter) and β = 57.4 (rate parameter). This distribution was based on a collection of 27 tests that are summarized in Table G-7 of NUREG/CR-6850. As covered in Section 2.2.2, some of the tests are not representative of expected transient combustibles in NPPs and no effort was made to weight the likelihood of the tests when developing the distribution. This report develops a new gamma distribution based on a much larger set of experiments that are weighted based on operating experience. Some of the tests from NUREG/CR-6850 are included in the new distribution. This new gamma distribution for peak HRR, presented in Section 4.1, replaces the gamma distribution from NUREG/CR-6850.

NUREG/CR-6850 Appendix E defines the SF of a fire scenario as the probability that the fire scenario, if not suppressed, could lead to target damage. For a scenario, k, this is represented as the product value $SF_kP_{ns,k}$, where SF is the fraction of fires that could cause damage and P_{ns} is the NSP associated with that fraction. For a transient fire, the HRR is represented by a probabilistic distribution of HRRs. Each unique HRR will have a unique time to damage and, therefore, a varying P_{ns}. Adequately representing the $SF_kP_{ns,k}$ requires converting the HRR distribution into a probability distribution for the time to damage, $p_{damage}(t)$. This allows $SF_kP_{ns,k\ t}$ to be evaluated as:

$$\mathbf{SF_k P_{ns,k}} = \int_{\mathbf{0}}^{\infty} \mathbf{p_{damage}(t) P_{ns}(t)} \, d\mathbf{t} \qquad \textbf{Eq. 2-3}$$

This can be estimated in a probabilistic risk assessment (PRA) by binning the HRR distribution, determining the time to damage for the midpoint fire size in each bin, and summing the product of the bin width, $P_{k,i}$, by the P_{ns} for the midpoint fire size of the bin, $P_{ns,k,i}$.

$$\mathbf{SF_k P_{ns,k}} = \sum_{\mathbf{i}} \mathbf{P_{k,i} P_{ns,k,i}} \qquad \textbf{Eq. 2-4}$$

The approach given in Equation 2-4 is not changed by this report; however, because this report provides new transient fire distributions in Section 4, the HRR bins in NUREG/CR-6850 are replaced with new bins in Section 5 that are tied to the new distributions.

2.1.2 Transient Fire Frequency Influence Factors (FAQ 12-0064 R1)

FAQ 12-0064 R1 [10] clarifies the treatment of influence factors in the fire ignition frequencies (Task 6) discussion in NUREG/CR-6850 [1]. The clarification was needed to better address areas with enhanced administrative controls on transient combustibles or hot work. The FAQ addresses the computation of $W_{IS,J,L}$ in Equation 2-1 of this report. For transient combustibles, the applicable ignition sources are general transients (GTs) (Bins 3, 7, 25, and 37), ignition source = GT, and transient fires caused by welding and cutting (WC) (Bins 6, 24, and 36), ignition source = WC. The weighting factors are computed as:

$$\mathbf{W_{GT,J,L}} = \frac{\mathbf{n_{m,J,L}+n_{o,J,L}+n_{s,J,L}}}{\mathbf{N_{GT,L}}}$$
$$\mathbf{N_{GT,L}} = \sum\nolimits_{\mathbf{i\ in\ L}}\left(\mathbf{n_{m,i,L}} + \mathbf{n_{o,i,L}} + \mathbf{n_{s,i,L}}\right) \quad \textbf{Eq. 2-5}$$

$$\mathbf{W_{WC,J,L}} = \frac{\mathbf{n_{h,J,L}}}{\mathbf{N_{WC,L}}}$$
$$\mathbf{N_{WC,L}} = \sum\nolimits_{\mathbf{i\ in\ L}}\mathbf{n_{h,i,L}} \quad \textbf{Eq. 2-6}$$

where n is an influence factor with h being hot work, m being general electromechanical maintenance, o being occupancy, and s being storage. Values for n can be 0 (none), 0.1 (extremely low—only for h), 0.3 (very low), 1 (low), 3 (medium), 10 (high), and 50 (very high—only for h and m). Detailed definitions for the categories are provided in the FAQ.

The result of applying this FAQ is a unique weighting factor for each room that is used to determine the transient fire ignition source frequency. This FAQ was later modified by FAQ 14-0007, covered in Section 2.1.4, which allows for a further refinement of $\lambda_{IS,J}$ within the compartment J. This report does not change the methods in FAQ 12-0064 R1 or FAQ 14-0007.

2.1.3 Damage to Enclosed Sensitive Electronics (FAQ 13-0004)

FAQ 13-0004 [12] clarifies the treatment of determining damage to solid state and sensitive electronics (SE). The FAQ provides guidance for when to apply the NUREG/CR-6850 [1] damage thresholds of 65°C (149°F) or 3 kW/m^2. That method states that if the SE is mounted inside of a cabinet in a manner in which the SE is shielded from the direct radiation of the fire by the cabinet wall, the exposure limits for thermoset (TS) cable can be used to evaluate damage to the SE.

This method is not changed by the contents of this report. Where this report refers to the SE ZOI or time to damage for SE, that reference is for SE directly exposed to the fire—that is, the SE is not in a cabinet and is either immersed in the fire plume or is directly exposed to radiation from the fire.

2.1.4 Transient Fire Likelihood (FAQ 14-0007)

FAQ 14-0007 [11] provides a refinement to the method presented in FAQ 12-0064 [10]. The methodology in FAQ 12-0064 applies at the physical analysis unit (PAU) level. FAQ 14-0007 notes that a PAU itself likely has areas with different levels of maintenance, occupancy, and storage. One example given is that a PAU could have an area marked as a transient combustible free zone even though another area of the PAU could have a storage area. The combustible free zone is likely present due to some risk significant equipment or cables in that area. The FPRA model would be more realistic if the combustible free zone were reflected in the modeling. FAQ-14-0007 was developed to provide a method for handling areas of the PAU with widely varying transient fire likelihoods.

The method applies to general transients (Bins 3, 7, 25, and 37) and transient fires due to WC (Bins 6, 24, and 36). The method does not apply for cable fires due to WC (Bins 5, 11, and 31).

FAQ 14-0007 defines a new region called a *transient ignition source region* (TISR). A TISR is a subdivision of a PAU that is identified as having varying ignition frequency characteristics. A transient scenario in TISR k is assigned a frequency, $\lambda_{scenario}$, based on the following equations:

$$\boldsymbol{\lambda}_{\mathbf{scenario}} = \boldsymbol{\lambda}_{\mathbf{TSIR},k} \frac{\mathbf{n}_{\mathbf{A,scenario}}}{\mathbf{n}_{\mathbf{A,TISR}}} \qquad \textbf{Eq. 2-7}$$

$$\boldsymbol{\lambda}_{\mathbf{TSIR}_k} = \boldsymbol{\lambda}_{\mathbf{IS,J}} \mathbf{TISRF}_{\mathbf{IS,k,J}} \qquad \textbf{Eq. 2-8}$$

where $\lambda_{\mathrm{TSIR}_k}$ is the ignition source frequency assigned to TISR k and $TISRF_{IS,k,J}$ is the transient ignition source region factor for ignition source IS (IS is either GT or WC) in TISR k in compartment J. Note that different TISRs can be defined for general transient fires (Bins 3, 7, 25, and 37) and for transient fires due to WC (Bins 6, 24, and 36).

$TISRF_{IS,k,J}$ is computed by dividing J into multiple TISRs or $TISR_{k,J}$. Each $TISR_{k,J}$ has a floor area, $n_{A,k,J}$, and its own set of influence factors $n_{M,k,J}$, $n_{O,k,J}$, $n_{S,k,J}$, and $n_{H,k,J}$. $TISRF_{IS,k,J}$ is then computed using the influence factors weighted by floor area as shown:

$$\mathbf{TIRSF}_{\mathbf{GT,k,J}} = \frac{(\mathbf{n}_{\mathbf{M,k,J}} + \mathbf{n}_{\mathbf{O,k,J}} + \mathbf{S}) \times \mathbf{n}_{\mathbf{A,k,J}}}{\sum_{\mathbf{i\ in\ J}} [(\mathbf{n}_{\mathbf{M,i,J}} + \mathbf{n}_{\mathbf{O,i,J}} + \mathbf{n}_{\mathbf{S,i,J}}) \times \mathbf{n}_{\mathbf{A,i,J}}]} \qquad \textbf{Eq. 2-9}$$

$$\mathbf{TIRSF}_{\mathbf{WC,k,J}} = \frac{\mathbf{n}_{\mathbf{H,k,J}} \times \mathbf{n}_{\mathbf{A,k,J}}}{\sum_{\mathbf{i\ in\ J}} (\mathbf{n}_{\mathbf{H,i,J}} \times \mathbf{n}_{\mathbf{A,i,J}})} \qquad \textbf{Eq. 2-10}$$

Detailed examples are provided in FAQ 14-0007. This report does not change the method in this FAQ.

2.1.5 Bulk Cable/Tray Ignition (FAQ 16-0011)

FAQ 16-0011 [13] clarified the method for the initiation of a propagating fire in a cable tray. The FAQ establishes a temperature threshold of 500°C (932°F) and a heat flux threshold of 25 kW/m^2 for bulk cable/tray ignition (TI). These are conditions that represent direct flame impingement. Bulk ignition represents the ignition of a large enough area of a tray that the fire intensity of the tray is large enough to cause fire spread along the tray or to trays above. Below the threshold exposures, cable failures due to thermal exposure may result in small areas of flame; however, those fires will not be sufficiently intense to sustain a growing, spreading fire.

The FAQ does not change the method for defining the effect of solid bottom trays presented in Appendix Q of NUREG/CR-6850 [1], nor does it change the method for determining the time of tray-to-tray propagation in Appendix R of NUREG/CR-6850.

The criteria in this FAQ were used to evaluate the TI ZOI and TI time to damage values that are presented in Sections 4 and 5 of this report.

2.1.6 Fire Growth Times (NUREG/CR-6850 Supplement 1)

Chapter 17 of NUREG/CR-6850 Supplement 1 [14] provides a suggested value for the NSP for transient fires in the main control room (MCR) and a method for determining the growth times for transient fires.

The suggested NSP was a clarification on which NSP curve to apply for transient fires in the MCR. The clarification is to use the MCR NSP curve instead of the transient fire NSP curve for transient fires in the MCR. This report does not modify any existing methods on applying NSP to transient fires.

Growth time suggestions were provided for three types of transient fires, as follows:

- For common trash items contained in a plastic or metal trash can, the time to peak HRR is 8 minutes. This is based upon two sets of experiments involving five tests of trash in trash receptacles. Growth times ranged from 7 to 13 minutes.
- For common trash items contained in a plastic trash bag, but not in a trash can, the time to peak HRR is 2 minutes. This is based upon two sets of experiments involving six tests of trash in plastic trash bags or a box. Growth times ranged from 1 to 4 minutes.
- For transient fires involving spilled solvents or flammable liquid fuels, the time to peak HRR is zero minutes—that is, the fire is instantly at its peak size.

The growth times provided are representative of those items; however, in a typical FPRA, specific transient fuel packages are not evaluated because the transient fire could be any transient combustible material. A more useful parameter would be a generic approach for fire growth that represents the overall expected hazard due to transient fires. Additionally, the method in NUREG/CR-6850 Supplement 1 does not address the length of time the fire burns or how the fire decays. Both of those parameters are important in assessing the HGL or the time to damage. The method in this report provides a comprehensive set of fire growth and decay guidance that is an improvement over the transient fire growth methodology in NUREG/CR-6850 Supplement 1.

2.1.7 Transient Fire Propagation Factor (EPRI 3002005303)

Section 4 of EPRI 3002005303 [15] describes a method of assessing the probability of propagation for transient fires. This method was an effort to reconcile the 317 kW, 98th percentile peak HRR for transient fires in NUREG/CR-6850 with the operating experience contained in *The Updated Fire Events Database* [16]. It was observed that there were events included in the fire ignition frequency for transient fires where the specific ignition source was not a significant combustible mass and was also not in proximity to a significant combustible mass. The method computes a weighting factor that reduces the transient ignition frequency to account for the fact that many of the events that are part of the frequency would never have developed into the large fires represented by the experiments used in NUREG/CR-6850.

The body of testing used in this report includes a much wider range of combustible materials compared with those in NUREG/CR-6850. The various events in the fire events database (FEDB) where no significant fuel load existed are represented in the test data used in this report. The distributions and modeling guidance in this report already incorporate transient events with no significant fuel load; therefore, the method covered in Section 4 of EPRI 3002005303 should not be applied when using the method in this report.

2.2 Prior Testing

A review was undertaken of prior testing efforts related to transient combustibles. The following sections review prior test efforts and disposition individual tests for their relevance to transient fires in NPPs during at-power operations.

2.2.1 EPRI/NRC Transient Fire Testing

The guidance in this report primarily relies upon the extensive fire test series performed in 2018 and documented by the NRC and EPRI [9]. This test series consisted of 99 fuel packages with a total of 290 tests. Full details of the test items and ignition sources, data collected during the testing, and analysis of the test results are provided in the test report. Familiarity with the contents of the test report may aid in the understanding of the method development in this report.

2.2.2 NUREG/CR-6850 Appendix G

The 98th percentile HRR of 317 kW recommended by NUREG/CR-6850 [1] was based upon a collection of 27 tests of fuel packages from prior experiments performed between 1978 and 1985 [17–20]. A list of the 27 tests is provided in Table 2-1. Table 2-1 provides a brief description of the test, comments on the test, and an indication if the test was included in the distributions developed in this report. It is noted that the data available for the tests in Table 2-1 consist of the published HRR curves in the various reports referenced in NUREG/CR-6850. The curves were digitized by hand using Plot Digitizer, an open source tool. Data on product yields were not published. This limits the derived test data to peak HRR, total energy release (TER), ZOIs, Q* (where Q* is based upon the fuel package description and the assumption that the entire footprint of the package was involved), and the heat of combustion (ΔH_c). Note that in the case of the Lee fabric test, the ΔH_c assumes complete combustion of the fuel package. HRR curves and summary details of the tests are provided in Appendix A.

Table 2-1
Dispositioned list of transient fire tests from NUREG/CR-6850

Test	Fuel Package	Comments	Use Test?
SNL—Nowlen Test 1 [17]	30 cm x 41 cm x 30 cm cardboard box with box of Kimwipes, 950 ml acetone, polyethylene wash bottle	These items are in FEDB events but not in the same fuel package. Low occurrence of flammable liquids in FEDB events. The quantity of liquid is plausible as is the grouping; therefore, it is included.	Y
SN—Nowlen Test 2 [17]	30 cm x 41 cm x 30 cm cardboard box with box of Kimwipes, 950 ml acetone, polyethylene wash bottle	These items are in FEDB events but not in the same fuel package. Low occurrence of flammable liquids in FEDB events. The quantity of liquid is plausible as is the grouping; therefore, it is included.	Y

Table 2-1 (continued)
Dispositioned list of transient fire tests from NUREG/CR-6850

Test	Fuel Package	Comments	Use Test?
SNL—Nowlen Test 3 [17]	2.5 gal polyethylene bucket with box of Kimwipes, 950 ml acetone, polyethylene wash bottle	These items are in FEDB events but not in the same fuel package. Low occurrence of flammable liquids in FEDB events. The quantity of liquid is plausible as is the grouping; therefore, it is included.	Y
SNL—Nowlen Test 4 [17]	2.5 gal polyethylene bucket with box of Kimwipes, 950 ml acetone, polyethylene wash bottle	These items are in FEDB events but not in the same fuel package. Low occurrence of flammable liquids in FEDB events. The quantity of liquid is plausible as is the grouping; therefore, it is included.	Y
SNL—Nowlen Test 5 [17]	30 cm x 41 cm x 30 cm cardboard box with computer paper and crumpled paper	Similar to FEDB Fire ID 30459.	Y
SNL—Nowlen Test 6 [17]	30 cm x 41 cm x 30 cm cardboard box with computer paper and crumpled paper	Similar to FEDB Fire ID 30459.	Y
SNL—Nowlen Test 7 [17]	5 gal trash can, polyethylene bag, cotton rags, paper	Similar fuels noted in FEDB Fire IDs 248, 20376, and 30351.	Y
SNL—Nowlen Test 8 [17]	5 gal polyethylene trash can, polyethylene bag, cotton rags, paper	Similar fuels noted in FEDB Fire IDs 248, 20376, and 30351.	Y
SNL—Nowlen Test 9 [17]	30 gal polyethylene trash can with polyethylene bag and paper	Similar to the plastic-trash-full item tested for this project.	Y
LBL—Volkinburg rubbish bag [18]	32 gal polyethylene bag with straw, grass, and eucalyptus duff	Vegetation materials not representative of materials expected in a NPP trash bag.	N
LBL—Volkinburg three airline bags [18]	Three 11 gal trash bags with 36 polystyrene cups, 51 paper cups, and paper towels	No events with multiple bags of trash in the FEDB. Little expectation of large amounts of polystyrene. It is noted that multiple bags of trash might occur during low power or shutdown operations.	N
LBL—Volkinburg two airline bags [18]	Two 11 gal trash bags with 24 polystyrene cups, 38 paper cups, and paper towels	No events with multiple bags of trash in the FEDB. Little expectation of large amounts of polystyrene. It is noted that multiple bags of trash might occur during low power or shutdown operations.	N

Table 2-1 (continued)
Dispositioned list of transient fire tests from NUREG/CR-6850

Test	Fuel Package	Comments	Use Test?
LBL—Volkinburg one airline bag [18]	One 11 gal trash bag with 12 polystyrene cups, 17 paper cups, and paper towels	Little expectation of large amounts of polystyrene; however, it is a single bag test, and the quantities of materials are reasonable for the contents of a small trash can.	Y
LBL—Volkinburg 6.6 L waste basket [18]	6.6 L (7 qt) polyethylene trash container with 12 qt size paper milk cartons	Polyethylene coated paper cartons not an expected item for a trash can in a NPP. This observation was echoed in NUREG/CR-4680 [17].	N
NBS—Lee clothing [18]	30 cm stack of clothing ~4.5 kg	Although clothing items are involved in FEDB events, the items involved were being worn or consisted of a single discarded item (outer layer like a sweatshirt). 4.5 kg is a significant clothing pile that exceeds the amounts noted in the FEDB events.	N
NBS—Lee fabric [18]	30 cm stack of fabric ~2.7 kg	Although clothing items are involved in FEDB events, the items involved were being worn or consisted of a single discarded item (outer layer such as a sweatshirt). 2.7 kg of clothing is not a large stack and should be bounding for the FEDB events. It is representative of a couple of winter jackets.	Y
SNL—Chavez [19]	30 cm x 41 cm x 30 cm cardboard box with box of Kimwipes, 950 ml acetone, polyethylene wash bottle	These items are in FEDB events but not in the same fuel package. Low occurrence of flammable liquids in FEDB events. Although this is the same as the package for SNL—Nowlen Tests 1 and 2, which were included, the HRR curve could not be located in an available publication.	N
SNL—Chavez Test 5 [19]	2.5 gal polyethylene bucket with box of Kimwipes, 950 ml acetone, and one polyethylene wash bottle	These items are in FEDB events but not in the same fuel package. Low occurrence of flammable liquids in FEDB events. Although this is the same as the package for SNL—Nowlen Tests 3 and 4, which was included, the HRR curve could not be located in an available publication.	N

Table 2-1 (continued)
Dispositioned list of transient fire tests from NUREG/CR-6850

Test	Fuel Package	Comments	Use Test?
SNL—Cline 3 [19]	Computer paper and two polyethylene trash bags	No history of multiple co-located bags in FEDB events. Nowlen notes issues with calorimetry during test, rendering data unreliable [1].	N
SNL—Cline 4 [19]	Rags, paper towels, gloves and tape, methanol (2 gal or 7.57 liters), and two 40 gal polyethylene bags	No history of large quantities of flammable liquid or multiple co-located bags in FEDB events. Nowlen notes issues with calorimetry during test, rendering data unreliable [1].	N
SNL—Cline 5 [19]	Computer paper and two 50 gal polyethylene trash cans	No history of multiple co-located trash containers in FEDB events. Nowlen notes issues with calorimetry during test, rendering data unreliable [1].	N
SNL—Cline 9 [19]	Computer paper, folded paper, and two polyethylene trash bags	No history of multiple co-located trash containers in FEDB events. Nowlen notes issues with calorimetry during test, rendering data unreliable [1].	N
SNL—Cline #10 [19]	Computer paper and two 50 gal polyethylene trash cans	No history of multiple co-located trash containers in FEDB events. Nowlen notes issues with calorimetry during test, rendering data unreliable [1].	N
SNL—Cline 11 [19]	Rags, paper towels, gloves and tape, methanol (2 gal or 7.57 liters), and two 40 gal polyethylene bags	No history of large quantities of flammable liquid or multiple co-located bags in FEDB events. Nowlen notes issues with calorimetry during test, rendering data unreliable [1].	N
LBL—Volkinburg 30 lb wood crib [20]	13.6 kg of white fir with excelsior and ethanol	This is not a realistic fuel package for a transient fire in a NPP. A wood crib is a fuel package engineered for standardized fire testing.	N
LBL—Volkinburg 20 lb wood crib [20]	9.1 kg of Douglas fir with jet fuel	This is not a realistic fuel package for a transient fire in a NPP. A wood crib is a fuel package engineered for standardized fire testing.	N
LBL—Volkinburg 14 lb wood crib [20]	6.4 kg of Douglas fir with jet fuel	This is not a realistic fuel package for a transient fire in a NPP. A wood crib is a fuel package engineered for standardized fire testing.	N

SNL = Sandia National Laboratories
LBL = Lawrence Berkeley National Laboratory
NBS = National Bureau of Standards

2.2.3 NUREG/CR-4679

While obtaining data for the tests listed in NUREG/CR-6850, an additional test publication [21] was located that contained three additional tests involving potential transient fuels. These additional tests are dispositioned in Table 2-2. HRR curves are provided in Appendix A. These tests lack mass loss data and species data; therefore, the ΔH_c and minor product yields are not available.

Table 2-2
Dispositioned list of additional tests NUREG/CR-4679 [21]

Test	Fuel Package	Comments	Use Test?
Lawson Test 51	Single molded fiberglass chair with metal legs	Similar to a school desk chair. This is a reasonable surrogate for chairs with metal frames and plastic seats.	Y
Lawson Test 56	Single metal chair with foam cushion	Chair was a typical metal chair with a thin foam cushion.	Y
Lawson Test 75	Three stackable metal chairs with foam cushions	The chairs were typical metal chairs with a thin foam cushion. Although a stack of chairs being stored is a possible fuel item, it would not be expected to be co-located with an ignition source, unlike a single chair that is being used during a maintenance or testing activity.	N

2.2.4 WPI Testing for Savannah River Site

In 2012, Worcester Polytechnic Institute (WPI) performed a series of fire tests on behalf of Savannah River Site (SRS) [22]. The fuel packages consisted of a plastic trash bag filled with varying quantities of personal protective equipment (PPE). The fires were ignited with a 10 kW propane ring burner that was applied for 80 seconds. This represents an ignition source that is much larger than those expected during an actual transient fire event. Test data include HRR, mass loss, and soot production; therefore, all quantities of interest except for carbon monoxide (CO) yield (which was not measured) can be derived from the test data. A total of nine tests were performed. These tests are described and dispositioned in Table 2-3. HRR curves and summary data for the tests used for creating distributions are provided in Appendix A.

Table 2-3
Dispositioned list of WPI PPE bag tests performed for SRS [22]

Test	Fuel Package	Comments	Use Test?
WPI quarter bag Corner 1	Polyethylene bag with approximately six groupings of the following: • A pair of shoe covers • Two balls of masking tape • Four yellow gloves • Two cotton gloves • One black rubber overshoe	Tests were done for SRS, which has areas with frequent need for workers in protective clothing. Generally, this type of fuel package is not expected for long-term NPP needs. This fill quantity would be representative of a plant dress-out area.	Y
WPI quarter bag Corner 2	Polyethylene bag with approximately six groupings of the following: • A pair of shoe covers • Two balls of masking tape • Four yellow gloves • Two cotton gloves One black rubber overshoe	Tests were done for SRS, which has areas with frequent need for workers in protective clothing. Generally, this type of fuel package is not expected for long-term NPP needs. This fill quantity would be representative of a plant dress-out area.	Y
WPI half bag Corner 3	Polyethylene bag with approximately 12 groupings of the following: • A pair of shoe covers • Two balls of masking tape • Four yellow gloves • Two cotton gloves • One black rubber overshoe	Tests were done for SRS, which has areas with frequent need for workers in protective clothing. Generally, this type of fuel package is not expected for long-term NPP needs. This quantity of material might be present in a dress-out area.	Y
WPI half bag Corner 4	Polyethylene bag with approximately 12 groupings of the following: • A pair of shoe covers • Two balls of masking tape • Four yellow gloves • Two cotton gloves • One black rubber overshoe	Tests were done for SRS, which has areas with frequent need for workers in protective clothing. Generally, this type of fuel package is not expected for long-term NPP needs. This quantity of material might be present in a dress-out area.	Y
WPI full bag Center 1	Polyethylene bag with approximately 25 groupings of the following: • A pair of shoe covers • Two balls of masking tape • Four yellow gloves • Two cotton gloves • One black rubber overshoe	Tests were done for SRS, which has areas with frequent need for workers in protective clothing. Generally, this type of fuel package is not expected for long-term NPP needs. This quantity of material would not be expected in typical dress-out areas during at-power operations but might be present during low-power or shutdown operations.	N

Table 2-3 (continued)
Dispositioned list of WPI PPE bag tests performed for SRS [22]

Test	Fuel Package	Comments	Use Test?
WPI full bag Center 2	Polyethylene bag with approximately 25 groupings of the following: • A pair of shoe covers • Two balls of masking tape • Four yellow gloves • Two cotton gloves • One black rubber overshoe	Tests were done for SRS, which has areas with frequent need for workers in protective clothing. Generally, this type of fuel package is not expected for long-term NPP needs. This quantity of material would not be expected in typical dress-out areas during at-power operations but might be present during low-power or shutdown operations.	N
WPI full bag Corner 2	Polyethylene bag with approximately 25 groupings of the following: • A pair of shoe covers • Two balls of masking tape • Four yellow gloves • Two cotton gloves • One black rubber overshoe	Tests were done for SRS, which has areas with frequent need for workers in protective clothing. Generally, this type of fuel package is not expected for long-term NPP needs. This quantity of material would not be expected in typical dress-out areas during at-power operations but might be present during low-power or shutdown operations.	N
WPI full bag Corner 3	Polyethylene bag with approximately 25 groupings of the following: • A pair of shoe covers • Two balls of masking tape • Four yellow gloves • Two cotton gloves • One black rubber overshoe	Tests were done for SRS, which has areas with frequent need for workers in protective clothing. Generally, this type of fuel package is not expected for long-term NPP needs. This quantity of material would not be expected in typical dress-out areas during at-power operations but might be present during low-power or shutdown operations.	N
WPI full bag Wall 2	Polyethylene bag with approximately 25 groupings of the following: • A pair of shoe covers • Two balls of masking tape • Four yellow gloves • Two cotton gloves • One black rubber overshoe	Tests were done for SRS, which has areas with frequent need for workers in protective clothing. Generally, this type of fuel package is not expected for long-term NPP needs. This quantity of material would not be expected in typical dress-out areas during at-power operations but might be present during low-power or shutdown operations.	N

2.3 Inspection Reports

In addition to actual fire events that have occurred in NPPs, findings from inspection reports provide some insights on potential transient events. The analysis performed in this report, covered in Section 3, used the set of challenging / potentially challenging events contained in the EPRI FEDB [16]. This implicitly contains the assumption that events that have occurred to date have a distribution of severity that matches the distribution that would exist if there were many more years of data collection. One check on this is to consider violations of transient material procedures found during NRC inspections over the period from 2000 to 2010. It is noted that such inspection findings are not fire events. They are only the discovery of some quantity of transient materials in a location where such materials and/or quantities should not be present. Transient materials also require a potential ignition source to ultimately result in a fire event. It is additionally noted that inspection findings likely bias toward significant violations—that is, a 55 gallon drum of lube oil in a combustible free zone would almost certainly result in a violation but a few sheets of paper fallen from a notebook would likely not.

A list of inspection findings where large amounts of transient combustibles were present is given in Table E-1. It is noted that that Table E-1 does not list all violations. Each finding is dispositioned in terms of its relevance to the data developed in this report. In general, the findings are dispositioned by one or more of the following basic responses:

- The plant was not at power, and the scope of this report is at-power PRA.
- Given the ignition sources associated with transient fire events, there is no credible ignition source that would ignite the fuel package—that is, another significant fire event would be required.
- The combustible materials in the finding were tested during this project either directly or with a closely matching experiment.

A review of Table E-1 shows that the most severe violations in terms of quantity were associated with items with no credible transient ignition source or occurred during an outage. Remaining events are fuel items contained in the test database directly or through a reasonable surrogate.

3
APPROACH FOR DEVELOPING DISTRIBUTIONS AND DETAILED FIRE MODELING INPUT PARAMETERS

The following sections describe the approach used to develop probabilistic distributions and input parameters for detailed fire modeling of transient fires.

3.1 Goals

There were three high level goals for the outcome of this research effort. They are as follows:

1. Provide improved realism in methods for transient fire probabilistic risk assessment (FPRA) by reflecting operational experience.

   This was achieved by weighting the available fire test data for transient combustibles to reflect the types and frequencies of events seen in the EPRI fire events database (FEDB). This process is covered in Section 3.2.

2. Provide for improved realism in the screening of targets by developing probabilistic distributions for target damage.

   The heat release rate (HRR) data from fire tests were processed to determine the zone of influence (ZOI) for each test. This process is described in detail in Section 5 of the test report [9]. Using the weightings developed in Section 3.2, distributions to support target screening were developed. This process is covered in Section 3.3 with the distributions presented in Section 4.

   2.1 The method accounts for vertical ZOI (plume temperature) and horizontal ZOI (radiative heat flux).

   2.2 The method considered the target damage categories of exposed sensitive electronics (SE), thermoplastic (TP) cable, Kerite-FR cable (KC), thermoset (TS) cable, and bulk cable tray ignition (TI). Note that based on test data, Kerite-FR II, FR III, and HT cables can use TS data [23].

3. Provide input data to support improved realism in the detailed modeling of transient fires to support assessment of hot gas layer (HGL) development, time to damage for targets, and the effectiveness of automatic or manual fire suppression.

   The HRR data from the test report [9], plus the additional tests identified in Section 2.2, were processed to characterize the fire growth and decay parameters for each test. This process is described in detail in the test report. Using the weightings developed in Section 3.2 and the distributions shown in Section 4, input data to support the detailed modeling of transient fires were developed. The process for developing the input data is covered in Sections 5.1 and 5.2. A discussion of time to damage is given in Section 5.3.

   3.1 Input data are as simple as reasonably achievable.

   3.2 Input data account for the probabilistic distribution of total energy release (TER). TER is significant for the potential to create a hazardous HGL and for determining the maximum ZOI.

3.3 Input data account for the probabilistic distribution of the peak HRR. The peak HRR influences HGL and ZOI.

3.4 Input data define the shape of the HRR curve—that is, how the fire grows and decays over time. This shape has a significant effect on the ZOI and the time to damage.

3.5 Input data define the size (through the fire Froude number) and location of the fire (distance off the floor). These influence the ZOI and HGL.

3.2 Weighting Test Data

The total testing data set that was used consists of 307 individual tests involving 110 fuel packages, which comprises the tests performed as part of this research effort [9] and the tests included as described in Sections 2.2.2, 2.2.3, and 2.2.4. One approach to developing model guidance would be to simply assign distributions based on the distributions of data in the individual tests. However, this approach would result in probabilistic distributions that consider each test as being an equally likely event. It would lack realism because the approach would not reflect the operating experience seen in the FEDB [16]. For example, there are multiple transient fire events in the FEDB involving a tarp but only one event with a plastic work cart. In developing distributions, it would not be appropriate to treat the fire tests involving a plastic work cart as being equally likely as the fire tests involving tarps. An approach was needed to weight the importance of each individual test and then use those weights to develop the modeling guidance.

The process of weighting test data consisted of the following four steps:

1. Assign each event from the FEDB into a fuel package category. A set of 28 categories derived from the test report was used. The result of this was a weighting of the relative occurrence of transient fires involving different types of fuels.
2. Assign each of the 110 fuel packages from testing to a fuel package category using the same list of categories from Step 1. This step linked the history of events from the FEDB to the data collected during testing.
3. Because there are more test fuel packages than categories, many categories had multiple test fuel packages assigned to them. This required an effort to define the relative importance of each fuel package within a category—that is, the likelihood that a transient fire in a specified fuel package category will involve a particular test fuel package.
4. Generate a per-individual test weight that combines the weights from Step 1 and Step 3 with the number of replicate tests for a specific test fuel package. For example, consider a FEDB fuel category with a Step 1 weight of 0.1 (that is, that fuel category represented 10% of the FEDB events) that had two test fuel packages assigned to that category in Step 2 that had equal relative importance (that is, both had Step 3 weights of 0.5). If both of those fuel packages had two replicate tests, each individual test would have a weight of 0.1 (Step 1) x 0.5 (Step 3) x 0.5 (1 of 2 tests) = 0.025 (FEDB weight x test item weight x test replicate weight). This final weight was used in developing the distributions (see Section 4) and detailed modeling method (see Section 5) for meeting the goals stated in Section 3.1.

3.2.1 Categorizing the FEDB Events (Step 1)

Typical event descriptions in the FEDB contain sparse details on the exact transient combustible involved in the fire event. Typically, a general description such as *cardboard boxes* is provided without significant detail on the specific amount or configuration of the fuel package. In examining the list of all FEDB transient events, provided in Appendix A of the test report [9], many of these general descriptions are seen multiple times. During test planning, these general descriptions were used to define 37 categories of fuels involved in transient fire events (that is, paper, cardboard, and so forth). This was done using all transient events (non-challenging [NC], potentially challenging [PC], and challenging [CH]) and served to aid in the selection of items to test. Some event descriptions did not fit a clear single category. These events were collected into an *Other* category. Events that lacked any meaningful descriptions were considered *Unknown* events.

The distributions developed in this report used a categorization of the subset of all transient events where the fire was CH or PC (139 events). This subset was chosen because the fire ignition frequency for transient events does not include events that were NC [2]. To maintain consistency with the testing effort, the list of categories based on all transient events was kept for use in developing the method presented in this report. Additionally, the 37 categories were reduced to 28 to reflect the items tested (for example, no paint coatings were tested, but there were NC events involving hot work and paint).

The categorization, Step 1, was performed by the project working group plus three additional persons (see Section 1.2). The three additional persons were all cognizant engineers operating out of different offices who have experience in performing FPRA walkdowns and fire modeling. Each was provided a spreadsheet containing the list of transient events from Appendix A of the test report [9]. A predefined list of the 28 categories was provided as a drop-down selection for each event. A note section in the spreadsheet provided some discussion on the definition of some of the categories. All were asked to pick the category that they believed best represented the event description. Responses were reviewed for consistency. In cases where events with similar descriptions were assigned different categories, a query was made to ensure that the intended selections were made. The final counts of the number of events in each category were then averaged over the four lists. *Unknown* events were then distributed proportionately among the other event categories. For example, if 10% of events were unknown, the number of events in all other categories was increased by 11% (1/0.9).

The result of this process, the average categorization after apportioning *Unknown* events, is shown in Table 3-1. Note that one of the 28 categories (oxy hose—that is, oxy-acetylene hose) did not have any PC or CH events. Table 3-1 lists the categories, the fraction of transient events each category represents, and the relative standard deviation in the voting for that category. Note that due to rounding Table 3-1 may not sum to 100%. For categories representing 3% or more of events (that is, at least four events), the relative standard deviation is 18% of the category weight and ranges from 8% to 35%. These events make up 80% of the operating experience. Below 3%, the relative standard deviation is 55%; however, because these categories consist of three events, single event differences in assigning events results in large deviations. The largest category of events, at 25.5%, is events involving power cords.

Table 3-1
Categorization of all PC or CH transient fire events in the FEDB

Category	Percent			Category	Percent		
Power cord	25.5%	±	4.7%	Cardboard	1.7%	±	0.3%
Other	13.2%	±	4.6%	Duct	1.5%	±	0.0%
Plastic	7.4%	±	1.7%	Vacuum	1.5%	±	0.5%
Trash	7.4%	±	0.4%	Blanket	1.3%	±	0.8%
Flammable liquid	6.8%	±	1.7%	Tool bag	1.1%	±	0.8%
Wood	5.5%	±	0.6%	Absorbent pad	0.8%	±	0.0%
Debris	5.1%	±	0.8%	Laptop+cart	0.8%	±	0.0%
Filter	4.9%	±	0.4%	Hose	0.6%	±	0.3%
Oily rag	3.0%	±	0.8%	Chair	0.4%	±	0.4%
Rag	3.0%	±	0.5%	PPE bag	0.4%	±	0.4%
Clothing	2.1%	±	1.0%	Mop	0.2%	±	0.3%
Tarp	2.1%	±	1.2%	Rope	0.2%	±	0.3%
Paper	1.9%	±	0.4%	Oxy hose	0.0%	±	0.0%
Tape	1.7%	±	0.3%				

The list of transient events provided in Appendix A of the test report [9] also indicates whether the events were due to hot work. This designation was used to split the number of events in each category into hot work (63) and non-hot work (76) events. The average percentage and deviations were recomputed. Tables 3-2 and 3-3, respectively, show the category percentages for hot work and non-hot work. Note that with the split there are a number of fuel categories that only appear in either hot work or non-hot work events. For example, there was only one Laptop+cart event, and it was a non-hot work event. For hot work events, there is no clearly dominant category. *Other*, *Filter*, and *Plastic* are the top three categories, and they range from 9% to 15% of all PC or CH events. For non-hot work fires, the *Power Cord* category is the dominant category at 40% of all PC or CH events.

Table 3-2
Categorization of all PC or CH hot work transient fire events in the FEDB

Category	Percent			Category	Percent		
Other	15.3%	±	1.1%	Tool bag	2.6%	±	1.9%
Filter	9.4%	±	0.9%	Paper	2.5%	±	0.8%
Plastic	8.5%	±	4.3%	Oily rag	1.7%	±	1.7%
Power cord	7.2%	±	2.2%	Cardboard	1.7%	±	0.0%
Rag	6.8%	±	1.2%	Hose	1.3%	±	0.7%
Debris	6.8%	±	1.2%	Chair	0.8%	±	0.8%
Trash	6.4%	±	0.8%	PPE bag	0.8%	±	0.8%
Flammable liquid	5.5%	±	2.2%	Absorbent pad	0.0%	±	0.0%
Wood	5.5%	±	0.7%	Laptop+cart	0.0%	±	0.0%
Tape	3.8%	±	0.8%	Mop	0.0%	±	0.0%
Tarp	3.8%	±	2.5%	Oxy hose	0.0%	±	0.0%
Duct	3.4%	±	0.0%	Rope	0.0%	±	0.0%
Clothing	3.0%	±	2.2%	Vacuum	0.0%	±	0.0%
Blanket	3.0%	±	1.8%				

Table 3-3
Categorization of all PC or CH non-hot work transient fire events in the FEDB

Category	Percent			Category	Percent		
Power cord	40.2%	±	6.8%	Paper	1.4%	±	0.0%
Other	11.5%	±	9.0%	Tarp	0.7%	±	0.7%
Trash	8.2%	±	0.1%	Mop	0.3%	±	0.6%
Flammable liquid	7.8%	±	2.1%	Rope	0.3%	±	0.6%
Plastic	6.5%	±	1.1%	Blanket	0.0%	±	0.0%
Wood	5.5%	±	1.0%	Chair	0.0%	±	0.0%
Oily rag	4.1%	±	0.0%	Duct	0.0%	±	0.0%
Debris	3.7%	±	0.6%	Hose	0.0%	±	0.0%
Vacuum	2.7%	±	0.9%	Oxy hose	0.0%	±	0.0%
Cardboard	1.7%	±	0.6%	PPE bag	0.0%	±	0.0%
Absorbent pad	1.4%	±	0.0%	Rag	0.0%	±	0.0%
Clothing	1.4%	±	0.0%	Tape	0.0%	±	0.0%
Filter	1.4%	±	0.0%	Tool bag	0.0%	±	0.0%
Laptop+cart	1.4%	±	0.0%				

The individual weighting votes corresponding to Tables 3-1 through 3-3 are shown respectively in Tables C-1 through C-3.

3.2.2 Assigning and Weighting Test Fuel Packages to FEDB Groups (Steps 2 and 3)

Assignment of the fuel packages to the FEDB groups, Step 2, was done by the working group and the same three individuals as in Section 3.2.1. Each was provided a spreadsheet containing a list describing all 110 test fuel packages and the range of peak HRRs seen during testing. A predefined list of the 27 categories (no *Unknown*) was provided as a drop-down selection for each package. After packages were assigned to categories, each individual then sorted the list by category and assigned weights to the packages within each category, Step 3. The instructions for this activity were to assign the weights based on their experiences and observations from walkdown activities as to the relative abundance of the test items in a fuel category. It was noted that, if they perceived the relative hazards of the packages in a category to be the same, it was acceptable to assign uniform weights.

The working group collated the four resulting lists and used them to develop a proposed list of assignments and weights to reconcile differences in the individual assignments. That list was then sent to the three individuals for concurrence. Concurrence was achieved with the first proposed list.

Table 3-4 shows the result of this activity. It lists each fuel category, the test items in each category, the weights assigned to each test item, the range of peak HRR for each test item, and the number of tests for each test item. The individual assessments are shown in Tables C-4 through C-7.

Table 3-4
Assignment of fuel packages to FEDB categories

Category	Test Fuel Package	Weight	Peak HRR (kW)	Number of Tests
Absorbent pad	Four oil pads	0.250	2.3–2.8	3
	Four oil pads with oil	0.250	2.7–3.2	2
	Single oil pad	0.250	3.2–3.6	3
	Single oil pad with oil	0.250	2.3–3.3	3
Blanket	Welding blanket draped	0.500	2.1–2.3	3
	Welding blanket folded	0.500	0.4–0.7	3
Cardboard	Large box empty	0.083	377–536	4
	Large box with paper	0.083	346–446	3
	Large box with packing peanuts	0.083	563–579	3
	Medium box empty	0.117	68–142	6
	Medium box with paper	0.117	55–85	3
	Medium box with packing peanuts	0.117	98–134	3
	Small box empty	0.100	28–50	4
	Small box with paper	0.100	43–50	3
	Small box with packing peanuts	0.100	52–71	3
	SNL—Nowlen Tests 5, 6	0.100	20–26	2

Table 3-4 (continued)
Assignment of fuel packages to FEDB categories

Category	Test Fuel Package	Weight	Peak HRR (kW)	Number of Tests
Chair	Lawson Test 51	0.300	33.6	1
	Lawson Test 56	0.300	85.5	1
	Metal chair	0.300	7.4–23	5
	Plastic chair	0.100	155–203	3
Clothing	NBS—Lee fabric	0.500	51.8	1
	Single PPE	0.500	17–26	3
Debris	Bucket with debris	0.500	7.2–15	3
	Debris pile	0.500	13–24	3
Duct	Blower duct	1.000	5.1–8.7	3
Filter	Heating, ventilation, and air conditioning (HVAC) filter	1.000	13–20	3
Flammable liquid	Alcohol bottle	0.500	143–211	3
	Oil bottle	0.500	1.7–2.5	3
Hose	Water hose	1.000	1.2–24	3
Laptop+cart	Laptop+cart	1.000	2214–2683	3
Mop	Mop+bucket	1.000	65–113	2
Oily rag	Five rags with heptane	0.333	30–51	6
	Rags with oil	0.333	10–11	2
	Single rag with heptane	0.333	9.1–12	4
Other	Laptop	0.167	4.2–18	3
	SNL—Nowlen Tests 1, 2	0.167	96–109	2
	SNL—Nowlen Tests 3, 4	0.167	32–143	2
	Tablet	0.167	13–22	3
	Tablet+metal case	0.167	9.1	1
	Tablet+plastic case	0.167	20–34	2
Oxy hose	Oxy-acetylene hose	1.000	1.7–3.2	2

Table 3-4 (continued)
Assignment of fuel packages to FEDB categories

Category	Test Fuel Package	Weight	Peak HRR (kW)	Number of Tests
Paper	Small binder closed	0.143	1.8	1
	Small binder open	0.143	6.0–11	2
	Large binder closed	0.143	0.1–1.2	3
	Large binder open	0.143	3.9–6.9	2
	Cardstock air	0.143	1.6–7.7	3
	Cardstock wall	0.143	0.5–1.4	3
	Pad of paper	0.143	1.3–1.8	3
Plastic	7.6 m coil chain	0.094	24–37	3
	7.6 m coil tubing	0.094	1.2–1.5	3
	Four cones	0.050	5.2–17	3
	15.2 m coil chain	0.050	1.1–29	5
	15.2 m coil tubing	0.050	1.3–1.7	3
	Empty bucket	0.094	11–31	4
	First aid kit	0.094	15–31	3
	Lift slings	0.094	16–19	3
	Plastic stanchion	0.094	47–67	3
	Single cone	0.094	6.0–9.5	3
	Uncoiled chain	0.094	1.1–1.3	3
	Uncoiled tubing	0.094	0.6–0.9	3
Power cord	3.0 m coil 120 V cord	0.167	1.2–1.5	3
	7.6 m coil 120 V cord	0.167	1.0–1.6	3
	7.6 m coil 250 V cord	0.167	0.8–1.2	3
	15.2 m coil 120 V cord	0.167	0.7–1.0	3
	Power spider	0.167	1.3–5.7	2
	Uncoiled 120 V cord	0.167	1	1

Table 3-4 (continued)
Assignment of fuel packages to FEDB categories

Category	Test Fuel Package	Weight	Peak HRR (kW)	Number of Tests
PPE bag	Scissor stand quarter	0.150	13–22	3
	Scissor stand full	0.200	109–181	3
	Scissor stand half	0.150	29–60	3
	Stack PPE	0.150	70–118	2
	WPI half bag	0.200	443–463	2
	WPI quarter bag	0.150	256–295	2
Rag	Five rags	0.333	7.5–14	4
	Bag of rags	0.333	4.0–6.3	3
	Single rag	0.333	2.6–4.7	4
Rope	7.6 m coil large rope	0.200	2.4–58	3
	7.6 m coil small rope	0.200	2.8–4.5	3
	15.2 m coil large rope	0.100	2.9–74	3
	15.2 m coil small rope	0.100	9.5–15	3
	Uncoiled large rope	0.200	2.7–3.2	3
	Uncoiled small rope	0.200	2.9–3.6	3
Tape	Long duct tape air	0.250	1.0–1.5	3
	Short duct tape air	0.250	0.5–0.8	2
	Duct tape roll	0.250	3.4–20	3
	Duct tape wall	0.250	0.3	1
Tarp	Canvas tarp draped	0.070	470–570	2
	Canvas tarp folded	0.070	2.5–12	4
	Fire-retardant plastic tarp draped	0.250	49–80	2
	Fire-retardant plastic tarp folded	0.250	79.8	1
	Plastic tarp draped	0.180	7.2–195	4
	Plastic tarp folded	0.180	2.9–60	3
Tool bag	Tool bag	1.000	51–56	2

Table 3-4 (continued)
Assignment of fuel packages to FEDB categories

Category	Test Fuel Package	Weight	Peak HRR (kW)	Number of Tests
Trash	LBL—Volkinburg one airline bag	0.025	136	1
	Metal trash quarter	0.150	75–95	3
	Metal trash full	0.150	61–81	3
	Metal trash full lid	0.350	16–21	2
	Metal trash half	0.150	83–87	3
	Plastic trash quarter	0.050	265–292	3
	Plastic trash full	0.025	181–273	3
	Plastic trash half	0.050	279–364	3
	SNL—Nowlen Tests 7, 8	0.025	11–24	2
	SNL—Nowlen Test 9	0.025	112	1
Vacuum	Vacuum closed	0.900	0.8–1.3	2
	Vacuum open	0.100	520–545	2
Wood	Pallet flame	0.167	2.1–2.5	2
	Pallet panel	0.167	0.2–1.4	3
	Plank flame	0.167	1.8–2.0	3
	Plank panel	0.167	0.7–1.1	3
	Wood block flame	0.167	0.7–1.1	5
	Wood block panel	0.167	1.3–1.7	3

3.2.3 Normalized Test Weights (Step 4)

The product of the category weight (Step 1) and the fuel package weight (Step 3) gives the fraction of FEDB events represented by that fuel package. For example, the *Clothing* category has an event fraction of 2.1% and the single personal protective equipment (PPE) fuel package has a fuel package weight of 0.5; therefore, the single PPE fuel package represents 0.0207 x 0.5 = 1.04% of transient events. The final weighting step, Step 4, is to assign a weight to each individual test. Because there were three tests of the single PPE fuel package, each test has a weight of 1.04% / 3 = 0.347%. Following this process, each individual test was assigned a weight.

The individual test weights were used to develop probabilistic distributions and modeling guidance. To develop a non-generic distribution for a subset of the fuel packages, the test weights must be renormalized so that the sum of all of the individual package weights sum to 1. The final normalized weights for each fuel package and the number of tests for that fuel package are shown in Table 3-5. The list is in descending order of weight starting in the left column and wrapping to the right column. Note that the oxy-acetylene hose package has a weight of zero because there were no PC or CH FEDB events for that fuel package.

Table 3-5
Final normalized test weights for the generic transient fire distributions

Fuel Package	Per Test Weight	Number of Tests	Fuel Package	Per Test Weight	Number of Tests
Uncoiled 120 V cord	4.25E-02	1	Wood block flame	1.83E-03	5
Tablet+metal case	2.21E-02	1	Empty bucket	1.74E-03	4
Power spider	2.13E-02	2	Five rags with heptane	1.68E-03	6
HVAC filter	1.64E-02	3	Duct tape roll	1.42E-03	3
3.0 m coil 120 V cord	1.42E-02	3	Long duct tape air	1.42E-03	3
15.2 m coil 120 V cord	1.42E-02	3	Large binder open	1.35E-03	2
7.6 m coil 120 V cord	1.42E-02	3	Small binder open	1.35E-03	2
7.6 m coil 250 V cord	1.42E-02	3	Plastic tarp folded	1.25E-03	3
Metal trash full lid	1.29E-02	2	15.2 m coil tubing	1.23E-03	3
Alcohol bottle	1.13E-02	3	Four cones	1.23E-03	3
Oil bottle	1.13E-02	3	Plastic trash quarter	1.23E-03	3
SNL—Nowlen Tests 1, 2	1.10E-02	2	Plastic trash half	1.23E-03	3
SNL—Nowlen Tests 3, 4	1.10E-02	2	Lawson Test 51	1.13E-03	1
Tablet+plastic case	1.10E-02	2	Lawson Test 56	1.13E-03	1
NBS—Lee fabric	1.04E-02	1	Four oil pads with oil	9.45E-04	2
Bucket with debris	8.51E-03	3	Mop+bucket	9.45E-04	2
Debris pile	8.51E-03	3	Plastic tarp draped	9.36E-04	4
Laptop	7.35E-03	3	SNL—Nowlen Tests 7, 8	9.22E-04	2
Tablet	7.35E-03	3	Cardstock air	9.00E-04	3
Vacuum closed	6.81E-03	2	Cardstock wall	9.00E-04	3
Tool bag	5.67E-03	2	Large binder closed	9.00E-04	3
Fire-retardant plastic tarp folded	5.20E-03	1	Pad of paper	9.00E-04	3
Blower duct	5.04E-03	3	SNL—Nowlen Tests 5, 6	8.51E-04	2
Rags with oil	5.04E-03	2	Vacuum open	7.56E-04	2
Pallet flame	4.57E-03	2	15.2 m coil chain	7.37E-04	5
Duct tape wall	4.25E-03	1	Canvas tarp draped	7.28E-04	2
Metal trash quarter	3.69E-03	3	Medium box with paper	6.62E-04	3
Metal trash full	3.69E-03	3	Medium box with peanuts	6.62E-04	3

Table 3-5 (continued)
Final normalized test weights for the generic transient fire distributions

Fuel Package	Per Test Weight	Number of Tests	Fuel Package	Per Test Weight	Number of Tests
Metal trash half	3.69E-03	3	Four oil pads	6.30E-04	3
Single PPE	3.47E-03	3	Single oil pad	6.30E-04	3
Bag of rags	3.36E-03	3	Single oil pad with oil	6.30E-04	3
Pallet panel	3.05E-03	3	Plastic trash full	6.14E-04	3
Plank flame	3.05E-03	3	Small box with paper	5.67E-04	3
Plank panel	3.05E-03	3	Small box with peanuts	5.67E-04	3
Wood block panel	3.05E-03	3	Large box with paper	4.73E-04	3
Small binder closed	2.70E-03	1	Large box with peanuts	4.73E-04	3
Fire-retardant plastic tarp draped	2.60E-03	2	Small box empty	4.25E-04	4
Five rags	2.52E-03	4	WPI half bag	3.78E-04	2
Laptop+cart	2.52E-03	3	Canvas tarp folded	3.64E-04	4
Single rag	2.52E-03	4	Large box empty	3.54E-04	4
Single rag with heptane	2.52E-03	4	Medium box empty	3.31E-04	6
7.6 m coil chain	2.32E-03	3	Stack PPE	2.84E-04	2
7.6 m coil tubing	2.32E-03	3	WPI quarter bag	2.84E-04	2
First aid kit	2.32E-03	3	Scissor stand full	2.52E-04	3
Lift slings	2.32E-03	3	Metal chair	2.27E-04	5
Plastic stanchion	2.32E-03	3	Scissor stand empty	1.89E-04	3
Single cone	2.32E-03	3	Scissor stand half	1.89E-04	3
Uncoiled chain	2.32E-03	3	7.6 m coil large rope	1.26E-04	3
Uncoiled tubing	2.32E-03	3	7.6 m coil small rope	1.26E-04	3
Welding blanket draped	2.21E-03	3	Plastic chair	1.26E-04	3
Welding blanket folded	2.21E-03	3	Uncoiled large rope	1.26E-04	3
Short duct tape air	2.13E-03	2	Uncoiled small rope	1.26E-04	3
Water hose	1.89E-03	3	15.2 m coil large rope	6.30E-05	3
LBL—Volkinburg one airline bag	1.84E-03	1	15.2 m coil small rope	6.30E-05	3
SNL—Nowlen Test 9	1.84E-03	1	Oxy-acetylene hose	0.00E+00	2

3.3 Probabilistic Distributions and Detailed Fire Modeling Input Data

This section describes how the test data were processed using the individual test weights to create probabilistic distributions of the peak HRR, TER, and ZOIs. These distributions formed the basis for developing input data for detailed fire modeling.

3.3.1 Classes of Distributions

Two classes of distributions were created. The first class is a set of generic transient fire distributions intended as an improved realism replacement for the distribution in Appendix G of NUREG/CR-6850 [1]. This class is referred to as the *generic transient fire distribution*. The second class is a set of generic transient fire distributions intended for use in transient combustible control locations (TCCLs). This class is referred to as the *TCCL transient fire distribution*. It recognizes that the use of a lower peak HRR has been allowed in some National Fire Protection Association (NFPA) 805 license amendments in plant areas where there are strict controls on transient combustibles. The definition and selection of fuel packages for this distribution is provided in Section 3.3.1.1.

3.3.1.1 Definition of TCCL

Because there is not a standard industrywide definition or terminology for defining plant locations where there are enhanced controls over transient combustibles, the working group developed a specific terminology and definition. This definition was developed using information from FAQ 12-0064 Hot Work/Transient Fire Frequency Influencing Factors [10], FAQ 14-0007 Transient Fire Frequency Likelihood [11], NUREG/CR-6850 [1], NUREG/CR-6850 Supplement 1 [14], NFPA 805 Request for Additional Information responses for using transient fire peak HRRs under 317 kW [24–27], Generic Letter 86-10 [28], and IMC 0609 Appendix F [29]. The terminology and definition are as follows:

A *transient combustible control location (TCCL)* is a designated location in a nuclear power plant (NPP) that meets the conditions provided in this section of the report. The location may be a physical analysis unit (PAU) or fire compartment, a single room within a PAU, or a well-defined floor space within a PAU. It is acknowledged that the term used for a *TCCL* may vary by NPP. Multiple locations can be defined as TCCLs. Regardless of the term that is used, the important factor is that the location meets the following conditions:

1. Control of transient combustible materials in these locations must be procedurally controlled with visual indication clearly marked (for example, floor is painted, the location is roped off or identified with multiple signs, or other method of clearly marking the area) so that someone unfamiliar with the administrative procedures would conclude that transient combustible storage is strictly controlled in that location.
2. No trend of violations of transient combustible administrative controls, for the subject TCCL (that if modeled, would have a measurable impact on the FPRA), have been observed for a reasonable prior period (that is, five years). A measurable impact implies a violation that lies above the hazard represented by the 98th percentile of the TCCL distribution (see Table 4-4).
3. Long-term storage of transient combustible material is strictly prohibited with no exceptions.
4. Temporary storage of transient combustible material is strictly controlled with appropriate compensatory measures for exceptions, as necessary. Any combustible material that is greater than negligible (see Note 1) and required to be in a TCCL must meet one of the following:
   4.1 Have a transient combustible permit evaluated by the fire protection program to show that there is no impact to credited equipment and cables (see Notes 2 and 3).

4.2 Be constantly attended. Exceptions are allowed for shift changes and short breaks such as a lunch break.

4.3 Be removed from the TCCL or contained (for example, closed metal containers, covered by fire blanket) when not constantly attended.

Note 1: Negligible combustibles would include small isolated items (that is, less than 0.5 kg [1 lb] of solid material).

Note 2: With no exceptions, flammable and combustible liquids cannot be left unattended in a TCCL.

Note 3: Temporary structures consisting at least in part of combustible materials (for example, wooden scaffolding) are not built, stored, or moved into the TCCL, without analysis and any necessary compensatory measures, as determined by a transient combustible permit evaluation.

3.3.1.2 Selection of Test Data for the TCCL Transient Fire Distribution

Using the definition of a TCCL provided in Section 3.3.1.1, the working group culled the list of test items to remove those items believed to be highly unlikely to be present in a TCCL. This was done by two rounds of selection. In the first round, members of the working group individually marked a list of test items to indicate which items would not be in a TCCL. The results were collected, tallied, and presented to the working group. The working group then undertook a second round of individually marking the list. After the second round, there were only a handful of items where a supermajority did not concur that the item should be either excluded or included in the list of fuels potentially present in a TCCL. These items were discussed by the working group to reach a consensus on their status. The resulting list of items removed is shown in Table 3-6. The results of the two rounds of selection are shown in Appendix C. When using the shortened list of test items to develop distributions, the relative test item weights were maintained and renormalized. For example, if one test item from a fuel category with three equally weighted test items (that is, all weighted one-third) was removed, the other two items had their weights scaled up to one-half. Table 3-7 contains the normalized test weights that result from removing the items in Table 3-6.

Table 3-6
Test items removed from TCCL transient fire distribution

Fuel Package	HRR Range (kW)	Fuel Package	HRR Range (kW)
Four cones	5.2–17	Pallet flame	2.1–2.5
Four oil pads	2.3–2.8	Pallet panel	0.2–1.4
Four oil pads with oil	2.7–3.2	Plank flame	1.8–2.0
Five rags with heptane	30–51	Plank panel	0.7–1.1
Canvas tarp draped	470–570	Plastic chair	155–203
Debris pile	13–24	Plastic tarp draped	7.2–195
Fire-retardant plastic tarp draped	49–80	Plastic trash full	181–273
Laptop	4.2–18	Plastic trash half	279–364
Laptop+cart	2214–2683	Plastic trash quarter	265–292
Large box empty	377–536	Scissor stand full	109–181
Large box with paper	346–446	Scissor stand half	29–60
Large box with peanuts	563–579	Scissor stand quarter	13–22
Lawson Test 51	33.6	SNL—Nowlen Tests 7, 8	11–24
LBL—Volkinburg one airline bag	136	SNL—Nowlen Test 9	112
Metal trash full	61–81	Stack PPE	70–118
Metal trash full lid	16–21	Vacuum open	520–545
Metal trash half	83–87	Welding blanket draped	2.1–2.3
Metal trash quarter	75–95	WPI half bag	443–463
Oxy-acetylene hose	1.7–3.2	WPI quarter bag	256–295

Table 3-7
Final normalized test weights for the TCCL transient fire distributions

Fuel Package	Per Test Weight	Number of Tests	Fuel Package	Per Test Weight	Number of Tests
Uncoiled 120 V cord	4.65E-02	1	Plastic stanchion	2.67E-03	3
Tablet+metal case	2.89E-02	1	Single cone	2.67E-03	3
Power spider	2.32E-02	2	Uncoiled chain	2.67E-03	3
Bucket with debris	1.86E-02	3	Uncoiled tubing	2.67E-03	3
HVAC filter	1.79E-02	3	Short duct tape air	2.32E-03	2
15.2 m coil 120 V cord	1.55E-02	3	Lawson Test 56	2.07E-03	1
3.0 m coil 120 V cord	1.55E-02	3	Water hose	2.07E-03	3
7.6 m coil 120 V cord	1.55E-02	3	Empty bucket	2.00E-03	4
7.6 m coil 250 V cord	1.55E-02	3	Duct tape roll	1.55E-03	3
SNL—Nowlen Tests 1, 2	1.45E-02	2	Long duct tape air	1.55E-03	3
SNL—Nowlen Tests 3, 4	1.45E-02	2	Large binder open	1.48E-03	2
Tablet+plastic case	1.45E-02	2	Small binder open	1.48E-03	2
Alcohol bottle	1.24E-02	3	15.2 m coil tubing	1.41E-03	3
Oil bottle	1.24E-02	3	Single oil pad	1.38E-03	3
Fire-retardant plastic tarp folded	1.14E-02	1	Single oil pad with oil	1.38E-03	3
NBS—Lee fabric	1.14E-02	1	SNL—Nowlen Tests 5, 6	1.24E-03	2
Wood block panel	9.99E-03	3	Mop+bucket	1.03E-03	2
Tablet	9.64E-03	3	Cardstock air	9.84E-04	3
Rags with oil	8.26E-03	2	Cardstock wall	9.84E-04	3
Vacuum closed	8.26E-03	2	Large binder closed	9.84E-04	3
Tool bag	6.20E-03	2	Pad of paper	9.84E-04	3
Wood block flame	5.99E-03	5	Medium box with paper	9.64E-04	3
Blower duct	5.51E-03	3	Medium box with peanuts	9.64E-04	3
Welding blanket folded	4.82E-03	3	15.2 m coil chain	8.48E-04	5
Duct tape wall	4.65E-03	1	Small box with paper	8.26E-04	3
Single rag with heptane	4.13E-03	4	Small box with peanuts	8.26E-04	3
Single PPE	3.79E-03	3	Canvas tarp folded	7.95E-04	4
Bag of rags	3.67E-03	3	Small box empty	6.20E-04	4

Table 3-7 (continued)
Final normalized test weights for the TCCL transient fire distributions

Fuel Package	Per Test Weight	Number of Tests	Fuel Package	Per Test Weight	Number of Tests
Small binder closed	2.95E-03	1	Medium box empty	4.82E-04	6
Five rags	2.76E-03	4	Metal chair	4.13E-04	5
Single rag	2.76E-03	4	7.6 m coil large rope	1.38E-04	3
Plastic tarp folded	2.73E-03	3	7.6 m coil small rope	1.38E-04	3
7.6 m coil chain	2.67E-03	3	Uncoiled large rope	1.38E-04	3
7.6 m coil tubing	2.67E-03	3	Uncoiled small rope	1.38E-04	3
First aid kit	2.67E-03	3	15.2 m coil large rope	6.89E-05	3
Lift slings	2.67E-03	3	15.2 m coil small rope	6.89E-05	3

3.3.2 Method for Creating Probabilistic Distributions

Probabilistic distributions were created for the peak HRR, the TER, and the ZOIs. This was done by using the runtime interpreted computer language R, which was developed for performing statistical analysis [30], and Microsoft Excel. A table of integer weighting factors, peak HRR, TER, and ZOIs was saved as a comma separated value (CSV) file. The integer weighting factor was the real number weight value from Table 3-5 or Table 3-7 converted to an integer by scaling it. The scaling factor was selected to convert the smallest real number weight to 10—that is, if the smallest weight in a table is y, the weight x was converted to an integer as Int(10 x / y). R was used to expand the table of test data using the integer test weights and the *rep* function. The *rep* function takes as input a two-column array of data and outputs a vector of the number in the first column repeated by the number in the second column. An example is shown in Figure 3-1.

$$\begin{vmatrix} 1 & 2 \\ 3 & 4 \\ 4 & 1 \end{vmatrix} \underset{rep}{\rightarrow} \{1,1,3,3,3,3,4\}$$

Figure 3-1
Example of R rep function

Expanded vectors of data were created for the peak HRR, the TER, and each of the ZOIs. The R *ecdf* command was then used to create an empirical cumulative probability distribution function for each vector of expanded test data. This function was then evaluated using each unique data point in the data set (that is, if the expanded HRR vector was 1.01, 1.01, 1.01, 2.02, 3.03, 3.03, the empirical function would be evaluated at 1.01, 2.02, and 3.03). The results were written for each quantity to a two-column CSV file where the first column is the list of unique HRR, TER, or ZOI values and the second column is the empirical function outputs for those values. One CSV file was written for each of the HRR, the TER, and the individual ZOIs. These files were read into Excel where functions evaluated the location of the 50th and 98th percentiles. The Excel solver function was then used to fit a gamma distribution that minimized the least square relative error to the 50th and 98th percentiles for each parameter. A gamma distribution was selected for consistency with other HRR distributions used in FPRA, such as the distributions for electrical cabinets [3].

The R commands used are provided in Appendix B.

3.3.3 Method for Creating Detailed Fire Modeling Parameters

Detailed fire modeling parameters refers to data needed as inputs to correlations (for example, the Fire Dynamics Tools [31], zone models (for example, Consolidated Model of Fire Growth and Transport (CFAST) [32, 33]) or field models (for example, Fire Dynamics Simulator (FDS) [34, 35]). These modeling parameters include the heat of combustion, the fire Froude number (Q^*), the yields of minor products of combustion, the elevation of the fire, and the time-dependent HRR. Not all tests have the full set of data available for them. Therefore, for these parameters, individual CSV files were created for each parameter (or group of parameters in the case of characterizing fire growth and decay).

For the heat of combustion (ΔH_c), soot and CO product yields (y_s and y_{CO}), and the source height (z_e), individual CSV files were created for each parameter and its integer weights. The data were scaled to a minimum integer weighting factor of 1. R was then used to expand the data set and generate empirical cumulative distribution functions. This was limited to fires with HRRs greater than 10 kW. Below 10 kW, the ignition source often provides a significant contribution to the HRR measured in the test, the relative errors in yields and the heat of combustion are generally larger due to measurement noise and load cell measurement uncertainty, and the small ZOI associated with small fires significantly limits their overall contribution to risk. The empirical distribution functions, along with the expanded data, were exported to CSV files and used to develop recommended values for use in detailed fire modeling.

The R commands used are provided in Appendix B.

4 PROBABILISTIC DISTRIBUTIONS FOR PEAK HRR, TER, AND ZOI

This section of the report contains the recommended distributions of peak heat release rate (HRR), total energy release (TER), and zones of influence (ZOIs) for generic transient fires and transient combustible control location (TCCL) transient fires. ZOI distributions were developed for the horizontal (heat flux) ZOI, vertical (plume temperature) ZOI, and vertical in a corner ZOI for exposed sensitive electronics (SE), thermoplastic (TP) cable, Kerite-FR cable (KC), thermoset (TS) cable, and bulk cable tray ignition (TI).

The method for determining the ZOI values is detailed in the test report [9]. In brief, this method used the time-dependent HRR data for each test as inputs to the Fire Dynamics Tools [31] for plume temperature (McCaffery plume temperature correlation [31]) and radiative flux (solid flame model [4]). For each test HRR curve, the vertical (plume) or radial (heat flux) distance from the fire was changed in 5 cm increments until the threshold between target damage and no target damage was located. Target damage was assessed using a heat soak method [4]. Because the search process used 5 cm (2 in.) increments, this meant that the minimum ZOI value was 5 cm (that is, if a target was not damaged at a distance of 5 cm (2 in.), the search process was ended, and 5 cm (2 in.) was considered to be the ZOI. For the vertical ZOI, the ZOI distance is measured from the base of the fire (that is, it does not account for any vertical elevation of the base of the fire above the floor of the room). For the horizontal ZOI, the distance is measured from the edge of the fire. For some categories (TS and TI), almost all of the computed horizontal ZOI values were 5 cm (2 in.). As a result, for these categories the gamma distribution does not provide a good visual fit to the data. There should be little impact on risk assessment associated with this. It just means that a transient fire must essentially be in direct contact with the target for that category.

The ZOIs developed in this report are subject to limitations in their applicability. These limitations include the following:

- The compartment is initially at a room temperature below the limits for long-term human habitability (<40°C [104°F]).
- The target is either below the hot gas layer (HGL), or the HGL temperature does not exceed the room temperature limit stated previously.
- The target is not within the ceiling jet of a fire.
- The target or fire is not subject to ventilation effects that might increase the ZOI. This is mostly relevant for horizontal targets where cross ventilation might result in flame lean. Note, typically cross ventilation below a threshold of 1 m/s at the fire is considered insignificant [36].
- The fire being modeled is either a generic transient fire or a TCCL transient fire using the full modeling methodology in this report. For applications where a specific, known fuel package is being evaluated, the time-dependent HRR and related modeling inputs should be developed based on the specifics of that fuel package. Data from specific similar fuel packages in the test report [9] may be applicable in this case.

4.1 Generic Transient Fire Distribution

Table 4-1 shows the generic transient fire distributions developed using the final normalized weighting values in Table 3-5. Plots of the probability density functions, cumulative distribution functions, and probability-probability (P-P) for each item in Table 4-1 are shown in Appendix D. A P-P plot shows the theoretical (in this case the gamma distribution fit) cumulative probability of a distribution value plotted against the empirical (in this case the weighted test data) cumulative probability. Perfectly matched distributions would be a diagonal line. In general, the P-P plots show that the distribution is well matched or conservative for values between the 50th and 98th percentile (the plot is to the right of the diagonal line) and nonconservative for values below the 50th percentile. However, the 50th percentile fire is below 10 kW, which is not a fire with significant risk.

Table 4-1
Generic transient fire distributions of peak HRR, TER, and ZOI

Distribution		Distribution Percentiles		Gamma Distribution Parameters	
		75th	98th	α	β
HRR (kW)		41.6	278	0.271	141
TER (MJ)		11.8	123	0.184	77.1
Vertical ZOI (m)	SE	1.90	5.49	0.954	1.44
	TP	0.56	1.78	0.768	0.525
	KC	0.53	1.64	0.814	0.470
	TS	0.45	1.47	0.748	0.439
	TI	0.41	1.33	0.760	0.395
Vertical in a corner ZOI (m)	SE	3.27	9.47	0.943	2.50
	TP	0.99	2.96	0.872	0.816
	KC	0.91	2.74	0.873	0.754
	TS	0.79	2.43	0.829	0.687
	TI	0.71	2.18	0.827	0.618
Horizontal ZOI (m)	SE	0.21	1.05	0.374	0.450
	TP	0.09	0.36	0.501	0.132
	KC	0.07	0.22	0.723	0.0666
	TS	0.05	0.11	1.42	0.0233
	TI	0.03	0.05	7.63	0.00345

The following are some observations on the results:

- The 98th percentile peak HRR value is 278 kW. This is a small reduction below the 317 kW value in NUREG/CR-6850 [1]; however, the 75th percentile peak HRR value of 42 kW is significantly below the 142 kW value in NUREG/CR-6850.
- The 98th percentile vertical ZOI for TP is 1.78 m (5.8 ft). A typical tray configuration is horizontal cable trays running 0.3–0.6 m (1–2 ft) above 1.8–2.1 m (6–7 ft) tall electrical cabinets. This means that trays at 2.1–2.7 m (7–9 ft) above the floor are not in the transient ZOI provided that the base of the fire is less than 0.3 m (1 ft) above the floor. As covered in Section 5.2, a conservative ignition source location is 0.15 m (6 in.) above the floor. This means cable targets that are not in a corner and that an average person can walk under can be screened. Exposed SE will not screen at that height.
- Although 98th percentile fires in a corner will not screen for cable targets at head height, at the 75th percentile all head height cable targets will screen. Exposed SE will not screen at that height for fires in a corner.
- For the horizontal ZOI component, a transient fire will need to be less than 0.36 m (1.2 ft) from a target to damage cables and essentially in direct contact with a cable, <5 cm (2 in.) to cause sustained ignition.
- To damage SE in a cabinet according to FAQ 13-0004 [12] (that is, the SE are not exposed and can be treated as TS), the fire will need to be within 11 cm (4 in.) of the cabinet.
- Even in a relatively small compartment (3 m [10 ft] on a side), a 278 kW transient fire releasing 123 MJ of total energy would not result in a damaging HGL without the involvement of secondary combustibles.

4.1.1 Sensitivity of Generic Transient Distributions to Event Type

The values in Table 3-5 were adjusted to use the category weights for hot work only (see Table 3-2) and non-hot work only (see Table 3-3) events. For categories where no events were seen, such as laptop+cart for hot-work only events, the category weight was adjusted to represent one-half the lowest category weight present. This was done to recognize that even though a specific category may not have been seen yet in operational experience, that specific category cannot be ruled out as a possible event. The exception was the blankets category representing welding blanket events, which was not adjusted for non-hot work.

Table 4-2 compares the 75th and 98th percentile values for the hot work only and non-hot work only distributions against the generic distribution. The hot work only distribution is slightly less severe than the generic distribution. The 98th percentile TER is one-third less, and the vertical ZOI values are 7–10% lower. The non-hot work only distribution is somewhat more severe than the generic distribution. The 98th percentile TER is one-third more, and the vertical ZOI values are 11–17% higher. However, from a risk perspective these differences are minor. Head height trays not in a corner still screen at the 98th percentile, head height trays in a corner still screen at the 75th percentile, a damaging HGL will still not occur without secondary combustibles, and the horizontal cable damage and ignition distances change by only a small distance. Based on these observations, the event specific distributions are not significantly different from the generic distribution from a risk perspective. Therefore, only the generic distribution was fully developed in the remainder of this report, and it is the recommended distribution to use for modeling both hot work and non-hot work events.

Table 4-2
Distributions of peak HRR, TER, and ZOI for hot work only or non-hot work only transient events

Distribution		Generic Distribution		Hot Work Only Distribution		Non-Hot Work Only Distribution	
		75th	98th	75th	98th	75th	98th
HRR (kW)		41.6	278	50.9	260	33.0	410
TER (MJ)		11.8	123	13.4	81.5	10.3	158
Vertical ZOI (m)	SE	1.90	5.49	1.99	5.14	1.78	6.16
	TP	0.56	1.78	0.58	1.63	0.55	1.98
	KC	0.53	1.64	0.56	1.53	0.51	1.89
	TS	0.45	1.47	0.48	1.33	0.46	1.67
	TI	0.41	1.33	0.43	1.24	0.41	1.56
Vertical in a corner ZOI (m)	SE	3.27	9.47	3.48	8.85	3.09	10.67
	TP	0.99	2.96	1.00	2.68	0.98	3.37
	KC	0.91	2.74	0.94	2.55	0.91	3.19
	TS	0.79	2.43	0.82	2.22	0.80	2.81
	TI	0.71	2.18	0.73	2.10	0.73	2.57
Horizontal ZOI (m)	SE	0.21	1.05	0.25	0.98	0.21	1.24
	TP	0.09	0.36	0.07	0.22	0.09	0.42
	KC	0.07	0.22	0.06	0.15	0.08	0.31
	TS	0.05	0.11	0.04	0.09	0.06	0.17
	TI	0.03	0.05	0.03	0.05	0.03	0.05

4.1.2 Sensitivity of Generic Transient Distributions to Category and Fuel Package Weightings

As covered in Section 3.2, there were four sets of EPRI FEDB category weights, fuel package category allocations, and fuel package category weights created that were then combined into a single set. A set of distributions was created for each independent effort to evaluate the sensitivity of the distributions to the weighting process. To assess this sensitivity, the independent efforts were processed into distributions with a summary of the results shown in Table 4-3. The HRR deviation from the generic distribution is 38% at the 98th percentile and 17% at the 75th percentile. The deviation in TER is 46% and 8.5%. Although 46% is a substantial deviation, the worst distribution of 510 kW and 194 MJ would not result in a TP damaging hot layer in a small (27 m^3) room. Vertical ZOIs have a deviation of 11–15% at the 98th percentile and 4–8% at the 75th percentile. In all cases, TP cable trays above head height for a fire not in a corner would screen. Horizontal ZOIs have larger percentage deviations;

however, the range for TP is 22–42 cm versus 36 cm for the generic distribution. In actual distance, the deviation is small. For the third independent assessor, the reason for the large HRR is primarily that the open vacuum (shop vacuum containing a debris mixture with the top removed) fuel package was considered to be equally likely to the closed vacuum fuel package. Because vacuum events are 2.2% of transient fire events, this made the open top tests with peak HRRs of over 500 kW 1.1% of the distribution. Combined with a 0.22% weight assigned to the large cardboard boxes (over 500 kW) and 0.75% for the laptop+cart fuel package (over 2 MW), this resulted in 500 kW fires sitting at the 98th percentile. This was the only individual to put such a high weight on the open vacuum. For the fourth independent assessor, equal weight was applied to all of the fuels in the tarp category compared with the consensus where the non-fire-retardant canvas tarps were considered less likely than the plastic or plastic fire-retardant tarps. Additionally, the fourth assessment had tarps at 3% of transient fire events versus 2% in the consensus distribution. Combined with slightly higher weights for the large cardboard tests, this pushed the 98th percentile peak HRR up to over 400 kW.

Table 4-3
Distributions of Peak HRR, TER, and ZOI for the individual assessments detailed in Appendix C.2

Distribution		Generic Distribution		1		2		3		4	
		75th	98th	75th	98th	75th	98th	75th	98th	75th	98th
HRR (kW)		41.6	278	51.7	268	32.8	269	58.2	510	47.1	438
TER (MJ)		11.8	123	14.2	81.6	12.1	152	15.7	194	12.9	164
Vertical ZOI (m)	SE	1.90	5.49	2.13	5.12	1.81	5.45	2.21	7.32	1.98	6.21
	TP	0.56	1.78	0.64	1.64	0.54	1.76	0.63	2.13	0.58	1.98
	KC	0.53	1.64	0.59	1.55	0.51	1.63	0.59	2.02	0.55	1.90
	TS	0.45	1.47	0.51	1.34	0.44	1.47	0.51	1.76	0.47	1.66
	TI	0.41	1.33	0.45	1.25	0.40	1.31	0.47	1.66	0.43	1.53
Vertical in a corner ZOI (m)	SE	3.27	9.47	3.65	8.80	3.21	9.40	3.78	12.51	3.44	10.71
	TP	0.99	2.96	1.08	2.70	0.95	2.98	1.09	3.52	1.02	3.37
	KC	0.91	2.74	0.99	2.58	0.87	2.78	1.03	3.33	1.03	3.33
	TS	0.79	2.43	0.85	2.26	0.76	2.43	0.89	2.90	0.82	2.77
	TI	0.71	2.18	0.77	2.13	0.69	2.16	0.80	2.71	0.75	2.53
Horizontal ZOI (m)	SE	0.21	1.05	0.26	0.97	0.19	1.02	0.26	1.53	0.21	1.25
	TP	0.09	0.36	0.07	0.20	0.09	0.38	0.10	0.48	0.10	0.43
	KC	0.07	0.22	0.06	0.15	0.07	0.24	0.08	0.34	0.08	0.31
	TS	0.05	0.11	0.04	0.09	0.05	0.11	0.06	0.19	0.06	0.17
	TI	0.03	0.05	0.03	0.05	0.03	0.05	0.03	0.05	0.03	0.05

4.2 TCCL Transient Fire Distribution

Table 4-4 shows the TCCL transient fire distributions developed using the final normalized weighting values in Table 3-7. Plots of the probability density functions, cumulative distribution functions, and P-P for each item in Table 4-4 are shown in Appendix D. A P-P plot shows the theoretical (in this case the gamma distribution fit) cumulative probability of a distribution value plotted against the empirical (in this case the weighted test data) cumulative probability. Perfectly matched distributions would be a diagonal line. In general, the P-P plots show that the distribution is well matched or conservative for values between the 50th and 98th percentiles (the plot is to the right of the diagonal line) and nonconservative for values below the 50th percentile. However, the 50th percentile fire is under 5 kW, which is not a fire with significant risk.

Compared with the generic transient fire distribution, the TCCL distribution has approximately a 50% reduction in peak HRR and TER and 35–50% reductions in ZOI at the 98th percentile. At the 75th percentile, the respective values are 40% and 24–32%.

Table 4-4
TCCL transient fire distributions of Peak HRR, TER, and ZOI

Distribution		Distribution Percentiles		Gamma Distribution Parameters	
		75th	98th	α	β
HRR (kW)		24.6	143	0.314	67.3
TER (MJ)		7.0	59.9	0.214	34.5
Vertical ZOI (m)	SE	1.44	3.26	1.76	0.604
	TP	0.40	1.00	1.33	0.218
	KC	0.38	0.94	1.36	0.203
	TS	0.32	0.80	1.36	0.173
	TI	0.29	0.76	1.25	0.171
Vertical in a corner ZOI (m)	SE	2.54	5.64	1.86	1.01
	TP	0.71	1.69	1.53	0.34
	KC	0.66	1.59	1.47	0.328
	TS	0.57	1.40	1.43	0.292
	TI	0.52	1.26	1.44	0.263
Horizontal ZOI (m)	SE	0.15	0.68	0.43	0.273
	TP	0.06	0.17	0.977	0.0442
	KC	0.05	0.10	1.93	0.0175
	TS	0.03	0.05	7.63	0.00343
	TI	0.03	0.05	7.63	0.00342

It is noted that some plants have used a value of 69 kW as the 98th percentile peak HRR in areas with increased combustible controls. This is half of the 143 kW value shown in Table 4-4. It might seem that this means the new TCCL distribution is more severe than prior approaches. However, it should be recognized that typical prior approaches for modeling transient fires generally used long plateaus at the peak HRR. A 69 kW fire with a long plateau would have a vertical TP ZOI of approximately 1.5 m vs. 1.0 m in Table 4-4. Therefore, using the new ZOIs in Table 4-4 should provide improvement even for plants that previously used 69 kW for transient fires.

5
DETAILED FIRE MODELING GUIDANCE

This section develops guidance for the detailed modeling of transient fires—that is, time-dependent modeling of a fire for evaluating time to damage, hot gas layer (HGL), or severity factor (SF) using Equation 2-4. In plots showing data from individual tests, the plots contain expanded test data. That is, each point on the plot represents a single test; however, that test is plotted as multiple collocated points based on the integer weighting factor covered in Section 3.3.3. Any curve fit displayed in a plot is also based upon the expanded data set.

5.1 Transient Fire Bins for Non-Suppression Probability

Table E-9 of NUREG/CR-6850 contains a 15-bin discretization of the transient fire heat release rate (HRR) distribution for computing the SF of unscreened targets (targets that do not screen at the 98th percentile during Task 8 of NUREG/CR-6850). With the new distributions developed in Sections 4.1 and 4.2, these bins are no longer well suited for computing the SF, and new bins are needed. NUREG/CR-6850 used bins spaced by equal HRR widths. Using the same equal HRR spacing approach with the new distributions would put approximately 60% of the distribution in the first bin. This would not give much resolution to computing SF by binning. Instead of uniformly equal HRR widths for the bins, the recommended bins use a set of bin spacings that increase in round numbers from 1% to 25%. This binning balances relatively uniform bin spacings at the upper end with a reasonable resolution of SF at the lower end. Tables 5-1 and 5-2 show the HRR and total energy release (TER) bins for the generic transient fire distribution and the transient combustible control location (TCCL) transient fire distribution.

Table 5-1
Bins of peak HRR and TER for determining SF for the generic transient fire distribution

Bin	Peak HRR (kW)			TER (MJ)			Bin Width
	Min	Max	Midpoint	Min	Max	Midpoint	
1	0.000	0.581	0.045	0.000	0.027	0.001	0.250
2	0.581	3.34	1.54	0.027	0.34	0.11	0.150
3	3.34	7.81	5.22	0.34	1.2	0.65	0.100
4	7.81	16.0	11.3	1.2	3.2	1.97	0.100
5	16.0	30.5	22.2	3.2	7.8	5.06	0.100
6	30.5	41.6	35.6	7.8	11.8	9.60	0.050
7	41.6	57.0	48.7	11.8	17.8	14.5	0.050
8	57.0	79.1	67.0	17.8	27.2	22.0	0.050
9	79.1	114	94.3	27.2	42.8	33.9	0.050
10	114	135	124	42.8	52.5	47.3	0.020
11	135	162	147	52.5	65.8	58.5	0.020
12	162	203	181	65.8	85.9	74.7	0.020
13	203	234	217	85.9	101	92.9	0.010
14	234	278	253	101	123	111	0.010
15	278	∞	278	123	∞	123	0.020

Table 5-2
Bins of Peak HRR and TER for determining SF for the TCCL transient fire distribution

Bin	Peak HRR (kW)			TER (MJ)			Bin Width
	Min	Max	Midpoint	Min	Max	Midpoint	
1	0.0	0.586	0.063	0.00	0.03	0.001	0.250
2	0.586	2.64	1.34	0.03	0.32	0.12	0.150
3	2.64	5.54	3.89	0.32	0.91	0.55	0.100
4	5.54	10.4	7.68	0.91	2.2	1.44	0.100
5	10.4	18.6	14.0	2.2	4.8	3.28	0.100
6	18.6	24.6	21.4	4.8	7.0	5.78	0.050
7	24.6	32.8	28.4	7.0	10.1	8.36	0.050
8	32.8	44.3	38.0	10.1	14.7	12.1	0.050
9	44.3	62.0	52.0	14.7	22.3	18.0	0.050
10	62.0	72.3	66.8	22.3	26.9	24.5	0.020
11	72.3	86.2	78.7	26.9	33.2	29.8	0.020
12	86.2	107	95.3	33.2	42.6	37.4	0.020
13	107	122	114	42.6	49.6	45.9	0.010
14	122	143	131	49.6	59.9	54.2	0.010
15	143	∞	143	59.9	∞	59.9	0.020

5.2 Input Parameters for Detailed Modeling

The parameters in this section were developed using the same expanded, weighted data set that was used for the generic transient fire distributions in Section 4.1. A separate set of parameters was not developed for the TCCL distribution. Fires below 10 kW were removed from the data set for all parameters except for the fire elevation. This was done due to measurement limitations for the heat of combustion, yields, Q^*, shape parameters (limitations are covered in the test report [9]), and the fact that many of the very small fires were dominated by the ignition source.

5.2.1 Heat of Combustion, Q, Source Height*

Figures 5-1 through 5-3 shows plots of the heat of combustion (ΔH_c), fire Froude number (Q^*), and source height (z_e) as a function of the fire size for all fires larger than 10 kW. Q^* is a non-dimensional scaling of the intensity of the fire source [37]. No clear trend can be seen in the ΔH_c, Q^*, and z_e data as a function of the HRR. This is expected because these parameters are largely driven by the type of material involved in the fire and the fire size is driven by the amount of material.

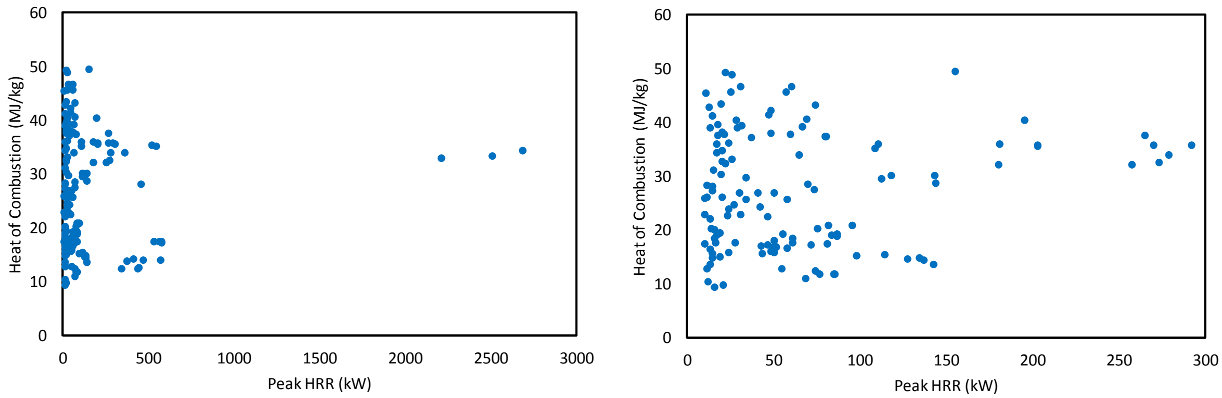

Figure 5-1
ΔHc versus fire size for all fires larger than 10 kW

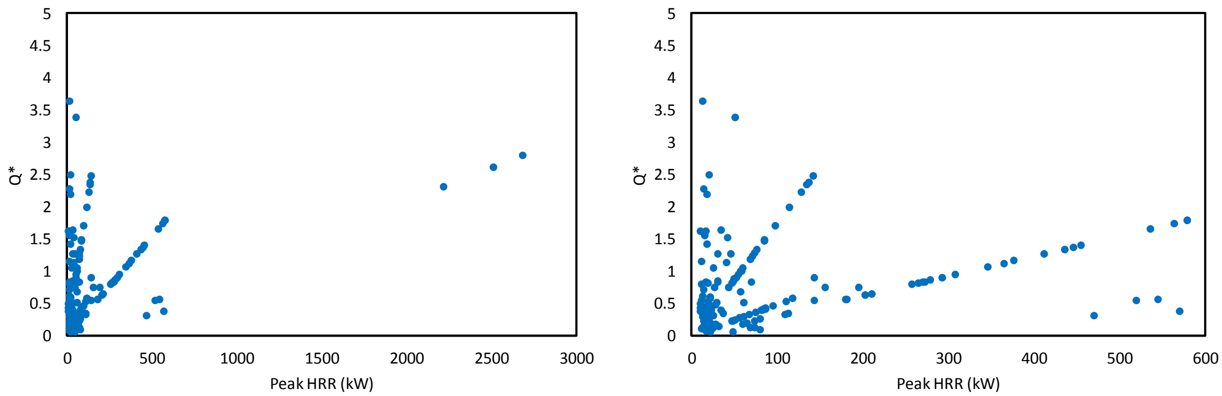

Figure 5-2
Q* versus fire size for all fires larger than 10 kW

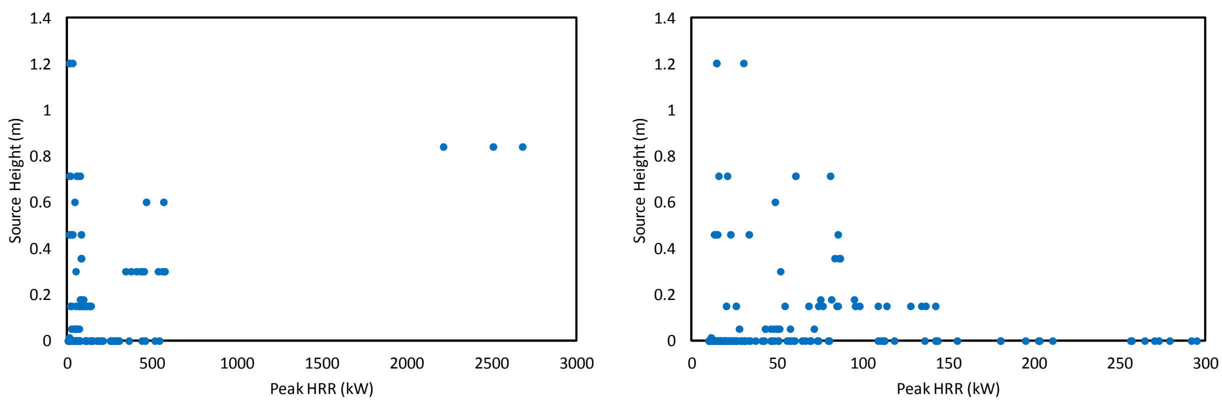

Figure 5-3
Source height versus fire size for all fires larger than 10 kW

Figure 5-4 shows the cumulative distribution function and probability density function for ΔH_c. The density function does not indicate a clear functional form (for example, normal, log-normal). Given a time-dependent HRR, ΔH_c does not have a significant influence on zone of influence (ZOI) or HGL. In a risk assessment, it is the time-dependent HRR that drives the hazard, and the ΔH_c simply changes the fuel mass flow needed to achieve that HRR. This lack of sensitivity in ZOI or HGL to the specific value of ΔH_c makes the median value a reasonable selection. The 50th percentile value is 25 MJ/kg. The 16th to 84th percentile range is 15–35 MJ/kg.

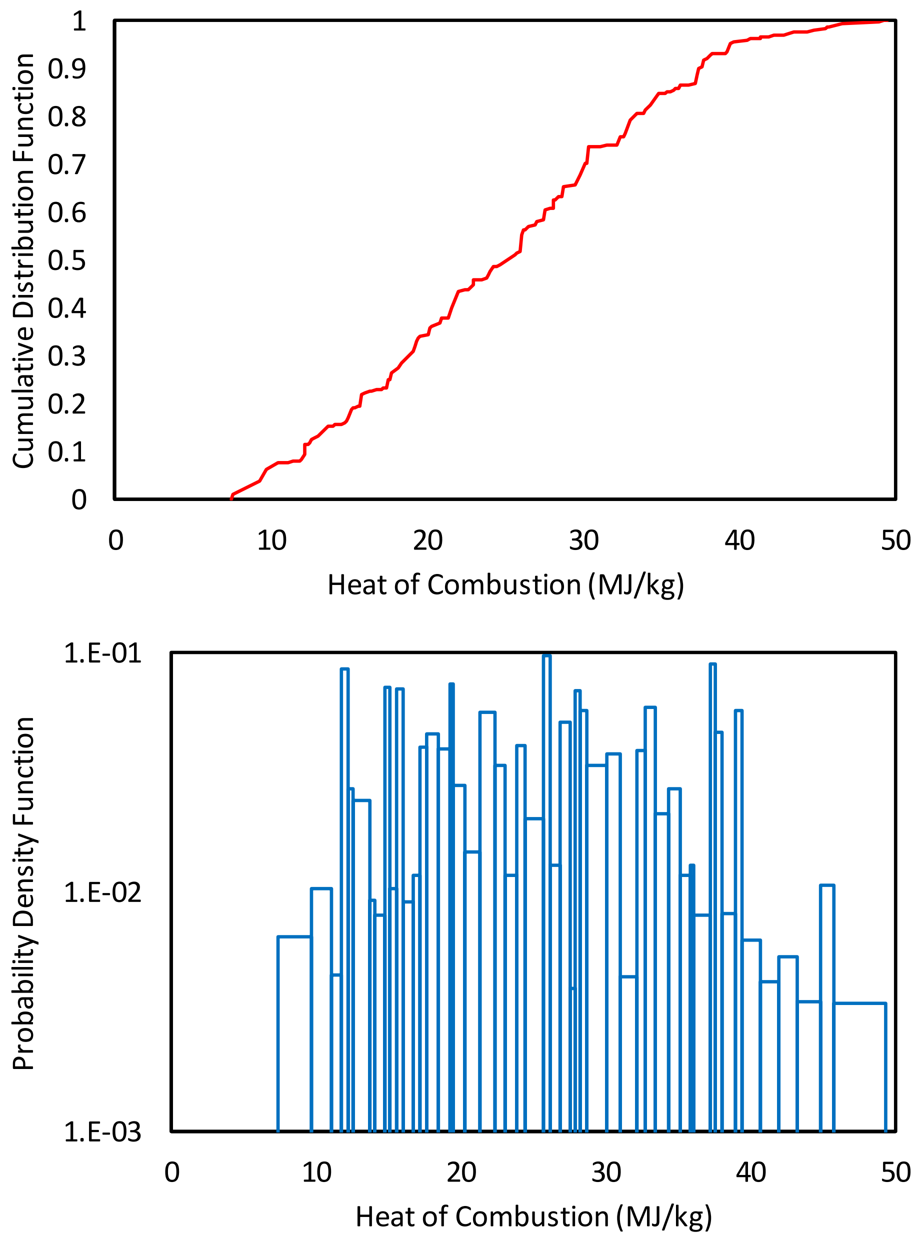

Figure 5-4
ΔHc cumulative distribution function (top) and probability density function (bottom)

Figure 5-5 shows the cumulative distribution function and probability density function for Q^*. Q^* has an impact on the ZOIs and the HGL development. Higher Q^* fires have larger vertical ZOIs, and lower Q^* fires have larger horizontal ZOIs. For the HGL development, a higher Q^* fire will see less entrainment than a lower Q^* fire. Most of the Q^* values are distributed in a relatively uniform manner at 1 or below. There are a few outlier points at higher Q^* values. To avoid having a generic method bias ZOIs in either the horizontal or vertical direction, using the median Q^* value is appropriate. The median Q^* value is 0.54. The 16th to 84th percentile range is 0.23–1.2. These values are consistent with NUREG-1934 [37], which indicates that most fires in a nuclear power plant are expected to have Q^* values on the order of 1.

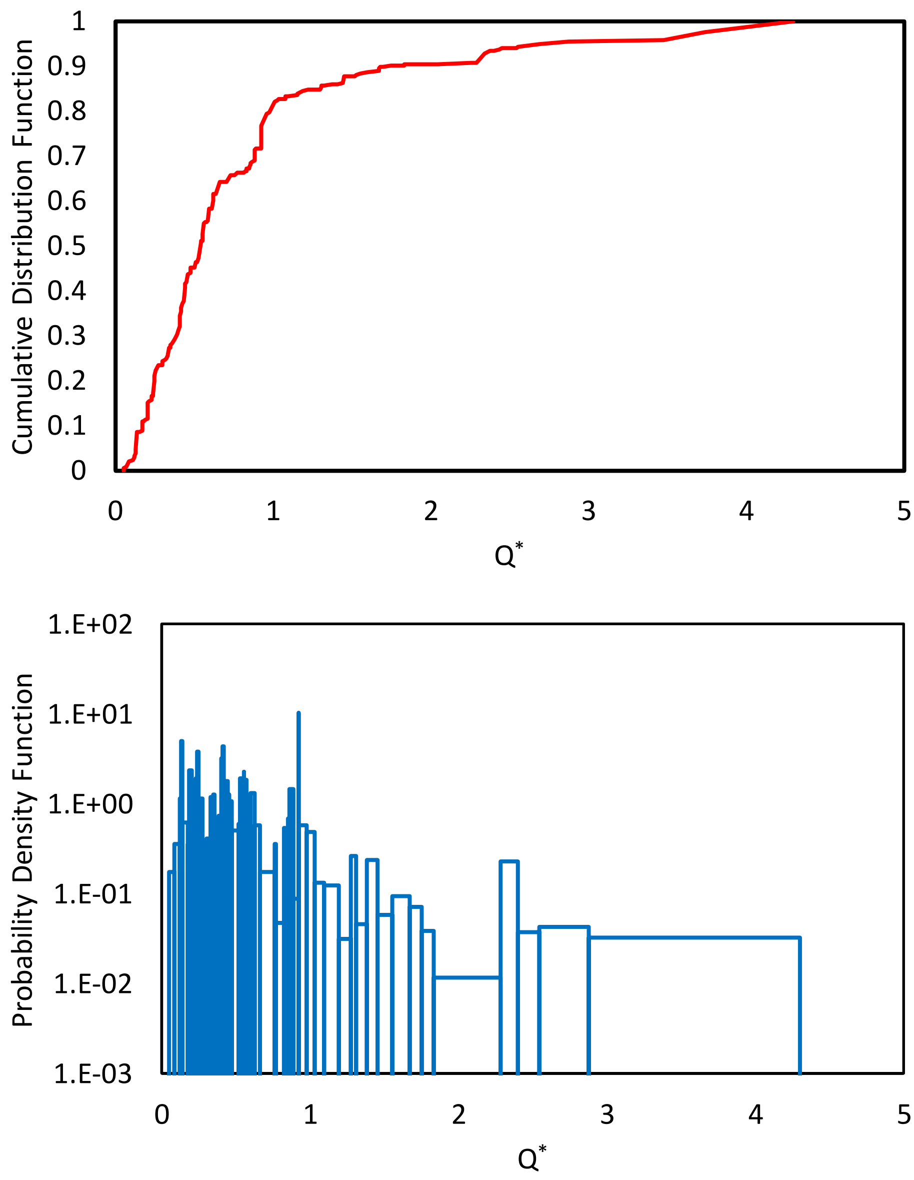

Figure 5-5
Q* cumulative distribution function (top) and probability density function (bottom)

Figure 5-6 shows the cumulative distribution function and probability density function for the source height, z_e. The vast majority of fires are expected to occur on the floor, and this is especially true for the fires near the 98th percentile where many test packages involved thermoplastic (TP) materials melting into a pool. The 79th percentile source height is 0 cm (0 in.). In recognition that some items involve non-zero source heights, a source height of 15 cm (6 in.) is recommended. This is approximately the 85th percentile source height. Note that if the specific fire scenario involves an elevated fire (fire on a raised portion of floor, on top of another object, and so forth), this source height should be added to the base fire elevation. The 79th to 98th percentile range is 0.00–0.71 m.

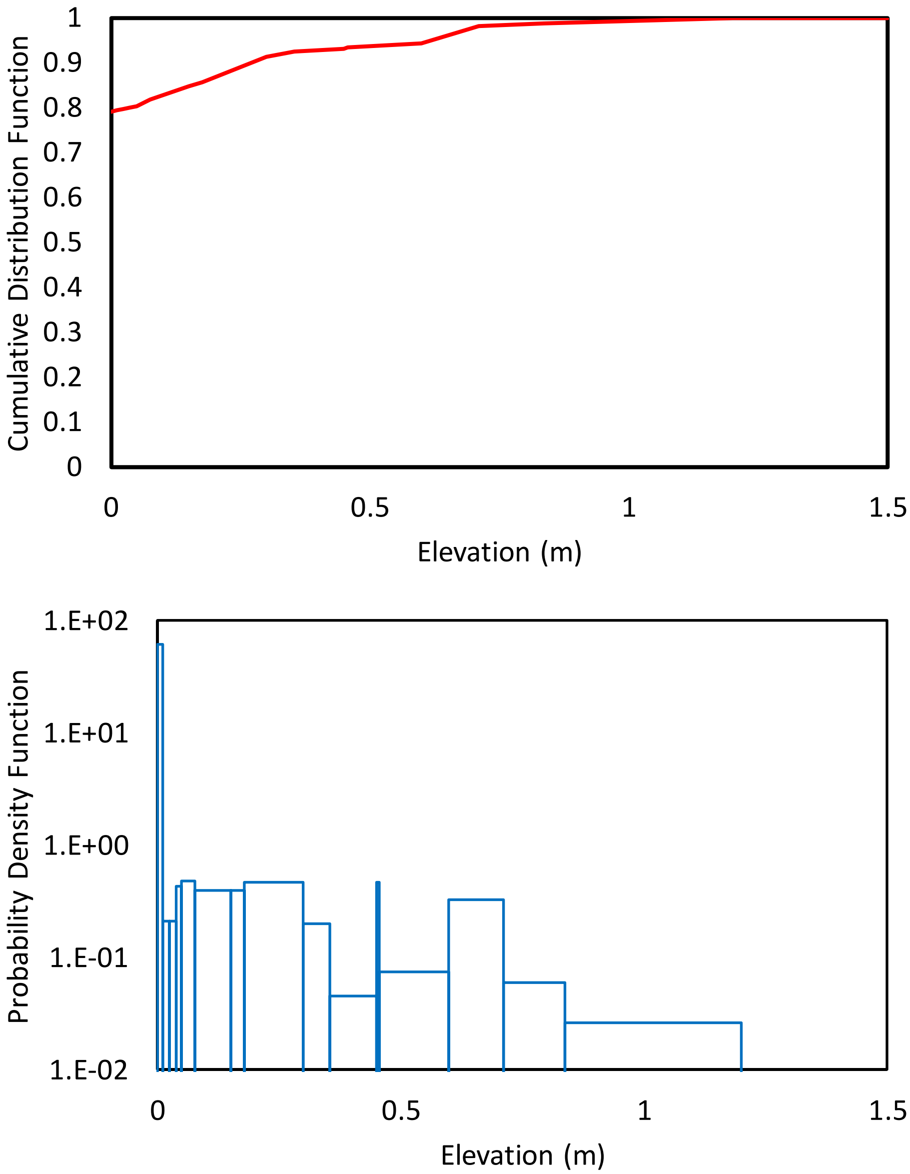

Figure 5-6
Source height cumulative distribution function (top) and probability density function (bottom)

5.2.2 Soot Yield and CO Yield

Soot and CO yield (often given as y_s and y_{CO}) are required parameters for fire models such as the Consolidated Model of Fire Growth and Smoke Transport (CFAST) [32, 33] and Fire Dynamics Simulator (FDS) [34, 35]. In terms of a fire probabilistic risk assessment, these yields determine the tenability in areas requiring human action. For detailed fire modeling, the goal is to accurately represent the hazard posed by the distribution of fires based on operational experience. The yield itself does not fully determine that hazard. Two fires with the same HRR and the same soot yield would create different hazards if the ΔH_c were different. A high ΔH_c fuel would require a lower burning rate to achieve a given HRR than a low ΔH_c fuel, and as a result would make less soot. Because the ΔH_c was fixed in Section 5.2.1 to be 25 MJ/kg, the yields measured in the test must be adjusted based on the ratio of the test ΔH_c to 25 MJ/kg. This puts all of the measured yields at the same relative production rate (kg/s) based on fire size. Figures 5-7 and 5-8 show the adjusted yields as a function of the fire size for all fires over 10 kW. There is no clear relationship between yields and the peak HRR. Yields are a function of the material being burned and its configuration. Because there were fires of different materials and configurations throughout the range of fire sizes seen in testing, the yields are not expected to correlate with the peak HRR.

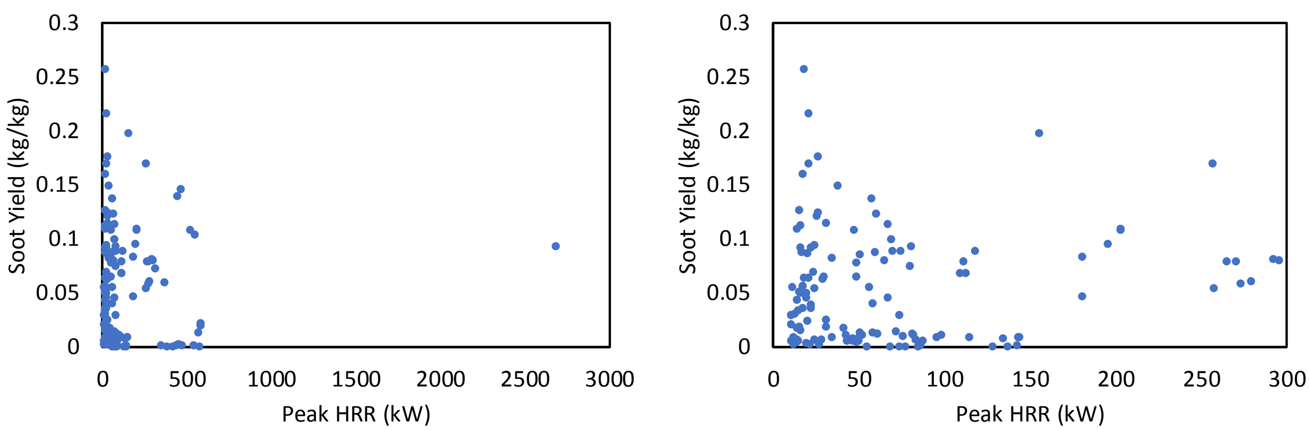

Figure 5-7
Adjusted soot yield versus fire size

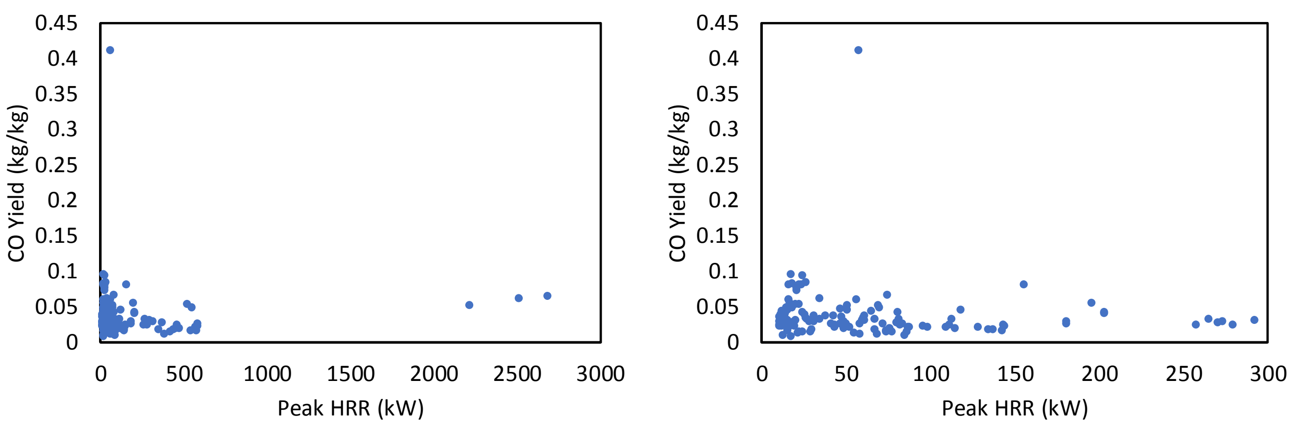

Figure 5-8
Adjusted CO yield versus fire size

Figures 5-9 and 5-10 show the cumulative distribution function and probability density function for the adjusted soot yield and adjusted CO yield. Because higher yields are conservative, the 75th percentile value is suggested as an input for detailed fire modeling. The 75th percentile adjusted yields for soot and CO are 5.2% and 4.3%, respectively. These yields are consistent with recommended yields used for life-safety in performance-based fire protection design. For example, the New Zealand fire code [38] suggests soot and CO yields of 7% and 4% for pre-flashover fires. All of the fire tests represented in the distribution were well-ventilated fire tests, although specific fuel packages might experience periods of ventilation limited burning due to configuration (for example, a fire in a container). These recommended yields should be generally applicable provided that the global equivalence ratio remains in the well-ventilated regime (equivalence ratio <1). The 41st (the equivalent of one deviation from 75th) to 98th percentile range for the soot and CO yields are 1.2–13.6% and 2.4–6.8%, respectively.

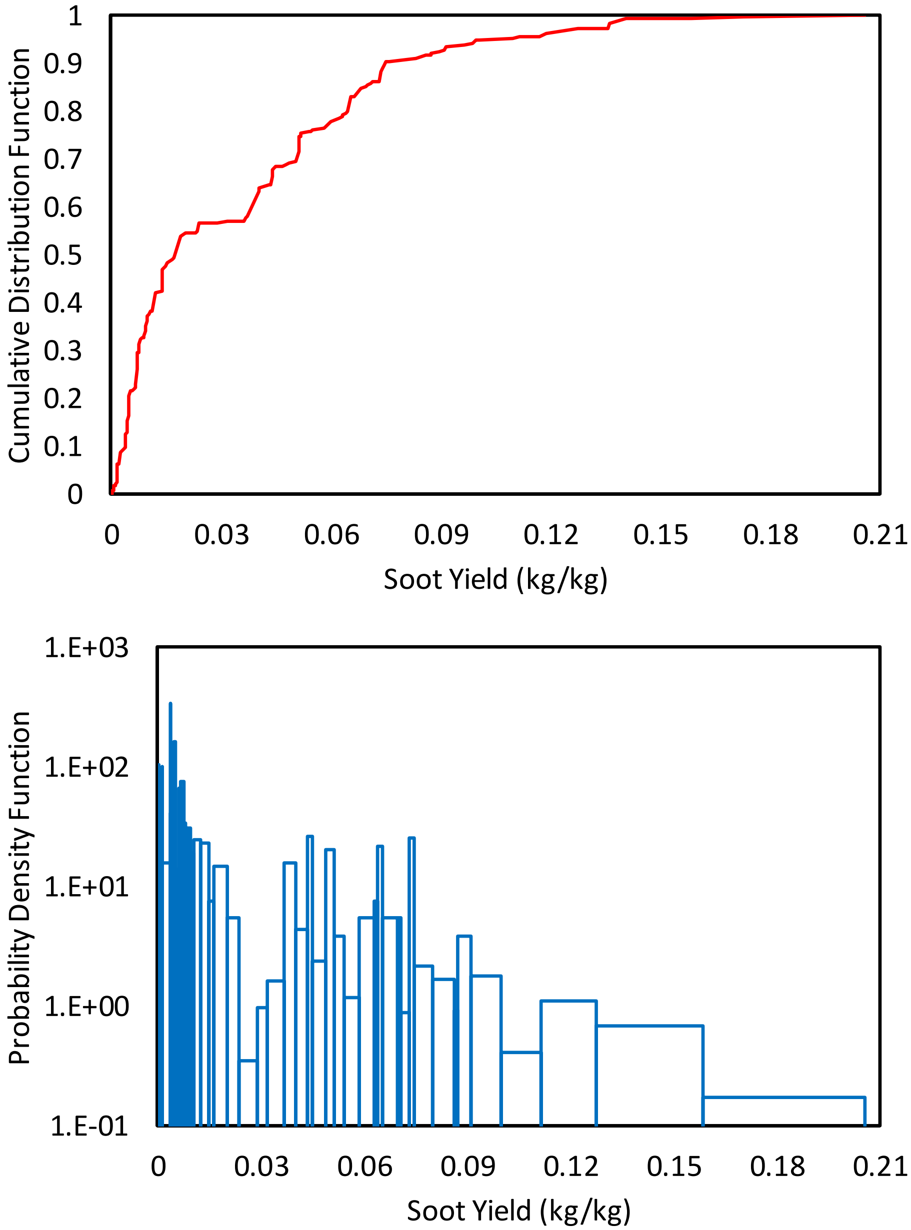

Figure 5-9
Soot yield cumulative distribution function (top) and probability density function (bottom)

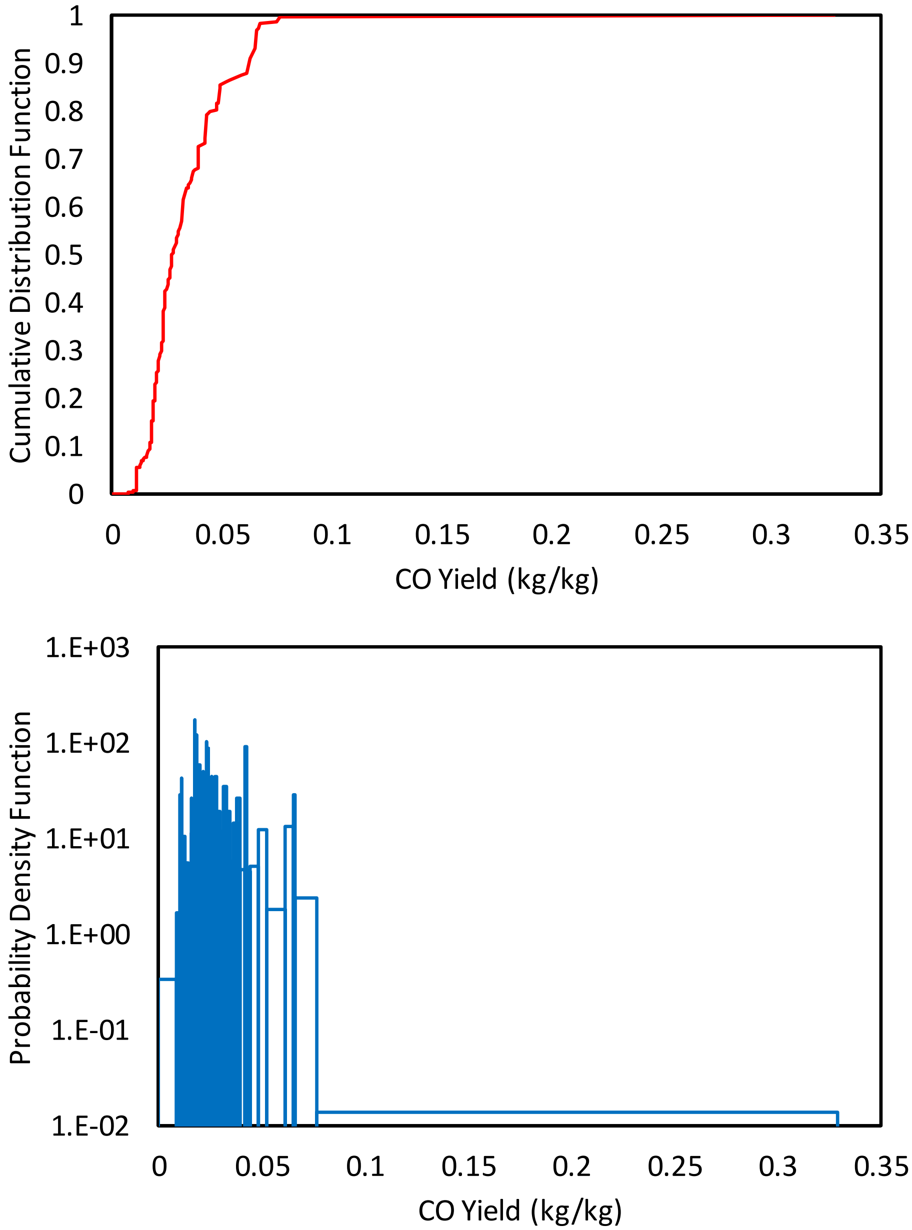

Figure 5-10
CO yield cumulative distribution function (top) and probability density function (bottom)

5.2.3 Fire Growth, Plateau, and Decay

All tests over 10 kW were fit with a three-part curve to define the fire profile. A description of the fitting process is presented in the test report [9]. Results are tabulated in the test report and in Appendix A for the additional tests from Section 2.2.2 through Section 2.2.4. The fit consists of a power law growth period from zero kW to the peak HRR in kW with growth time, t_g in seconds, and growth exponent, n_1; a plateau time, t_p in seconds; and decay period with decay time, t_d in seconds, and decay exponent n_2. The resulting equation for the HRR is:

$$\dot{q}(t) = \begin{cases} \dot{q}_{peak}\left(\frac{t}{t_g}\right)^{n_1} & t \le t_g \\ \dot{q}_{peak} & t_g < t \le t_g + t_p \\ \dot{q}_{peak}\left(1 - \left(\frac{t - t_g - t_p}{t_d}\right)^{n_2}\right) & t_g + t_p < t \le t_d + t_g + t_p \end{cases} \quad \textbf{Eq. 5-1}$$

This is the same basic form of equation used for electrical cabinets following the guidance in NUREG/CR-6850. Only for electrical cabinets, the times and exponents are fixed with the same values used for all cabinets and all fire sizes. This approach makes defining the HRR simpler because only one HRR curve needs to be developed. However, this approach also means that the modeled fires do not reflect the distribution of energy content and ZOI that was seen in the underlying test data. Accomplishing this requires more complexity; therefore, constant values for all parameters were not possible.

A typical fit of experimental data is shown in Figure 5-11. The ZOIs and any HGL formed by the transient fire are largely driven by the peak HRR, the time spent near the peak, and the total area under the HRR curve (the TER). The time prior to the peak is characterized by lower HRRs, and these contribute little to the ZOI or to the HGL. After the fire has decayed away from the peak, the lower fire size means targets near the ZOI no longer see damaging temperatures. Additionally, as the fire size decreases, eventually heat losses to the walls and ceiling from the HGL will be larger than the heat input from the fire, which will stop any further increase in HGL temperature. The goal was to define the curve shape so that it reproduces the correct TER and ZOIs over the HRR distribution—that is, the curve fit focus was on matching the shape of the top of the peak.

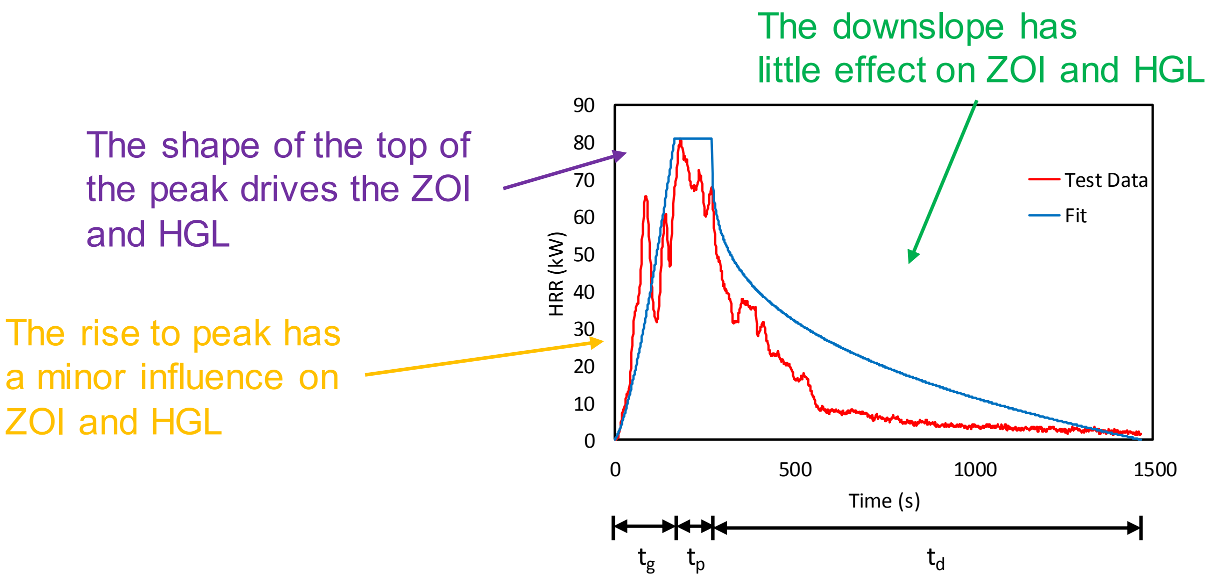

Figure 5-11
Typical fit of growth, plateau, and decay parameters to a test

The approach taken was to determine correlations that exist between the different fire growth parameters and ultimately define parameters as a function of a single parameter in manner that yields the correct percentile TER given the percentile peak HRR. It can be seen in Figure 5-12 that there is a clear trend between TER and peak HRR, which justifies this approach of coupling the peak HRR and the TER to the probabilistic distributions. Additionally, the figure overlays the gamma fits of HRR and TER from Table 4-1. For the smallest fires, which pose little contribution to overall risk, the approach of jointly selecting HRR and TER based on percentile likely underpredicts the hazard. However, once in the range of fires that are 25 to 30 kW, the gamma fit trends through the center of the TER data. At the largest fires, the gamma fit trends to the upper end of the TER data.

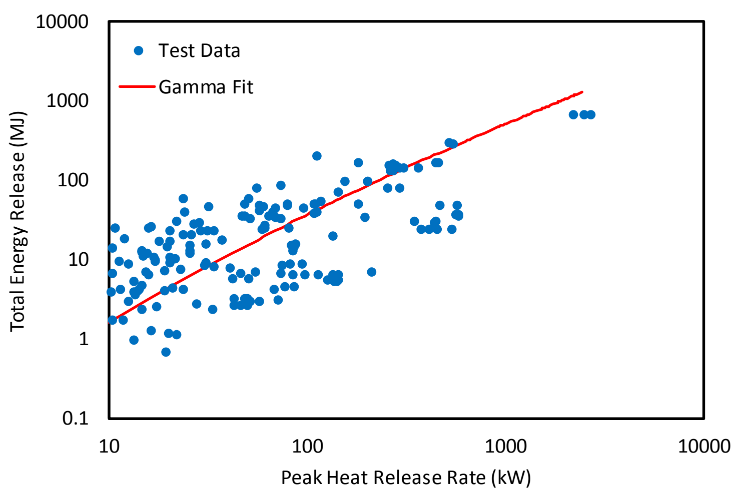

Figure 5-12
TER versus peak HRR for Test Data and Gamma Fit from Table 4-1

5.2.3.1 Growth and Decay Exponents

Figure 5-13 plots the growth exponent (n_1) versus the peak HRR, TER, growth time (t_g), the plateau time (t_p), the decay time (t_p), and the decay exponent (n_2). For each plot, the best fit functional form (log, exponential, linear, or power) is shown along with the R^2 value. Because the R^2 values are all very low, this indicates that there is not a strong correlation for n_1 as a function of any of the fire curve shape parameters. Similar results are seen for the decay exponent in Figure 5-14. The rates of growth and decay are tied to the type of fuel and its arrangement. Fire spreads over a surface at a rate determined by how quickly the advancing flame front can heat virgin material to its ignition. A material that chars or undergoes multiple solid phase reactions will decay at a different rate than a material that is initially a flammable liquid or a material that becomes a flammable liquid (for example, a TP). Because the exponents are not strongly tied to other fire parameters, they were set to median values. Figures 5-15 and 5-16, respectively, show the cumulative distribution function and probability density functions for the growth and decay exponents. The median growth exponent (n_1) is 2.7 with 16th and 84th percentiles of 1.1 and 6.8, respectively. The median decay exponent (n_2) is 0.32 with 16th and 84th percentiles of 0.14 and 0.45, respectively.

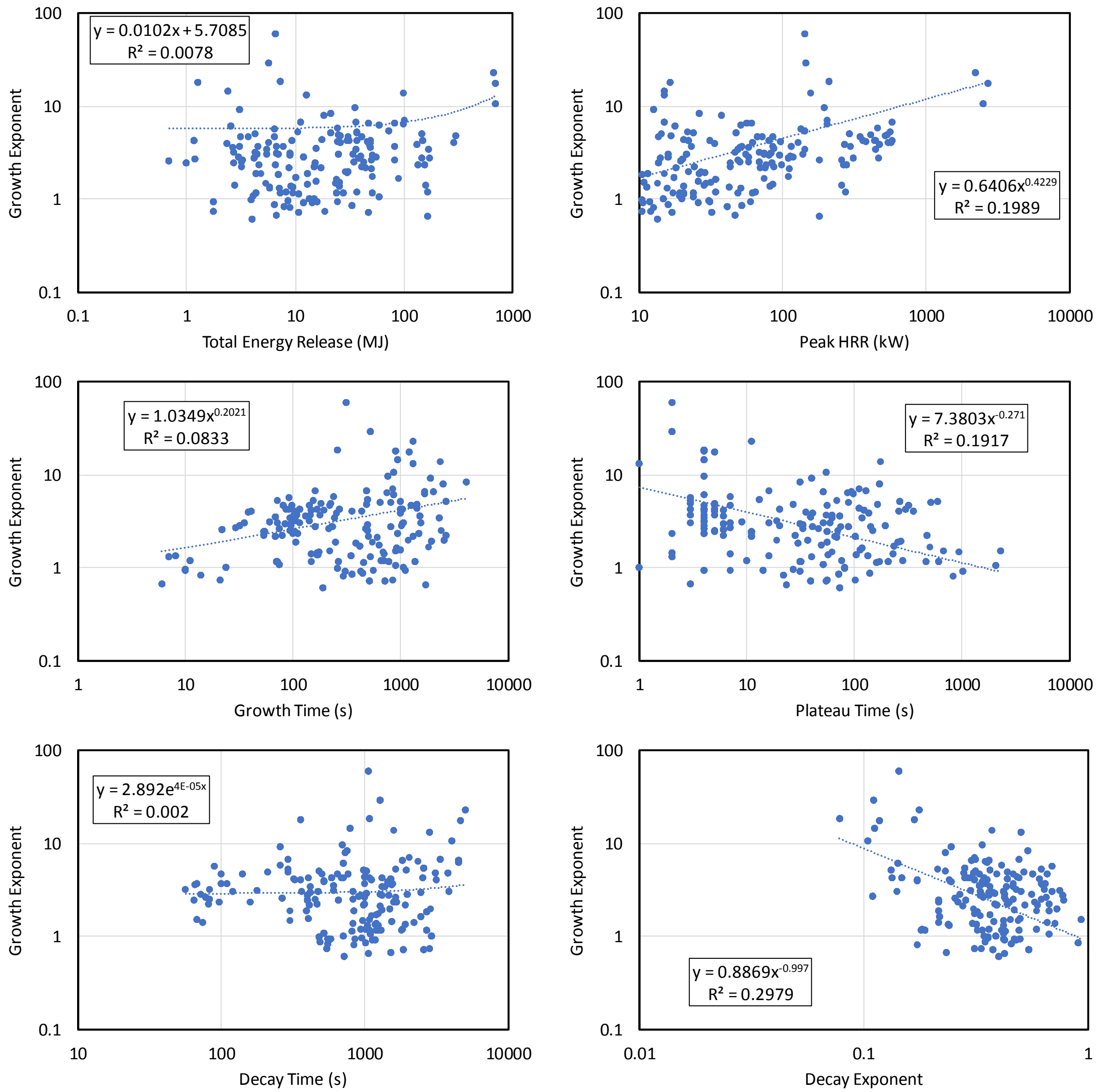

Figure 5-13
Plots of the growth exponent (n_1) versus TER, peak HRR, growth time, plateau time, decay time, and decay exponent

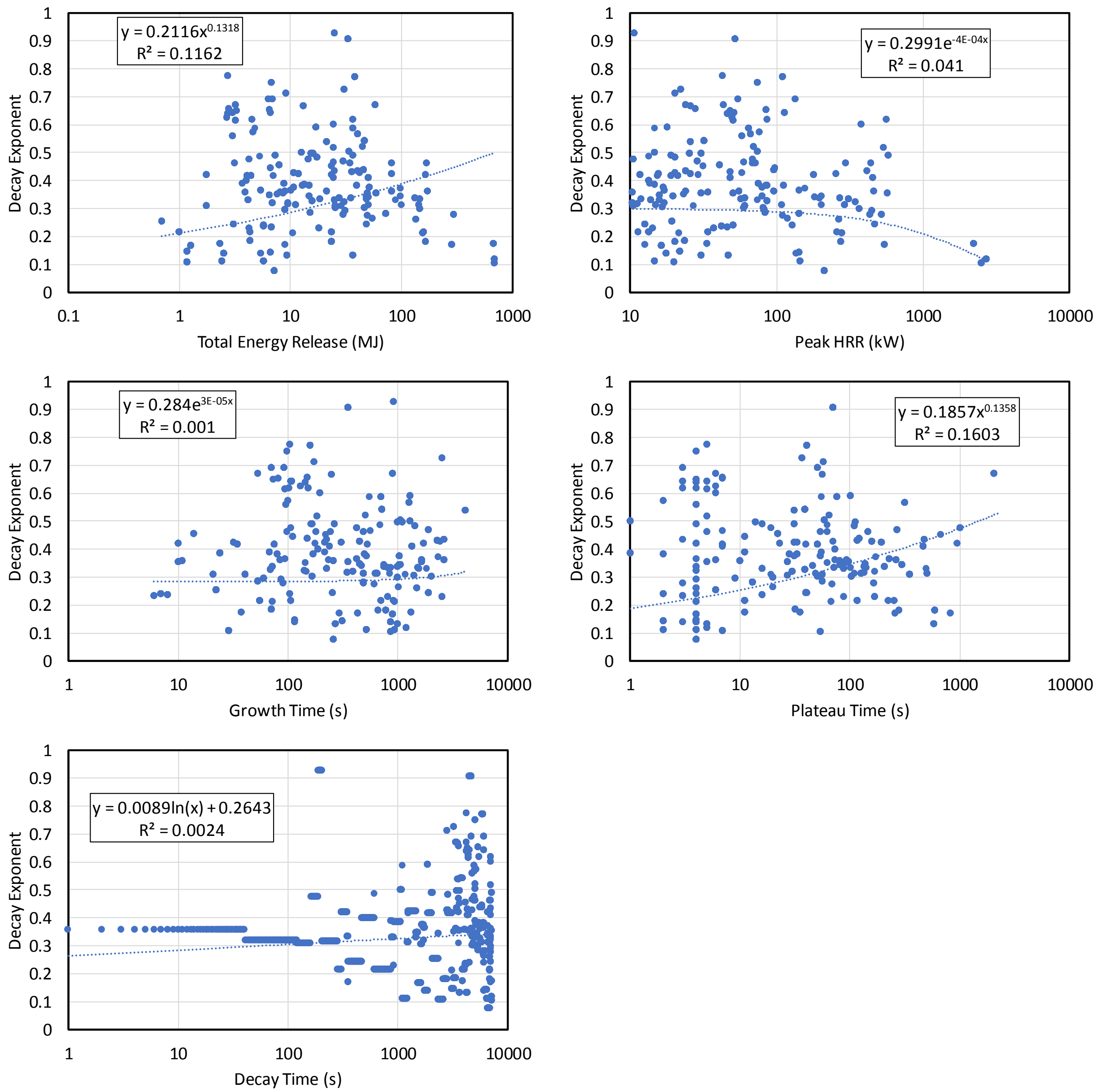

Figure 5-14
Plots of the decay exponent (n_2) versus TER, peak HRR, growth time, plateau time, and decay time

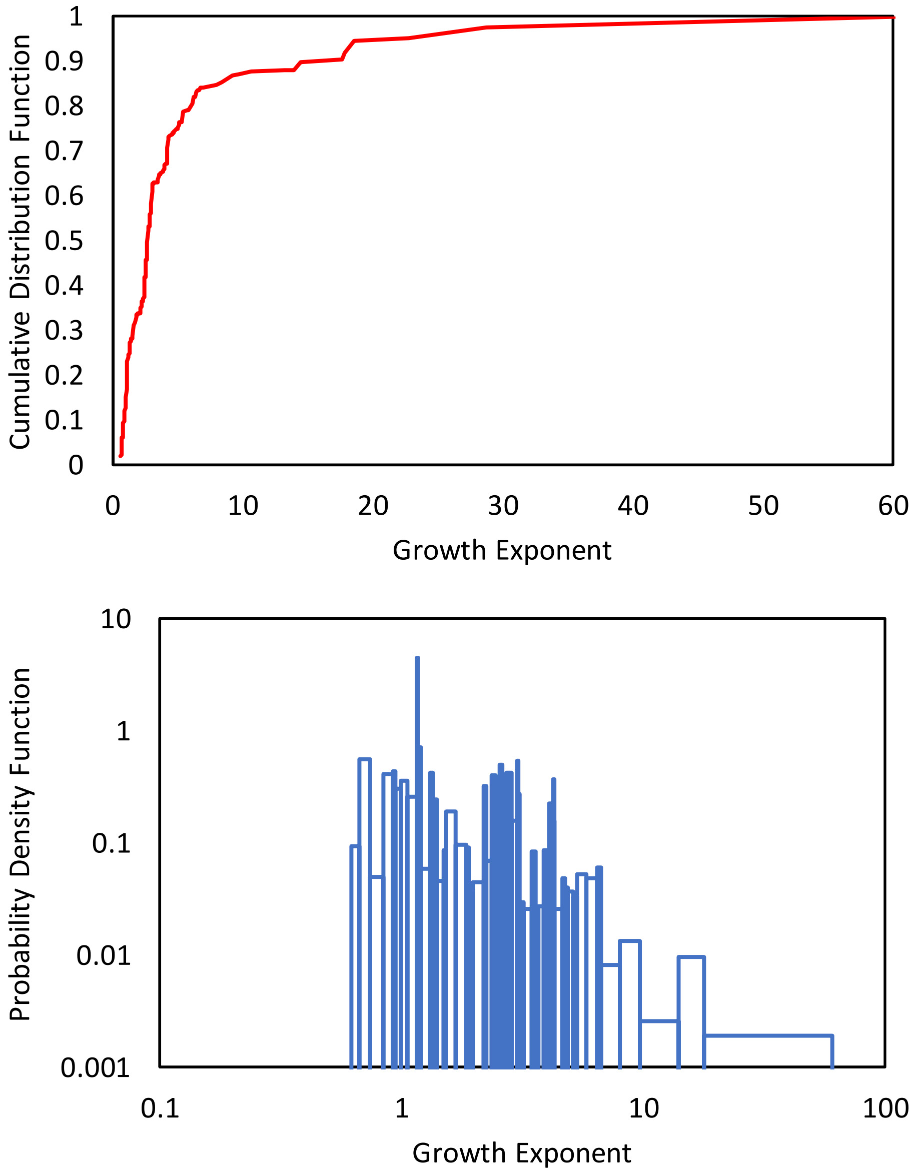

Figure 5-15
Growth exponent cumulative distribution function (top) and probability density function

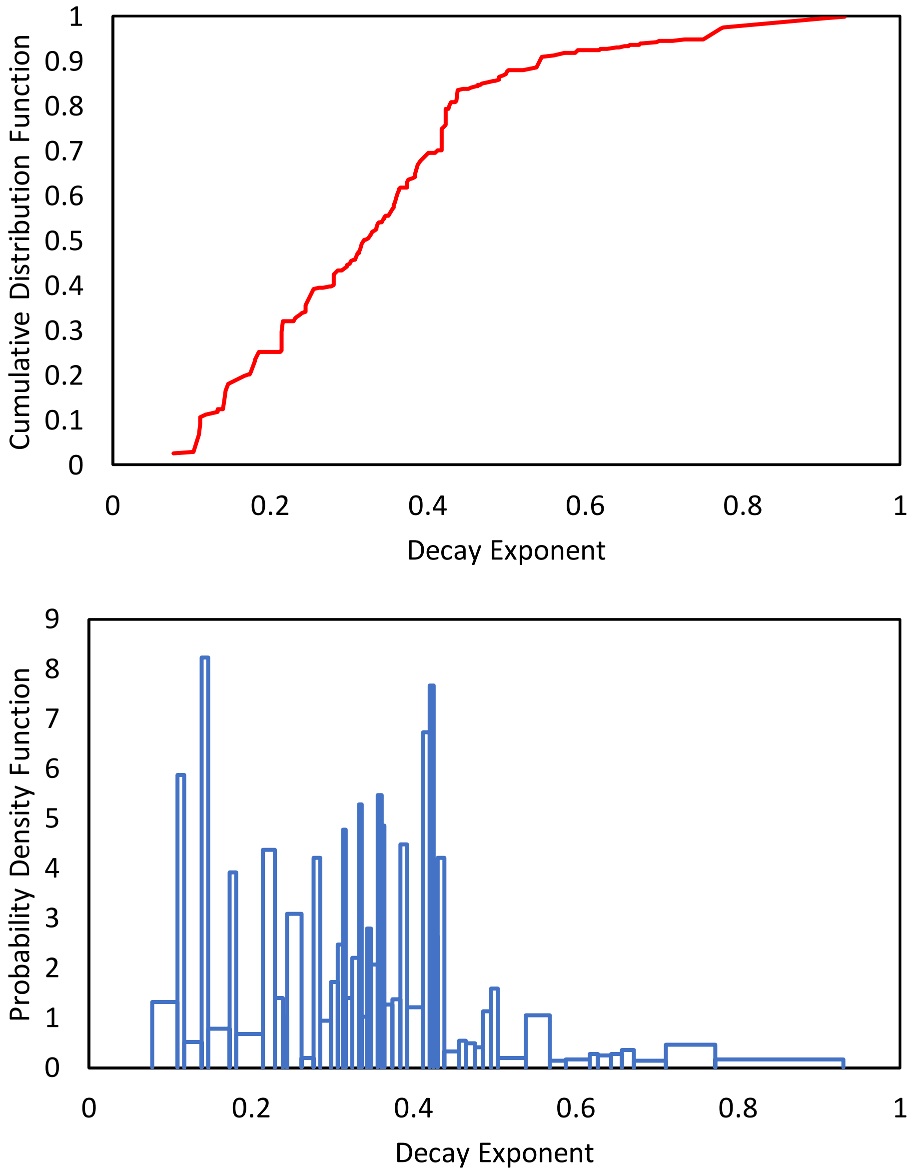

Figure 5-16
Decay exponent cumulative distribution function (top) and probability density function

5.2.3.2 Growth, Plateau, and Decay Times

Similar to the growth and decay exponents, plots were made of the growth time (t_g), plateau time (t_p), and decay time (t_d) as functions of other shape variables. Unlike the exponents, clear trends were seen when the energy release during the growth and decay phases was plotted against the TER from the fire. These plots are shown in Figure 5-17, where it is seen that relatively high R^2 values exist for both parameters. Because the generic values of the growth and decay exponents are fixed values, a relationship between energy release during growth and energy release during decay to the total energy uniquely determines the growth and decay times. After growth and decay times are known, the plateau time is determined by the remaining energy left in the TER.

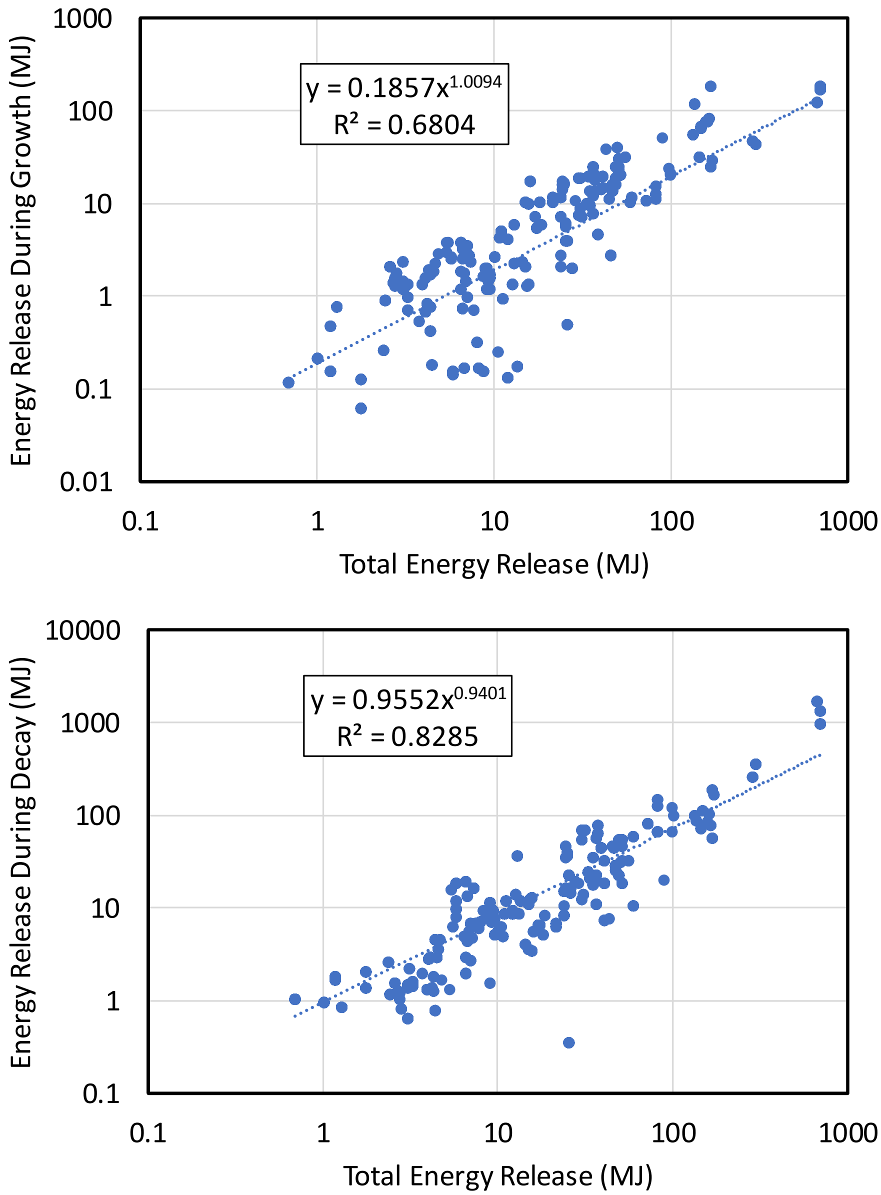

Figure 5-17
Plots of the energy release during growth versus TER (top) and energy release during decay versus TER (bottom)

The resulting equations for the growth, decay, and plateau times are shown in Equations 5-2 through 5-4.

$$\frac{\dot{q}_{peak}}{1000}\frac{t_g}{n_1+1} = 0.186TER^{1.01}$$
$$t_g = \frac{3700}{\dot{q}_{peak}}0.186TER^{1.01} = \frac{690}{\dot{q}_{peak}}TER^{1.01}$$ **Eq. 5-2**

$$\frac{\dot{q}_{peak}}{1000}\frac{t_d n_2}{n_2+1} = 0.955TER^{0.940}$$
$$t_d = \frac{1320}{0.32\dot{q}_{peak}}0.955TER^{0.940} = \frac{3940}{\dot{q}_{peak}}TER^{0.94}$$ **Eq. 5-3**

$$t_p = \frac{1000TER}{\dot{q}_{peak}} - \frac{t_g}{n_1+1} - \frac{t_d n_2}{n_2+1}$$ **Eq. 5-4**

For small fires, this fit can yield a negative plateau time. In that case the plateau time should be set to 1 second, and the growth and decay times scaled proportionately to yield the correct energy, as shown in Equations 5-5 and 5-6. This can be determined by setting the total growth and decay energy proportional to the original value as a fraction of the remaining TER after a 1 second plateau time.

$$\frac{\dot{q}_{peak}}{1000}\frac{t_g}{n_1+1} = \left(TER - \frac{\dot{q}_{peak}}{1000}\right)\frac{0.186TER^{1.01}}{0.186TER^{1.01}+0.955TER^{0.940}}$$
$$t_g = \frac{3700}{\dot{q}_{peak}}\left(TER - \frac{\dot{q}_{peak}}{1000}\right)\frac{0.186TER^{1.01}}{0.186TER^{1.01}+0.955TER^{0.940}}$$ **Eq. 5-5**

$$\frac{\dot{q}_{peak}}{1000}\frac{t_d n_2}{n_2+1} = \left(TER - \frac{\dot{q}_{peak}}{1000}\right)\frac{0.955TER^{0.940}}{0.186TER^{1.01}+0.955TER^{0.940}}$$
$$t_d = \frac{1320}{0.32\dot{q}_{peak}}\left(TER - \frac{\dot{q}_{peak}}{1000}\right)\frac{0.955TER^{0.940}}{0.186TER^{1.01}+0.955TER^{0.940}}$$ **Eq. 5-6**

5.2.4 Summary of Input Parameters

Table 5-3 summarizes the input parameters for detailed fire modeling. The same parameters apply to generic transient fires and TCCL transient fires. Table 5-3 gives the recommended value and, where applicable, the range of the value over the equivalent of one standard deviation (for example, the range capturing 68% of the values).

Table 5-3
Summary of input parameters for detailed modeling

Parameter	Recommended Value	Uncertainty Range[1]	Comment
Peak HRR (kW)	Distribution in Table 4-1 or 4-4	N/A	Determined by the percentile fire being modeled.
TER (MJ)	Distribution in Table 4-1 or 4-4	N/A	Determined by the percentile fire being modeled.
ΔH_C (MJ/kg)	25	15–35	When using a generic HRR curve, varying ΔH_C does not impact ZOI or HGL. Note that the species yield range already incorporates the variance in the ΔH_C of test items. If ΔH_C is changed, yields need to be rescaled to preserve the effective hazard.
Q^*	0.54	0.23–1.2	
z_e (m)	0.15	0.00–0.71	Effective elevation of the base of the fire above the local floor height.
Soot yield (kg/kg)	0.052	0.012–0.136	Note that the yield values are tied to the selected ΔH_C.
CO yield (kg/kg)	0.043	0.024–0.068	Note that the yield values are tied to the selected ΔH_C.
Growth exponent n_1	2.7	1.1–6.8	Changing exponents must be propagated through Equations 5-2 through 5-6.
Decay exponent n_2	0.32	0.14–0.45	Changing exponents must be propagated through Equations 5-2 through 5-6.
Growth time t_g (s)	Equation 5-2 or 5-5	300–4090*	First, use Equation 5-2. Switch to Equation 5-5 if plateau time is set to 1 second. *Uncertainty range applies to the 690 constant in Equation 5-2.
Plateau time t_p (s)	Equation 5-4 or 1 second	N/A	First, determine the growth and decay time. If plateau is less than 1 second, set to 1 second and redo growth time and decay time.
Decay time t_d (s)	Equation 5-3 or 5-6	2200–9560*	First, use Equation 5-3. Switch to Equation 5-6 if plateau time is set to 1 second. *Uncertainty range applies to 3940 constant in Equation 5-3.

[1]Range is the equivalent of one standard deviation (16th and 84th percentiles) except for soot and CO, which are 41st to 98th, and z, which is 79th to 98th.

5.3 Time to Damage and ZOI Comparison

This section covers the time to damage for targets exposed to a transient fire based on the modeling parameters from Table 5-3. The section also covers how well those parameters reproduce the distribution of ZOIs.

5.3.1 Generic Transient Fire Distribution

With the Q* from Section 5.2.1 and the fire growth parameters from Section 5.2.3.2, one can select a percentile, use the gamma distributions in Section 4.1 to obtain the peak HRR and TER, and then apply Equations 5-2 through 5-6 to determine the time-dependent HRR curve. For example, the 90th percentile fire has a peak HRR of 114 kW and a TER of 42.8 MJ. If those values are entered into Equations 5-2 through 5-4, the solution for the growth time (t_g), the plateau time (t_p), and the decay time (t_d) are respectively 269 seconds, 16.5 seconds, and 1182 seconds. Table 5-4 shows the fire growth parameters (times and the growth (n_1) and decay (n_2) exponents) and key Fire Dynamics Tools (FDT^S) [31] parameters (maximum diameter (Max D), flame height (L_f), and z_0, which is the virtual origin input used in the plume temperature correlation) for a selection of percentiles. Total transient fire durations range from 3 minutes for the 25th percentile fire of 0.6 kW up to 28 minutes for the 98th percentile fire of 278 kW. Note that current recommendations [4] for modeling plume temperature for a fire in a corner remain the same – multiply the heat release rate by 4 and the diameter by 2.

Table 5-4
HRR parameters and key FDT^S parameters for a selection of percentiles for the generic transient fire distribution

%	Peak HRR (kW)	TER (MJ)	t_g (s)	n_1	t_p (s)	n_2	t_d (s)	Q^*	Max D (m)	L_f (m)	z_0 (m)
98	278	123	322	2.7	39.5	0.32	1311	0.54	0.74	1.48	0.03
95	180	74.7	298	2.7	28.1	0.32	1258	0.54	0.62	1.24	0.03
90	114	42.8	269	2.7	16.5	0.32	1182	0.54	0.52	1.03	0.02
85	79.1	27.2	245	2.7	8.2	0.32	1110	0.54	0.45	0.89	0.02
80	57.0	17.8	222	2.7	1.4	0.32	1038	0.54	0.39	0.78	0.02
75	41.6	11.8	197	2.7	1.0	0.32	947	0.54	0.35	0.69	0.02
50	7.8	1.17	90.2	2.7	1.0	0.32	511	0.54	0.18	0.35	0.01
25	0.58	0.027	21.7	2.7	1.0	0.32	160	0.54	0.06	0.13	0.00

The time-dependent HRR curve can be used as an input to the FDT^S to obtain the plume temperature [31] and heat flux [4] at a target location. The heat soak method [4] can then be applied to compute the time to damage at that target location.

The parameters in Table 5-4 were used to compute the time to damage for targets located at the ZOI boundary. Table 5-5 shows the results for the vertical TP ZOI from the base of the fire. Because a predefined fire curve shape is being imposed onto test data that are not perfectly represented by that shape (see Figure 5-11), it is expected that the ZOI resulting from the curve fit process will not be identical to the ZOI given by the gamma distribution—that is, if the HRR curve using Table 5-4 were used to find the ZOI boundary, it is expected that the result would be a slightly different value from the value listed Table 4-1. The Fit HRR ZOI column in Table 5-5 shows the result of recomputing the ZOI based on the curve fit for the HRR. For the vertical TP ZOI, it is seen that the fire shape parameters generally result in ZOI values that are slightly larger, by 10–22 cm (4–9 in.). The exception is the 98th percentile where the fit ZOI is 1 cm less. This, however, is not a significant nonconservatism. Note that the damage time for the 98th percentile in Table 5-5 uses the Fit HRR ZOI height. Because overall, the fire exposure from the shape parameters is slightly more severe than the fire exposure based on the actual test data, the time to damage values should be biased conservatively. As previously noted, these ZOIs are measured from the base of the fire; therefore, they do not include the additional 15 cm elevation from Section 5.2.1.

Table 5-5
Time to damage for targets located on the vertical TP ZOI boundary using the parameters from Table 5-4 along with the ZOI based on Table 4-1

%	ZOI (m)	Time to Damage (s)	Fit HRR ZOI (m)	ΔZOI (m)
98	1.78	671	1.77	-0.01
95	1.33	312	1.47	0.14
90	0.99	264	1.21	0.22
85	0.80	232	1.02	0.22
80	0.66	208	0.88	0.22
75	0.56	185	0.76	0.20
50	0.25	110	0.36	0.11
25	0.09	72	0.10	0.01

The damage times range from 11 minutes at the 98th percentile to 1.2 minutes at the 25th percentile. The 25th percentile has a short time to damage due to the small ZOI of 9 cm (3.5 in.) and the rapid growth time of 20 seconds. The growth time quickly puts the target in the flame which, according to the tables in Appendix H of NUREG/CR-6850, is associated with a 1 minute time to damage.

To assess reasonableness of the time to damage values in Table 5-5, a comparison is made against the experimental data. The time to damage was computed for each experiment using the HRR for that experiment along with the vertical TP ZOI determined for that test (see the test report [9] for details on determining the ZOI values for the tests). This was used to create a list of peak HRRs and times to damage, which was expanded using R and the normalized test weights covered in Section 3.2.3. The results are plotted as individual points in Figure 5-18. There is a significant amount of scatter in the data. The red dot-dot-dash line shows the values from Table 5-5. The solid black line is the median time to damage for the experiments, which was determined by selecting a peak HRR value and finding the median time to damage for all tests within 20% of that value. This was done for peak HRR values starting at 8.9 kW by 50% up to 512 kW (13.3, 20, 30, 45, and so forth). Therefore, the value at 20 kW represents the average time to damage using all tests with a peak HRR between 16.7 and 24 kW. The black dashed lines represent the 14th and 86th percentile (68% of the data or one standard deviation for a normal distribution) times to damage. The Table 5-5 values generally lie below the median curve but above the 14th percentile curve. This indicates that the time to damage predictions are biased conservative but are not bounding times, which meets the goal of improved realism.

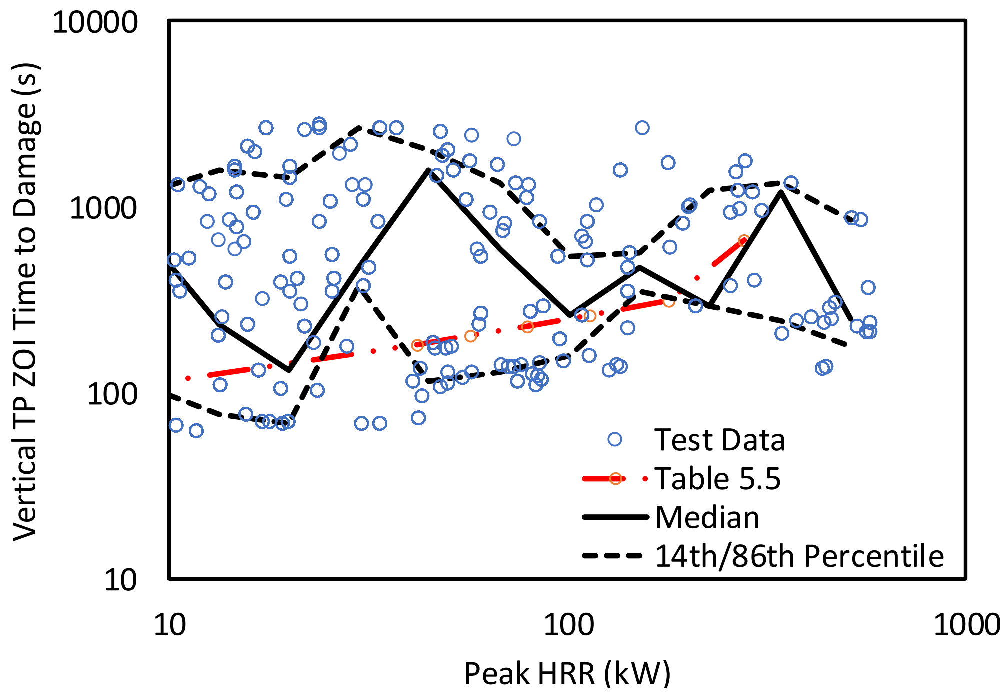

Figure 5-18
Time to damage at the vertical TP ZOI for the experiments along with the times from Table 5-5

Predictions of all times to damage for all three sets of ZOIs (vertical, vertical in a corner, and horizontal) are shown in Tables 5-6 through 5-8, respectively. If the time value is underlined, it indicates that the fit HRR curve did not result in damage at the distribution ZOI. In this case the distribution ZOI was decreased until the fit HRR curve resulted in a time to damage. In the case that no time to damage exists even for a 1 cm ZOI, the damage time was set to 1 minute. In this case the target is essentially exposed to direct flame contact at the onset of the fire where the time to damage is 1 minute. Note that each column uses the ZOI for that specific target. For example, the 75th and 98th rows in the tables would use the ZOI values from Table 4-1 for each column in the tables.

Table 5-6
Time to damage for the vertical ZOI using the parameters from Table 5-4 along with the ZOIs based on Table 4-1

%	Vertical ZOI Time to Damage (s)				
	SE	**TP**	**KC**	**TS**	**TI**
98	283	<u>671</u>	481	370	294
95	239	312	310	308	240
90	199	264	264	259	197
85	173	232	233	227	176
80	159	208	209	203	159
75	146	185	187	180	144
50	98	110	112	108	94
25	<u>70</u>	72	73	71	68

Table 5-7
Time to damage for the vertical in a corner ZOI using the parameters from Table 5-4 along with the ZOIs based on Table 4-1

%	Vertical in a Corner ZOI Time to Damage (s)				
	SE	TP	KC	TS	TI
98	285	691	540	364	300
95	240	320	318	316	245
90	200	273	271	267	199
85	173	242	240	236	178
80	159	218	216	212	162
75	145	195	193	189	147
50	98	117	116	113	96
25	70	74	77	73	69

Table 5-8
Time to damage for the horizontal ZOI using the parameters from Table 5-4 along with the ZOIs based on Table 4-1

%	Horizontal ZOI Time to Damage[1] (s)				
	SE	TP	KC	TS	TI
98	272	745	468	351	60
95	227	713	520	921	60
90	188	751	597	927	60
85	167	798	745	924	60
80	152	783	716	930	60
75	137	741	691	60	60
50	89	60	60	60	60
25	68	60	60	60	60

The following observations are made on the results in the tables:

- The method of defining the fire curve results in a time-to-plume temperature damage that generally decreases with fire size. A decrease in the lower bound of the time to damage as a function of fire size can be seen in Figure 5-18. The reason for this decrease is the fire duration. The 25th percentile fire releases 0.03 MJ of energy and lasts 3 minutes. The 98th percentile fire releases 123 MJ of energy and lasts 28 minutes. If a fire lasts only 3 minutes including the decay period, the time available to damage a target is less than for a fire lasting 28 minutes.
- For the vertical ZOI and the vertical ZOI in a corner, sensitive electronics (SE) has the shortest time to damage followed by TI. This is primarily due to the limited data available for predicting either TI or damage to SE. In both cases there is only a threshold temperature or heat flux provided in either FAQ 16-0011 [13] or NUREG/CR-6850 [1].
- For the vertical ZOI and vertical ZOI in a corner, the times to damage are generally similar for a given percentile.

For the horizontal ZOI, as the damage exposure threshold increases (for example, 3 kW/m^2 for SE to 25 kW/m^2 for TI), there are fewer cases where a time to damage is predicted using the distribution ZOI. This is an artifact of using a gamma distribution for the ZOI combined with the method used to determine the ZOI in the test report [9], which limited the ZOI to a minimum value of 5 cm (2 in.). Table 5-9 shows the ZOI based on Table 4-1 and the actual ZOI based on the parameters in Table 5-4 for the largest percentile in Table 5-8 where the distribution ZOI did not result in damage. Note that there is no entry in Table 5-9 for SE because all SE entries in Table 5-4 had a time to damage using the fit parameters. It is seen that the ZOI values are all small. In some cases, a slight reduction in the distribution ZOI results in a time to damage using the parameters in Table 5-4. In other cases, where the Table 4-1 ZOI value is very small, such as the TI row in Table 5-9, no ZOI is seen at the limiting value. In these cases, the target needs to be in direct contact or almost in direct contact with the fire for damage to occur. A conservative estimate for the time to damage in these cases would be 1 minute, which is the minimum time to damage based on the guidance in NUREG/CR-6850 Appendix H for flame impingement. Although this will not allow for any significant credit for suppression, the small ZOI means that apportioning the fire frequency for a horizontal target by the floor area fraction where the fire could be located should result in low risk contributions in most cases.

Table 5-9
Actual ZOI using the parameters from Table 5-4 versus the ZOIs based on Table 4-1 for the largest no target damage percentile for each ZOI in Table 5-8

Distribution	%	Table 4-1 ZOI (m)	Table 5-4 ZOI (m)
TP	85	0.136	0.135
KC	80	0.079	0.067
TS	95	0.088	0.085
TI	98	0.049	0.000

5.3.2 TCCL Transient Fire Distribution

The exercise in Section 5.3.1 is repeated in this section for the TCCL transient fire distribution. Table 5-10 shows the detailed modeling parameters for a selection of percentiles.

Table 5-10
HRR parameters and key FDT^S parameters for a selection of percentiles for the TCCL transient fire distribution

%	Peak HRR (kW)	TER (MJ)	t_g (s)	n_1	t_p (s)	n_2	t_d (s)	Q^*	Max D (m)	L_f (m)	z_0 (m)
98	143	59.9	301	2.7	25	0.32	1290	0.54	0.57	1.13	0.03
95	95.3	37.4	281	2.7	15	0.32	1244	0.54	0.48	0.96	0.02
90	62.0	22.3	256	2.7	5	0.32	1178	0.54	0.41	0.81	0.02
85	44.3	14.7	234	2.7	1	0.32	1108	0.54	0.36	0.71	0.02
80	32.8	10.1	211	2.7	1	0.32	1028	0.54	0.31	0.63	0.01
75	24.6	7.0	190	2.7	1	0.32	949	0.54	0.28	0.56	0.01
50	5.5	0.91	98	2.7	1	0.32	565	0.54	0.15	0.31	0.01
25	0.6	0.035	29	2.7	1	0.32	213	0.54	0.06	0.12	0.00

Table 5-11 shows the time to damage results for the vertical TP ZOI from the base of the fire along with the ZOI based on the parameters in Table 5-10. For the vertical TP ZOI, it is seen that the fire shape parameters result in ZOI values that are approximately 30 cm (1 ft) higher over most of the range of percentiles. Because overall, the fire exposure from the shape parameters is slightly more severe than the fire exposure based on the actual test data, the time to damage values should be biased conservatively.

Table 5-11
Time to damage for targets located on the vertical TP ZOI boundary using the parameters from Table 5-10 along with the ZOI based on Table 4-4

%	ZOI (m)	Time to Damage (s)	Fit HRR ZOI (m)	ΔZOI (m)
98	1.00	271	1.34	0.34
95	0.79	242	1.13	0.34
90	0.62	216	0.92	0.30
85	0.52	197	0.79	0.27
80	0.45	181	0.70	0.25
75	0.62	167	0.96	0.34
50	0.22	116	0.31	0.09
25	0.11	102	0.11	0.00

The damage times range from 4.5 minutes at the 98th percentile to 1.7 minutes at the 25th percentile. The 25th percentile has a short time to damage due to the small ZOI of 0.11 m (4.3 in.) and the rapid growth time of 29 seconds. The growth time quickly puts the target in the flame which, according to the tables in Appendix H of NUREG/CR-6850, is associated with a 1 minute time to damage.

Predictions of all times to damage for all three sets of ZOIs (vertical, vertical in a corner, and horizontal) are shown respectively in Tables 5-12 through 5-14. If the time value is underlined, it indicates that the fit HRR curve did not result in damage at the distribution ZOI and that the values represent instead the fit ZOI. In the case that no time to damage exists even for a 1 cm ZOI, the damage time was set to 1 minute. In this case the target is essentially exposed to direct flame contact where the time to damage is 1 minute.

Table 5-12
Time to damage for the vertical ZOI using the parameters from Table 5-10 along with the ZOIs based on Table 4-4

%	Vertical ZOI Time to Damage (s)				
	SE	TP	KC	TS	TI
98	208	270	271	261	203
95	184	241	242	233	183
90	167	216	217	209	165
85	156	197	198	191	152
80	146	181	182	176	141
75	138	473	168	162	131
50	104	116	117	114	97
25	74	102	116	82	73

Table 5-13
Time to damage for the vertical in a corner ZOI using the parameters from Table 5-10 along with the ZOIs based on Table 4-4

%	Vertical in a Corner ZOI Time to Damage (s)				
	SE	TP	KC	TS	TI
98	210	276	278	274	207
95	186	248	249	245	185
90	168	224	223	219	168
85	157	205	204	201	156
80	147	189	188	185	145
75	139	176	174	171	136
50	105	123	122	119	101
25	74	152	125	116	75

Table 5-14
Time to damage for the horizontal ZOI using the parameters from Table 5-10 along with the ZOIs based on Table 4-4

%	Horizontal ZOI Time to Damage (s)				
	SE	**TP**	**KC**	**TS**	**TI**
98	243	472	416	413	60
95	206	534	467	961	60
90	177	623	597	983	60
85	160	799	745	60	60
80	145	791	753	60	60
75	133	766	723	60	60
50	92	60	60	60	60
25	70	60	60	60	60

6
DISCUSSION OF PROJECT UNCERTAINTIES

This section of the report covers the potential sources of uncertainties that occur in the distributions and input data developed in Sections 4 and 5. In general, it is difficult to quantify the exact magnitude of these uncertainties. A list of the major elements where uncertainties may be introduced is discussed in Sections 6.1 through 6.4 and summarized below:

- Experimental design
  - Test items
  - Ignition sources
  - Hood calorimetry
- Derived data
  - Diameter
  - Zone of influence (ZOI)
  - Growth and decay
- Creation of probabilistic distributions
- Detailed fire modeling guidance

6.1 Experimental Design

Full details of the experimental design, including detailed descriptions of test items, descriptions of ignition sources, and the test setup and instrumentation, can be found in the test report [9]. The experimental uncertainties are also presented in the test report.

6.1.1 Test Items

Test item uncertainty relates to the types of items selected and the sizes of fuel packages as they relate to the spectrum of events seen in operational experience. Event descriptions in the EPRI fire events database (FEDB) [16] are generally sparse in detail. Efforts were made to select test items believed to be reasonable surrogates of actual transient combustibles in a nuclear power plant (NPP). One item, the laptop+cart test item consisting of a two-shelf plastic work cart, laptop, and printer was selected purposefully to capture the most severe transient fire event seen in operational experience. This event also had a detailed description in the FEDB. There are a few items that arguably may not be reasonable surrogates (for example, the non-fire-resistant (FR) treated canvas tarp and the plastic patio chair); however, in the end those items had a very low weighting and do not contribute significantly to final probabilistic risk assessment (PRA) guidance. There are a couple of items where the testing was more toward a worst-case configuration—for example mop+bucket, but no mop alone and the mop+bucket was dry. Overall although there is uncertainty in the relationship between the test items and the operating experience, there is likely some conservatism in the test items.

6.1.2 Ignition Sources

Like the selection of test items, the ignition sources were selected to be representative of those seen in NPP events. The actual energy content and intensity of ignition sources in NPP events is, however, unknown. If the selected ignition sources were biased to conservative source strengths, this could have resulted in faster fire growth rates (lower time to damage) and more complete burning for some test items. Some ignition sources had conservative aspects to them, but the net effect on the end PRA guidance is believed to be low. This conclusion is based on the following observations:

- The lighter is a very brief, very low intensity source that was only used for items that were easy to ignite; this does not add any noticeable conservatism.
- The radiant panel was set to a higher heat flux than one would likely see from a work light. However, the items it was used for did not sustain a significant fire. Therefore, although the source was conservative, the outcome was not.
- The heptane wick is also a longer duration ignition source and longer than some sources expected in a plant. In most cases, items where the wick was used were easily ignited and the source duration did not have a large impact on the outcome (cardboard boxes, trash bags, personnel protective equipment [PPE] bags). In some cases (for example, temporary blower duct), no significant fire resulted. Although the wick burned for minutes, its heat release rate (HRR) is low (~1–2 kW) and the additional hazard contributed by the wick itself is near zero. For a few items such as the plastic tarps and the stack of PPE, the longer duration wick may have exacerbated the fire. It is possible that the fire-retardant tarp might not have seen as large an HRR as it did if it had a shorter duration ignition source.
- The continuous flame is like the wick in that it is a long duration source. Many items it was used for did not ignite or did not result in a significant fire—for example, the various wood items. This source was used to drive the laptop and cart to ignition, but that was intentional to reproduce an actual plant event that resulted in sprinkler operation. This was necessary to give credibility to the overall results. For items such as the water hose and the large rope, the continuous flame probably resulted in somewhat larger fires than would have occurred with a shorter duration source. Most of those tests had a small fire size, but one hose test and one large rope test did get a larger fire; however; those cases where full involvement of the fuel package occurred represent a very small portion of the fire frequency used in developing the distributions.

6.1.3 Hood Calorimetry

The time-dependent HRR, the total energy release (TER), and the yields of carbon monoxide (CO) and soot were measured through oxygen consumption calorimetry using a hood to collect the combustion products from the fire.

Due to its design, the hood imposes a small amount of smoothing to the HRR signal. There is a short residence time in the hood and its attached duct that results in mixing of combustion products over a short time interval. This means that very sharp peaks in HRR will be smoothed and have a slightly lower peak HRR. Longer duration peaks will not be affected as much. This is a nonconservative effect. Overall, the HRR measurement has an 11% uncertainty.

However, the TER is not affected by the time smoothing. The TER is the time integration of the HRR. That integrated measurement is not affected by mixing in the hood and duct because eventually all of the combustion products are exhausted. As an integrated value, random fluctuations in the HRR are expected to average out in time and the total error for the TER is less than that for the HRR. The same applies to the CO and soot measurements. The uncertainty for these measurements respectively ranges from 2% to 10% and from 15% to 18% with the higher values applying for smaller TERs. This is due to the resolution of the load cell used for mass loss, which limits the accuracy for small mass losses.

6.1.4 Other Test Data

Data such as temperature, heat flux, and mass loss are not expected to have a conservative or nonconservative bias. These quantities are also not drivers of the PRA modeling guidance. They were used in the test report to validate the approaches used to determine the ZOIs for test items.

6.2 Derived Data

Full details of the how derived data were obtained from the experiments and their uncertainties can be found in the test report [9].

6.2.1 Fire Diameter and Effective Elevation

The maximum diameter was estimated from test video and test photos. This process is not expected to have a bias. When doing the ZOI calculations, the fire diameter was scaled to HRR to preserve the burning rate at the maximum diameter. At low fire sizes, this probably underestimates the diameter. This will have a nonconservative effect on the vertical ZOI and a conservative effect on the horizontal ZOI. However, this effect will be small because it is the fire period around the peak that primarily determines the ZOI. The very early growth has little impact on the ZOI, and the late decay period is beyond the time to damage.

The effective fire elevation was estimated based on the observed burning behavior of test items near the peak HRR. The selected value in Section 5.2.1 of 15 cm (6 in.) is the 85th percentile elevation and does provide a degree of conservatism without being a large bounding value.

6.2.2 ZOI

The ZOI is computed using the Fire Dynamics Tools (FDT^S). The correlations used include the McCaffery plume temperature [31] and solid flame model [4] along with the heat soak approach [4]. Damage criteria for sensitive electronics (SE), thermoplastic (TP), and thermoset (TS) cables were taken from NUREG/CR-6850 [1]. Damage criteria for Kerite-FR cables were developed in the test report [9] using data from NUREG/CR-7102 [39]. These all contain conservatisms. The total estimated uncertainty in the ZOI values are 20% for vertical and 16% for horizontal. This incorporates the uncertainty of the correlations and the uncertainty in the test data used as input (for example, the HRR and fire diameter).

Comparison of FDT^S predicted temperature and heat flux with that measured during the test showed that the FDT^S were conservative. When used to compute the time to damage at the location of test instrumentation (temperature or heat flux), the FDT^S usage had faster times to damage. This suggests that the overall ZOI values are also conservative; however, these calculations were done for thermoplastic (TP), which has a rapid decrease in time to damage as a function of temperature.

The heat soak method also introduces conservatism. For TP, Kerite-FR, and TS cables, the heat soak uses time to damage derived from experiments. The Appendix H data in NUREG/CR-6850 Volume II [1] took all of the penlight test results for all of the cables in a plastic category, plotted them, and drew a bounding curve that was then tabulated. This means that the damage times will be conservative for larger diameter cables because larger cables have more mass and require a longer time to heat. The bulk cable tray ignition (TI) uses the new ignition temperature from FAQ 16-0011 [13]. There are not many available data to base a time to TI on, and a 1 minute time was assumed. This is probably conservative; however, this ZOI is small and, therefore, its impact on risk is not likely to be large. Sensitive electronics have no test data for time to damage. As with the trays, a 1 minute time was assumed at the threshold temperature from NUREG/CR-6850. The exposed SE ZOIs are probably very conservative because at the threshold temperature it is likely that multiple minutes are needed before damage occurs. The impact of this on a PRA, however, will be limited because many SE are contained in an enclosure of some form. Enclosed SE would use the TS ZOIs (that is, based on FAQ 13-0004 [12]), which are not as conservative as the exposed SE ZOIs.

6.3 Growth, Plateau, and Decay Parameters

The growth and decay parameters were determined from visual inspection of plots of the HRR of tests. The fire endpoint is a known fixed value based on there being no more visible flame during testing. The time the ignition source was applied is also a known point in time. Uncertainty in these parameters relates to picking the growth time and the plateau time. The decay time is whatever remains. For most fires, there is a single significant peak in the HRR, and there is little uncertainty in the time one would pick to identify that peak. Some fires have multiple peaks where the first peak may not be the dominant peak. Different individuals might select very different peak times for such fires; however, most fires did not have this behavior, and the largest fires did not have this behavior. The growth exponent was picked to try to match the shape of the top of the peak. This was done using a power law fit to the data. Many fires exhibit a pre-growth phase where the burning intensity remains low for a period of time before taking off. Matching the shape of the curve for these fires means using a starting point other than the ignition point for determining the growth exponent. This introduces uncertainty, into the growth exponent, which is not easily quantified. The length of the plateau also has some uncertainty to it. No fire actually burns at a fixed peak rate for a length of time. In most of the fires, however, there is a clear point where the HRR begins a rapid and continuous drop. Although the selection of when that point begins may vary, it is not likely to be a large variance in actual time. Similar to the growth exponent, the decay exponent is picked to try to visually match the HRR curve at the start of the decay. Doing this requires a power law fit that is limited to some portion of the decay data starting at the end of the plateau. This introduces uncertainty into the decay exponent that is not easily quantified.

The growth and decay parameters impact the time to damage and, to some extent, hot gas layer (HGL) calculations when doing detailed modeling. The screening ZOIs use the actual test data in the development of those distributions. It is the time to the peak and the shape of the curve near the peak that drives the time to damage. The method for analyzing the growth and decay portions of the HRR curve generally does well in capturing the final growth to peak and the initial part of the decay. There is some conservatism on the decay side. The plateau does have some conservatism to it. In the test data, fires are only briefly at the exact peak and most of the plateau region is at a lower fire size. The fire characterization used assumes the HRR remains at its peak for the entire duration of the plateau. This will result in a decrease in the time to damage. The HGL is determined by the total energy released, as well as the shape of the curve. The growth and decay shape for detailed modeling preserves the total energy. There should be a lesser impact of the plateau conservatism on the HGL. Full details of the process and the determined parameters can be found in the test report [9] and in Appendix A for the additional tests from Section 2.2.

6.4 Creation of Probabilistic Distributions

The creation of probabilistic distributions used the following four-step process:

1. **Section 3.2.1**. Apportion all of the challenging and potentially challenging transient events in the EPRI FEDB into categories. How this is done will have some effect on the distributions. Most FEDB events are easily categorized (that is—the only fuel mentioned is rags or wood or cardboard). Some events require judgment. This subjectivity was accounted for by having multiple independent assessments of the events. This should limit the possibility for a significant conservatism due to this process. All categories had uncertainty to them that is covered within the section.
2. **Section 3.2.2**. Apportion all of the test fuel packages to the FEDB categories. Similar to step 1, this will have some effect on the distributions because some fuel packages require judgment as to which category is the best fit. The same process used in Step 1—multiple independent assessments—was applied.
3. **Section 3.2.3**. Within each category, weight the individual fuel packages. This was also done by multiple independent assessments. It is likely that each assessor tended to be conservative. Engineers are trained to consider margin in design applications, and that has likely carried over into this assessment—that is, it is likely that rare events (the large box) were assigned weights that biased high. This likely shifted the distributions to the right (more severe) a small amount.
4. **Section 3.3**. Fit a gamma distribution to the data. The probability-probability plots in Appendix D provide an indication of goodness of fit for the distributions.

6.5 Inputs for Detailed Modeling

Inputs for detailed fire modeling consist of the heat of combustion, Q*, yields, and the fire growth parameters, as follows:

- **Heat of combustion**. This parameter has little impact on the resulting risk. The recommended value is a midpoint value. This parameter should be neutral in terms of PRA conservatism.
- **Q***. Lower values increase the vertical ZOI, and higher values increase the horizontal ZOI. For the HGL, lower values result in deeper but cooler HGL, and higher values result in a shallower but hotter HGL. The recommended value is a midpoint value of the range of fire sizes of most interest. This parameter should be neutral in terms of PRA conservatism.
- **Yields**. For yields, the recommendation is for the 75% yield values. These only apply to abandonment type calculations. These are also consistent with published guidance for doing performance-based design for commercial and residential structures; however, the recommended values do have some conservatism.
- **Fire growth parameters**. These are difficult to evaluate. There are no clear trends in the rate of growth or decay. There are some trends relating the length of the decay to steady-state plateau and to the growth time. When used in detailed modeling, the growth parameters need to achieve a number of objectives: get the right peak HRR, get the right TER, get the right ZOIs, and do it all with a simple formula for the shape of the HRR curve. This cannot be done perfectly because real fire curves are not simple. The parameters generated get the correct HRR and the TER. They are slightly conservative for ZOI (generally off by 10–20 cm [4–8 in.]). The resulting time to damage appears to be biased slightly conservative when compared with median values based on the experiments.

7 COMBINING NEW DATA WITH EXISTING PRAS

Although the largest benefit of the distributions and input data in this report will be seen by using the entire data set developed, it is possible to combine portions of the data with this report with existing fire probabilistic risk assessments (FPRAs) data. Potential options include the following:

- Use the complete set of distributions and input data developed in Sections 4 and 5. Although this requires the largest effort, it should also yield the largest benefit.
- Rescreen targets using the new zone of influence (ZOI) distributions while maintaining time to damage calculations using the NUREG/CR-6850 heat release rate (HRR) distribution and NUREG/CR-6850 Supplement 1 growth times. The use of the ZOI distributions in this report may result in the screening of additional targets. For those targets remaining, the use of the more severe NUREG/CR-6850 distribution will mean faster times to damage than those that would be computed using the data in this report. For example, Table 5-5 shows that the vertical TP time to damage at the 98th percentile ZOI of 1.78 minutes is 671 seconds. Using the 98th percentile NUREG/CR-6850 fire of 317 kW with a 2 minute growth time and a fire Froude (Q^*) number of 1 would result in a time to damage of 150 seconds.
- The NUREG/CR-6850 HRR distribution can be used with the new detailed fire modeling parameters. This requires first determining the equivalent percentile in the new distribution in order to obtain the total energy release (TER) for use in determining the growth time and decay time. For example, the old 75th percentile of 142 kW is equivalent to the 92.6th percentile in the new distribution, which has a TER of 56 MJ. The values of 142 kW and 56 MJ would then be used as inputs to Equations 5-2 through 5-4.
- For fire sizes above the 50th percentile HRR in the new generic distribution, the NUREG/CR-6850 Supplement 1 approach of a 2 minute, t^2 growth can be used with the new HRR and TER distributions. For example, for the new 98th percentile fire of 278 kW and 123 MJ, the fire could be modeled with 120 second t^2 growth followed by a constant 404 second plateau (404 seconds at 278 kW plus the growth gives 123 MJ). At or below the 50th percentile and the new detailed modeling parameters give growth times less than 2 minutes.
- In some cases, a FPRA may have a set of tables of the time to damage based on an ignition source, a percentile, and a distance from the ignition source. In this case, one can substitute the new HRR distribution and maintain the old time to damage for the closest larger percentile. For example, the 90th percentile peak HRR from the NUREG/CR-6850 distribution is 206 kW. With a 2 minute growth time and a fire Froude (Q^*) number of 1, at 1 m above the fire, the time to damage would be 115 seconds. The 90th percentile using the gamma distribution in Table 4-1 is 114 kW. With the same 2 minute growth time and a fire Froude (Q^*) number of 1, for targets at 1 m above the fire, the time to damage would be 136 seconds. This is an 18% increase in the time to damage; however, it is not as much increase as using the full set of data in this report, which would give a time to damage of 266 seconds. When doing this, the goal would be to select the tabulated HRR nearest to and larger than the value from the HRR distribution in Table 4-1. For example, if one had transient fires tabulated in 25 kW increments, one would use the 125 kW fire, which would be the closest value still larger than 114 kW.

- As covered in Section 5.2.2, the effects of soot and CO are related to their total production rates, which are a function of the soot and CO yields, the heat of combustion, and the HRR of the fire. A 100 kW fire with a 5% soot yield and a 20 MJ/kg heat of combustion will make twice as much soot as a 100 kW fire with a 5% soot yield and a 40 MJ/kg heat of combustion. This is because the first fire must burn twice as much fuel to achieve the same HRR as the second fire. Based on this, an existing main control room (MCR) abandonment calculation can be evaluated against the yields in Section 5.2.2. If a higher effective soot yield was used, then the abandonment time could be reevaluated. For example, if a MCR abandonment calculation used a 20 MJ/kg heat of combustion with a 4.5% soot yield, this would be equivalent to a 5.6% soot yield using the heat of combustion of 25 MJ/kg in Section 5.2.1 ($25/20 \times 4.5 = 5.6$). This is larger than the recommended value of 5.2% in Section 5.2.2. This means that the existing fire modeling output files could be revaluated to reflect the fact that the soot yield used was effectively 8% too high. Typically, abandonment is based on visibility, which is inversely proportional to soot density, and soot density is proportional to the soot yield. For this example, the existing model outputs could be reprocessed at 93% (1/1.08) of the abandonment visibility threshold to account for the soot yield. Therefore, if a visibility of 3 m was used in the abandonment calculation, in this example the modeling output files could be reprocessed for a visibility of 2.8 m.

8
SUMMARY AND CONCLUSIONS

This report documents the working group's effort to combine the data collected in the testing phase [9] with data from previous experimental programs and to develop a methodology for weighting the combined data set based on industry experience with transient fires. The combined data set, covered in Section 2, consisting of 307 fire experiments involving 110 fuel packages, was used to develop the probabilistic distributions for peak heat release rate (HRR), total energy release (TER), and zones of influence (ZOI) for transient fires. ZOI values are included for vertical, vertical in a corner, and horizontal for exposed sensitive electronics (SE), thermoplastic (TP) cables, Kerite-FR cables (KC), thermoset (TS) cables, and bulk cable/tray ignition (TI). Additionally, this report recommends input values for the detailed fire modeling of transient fires that includes fire growth and decay parameters, yields of minor products of combustion, heat of combustion, and the physical size and effective elevation of the fire.

The distributions were created by weighting each experiment based on the challenging or potentially challenging transient fire events in the EPRI fire events database (FEDB) [16]. This process, which was covered in Section 3, involved categorizing each transient FEDB event to a predefined list of fuel categories, assigning each experiment to a predefined fuel category, and then weighting the individual events within each category. This process resulted in individual weights for each of the 307 experiments.

The weighted set of test data was used to develop two generic sets of distributions. The first set is a generic fire transient distribution intended as a replacement for the current transient fire distribution in Appendix G of NUREG/CR-6850 [1]. The second set is a transient combustible control location (TCCL) distribution. This is a less severe distribution, and it is intended for use in plant locations that meet the TCCL definition in Section 3.3.1.1.

The statistical programming language R was used to process the weighted test data into empirical cumulative distribution functions. Gamma distributions were then fit to the empirical functions. These distributions are presented in Section 4.1 for the generic transient fire distributions and in Section 4.2 for the TCCL transient fire distributions. Additional investigation of the sensitivity of the distributions is examined in Sections 4.1.1 and 4.1.2. The recommended gamma distributions are shown in Tables 4-1 and 4-4. These tables also contain values of the distributions at the 75th and 98th percentiles to support target screening. These tables are repeated for convenience as Tables 8-1 and 8-2.

Table 8-1
Recommended generic transient fire distributions of peak HRR, TER, and ZOI

Distribution		Distribution Percentiles		Gamma Distribution Parameters	
		75th	**98th**	α	β
HRR (kW)		41.6	278	0.271	141
TER (MJ)		11.8	123	0.184	77.1
Vertical ZOI (m)	SE	1.90	5.49	0.954	1.44
	TP	0.56	1.78	0.768	0.525
	KC	0.53	1.64	0.814	0.470
	TS	0.45	1.47	0.748	0.439
	TI	0.41	1.33	0.760	0.395
Vertical in a corner ZOI (m)	SE	3.27	9.47	0.943	2.50
	TP	0.99	2.96	0.872	0.816
	KC	0.91	2.74	0.873	0.754
	TS	0.79	2.43	0.829	0.687
	TI	0.71	2.18	0.827	0.618
Horizontal ZOI (m)	SE	0.21	1.05	0.374	0.450
	TP	0.09	0.36	0.501	0.132
	KC	0.07	0.22	0.723	0.0666
	TS	0.05	0.11	1.42	0.0233
	TI	0.03	0.05	7.63	0.00345

Table 8-2
Recommended TCCL transient fire distributions of Peak HRR, TER, and ZOI

Distribution		Distribution Percentiles		Gamma Distribution Parameters	
		75th	98th	α	β
HRR (kW)		24.6	143	0.314	67.3
TER (MJ)		7.0	59.9	0.214	34.5
Vertical ZOI (m)	SE	1.44	3.26	1.76	0.604
	TP	0.40	1.00	1.33	0.218
	KC	0.38	0.94	1.36	0.203
	TS	0.32	0.80	1.36	0.173
	TI	0.29	0.76	1.25	0.171
Vertical in a corner ZOI (m)	SE	2.54	5.64	1.86	1.01
	TP	0.71	1.69	1.53	0.34
	KC	0.66	1.59	1.47	0.328
	TS	0.57	1.40	1.43	0.292
	TI	0.52	1.26	1.44	0.263
Horizontal ZOI (m)	SE	0.15	0.68	0.43	0.273
	TP	0.06	0.17	0.977	0.0442
	KC	0.05	0.10	1.93	0.0175
	TS	0.03	0.05	7.63	0.00343
	TI	0.03	0.05	7.63	0.00342

Detailed fire modeling parameters were developed using the same set of weighted test data minus tests with low HRRs. A summary of these parameters is given in Table 5-3 and repeated as Table 8-3. ΔH_C and Q^* are median values based on the test data. Median was used for these parameters because ΔH_C is not a risk-determining parameter and median for Q^* avoids biasing ZOI values toward one direction (for example, vertical or horizontal) and away from the other. Soot and CO yields are the 75th percentile values. This adds a degree of conservatism to a fire probabilistic risk assessment (FPRA) without the use of bounding values that introduce significant non-realism. The fire elevation, z_e, was set to the 85th percentile. This also adds a slight amount of conservatism to the FPRA without being a bounding value that introduces significant non-realism. The remaining parameters either are directly taken from the probabilistic distributions or are derived from the probabilistic distributions in a manner designed to reasonably replicate the percentile ZOI given a percentile peak HRR and TER.

Table 8-3
Summary of input parameters for detailed modeling

Parameter	Recommended Value	Uncertainty Range[1]	Comment
Peak HRR (kW)	Distribution in Table 4-1 or Table 4-4	N/A	Determined by the percentile fire being modeled.
TER (MJ)	Distribution in Table 4-1 or Table 4-4	N/A	Determined by the percentile fire being modeled.
ΔH_C (MJ/kg)	25	15–35	When using a generic HRR curve, varying ΔH_C does not impact ZOI or hot gas layer. Note that the species yield range already incorporates the variance in the ΔH_C of test items. If ΔH_C is changed, yields need to be rescaled to preserve the effective hazard.
Q^*	0.54	0.23–1.2	
z_e (m)	0.15	0.00–0.71	Effective elevation of the base of the fire above the local floor height.
Soot yield (kg/kg)	0.052	0.012–0.136	Note that the yield values are tied to the selected ΔH_C.
CO yield (kg/kg)	0.043	0.024–0.068	Note that the yield values are tied to the selected ΔH_C.
Growth exponent n_1	2.7	1.1–6.8	Changing exponents must be propagated through Equations 5-2 through 5-6.
Decay exponent n_2	0.32	0.14–0.45	Changing exponents must be propagated through Equations 5-2 through 5-6.
Growth time t_g (s)	Equation 5-2 or 5-5	300–4090*	First use Equation 5-2. Switch to Equation 5-5 if plateau time is set to 1 second. *Uncertainty range applies to the 690 constant in Equation 5-2.
Plateau time t_p (s)	Equation 5-4 or 1 second	N/A	First, determine the growth and decay time. If plateau is less than 1 second, set to 1 second and redo growth time and decay time.
Decay time t_d (s)	Equation 5-3 or 5-6	2200–9560*	First use Equation 5-3. Switch to Equation 5-6 if plateau time is set to 1 second. *Uncertainty range applies to 3940 constant in Equation 5-3.

[1]Range is the equivalent of one standard deviation (16th and 84th percentiles) except for soot and CO, which are 41st to 98th, and z_e, which is 79th to 98th.

The distributions in Tables 4-1 and 4-4 were used to develop a set of bins for use in determining severity factors (SFs). These bins and their key detailed fire modeling parameters are shown in Tables 8-4 and Table 8-5. The tables show the peak HRR, the TER, the fire growth and decay parameters, the maximum diameter computed using Q^* and the peak HRR, the flame height computed using Heskestad's correlation [31], and the virtual origin used in the plume temperature correlation [31]. Note: This is not the same as the 15 cm [6 in.] effective floor elevation.

Table 8-4
Generic transient fire HRR bins, fire growth parameters, and key Fire Dynamics Tools (FDT^S) parameters for determining SF

Bin Width %	Peak HRR (kW)	TER (MJ)	t_g (s)	n_1	t_p (s)	t_d (s)	n_2	Q^*	Max D (m)	L_f (m)	z_0 (m)
2	278	123	322	2.7	39	1311	0.32	0.54	0.74	1.48	0.03
1	253	111	317	2.7	37	1301	0.32	0.54	0.71	1.42	0.03
1	217	92.9	309	2.7	33	1283	0.32	0.54	0.67	1.34	0.03
2	181	74.7	298	2.7	28	1258	0.32	0.54	0.62	1.24	0.03
2	147	58.5	286	2.7	23	1227	0.32	0.54	0.57	1.14	0.03
2	124	47.3	275	2.7	19	1197	0.32	0.54	0.54	1.07	0.02
5	94	33.9	257	2.7	12	1146	0.32	0.54	0.48	0.96	0.02
5	67.0	22.0	233	2.7	5	1074	0.32	0.54	0.42	0.84	0.02
5	48.7	14.5	209	2.7	1	993	0.32	0.54	0.37	0.74	0.02
5	35.6	9.60	185	2.7	1	902	0.32	0.54	0.33	0.65	0.01
10	22.2	5.06	150	2.7	1	768	0.32	0.54	0.27	0.54	0.01
10	11.3	1.97	109	2.7	1	594	0.32	0.54	0.21	0.41	0.01
10	5.2	0.65	73	2.7	1	431	0.32	0.54	0.15	0.30	0.01
15	1.54	0.11	38	2.7	1	251	0.32	0.54	0.09	0.18	0.00
25	0.045	0.001	5	2.7	1	47	0.32	0.54	0.02	0.04	0.00

Table 8-5
TCCL transient fire HRR bins, fire growth parameters, and key FDT[S] parameters for determining SF

Bin Width %	Peak HRR (kW)	TER (MJ)	t_g (s)	n_1	t_p (s)	t_d (s)	n_2	Q^*	Max D (m)	L_f (m)	z_0 (m)
2	143	60	301	2.7	25	1290	0.32	0.54	0.57	1.13	0.03
1	131	54	297	2.7	22	1282	0.32	0.54	0.55	1.09	0.02
1	114	45.8	290	2.7	19	1266	0.32	0.54	0.52	1.03	0.02
2	95.3	37.4	281	2.7	15	1244	0.32	0.54	0.48	0.96	0.02
2	78.7	29.8	270	2.7	11	1216	0.32	0.54	0.45	0.89	0.02
2	66.8	24.5	261	2.7	7	1190	0.32	0.54	0.42	0.83	0.02
5	52.0	18.0	246	2.7	2	1147	0.32	0.54	0.38	0.76	0.02
5	38.0	12.1	222	2.7	1	1067	0.32	0.54	0.33	0.67	0.01
5	28.4	8.4	200	2.7	1	988	0.32	0.54	0.30	0.59	0.01
5	21.4	5.8	180	2.7	1	910	0.32	0.54	0.27	0.53	0.01
10	14.0	3.28	151	2.7	1	794	0.32	0.54	0.22	0.45	0.01
10	7.7	1.44	115	2.7	1	641	0.32	0.54	0.18	0.35	0.01
10	3.9	0.55	82	2.7	1	490	0.32	0.54	0.13	0.27	0.01
15	1.3	0.12	47	2.7	1	311	0.32	0.54	0.09	0.17	0.00
25	0.063	0.001	8	2.7	1	76	0.32	0.54	0.03	0.05	0.00

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A
SUMMARY OF PRIOR TESTING

This appendix contains the heat release rate (HRR) and other test derived data for the experiments identified in Section 2.2.

A.1 Tests from NUREG/CR-4680

This section contains the HRR data and the test summary data for the nine tests from NUREG/CR-4680 [17] included in the distributions. Plots of the HRR also show the curve resulting from the fitting fire growth and decay parameters according to Equation 5-1 (see Figures A-1 through A-9).

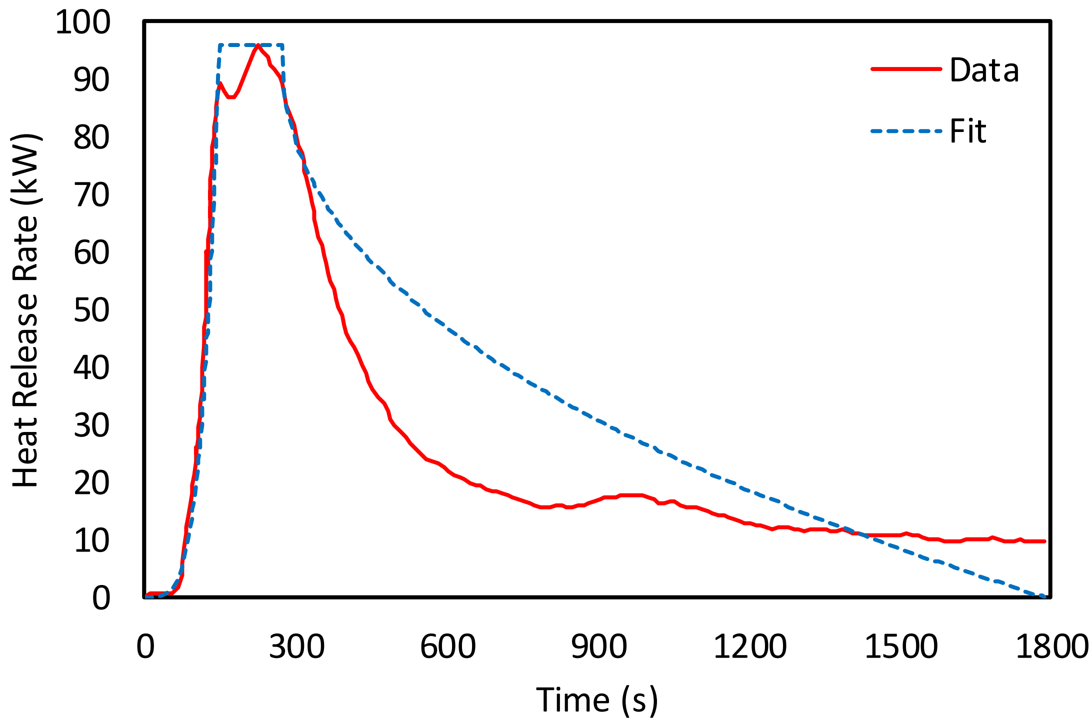

Figure A-1
HRR for Nowlen Test 1 (30 cm x 41 cm x 30 cm cardboard box with box of Kimwipes, 950 ml acetone, polyethylene wash bottle)

Summary details for the test are as follows:

Peak HRR (kW): 95.9	TER (MJ): 45.7		ΔH_c (MJ/kg): 25.6	
Vertical zone of influence (ZOI) (m):				
SE	TP	KC	TS	TI
0.55	0.15	0.15	0.15	0.15
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
0.95	0.30	0.25	0.25	0.25
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.70	0.15	0.10	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
149	123	1515	4.178	0.438

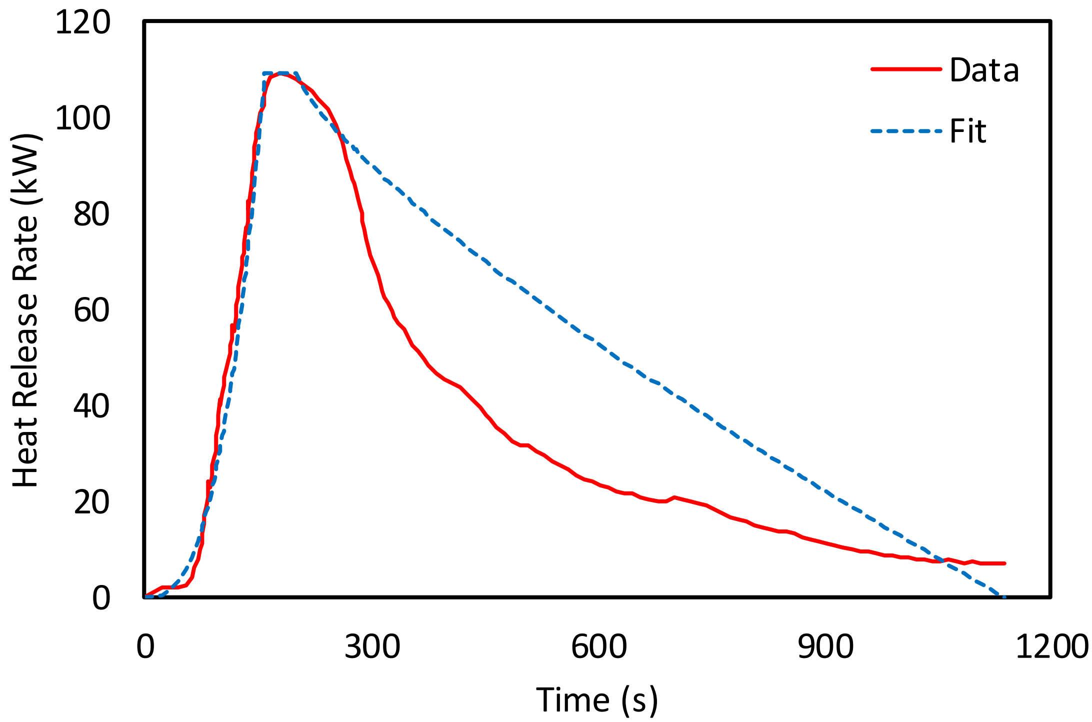

Figure A-2
HRR for Nowlen Test 2 (30 cm x 41 cm x 30 cm cardboard box with box of Kimwipes, 950 ml acetone, polyethylene wash bottle)

Summary details for the test are as follows:

Peak HRR (kW): 109.3		TER (MJ): 38.4		ΔH_c (MJ/kg): 21.6
Vertical ZOI (m):				
SE	TP	KC	TS	TI
2.5	0.80	0.75	0.65	0.65
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
4.30	1.35	1.25	1.15	1.05
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.80	0.15	0.10	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
159	41	939	2.745	0.773

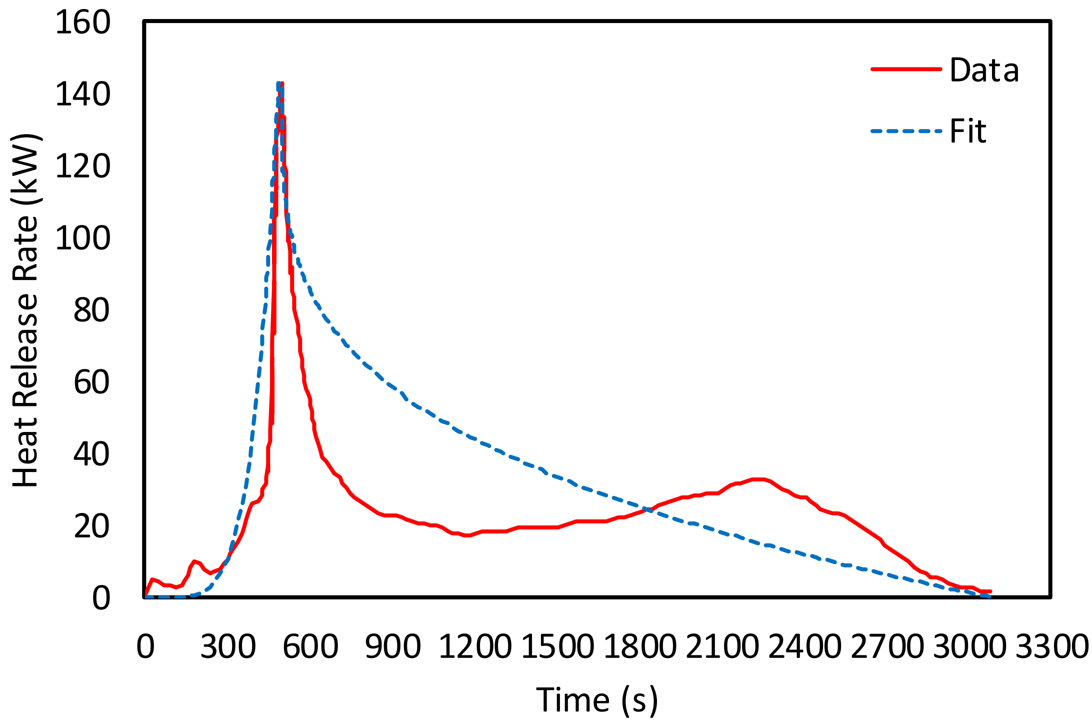

Figure A-3
HRR for Nowlen Test 3 (2.5 gal polyethylene bucket with box of Kimwipes, 950 ml acetone, polyethylene wash bottle)

Summary details for the test are as follows:

Peak HRR (kW): 142.9	TER (MJ): 71.8	ΔH_c (MJ/kg): 33.0		
Vertical ZOI (m):				
SE	TP	KC	TS	TI
2.60	0.85	0.80	0.75	0.70
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
4.50	1.45	1.40	1.25	1.25
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.65	0.20	0.15	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
487	13	2581	5.424	0.282

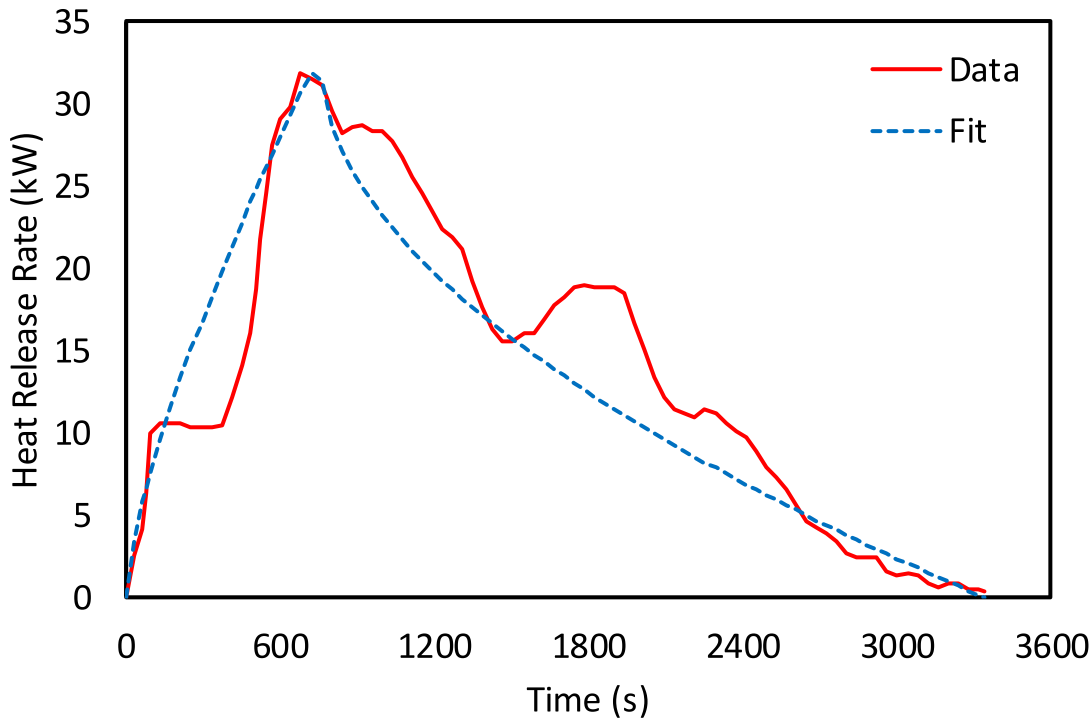

Figure A-4
HRR for Nowlen Test 4 (2.5 gal polyethylene bucket with box of Kimwipes, 950 ml acetone, polyethylene wash bottle)

Summary details for the test are as follows:

Peak HRR (kW): 31.8		TER (MJ): 46.8		ΔH_c (MJ/kg): 27.6
Vertical ZOI (m):				
SE	TP	KC	TS	TI
2.65	0.95	0.90	0.75	0.65
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
4.60	1.60	1.50	1.25	1.05
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.40	0.15	0.10	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
722	39	2576	0.720	0.545

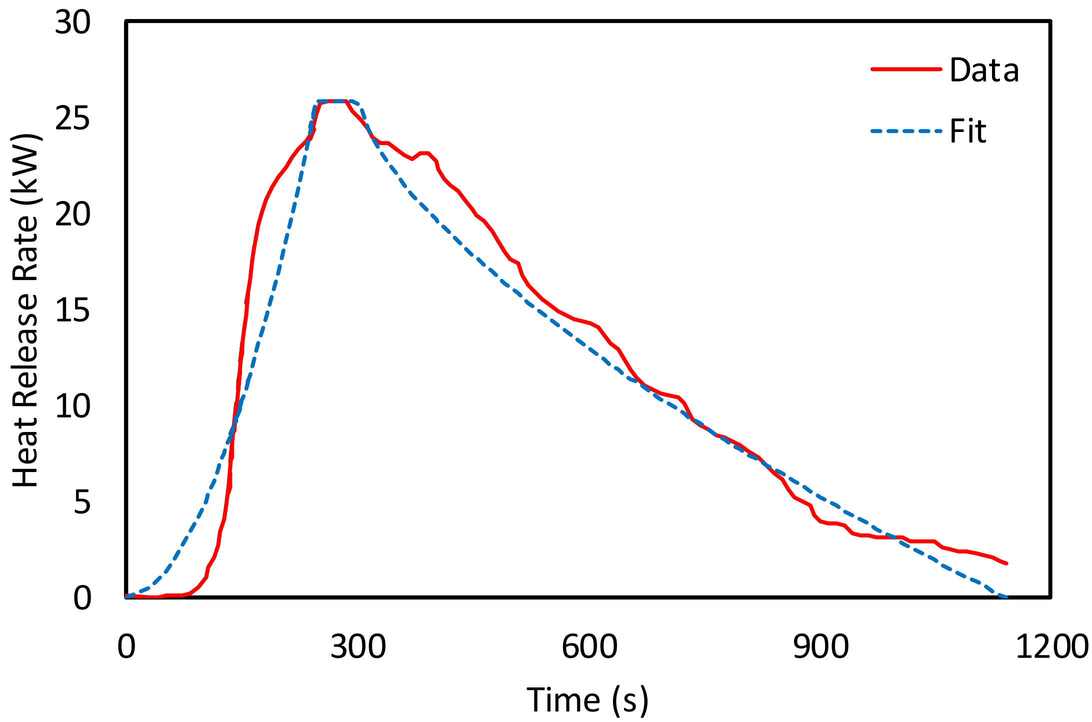

Figure A-5
HRR for Nowlen Test 5 (30 cm x 41 cm x 30 cm cardboard box with computer paper and crumpled paper)

Summary details for the test are as follows:

Peak HRR (kW): 25.9		TER (MJ): 13.0		ΔH_c (MJ/kg): 13.0
Vertical ZOI (m):				
SE	TP	KC	TS	TI
0.25	0.05	0.05	0.05	0.05
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
0.50	0.15	0.10	0.10	0.10
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.30	0.05	0.05	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
247	56	837	1.888	0.670

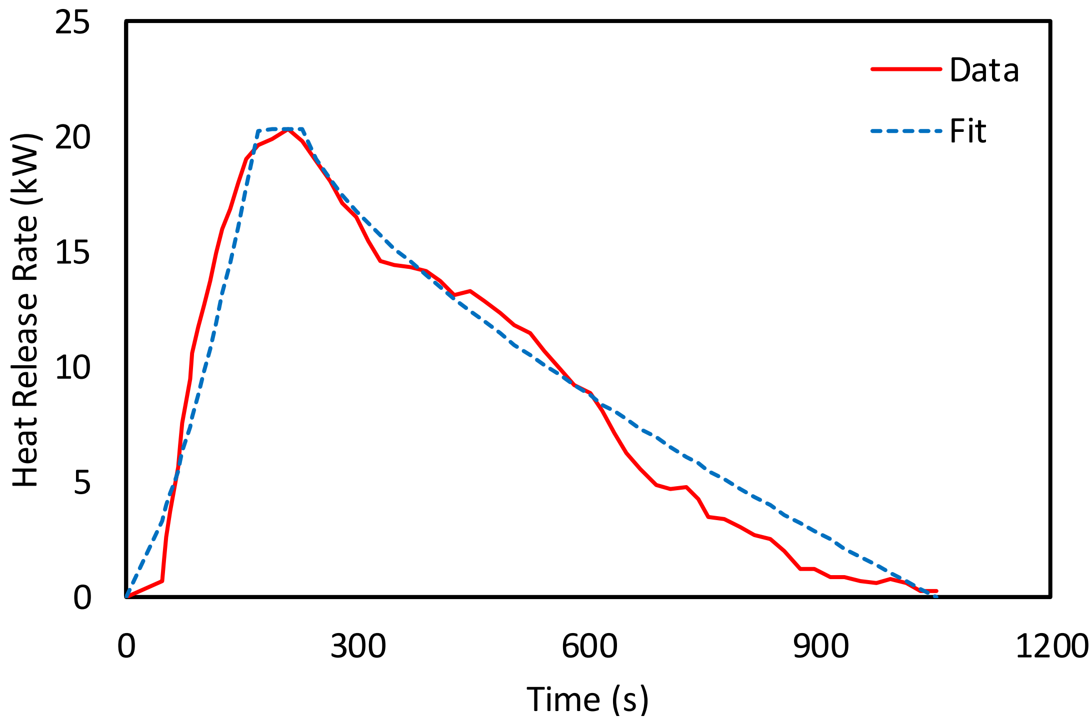

Figure A-6
HRR for Nowlen Test 6 (30 cm x 41 cm x 30 cm cardboard box with computer paper and crumpled paper)

Summary details for the test are as follows:

Peak HRR (kW): 20.3		TER (MJ): 9.2		ΔH_c (MJ/kg): 11.5
Vertical ZOI (m):				
SE	TP	KC	TS	TI
2.00	0.50	0.50	0.40	0.35
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
3.45	0.80	0.75	0.60	0.50
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.30	0.05	0.05	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
172	57	821	1.395	0.712

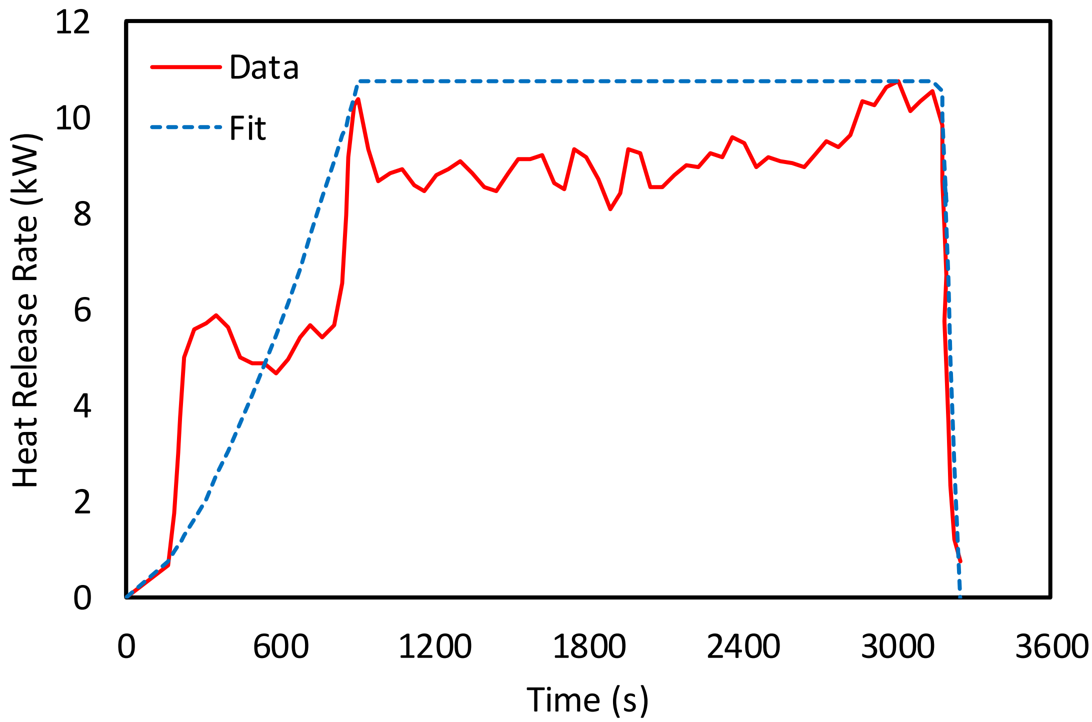

Figure A-7
HRR for Nowlen Test 7 (5 gal polyethylene trash can, polyethylene bag, cotton rags, paper)

Summary details for the test are as follows:

Peak HRR (kW): 10.8		TER (MJ): 25.2		ΔH_c (MJ/kg): 31.5
Vertical ZOI (m):				
SE	TP	KC	TS	TI
1.60	0.55	0.50	0.35	0.30
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
2.70	0.90	0.75	0.60	0.45
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.20	0.05	0.05	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
907	2268	68	1.545	0.930

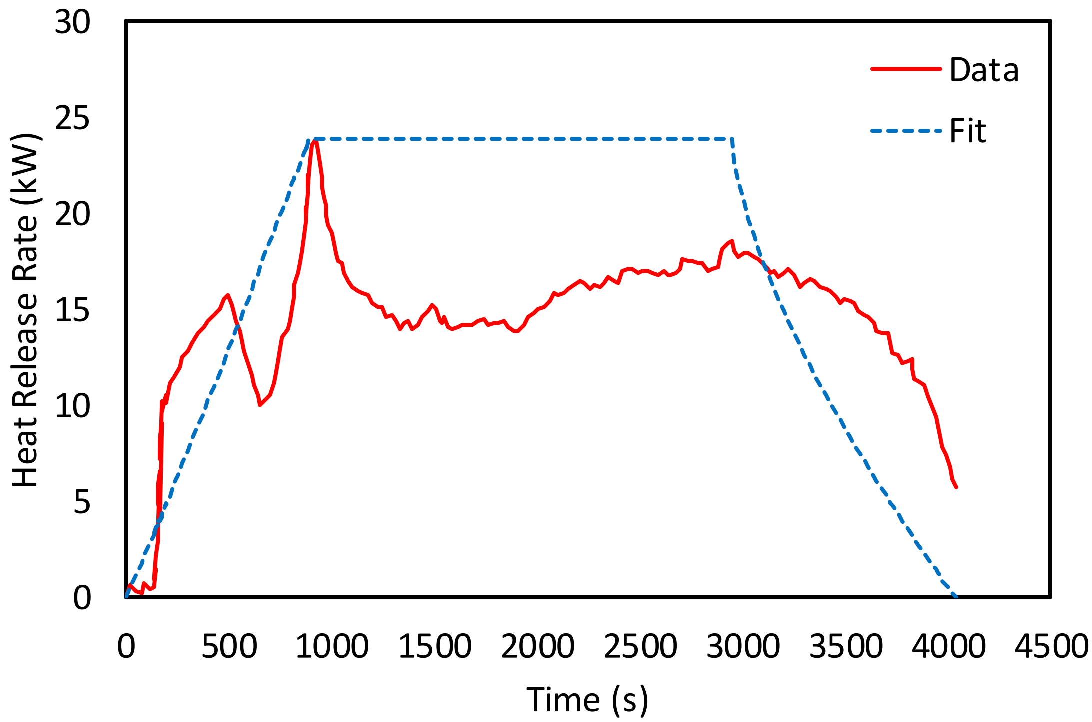

Figure A-8
HRR for Nowlen Test 8 (5 gal polyethylene trash can, polyethylene bag, cotton rags, paper)

Summary details for the test are as follows:

Peak HRR (kW): 23.9	TER (MJ): 58.5		ΔH_c (MJ/kg): 38.0	
Vertical ZOI (m):				
SE	TP	KC	TS	TI
0.50	0.15	0.15	0.10	0.10
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
0.90	0.25	0.25	0.20	0.20
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.30	0.10	0.05	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
897	2049	1088	1.060	0.673

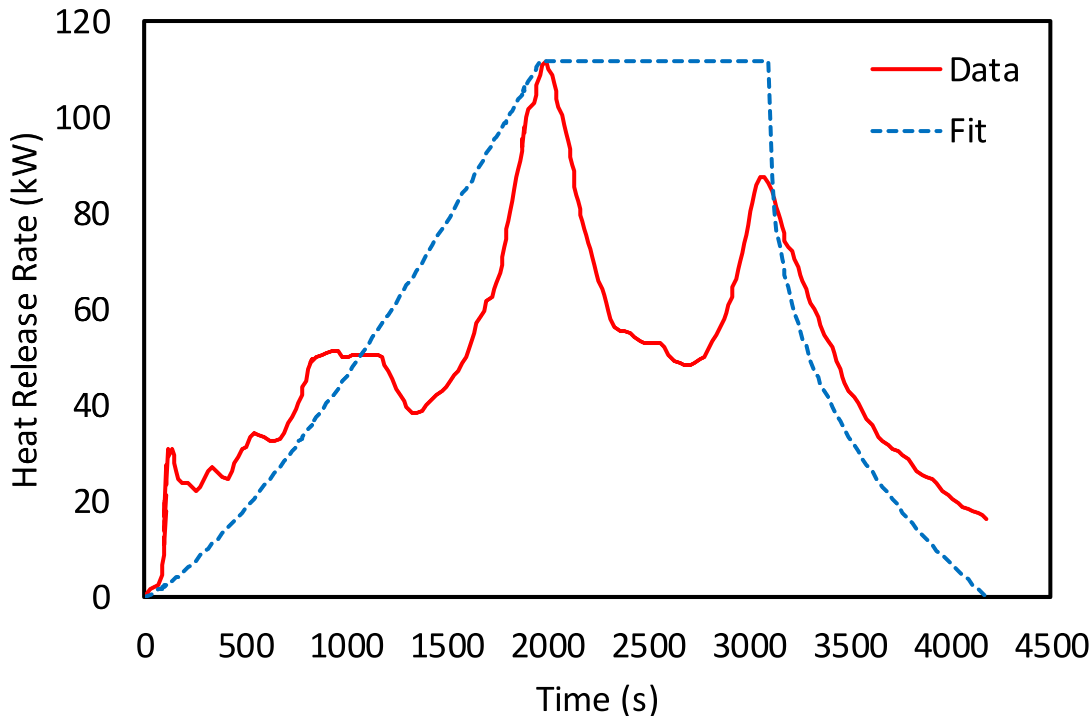

Figure A-9
HRR for Nowlen Test 9 (30 gal polyethylene trash can, polyethylene bag, cotton rags, paper)

Summary details for the test are as follows:

Peak HRR (kW): 111.5		TER (MJ): 206.3		ΔH_c (MJ/kg): 32.1
Vertical ZOI (m):				
SE	TP	KC	TS	TI
4.25	1.45	1.35	1.15	0.95
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
7.30	2.45	2.25	1.85	1.50
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.80	0.40	0.25	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
1961	1137	1082	1.318	0.355

A.2 Tests from NBSIR 85-3195

This section contains the HRR data and the test summary data for the two tests from the test report [18] included in the distributions (see Figures A-10 and A-11).

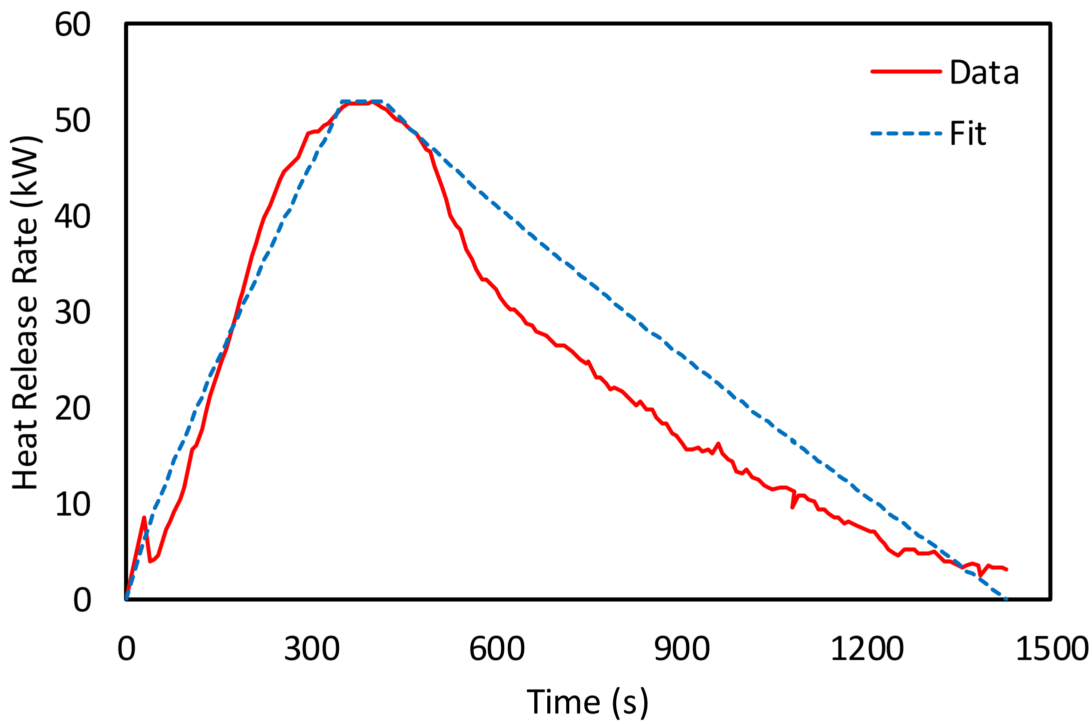

Figure A-10
HRR for Lee fabric pile test (30 cm stack of clothing ~2.7 kg)

Summary details for the test are as follows:

Peak HRR (kW): 51.8	TER (MJ): 32.9	ΔH_c (MJ/kg): 12.2		
Vertical ZOI (m):				
SE	TP	KC	TS	TI
3.25	1.05	1.00	0.85	0.80
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
5.60	1.80	1.70	1.45	1.30
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.50	0.15	0.10	0.05	0.05
Fire Growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
352	71	1005	0.854	0.907

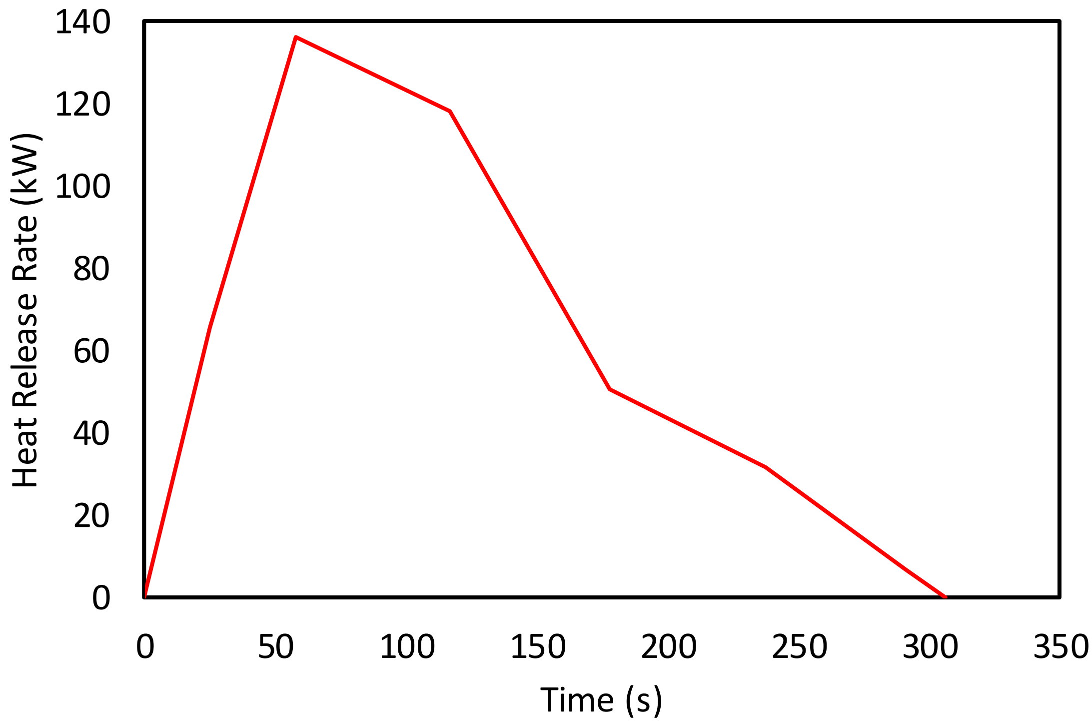

Figure A-11
HRR Volkinburg single airline trash bag test (one 11 gal trash bag with 12 polystyrene cups, 17 paper cups, and paper towels)

Summary details for the test are as follows:

Peak HRR (kW): 136.1		TER (MJ): 20.3		ΔH_c (MJ/kg): 17.3
Vertical ZOI (m):				
SE	TP	KC	TS	TI
4.75	1.50	1.45	1.30	1.25
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
8.20	2.60	2.45	2.20	2.15
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.85	0.15	0.10	0.10	0.05

Note: Growth and decay parameters were not created due to the very low temporal resolution of the test data (only seven points from test start to end).

A.3 Tests from NUREG/CR-4679

This section contains the HRR data and the test summary data for the two tests from NUREG/CR-4679 [21] included in the distributions (see Figures A-12 and A-13).

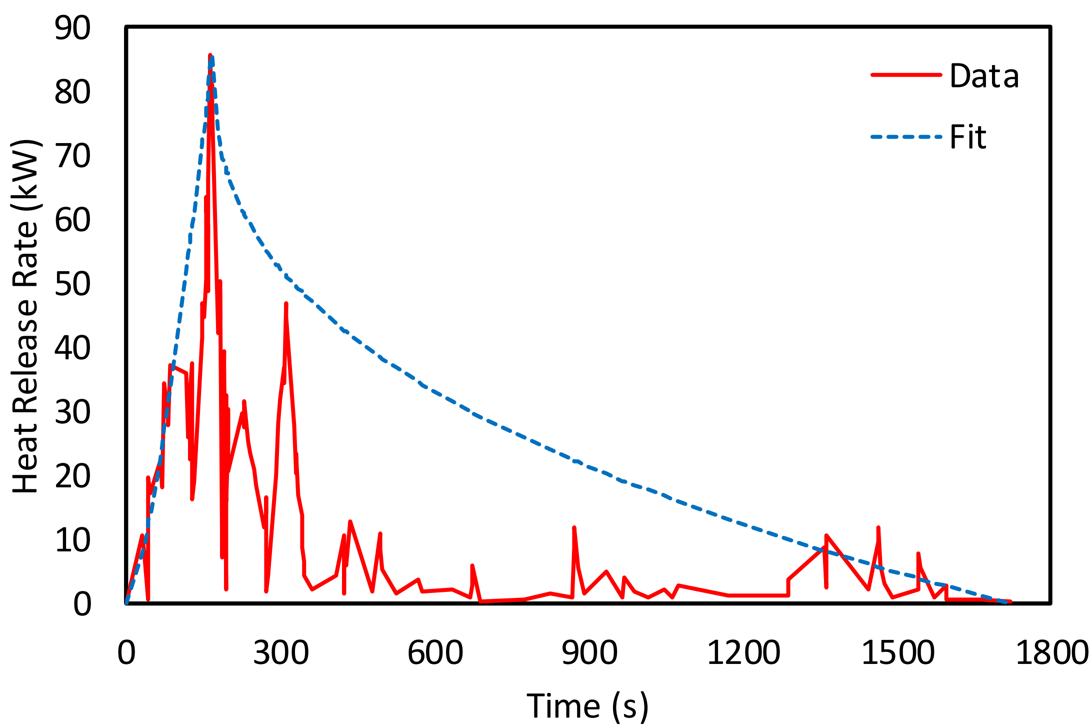

Figure A-12
HRR for Lawson metal framed chair with foam seat test

Summary details for the test are as follows:

Peak HRR (kW): 85.5		TER (MJ): 12.9		ΔH_c (MJ/kg): N/A
Vertical ZOI (m):				
SE	TP	KC	TS	TI
2.80	0.85	0.80	0.70	0.65
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
4.85	1.45	1.35	1.20	1.05
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.40	0.05	0.05	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
168	2	1551	1.445	0.382

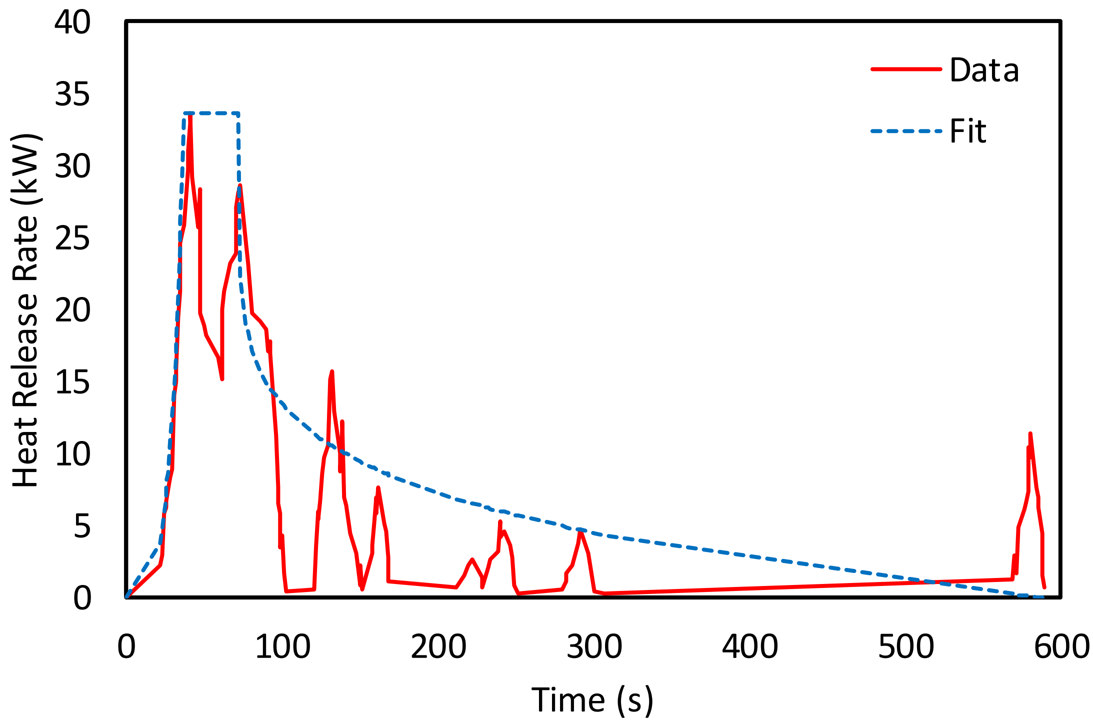

Figure A-13
HRR for Lawson metal framed chair with fiberglass seat test

Summary details for the test are as follows:

Peak HRR (kW): 33.6	TER (MJ): 2.4	ΔH_c (MJ/kg): N/A		
Vertical ZOI (m):				
SE	TP	KC	TS	TI
1.95	0.45	0.45	0.40	0.35
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
3.30	0.75	0.70	0.60	0.55
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
0.25	0.05	0.05	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
38	35	516	3.991	0.174

A.4 WPI Waste Bag Tests

This section contains the HRR data and the test summary data for the four Worcester Polytechnic Institute (WPI) waste bag tests [22] included in the distributions (see Figures A-14 through A-17).

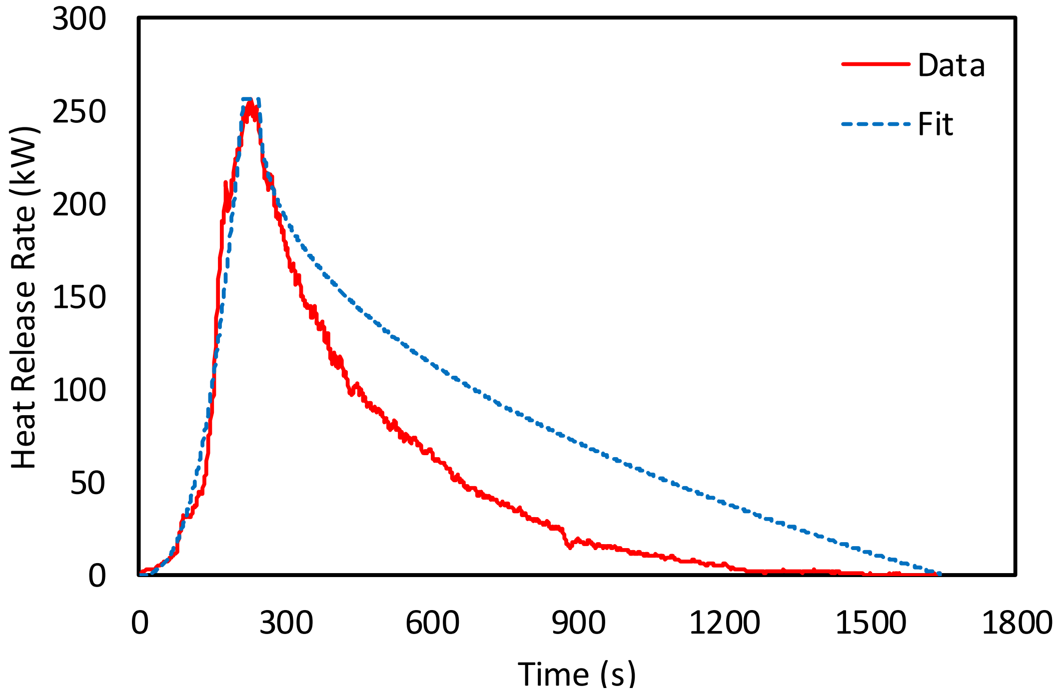

Figure A-14
HRR for WPI quarter waste bag Test 1 (One polyethylene bag with approximately six groupings of the following: a pair of shoe covers, two balls of masking tape, four yellow gloves, two cotton gloves, and one black rubber overshoe)

Summary details for the test are as follows:

Peak HRR (kW): 256.4	TER (MJ): 82.1	ΔH_c (MJ/kg): 27.8		
Soot yield (kg/kg): 0.122				
Vertical ZOI (m):				
SE	TP	KC	TS	TI
5.55	1.50	1.40	1.20	1.15
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
9.50	2.40	2.25	1.90	1.80
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
1.15	0.30	0.20	0.05	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
214	33	1402	2.623	0.426

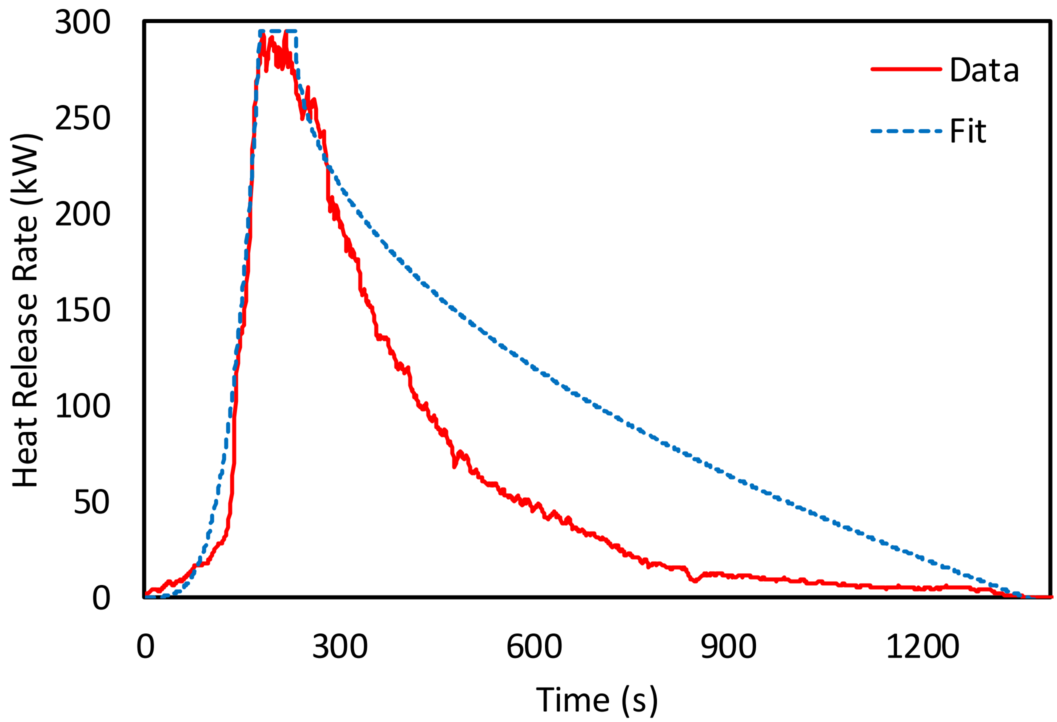

Figure A-15
HRR for WPI quarter waste bag Test 2 (One polyethylene bag with approximately six groupings of the following: a pair of shoe covers, two balls of masking tape, four yellow gloves, two cotton gloves, and one black rubber overshoe)

Summary details for the test are as follows:

Peak HRR (kW): 295.2		TER (MJ): 81.2		ΔH_c (MJ/kg): 21.4
Soot yield (kg/kg): 0.122				
Vertical ZOI (m):				
SE	TP	KC	TS	TI
6.05	1.65	1.55	1.35	1.30
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
10.35	2.65	2.5	2.15	2.00
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
1.25	0.30	0.20	0.10	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
179	54	1128	3.705	0.4641

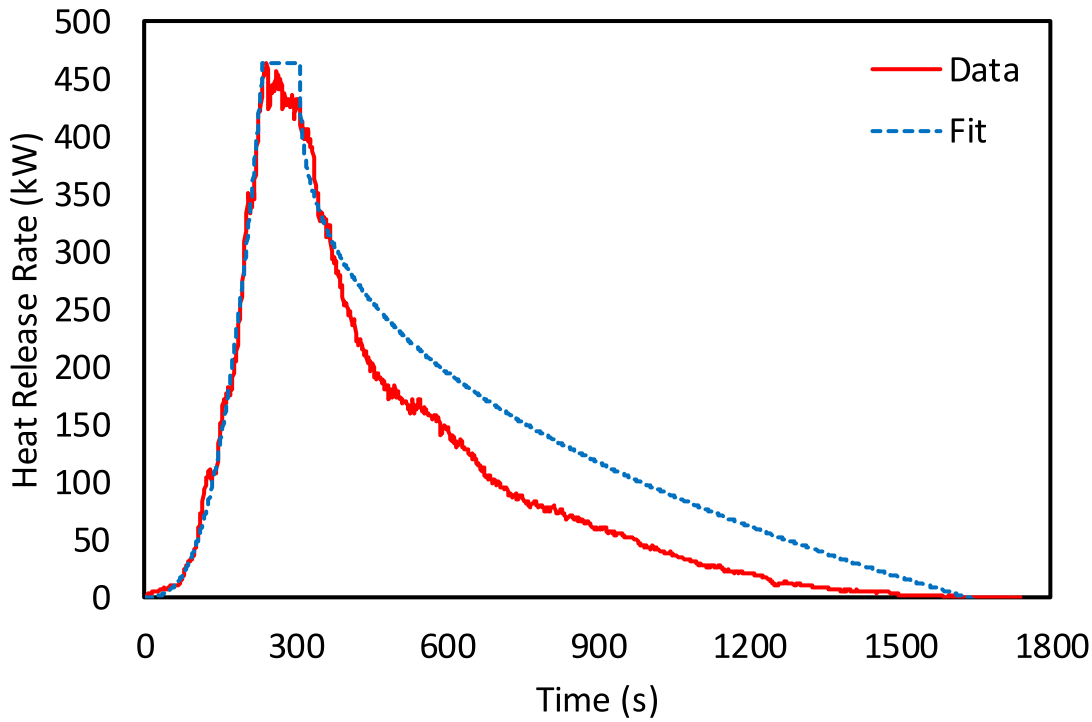

Figure A-16
HRR for WPI half waste bag Test 3 (One polyethylene bag with approximately 12 groupings of the following: a pair of shoe covers, two balls of masking tape, four yellow gloves, two cotton gloves, and one black rubber overshoe)

Summary details for the test are as follows:

Peak HRR (kW): 463.3		TER (MJ): 170.8		ΔH_c (MJ/kg): 28.1
Soot yield (kg/kg): 0.104				
Vertical ZOI (m):				
SE	TP	KC	TS	TI
6.05	1.65	1.55	1.35	1.30
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
10.35	2.65	2.5	2.15	2.00
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
1.25	0.30	0.20	0.10	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
235	74	1323	2.789	0.362

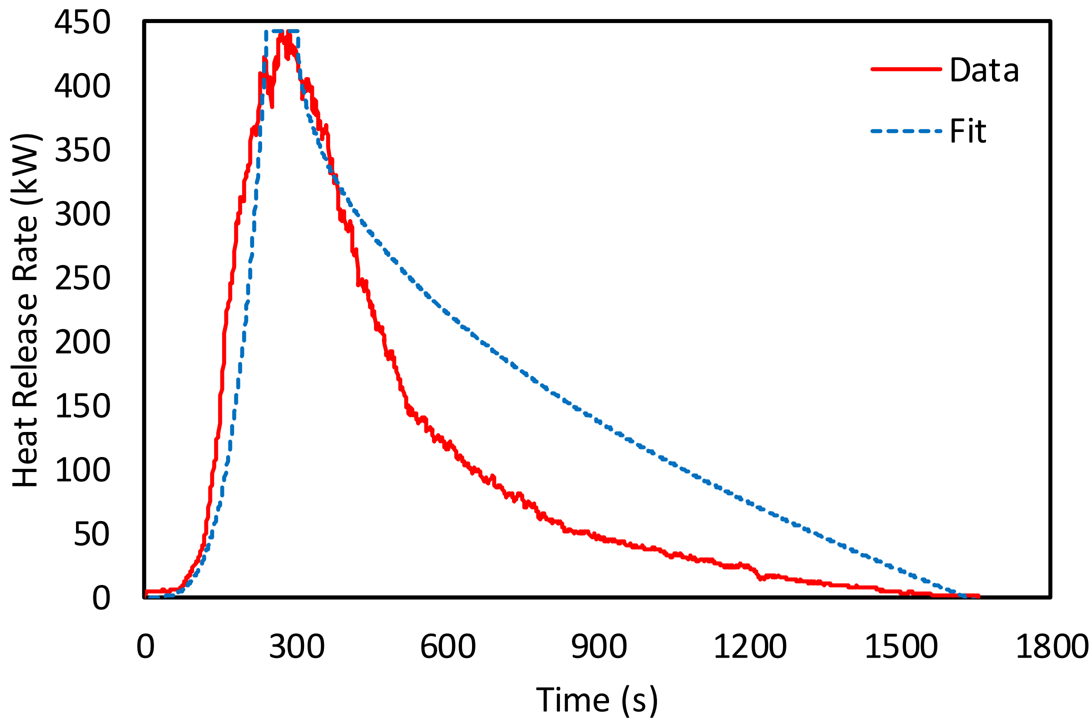

Figure A-17
HRR for WPI half waste bag Test 4 (One polyethylene bag with approximately 12 groupings of the following: a pair of shoe covers, two balls of masking tape, four yellow gloves, two cotton gloves, and one black rubber overshoe)

Summary details for the test are as follows:

Peak HRR (kW): 442.7	TER (MJ): 167.2		ΔH_c (MJ/kg): 27.9	
Soot yield (kg/kg): 0.100				
Vertical ZOI (m):				
SE	TP	KC	TS	TI
6.05	1.65	1.55	1.35	1.30
Vertical ZOI in a corner (m):				
SE	TP	KC	TS	TI
10.35	2.65	2.5	2.15	2.00
Horizontal ZOI (m):				
SE	TP	KC	TS	TI
1.25	0.30	0.20	0.10	0.05
Fire growth and decay parameters:				
Growth (s)	Plateau (s)	Decay (s)	n_1	n_2
243	62	1327	3.415	0.465

B
R SCRIPTS

This section contains the R scripts used to process data and create the PRA guidance in Sections 4 and 5. Appendix B.5 contains a brief summary of the process for creating new distributions of heat release rate (HRR), total energy release (TER), and zones of influence (ZOIs). Information about R and installation files for R can be found at https://www.r-project.org.

B.1 Script for Distributions of TER, HRR, and ZOIs

The script in this section creates empirical cumulative distribution functions for TER, HRR, and each of the ZOI categories.

It takes a comma separated value (CSV) file as input. The CSV file should have a header row with column names and a single row for each transient fire test being included in the distributions. The contents of the columns are indicated in the R script where *Frequency* is the integer weighting factor generated from Table 3-7, *Peak HRR* is the peak heat release rate, *MJ* is the total energy released by the fire, and the ZOI column names are *H* for horizontal, *V* for vertical, and *VC* for vertical in a corner. The peak HRR, TER, and ZOI values are tabulated for the 2018 testing program in Appendix B and Appendix D of Reference 9 and in Appendix A of this report for the prior testing summarized in Section 2.2.

The script outputs a file of each parameter in the input CSV file. This output file is a CSV file containing two columns where the first column is a unique data value from the parameter set and the second column is the cumulative distribution function for that data value.

To run the script, change the string for `dirname` to be the path to the working directory containing the CSV file of test data, and change the string for `chid` to the CSV filename without the ".csv" extension.

```
dirname<-''C:/your path to the working directory/'
chid<-'filename'
readfile<-paste(dirname,chid,'.csv',sep="")
indata=read.csv(readfile)
colnames(indata)[1]<-'Frequency'
colnames(indata)[2]<-'Peak HRR'
colnames(indata)[3]<-'MJ'
colnames(indata)[4]<-'H ZOI Sensitive (m)'
colnames(indata)[5]<-'H ZOI TP (m)'
colnames(indata)[6]<-'H ZOI Kerite (m)'
colnames(indata)[7]<-'H ZOI TS (m)'
colnames(indata)[8]<-'H ZOI Tray Ignition (m)'
colnames(indata)[9]<-'V ZOI Sensitive (m)'
colnames(indata)[10]<-'V ZOI TP (m)'
colnames(indata)[11]<-'V ZOI Kerite (m)'
colnames(indata)[12]<-'V ZOI TS (m)'
colnames(indata)[13]<-'V ZOI Tray Ignition (m)'
colnames(indata)[14]<-'VC ZOI Sensitive (m)'
colnames(indata)[15]<-'VC ZOI TP (m)'
```

```
colnames(indata)[16]<-'VC ZOI Kerite (m)'
colnames(indata)[17]<-'VC ZOI TS (m)'
colnames(indata)[18]<-'VC ZOI Tray Ignition (m)'

plotdata<-rep(indata[1:nrow(indata),"Peak HRR"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_hrr.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"MJ"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_mj.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"H ZOI Sensitive
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_hs.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"H ZOI TP
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_htp.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"H ZOI Kerite
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_hk.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"H ZOI TS
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_hts.csv',sep="")
write.csv(outdata,file=outfile)
```

```
plotdata<-rep(indata[1:nrow(indata),"H ZOI Tray Ignition
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_ht.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"V ZOI Sensitive
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vs.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"V ZOI TP
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vtp.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"V ZOI Kerite
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vk.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"V ZOI TS
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vts.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"V ZOI Tray Ignition
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vt.csv',sep="")
write.csv(outdata,file=outfile)
```

```
plotdata<-rep(indata[1:nrow(indata),"VC ZOI Sensitive
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vcs.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"VC ZOI TP
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vctp.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"VC ZOI Kerite
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vck.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"VC ZOI TS
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vcts.csv',sep="")
write.csv(outdata,file=outfile)

plotdata<-rep(indata[1:nrow(indata),"VC ZOI Tray Ignition
(m)"],indata[1:nrow(indata),"Frequency"])
fn<-ecdf(plotdata)
out1<-unique(sort(plotdata))
out2<-fn(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_vct.csv',sep="")
write.csv(outdata,file=outfile)
```

B.2 Script for Histograms of Q^* and Fire Elevation

The script in this section outputs the cumulative distribution functions for Q^* and the fire elevation along with the associated expanded data set.

It takes two CSV files as input. The CSV file should have a header row with column names and a single row for each transient fire test being included in the distributions. The contents of the columns are indicated in the R script where *Fadj* is the integer weighting factor generated from Table 3-7, *HRR* is the peak heat release rate, and the final column is either Q^* or the fire elevation (one file for each). Only include tests in each file where the applicable data exists.

The script outputs two types of files. The first type is a cumulative distribution function file. This output file is a CSV file containing two columns where the first column is a unique data value from the parameter set and the second column is the cumulative distribution function for that data value. The second type is a file containing the expanded data set with a column for peak HRR, and a column for either Q^* or fire elevation. This file consists of Fadj copies of each row in the input file. For example, if Fadj for the first test was 10, the script would write 10 copies of the data for that test. This file allows one to plot one quantity against another and have best fits to the plotted data reflect the actual weight of each test. One set of files is written for both Q^* and the fire elevation.

To run the script, change the string for `dirname` to be the path to the working directory containing the CSV file of test data, and change the string for `chid` to the CSV filename without the “.csv” extension.

```
dirname<-'C:/your path to the working directory/'
chid<-'z filename'

readfile<-paste(dirname,chid,'.csv',sep="")
indata=read.csv(readfile)
colnames(indata)[1]<-'Fadj'
colnames(indata)[2]<-'HRR'
colnames(indata)[3]<-'Z'

HRRdata<-rep(indata[1:nrow(indata),"HRR"],indata[1:nrow(indata),"Fadj"])

Zdata<-rep(indata[1:nrow(indata),"Z"],indata[1:nrow(indata),"Fadj"])
fnZ<-ecdf(Zdata)
out1<-unique(sort(Zdata))
out2<-fnZ(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_den.csv',sep="")
write.csv(outdata,file=outfile)

alldata <- array(c(HRRdata,Zdata),dim=c(length(HRRdata),2))
outfile<- paste(dirname,chid,'_expandeda.csv',sep="")
write.csv(alldata,file=outfile)

chid<-'qstar filename'

readfile<-paste(dirname,chid,'.csv',sep="")
indata=read.csv(readfile)
colnames(indata)[1]<-'Fadj'
colnames(indata)[2]<-'HRR'
colnames(indata)[3]<-'QS'
```

```
HRRdata<-rep(indata[1:nrow(indata),"HRR"],indata[1:nrow(indata),"Fadj"])

QSdata<-rep(indata[1:nrow(indata),"QS"],indata[1:nrow(indata),"Fadj"])
fnQS<-ecdf(QSdata)
out1<-unique(sort(QSdata))
out2<-fnQS(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_qsa_den.csv',sep="")
write.csv(outdata,file=outfile)

alldata <- array(c(HRRdata,QSdata),dim=c(length(HRRdata),2))
outfile<- paste(dirname,chid,'_expandeda.csv',sep="")
write.csv(alldata,file=outfile)
```

B.3 Script for Histograms of Heat of Combustion, Soot Yield, and CO Yield

The script in this section outputs histogram distributions and expanded data sets for ΔH_C, soot yield, and the heat of combustion.

The script takes three CSV files as input. Each CSV file should have a header row with column names and a single row for each transient fire test being included in the distributions. For each CSV file, only include tests for which the applicable data are available. The first column in each file is *Fadj*, which is the integer weighting factor generated from Table 3-7, and the second column in each is either ΔH_C, the soot yield, or the CO yield.

The script outputs a cumulative distribution function file for each parameter. The output files are a CSV file containing two columns where the first column is a unique data value from the parameter set and the second column is the cumulative distribution function for that data value.

To run the script, change the string for `dirname` to be the path to the working directory containing the CSV file of test data, and change the string for each of the three `chid` to the CSV filename containing the quantity being processed next without the .csv extension.

```
dirname<-'C:/your path to the working directory/'
chid<-'hoc filename'

readfile<-paste(dirname,chid,'.csv',sep="")
indata=read.csv(readfile)
colnames(indata)[1]<-'Fadj'
colnames(indata)[2]<-'HoC'

HOCdata<-rep(indata[1:nrow(indata),"HoC"],indata[1:nrow(indata),"Fadj"])
fnHOC<-ecdf(HOCdata)
out1<-unique(sort(HOCdata))
out2<-fnHOC(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_hoc_den.csv',sep="")
write.csv(outdata,file=outfile)

chid<-'co filename'
readfile<-paste(dirname,chid,'.csv',sep="")
indata=read.csv(readfile)
colnames(indata)[1]<-'Fadj'
colnames(indata)[2]<-'YCO'
```

```
YCOdata<-rep(indata[1:nrow(indata),"YCO"],indata[1:nrow(indata),"Fadj"])
fnCO<-ecdf(YCOdata)
out1<-unique(sort(YCOdata))
out2<-fnCO(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_yco_den.csv',sep="")
write.csv(outdata,file=outfile)

chid<-'ys filename'

readfile<-paste(dirname,chid,'.csv',sep="")
indata=read.csv(readfile)
colnames(indata)[1]<-'Fadj'
colnames(indata)[2]<-'YS'

YSdata<-rep(indata[1:nrow(indata),"YS"],indata[1:nrow(indata),"Fadj"])
fnS<-ecdf(YSdata)
out1<-unique(sort(YSdata))
out2<-fnS(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_yS_den.csv',sep="")
write.csv(outdata,file=outfile)
```

B.4 Script for Fire Growth and Decay Parameters

The script in this section outputs the histogram distributions for fire growth and decay parameters.

The script takes a CSV file as input. The CSV file should have a header row with column names and a single row for each transient fire test being included in the distributions. For the CSV file, only include tests for which the fire growth and decay data are available. The first column in each file is *Fadj*, which is the integer weighting factor generated from Table 3-7; the second column in each file is *HRR*, which is the peak heat release rate; the third column is the TER; and the fourth through eighth columns are respectively the fire growth time, the growth exponent, the plateau length, the decay time, and the decay exponent.

The script outputs two types of files. The first type is a cumulative distribution function file for each of the five growth parameters. The output files are a CSV file containing two columns where the first column is a unique data value from the parameter set and the second column is the cumulative distribution function for that data value. The second file is a CSV file containing the expanded peak HRR, TER, and the five fire growth and decay parameters.

To run the script, change the string for `dirname` to be the path to the working directory containing the CSV file of test data, and change the string for `chid` to the CSV filename without the .csv extension.

```
dirname<-'C:/your path to the working directory/'
chid<-'filename'

readfile<-paste(dirname,chid,'.csv',sep="")
indata=read.csv(readfile)
colnames(indata)[1]<-'Fadj'
colnames(indata)[2]<-'HRR'
colnames(indata)[3]<-'MJ'
colnames(indata)[4]<-'Growth'
colnames(indata)[5]<-'n1'
```

```
colnames(indata)[6]<-'Plateau'
colnames(indata)[7]<-'Decay'
colnames(indata)[8]<-'n2'

HRRdata<-rep(indata[1:nrow(indata),"HRR"],indata[1:nrow(indata),"Fadj"])

MJdata<-rep(indata[1:nrow(indata),"MJ"],indata[1:nrow(indata),"Fadj"])

Grdata<-rep(indata[1:nrow(indata),"Growth"],indata[1:nrow(indata),"Fadj"])
fnGr<-ecdf(Grdata)
out1<-unique(sort(Grdata))
out2<-fnGr(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_gr_den.csv',sep="")
write.csv(outdata,file=outfile)

n1data<-rep(indata[1:nrow(indata),"n1"],indata[1:nrow(indata),"Fadj"])
fnn1<-ecdf(n1data)
out1<-unique(sort(n1data))
out2<-fnn1(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_n1_den.csv',sep="")
write.csv(outdata,file=outfile)

Pldata<-rep(indata[1:nrow(indata),"Plateau"],indata[1:nrow(indata),"Fadj"])
fnPl<-ecdf(Pldata)
out1<-unique(sort(Pldata))
out2<-fnPl(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_pl_den.csv',sep="")
write.csv(outdata,file=outfile)

Dedata<-rep(indata[1:nrow(indata),"Decay"],indata[1:nrow(indata),"Fadj"])
fnDe<-ecdf(Dedata)
out1<-unique(sort(Dedata))
out2<-fnDe(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_de_den.csv',sep="")
write.csv(outdata,file=outfile)

n2data<-rep(indata[1:nrow(indata),"n2"],indata[1:nrow(indata),"Fadj"])
fnn2<-ecdf(n2data)
out1<-unique(sort(n2data))
out2<-fnn2(out1)
outdata<-array(c(out1,out2),dim=c(length(out1),2))
outfile<- paste(dirname,chid,'_n2_den.csv',sep="")
write.csv(outdata,file=outfile)

alldata <-
array(c(HRRdata,MJdata,Grdata,n1data,Pldata,Dedata,n2data),dim=c(length(n2data),7))
outfile<- paste(dirname,chid,'_expanded_shape.csv',sep="")
write.csv(alldata,file=outfile)
```

B.5 Creating New Distributions of Peak HRR, TER, and ZOI

This section provides instructions for creating new distributions of peak HRR, TER, and ZOI.

1. Ensure that R is installed on the computer being used to create the distributions. R can be obtained from https://www.r-project.org. The project home page contains a download link containing a list of mirror sites for R. A site close to your location is likely to have higher download speeds.
2. Create a spreadsheet of the fire test data. From the test report [9], copy the test ID, fuel package name, HRR, and TER from Table B-1 and the ZOI data from Tables D-1 through D-3 to a spreadsheet. Note that the test data in all of the tables are listed in the same order. Add the same data from the tables in Appendix A.
3. Using the contents of Table 3-4, assign the FEDB fuel categories based on the fuel package to each row in the spreadsheet. It is recommended at this point to sort the rows first on the FEDB fuel category and then on the fuel package name.
4. Using the contents of Table 3-1, assign the FEDB category weights for each category to each row in the spreadsheet.
5. Using the contents of Table 3-5, assign the fuel package weights for each category to each row in the spreadsheet.
6. Assign a test replicate weight based on the number of repeat tests for each fuel package to each row in the spreadsheet. For example, large box empty had four repeats and would be assigned a replicate weight of 1/4 or 0.25.
7. Determine what fuel packages will be removed for the new distribution. For example, if a plant were to have a written policy with documentation of enforcement with surveillance that banned non-fire-retardant plastic tarps, the three rows containing the plastic tarp draped and plastic tarp folded fuel packages could be removed.
8. For any category where a fuel package was removed, renormalize the fuel package weights for that category. Using the example from Step 7, removing the two non-fire-retardant plastic tarp packages removes two fuel packages that each had a weight of 0.18 for a total weight of 0.36. The remaining fuel packages in the tarp category would be multiplied by 1/0.82 to renormalize the weights.
9. For each row in the spreadsheet, multiply the values from steps 4 through 6.
10. Sum the column created in step 9.
11. Divide the values from step 9 to normalize all sum of all weights to 1.
12. Find the minimum weight and compute a scaling factor by dividing 10 by the minimum weight.
13. Multiply the value from step 11 by the scaling factor in step 12 and convert to an integer value.
14. Copy the columns listed in the order given by the *colnames* functions in the script in Appendix B.1 to a new sheet and save as a CSV file.
15. Copy the script in Appendix B.1 to a text editor (for example, Notepad and not Word) and save as an R file in the same directory as the CSV file.
16. Edit the script to change dirname to the directory containing the CSV file and R file.

17. Edit the script to change chid to the name of the CSV file without the .csv extension (that is, *datafile* and not *datafile.csv*).
18. Run R.
19. Load the script into R by doing File->Open Script.
20. In the script window, type crtl-A to select the entire script. Then, right click and select run.
21. The script will execute and create a series of files containing the empirical cumulative distribution functions. Load each file into Excel, and determine the 50th and 98th percentile for the peak HRR, TER, and the ZOIs.
22. Use Excel to fit a gamma distribution to the percentiles. This can be done by using the gamma distribution parameters in this report to compute the 50th and 98th percentiles for each parameter and then summing the squares of the percent differences between the data percentiles and the distribution percentiles for each parameter. The Excel Solver function can now be used to find the minimum sum of the squares by solving for the gamma distribution parameters.

C
TEST WEIGHTING DATA

This appendix contains the inputs used to develop the individual test weights in Section 3.

C.1 FEDB Category Weights

Tables C-1 through C-3 contain the independent weightings of fire events database (FEDB) data used to develop the distributions shown in Sections 4 and the detailed modeling input data in Section 5. Table C-1 is for all events, Table C-2 is for hot work events only, and Table C-3 is for non-hot work events. Each individual assessor was provided a list of FEDB events and the list of FEDB categories shown in the tables. Each event was assigned to a single category with the total number in each category used to determine the fraction weights shown in the tables. The tables show the list of categories, each independent assessment, the average assessment, and the variance. All of the quantities are in terms of the total weighted fraction—for example in Table C-1 the average and deviation for the absorbent pad category would be 0.95 ± 0.35%. Note that the unknown category was uniformly distributed over the other categories when creating the tables shown in Section 3.

Table C-1
Independent weightings of all FEDB transient fires used for Table 3-1

Category	Category Weights (%)					
	#1	#2	#3	#4	Average	Deviation
Absorbent pad	1.32	0.73	0.59	1.17	0.95	0.35
Blanket	6.30	5.28	5.57	5.72	5.72	0.43
Cardboard	0.73	0.73	0.88	1.03	0.84	0.14
Chair	0.29	0.15	0.29	0.44	0.29	0.12
Clothing	7.04	4.55	6.60	6.74	6.23	1.14
Debris	4.69	3.08	4.55	4.55	4.22	0.76
Duct	0.59	0.59	0.59	0.59	0.59	0.00
Filter	1.91	1.91	1.91	1.91	1.91	0.00
Flammable liquid	2.05	2.64	5.72	3.23	3.41	1.61
Hose	0.44	0.15	0.44	0.44	0.37	0.15
Laptop+cart	0.15	0.15	0.15	0.15	0.15	0.00
Mop	1.17	1.32	1.17	1.17	1.21	0.07
Oily rag	2.20	2.79	2.49	2.20	2.42	0.28
Other	7.18	16.13	5.57	6.30	8.80	4.93
Oxy hose	2.35	2.49	2.35	2.35	2.38	0.07
Paper	3.37	2.49	2.49	3.23	2.90	0.47
Plastic	9.68	11.88	9.53	8.50	9.90	1.42
Power cord	17.01	11.14	17.01	17.01	15.54	2.93
PPE bag	0.88	1.76	2.20	1.03	1.47	0.62
Rag	6.89	7.04	6.60	6.89	6.85	0.18
Rope	0.44	0.44	0.59	0.73	0.55	0.14
Tape	7.62	7.77	7.18	7.62	7.55	0.25
Tarp	2.93	1.17	1.03	3.81	2.24	1.36
Tool bag	1.61	1.91	1.32	1.91	1.69	0.28
Trash	5.13	5.57	4.99	5.28	5.24	0.25
Unknown	2.79	2.93	4.55	2.79	3.26	0.86
Vacuum	0.29	0.29	0.15	0.44	0.29	0.12
Wood	2.93	2.93	3.52	2.79	3.04	0.33

Table C-2
Independent weightings of hot work FEDB transient fires used for Table 3-2

Category	Category Weights (%)					
	#1	#2	#3	#4	Average	Deviation
Absorbent pad	1.57	0.67	0.45	1.35	1.01	0.53
Blanket	9.44	7.87	8.31	8.54	8.54	0.66
Cardboard	0.90	0.67	1.12	1.12	0.96	0.22
Chair	0.45	0.22	0.45	0.67	0.45	0.18
Clothing	9.44	5.84	9.21	9.44	8.48	1.76
Debris	4.49	2.92	3.37	4.27	3.76	0.74
Duct	0.90	0.90	0.90	0.90	0.90	0.00
Filter	2.25	2.47	2.47	2.25	2.36	0.13
Flammable liquid	1.35	2.25	4.72	2.92	2.81	1.43
Hose	0.45	0.22	0.45	0.45	0.39	0.11
Laptop+cart	0.00	0.00	0.00	0.00	0.00	0.00
Mop	1.35	1.35	1.35	1.35	1.35	0.00
Oily rag	1.57	2.47	2.25	1.57	1.97	0.46
Other	7.64	11.91	6.29	6.07	7.98	2.71
Oxy hose	3.60	3.82	3.60	3.60	3.65	0.11
Paper	3.37	3.15	3.15	3.15	3.20	0.11
Plastic	11.01	15.06	11.46	10.34	11.97	2.11
Power cord	4.27	1.80	4.72	4.04	3.71	1.30
PPE bag	1.12	2.70	3.15	1.35	2.08	0.99
Rag	9.21	9.21	8.76	8.99	9.04	0.22
Rope	0.45	0.45	0.45	0.45	0.45	0.00
Tape	11.01	11.24	10.34	11.01	10.90	0.39
Tarp	3.60	1.12	1.12	4.94	2.70	1.90
Tool bag	2.47	2.92	2.02	2.92	2.58	0.43
Trash	2.02	2.25	2.02	2.25	2.13	0.13
Unknown	3.37	3.60	5.17	3.37	3.88	0.87
Vacuum	0.00	0.00	0.00	0.00	0.00	0.00
Wood	2.70	2.92	2.70	2.70	2.75	0.11

Table C-3
Independent weightings of non-hot work FEDB transient fires used for Table 3-3

Category	Category Weights (%)					
	#1	#2	#3	#4	Average	Deviation
Absorbent pad	0.84	0.84	0.84	1.35	0.84	0.00
Blanket	0.42	0.42	0.42	8.54	0.42	0.00
Cardboard	0.42	0.84	0.42	1.12	0.63	0.24
Chair	0.00	0.00	0.00	0.67	0.00	0.00
Clothing	2.53	2.11	1.69	9.44	2.00	0.40
Debris	5.06	3.38	6.75	4.27	5.06	1.38
Duct	0.00	0.00	0.00	0.90	0.00	0.00
Filter	1.27	0.84	0.84	2.25	1.05	0.24
Flammable liquid	3.38	3.38	7.59	2.92	4.54	2.05
Hose	0.42	0.00	0.42	0.45	0.32	0.21
Laptop+cart	0.42	0.42	0.42	0.00	0.42	0.00
Mop	0.84	1.27	0.84	1.35	0.95	0.21
Oily rag	3.38	3.38	2.95	1.57	3.27	0.21
Other	6.33	24.05	4.22	6.07	10.34	9.21
Oxy hose	0.00	0.00	0.00	3.60	0.00	0.00
Paper	3.38	1.27	1.27	3.15	2.32	1.22
Plastic	7.17	5.91	5.91	10.34	6.01	0.87
Power cord	40.93	28.69	40.08	4.04	37.76	6.07
PPE bag	0.42	0.00	0.42	1.35	0.32	0.21
Rag	2.53	2.95	2.53	8.99	2.74	0.24
Rope	0.42	0.42	0.84	0.45	0.74	0.40
Tape	1.27	1.27	1.27	11.01	1.27	0.00
Tarp	1.69	1.27	0.84	4.94	1.37	0.40
Tool bag	0.00	0.00	0.00	2.92	0.00	0.00
Trash	10.97	11.81	10.55	2.25	11.08	0.53
Unknown	1.69	1.69	3.38	3.37	2.11	0.84
Vacuum	0.84	0.84	0.42	0.00	0.84	0.34
Wood	3.38	2.95	5.06	2.70	3.59	1.00

C.2 Results of Independent Assessments of Fuel Package Category and Weights

Table C-4 through C-7 show the four individual assignments of fuel packages to FEDB categories along with the weighting. The tables are organized by category. Note that weights in each fuel category may not sum to 1 due to rounding.

Table C-4
First independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Absorbent pad	Four oil pads	0.250	Power Cord	15.2 m coil 120 V cord	0.167
	Four oil pads with oil	0.250		3.0 m coil 120 V cord	0.167
	Single oil pad	0.250		7.6 m coil 120 V cord	0.167
	Single oil pad with oil	0.250		7.6 m coil 250 V cord	0.167
Blanket	Welding blanket draped	0.500		Power spider	0.167
	Welding blanket folded	0.500		Uncoiled 120 V cord	0.167
Cardboard	Large box empty	0.100	PPE bag	Scissor stand full	0.200
	Large box with peanuts	0.100		Scissor stand half	0.100
	Medium box empty	0.250		Scissor stand quarter	0.100
	Medium box with peanuts	0.250		Single PPE	0.100
	Small box empty	0.150		Stack PPE	0.100
	Small box with peanuts	0.150		WPI half bag	0.200
Chair	Lawson Test 51	0.100		WPI quarter bag	0.200
	Lawson Test 56	0.100	Rag	Five rags	0.333
	Metal chair	0.700		Bag of rags	0.333
	Plastic chair	0.100		Single rag	0.333
Clothing	NBS—Lee fabric	1.000	Rope	15.2 m coil large rope	0.167
Debris	Bucket with debris	0.500		15.2 m coil small rope	0.167
	Debris pile	0.500		7.6 m coil large rope	0.167
Duct	Blower duct	1.000		7.6 m coil small rope	0.167
Filter	Heating, ventilation, and air conditioning (HVAC) filter	1.000		Uncoiled large rope	0.167
Flammable Liquid	Alcohol bottle	0.250		Uncoiled small rope	0.167
	Oil bottle	0.750	Tape	Duct tape roll	0.500
Hose	Water hose	1.000		Duct tape wall	0.167

Table C-4 (continued)
First independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Laptop+cart	Laptop+cart	1.000		Long duct tape air	0.167
Mop	Mop+bucket	1.000		Short duct tape air	0.167
Oily rag	Five rags with heptane	0.250	Tarp	Canvas tarp draped	0.167
	Rags with oil	0.250		Canvas tarp folded	0.167
	Single rag with heptane	0.500		Fire-retardant plastic tarp draped	0.167
Other	Laptop	0.167		Fire-retardant plastic tarp folded	0.167
	SNL—Nowlen Tests 1, 2	0.167		Plastic tarp draped	0.167
	SNL—Nowlen Tests 3, 4	0.167		Plastic tarp folded	0.167
	Tablet	0.167	Tool Bag	Tool bag	1.000
	Tablet+metal case	0.167	Trash	LBL—Volkinburg one airline bag	0.111
	Tablet+plastic case	0.167		Metal trash full	0.111
Oxy hose	Oxy-acetylene hose	1.000		Metal trash full lid	0.111
Paper	Cardstock air	0.080		Metal trash half	0.111
	Cardstock wall	0.200		Metal trash quarter	0.111
	Large binder closed	0.080		Plastic trash full	0.111
	Large binder open	0.080		Plastic trash half	0.111
	Large box with paper	0.050		Plastic trash quarter	0.111
	Medium box with paper	0.050		SNL—Nowlen Tests 7 ,8	0.111
	Pad of paper	0.200	Vacuum	Vacuum closed	0.750
	Small binder closed	0.080		Vacuum open	0.250
	Small binder open	0.080	Wood	Pallet flame	0.167
	Small box with paper	0.050		Pallet panel	0.167
	SNL—Nowlen Tests 5, 6	0.050		Plank flame	0.167

Table C-4 (continued)
First independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Plastic	15.2 m coil chain	0.077		Plank panel	0.167
	15.2 m coil tubing	0.077		Wood block flame	0.167
	Four cones	0.077		Wood block panel	0.167
	7.6 m coil chain	0.077			
	7.6 m coil tubing	0.077			
	Empty bucket	0.077			
	First aid kit	0.077			
	Lift slings	0.0769			
	Plastic stanchion	0.0769			
	Single cone	0.0769			
	SNL—Nowlen Test 9	0.0769			
	Uncoiled chain	0.0769			
	Uncoiled tubing	0.0769			

Table C-5
Second independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Absorbent pad	Four oil pads	0.600	Power Cord	15.2 m coil 120 V cord	0.100
	Single oil pad	0.400		3.0 m coil 120 V cord	0.200
Blanket	Welding blanket draped	0.500		7.6 m coil 120 V cord	0.300
	Welding blanket folded	0.500		7.6 m coil 250 V cord	0.100
Cardboard	Large box empty	0.100		Power spider	0.200
	Large box with paper	0.100		Uncoiled 120 V cord	0.100
	Large box with peanuts	0.100	PPE bag	Stack PPE	1.000
	Medium box empty	0.200	Rag	Five rags	0.400
	Medium box with paper	0.100		Bag of rags	0.400
	Medium box with peanuts	0.050		Single rag	0.200
	Small box empty	0.100	Rope	15.2 m coil large rope	0.200
	Small box with paper	0.100		15.2 m coil small rope	0.200
	Small box with peanuts	0.050		7.6 m coil large rope	0.200
	SNL—Nowlen Tests 5, 6	0.100		7.6 m coil small rope	0.200
Chair	Lawson Test 51	0.200		Uncoiled large rope	0.100
	Lawson Test 56	0.300		Uncoiled small rope	0.100
	Metal chair	0.300	Tape	Duct tape roll	0.300
	Plastic chair	0.200		Duct tape wall	0.300
Clothing	NBS—Lee fabric	0.400		Long duct tape air	0.200
	Single PPE	0.600		Short duct tape air	0.200
Debris	Bucket with debris	0.600	Tarp	Canvas tarp draped	0.200
	Debris pile	0.400		Canvas tarp folded	0.100
Duct	Blower duct	1.000		Fire-retardant plastic tarp draped	0.300
Filter	HVAC filter	1.000		Fire-retardant plastic tarp folded	0.100

Table C-5 (continued)
Second independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Flammable liquid	Alcohol bottle	0.300		Plastic tarp draped	0.200
	Oil bottle	0.300		Plastic tarp folded	0.100
	SNL—Nowlen Tests 1, 2	0.200	Tool Bag	Tool bag	1.000
	SNL—Nowlen Tests 3, 4	0.200	Trash	LBL—Volkinburg one airline bag	0.100
Hose	Water hose	1.000		Metal trash full	0.100
Laptop+cart	Laptop+cart	1.000		Metal trash full lid	0.100
Mop	Mop+bucket	1.000		Metal trash half	0.100
Oily rag	Four oil pads with oil	0.100		Metal trash quarter	0.100
	Five rags with heptane	0.300		Plastic trash full	0.050
	Rags with oil	0.200		Plastic trash half	0.050
	Single oil pad with oil	0.200		Plastic trash quarter	0.050
	Single rag with heptane	0.200		Scissor stand full	0.050
Other	Laptop	0.200		Scissor stand half	0.050
	Lift slings	0.100		Scissor stand quarter	0.050
	Tablet	0.300		SNL—Nowlen Tests 7, 8	0.050
	Tablet+metal case	0.200		SNL—Nowlen Test 9	0.050
	Tablet+plastic case	0.200		WPI half bag	0.050
Oxy hose	Oxy-acetylene hose	1.000		WPI quarter bag	0.050
Paper	Cardstock air	0.050	Vacuum	Vacuum closed	0.500
	Cardstock wall	0.050		Vacuum open	0.500
	Large binder closed	0.200	Wood	Pallet flame	0.200
	Large binder open	0.200		Pallet panel	0.200
	Pad of paper	0.200		Plank flame	0.300
	Small binder closed	0.150		Plank panel	0.050
	Small binder open	0.150		Wood block flame	0.200

Table C-5 (continued)
Second independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Plastic	15.2 m coil chain	0.050		Wood block panel	0.050
	15.2 m coil tubing	0.050			
	Four cones	0.200			
	7.6 m coil chain	0.050			
	7.6 m coil tubing	0.050			
	Empty bucket	0.100			
	First aid kit	0.150			
	Plastic stanchion	0.050			
	Single cone	0.200			
	Uncoiled chain	0.050			
	Uncoiled tubing	0.050			

Table C-6
Third independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Absorbent pad	Four oil pads	0.250	Power cord	15.2 m coil 120 V cord	0.250
	Four oil pads with oil	0.250		3.0 m coil 120 V cord	0.125
	Single oil pad	0.250		7.6 m coil 120 V cord	0.125
	Single oil pad with oil	0.250		7.6 m coil 250 V cord	0.125
Blanket	Welding blanket draped	0.500		Power spider	0.125
	Welding blanket folded	0.500		Uncoiled 120 V cord	0.250
Cardboard	Large box empty	0.111	PPE bag	Scissor stand full	0.143
	Large box with paper	0.111		Scissor stand half	0.143
	Large box with peanuts	0.111		Scissor stand quarter	0.143
	Medium box empty	0.111		Single PPE	0.143
	Medium box with paper	0.111		Stack PPE	0.143
	Medium box with peanuts	0.111		WPI half bag	0.143
	Small box empty	0.111		WPI quarter bag	0.143
	Small box with paper	0.111	Rag	Five rags	0.333
	Small box with peanuts	0.111		Bag of rags	0.333
Chair	Lawson Test 51	0.100		Single rag	0.333
	Lawson Test 56	0.200	Rope	15.2 m coil large rope	0.167
	Metal chair	0.600		15.2 m coil small rope	0.167
	Plastic chair	0.100		7.6 m coil large rope	0.167
Clothing	NBS—Lee fabric	0.333		7.6 m coil small rope	0.167
	Lift slings	0.667		Uncoiled large rope	0.167
Debris	Bucket with debris	0.500		Uncoiled small rope	0.167
	Debris pile	0.500	Tape	Duct tape roll	0.250
Duct	Blower duct	1.000		Duct tape wall	0.250
Filter	HVAC filter	1.000		Long duct tape air	0.250
Flammable liquid	Alcohol bottle	0.500		Short duct tape air	0.250
	Oil bottle	0.500	Tarp	Canvas tarp draped	0.0625

Table C-6 (continued)
Third independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Hose	15.2 m coil tubing	0.333		Canvas tarp folded	0.0625
	7.6 m coil tubing	0.333		Fire-retardant plastic tarp draped	0.250
	Uncoiled tubing	0.333		Fire-retardant plastic tarp folded	0.250
Laptop+cart	Laptop	0.200		Plastic tarp draped	0.1875
	Laptop+cart	0.200		Plastic tarp folded	0.1875
	Tablet	0.200	Tool Bag	Tool bag	1.000
	Tablet+metal case	0.200	Trash	LBL—Volkinburg one airline bag	0.100
	Tablet+plastic case	0.200		Metal trash full	0.050
Mop	Mop+bucket	1.000		Metal trash full lid	0.100
Oily rag	Five rags with heptane	0.333		Metal trash half	0.050
	Rags with oil	0.333		Metal trash quarter	0.050
	Single rag with heptane	0.333		Plastic trash full	0.050
Oxy hose	Oxy-acetylene hose	1.000		Plastic trash half	0.050
Paper	Cardstock air	0.050		Plastic trash quarter	0.050
	Cardstock wall	0.050		SNL—Nowlen Tests 1, 2	0.100
	Large binder closed	0.200		SNL—Nowlen Tests 3, 4	0.100
	Large binder open	0.200		SNL—Nowlen Tests 5, 6	0.100
	Pad of paper	0.100		SNL—Nowlen Tests 7, 8	0.100
	Small binder closed	0.200		SNL—Nowlen Test 9	0.100
	Small binder open	0.200	Vacuum	Vacuum closed	0.500
Plastic	15.2 m coil chain	0.150		Vacuum open	0.500
	Four cones	0.050	Wood	Pallet flame	0.166
	7.6 m coil chain	0.150		Pallet panel	0.166
	Empty bucket	0.100		Plank flame	0.166
	First aid kit	0.050		Plank panel	0.167
	Plastic stanchion	0.250		Wood block flame	0.167
	Single cone	0.100		Wood block panel	0.167
	Uncoiled chain	0.100			
	Water hose	0.050			

Table C-7
Fourth independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Absorbent pad	Four oil pads	0.200	Plastic	15.2 m coil tubing	0.067
	Four oil pads with oil	0.300		Four cones	0.067
	Single oil pad	0.100		7.6 m coil tubing	0.067
	Single oil pad with oil	0.400		Empty bucket	0.150
Blanket	Welding blanket draped	0.500		Lift slings	0.067
	Welding blanket folded	0.500		Plastic stanchion	0.450
Cardboard	Large box empty	0.133		Single cone	0.067
	Large box with paper	0.133		Uncoiled tubing	0.067
	Large box with peanuts	0.133	Power cord	15.2 m coil 120 V cord	0.200
	Medium box empty	0.133		3.0 m coil 120 V cord	0.200
	Medium box with paper	0.133		7.6 m coil 120 V cord	0.200
	Medium box with peanuts	0.133		7.6 m coil 250 V cord	0.200
	Small box empty	0.050		Uncoiled 120 V cord	0.200
	Small box with paper	0.050	PPE bag	Scissor stand full	0.100
	Small box with peanuts	0.050		Scissor stand half	0.200
	SNL—Nowlen Tests 5,6	0.050		Scissor stand quarter	0.400
Chair	Lawson Test 51	0.300		WPI half bag	0.100
	Lawson Test 56	0.300		WPI quarter bag	0.200
	Metal chair	0.300	Rag	Five rags	0.333
	Plastic chair	0.100		Bag of rags	0.333
Clothing	NBS—Lee fabric	0.125		Single rag	0.333
	Single PPE	0.750	Rope	15.2 m coil chain	0.040
	Stack PPE	0.125		15.2 m coil large rope	0.040
Debris	Bucket with debris	0.500		15.2 m coil small rope	0.040
	Debris pile	0.500		7.6 m coil chain	0.200
Duct	Blower duct	1.000		7.6 m coil large rope	0.040
Filter	HVAC filter	1.000		7.6 m coil small rope	0.040
Flammable liquid	Alcohol bottle	0.800		Uncoiled chain	0.200
	Oil bottle	0.200		Uncoiled large rope	0.200
Hose	Water hose	1.000		Uncoiled small rope	0.200

Table C-7 (continued)
Fourth independent assigning of fuel packages to FEDB fuel category and category weighting

Category	Fuel Package	Weight	Category	Fuel Package	Weight
Laptop+cart	Laptop+cart	1.000	Tape	Duct tape roll	0.200
Mop	Mop+bucket	1.000		Duct tape wall	0.400
Oily rag	Five rags with heptane	0.333		Long duct tape air	0.200
	Rags with oil	0.333		Short duct tape air	0.200
	Single rag with heptane	0.333	Tarp	Canvas tarp draped	0.050
Other	First aid kit	0.125		Canvas tarp folded	0.025
	Laptop	0.125		Fire-retardant plastic tarp draped	0.250
	Power spider	0.125		Fire-retardant plastic tarp folded	0.250
	SNL—Nowlen Tests 1, 2	0.125		Plastic tarp draped	0.325
	SNL—Nowlen Tests 3, 4	0.125		Plastic tarp folded	0.100
	Tablet	0.125	Tool Bag	Tool bag	1.000
	Tablet+metal case	0.125	Trash	LBL—Volkinburg one airline bag	0.050
	Tablet+plastic case	0.125		Metal trash full	0.100
Oxy hose	Oxy-acetylene hose	1.000		Metal trash full lid	0.500
Paper	Cardstock air	0.143		Metal trash half	0.100
	Cardstock wall	0.143		Metal trash quarter	0.100
	Large binder closed	0.143		Plastic trash full	0.017
	Large binder open	0.143		Plastic trash half	0.033
	Pad of paper	0.143		Plastic trash quarter	0.033
	Small binder closed	0.143		SNL—Nowlen Tests 7, 8	0.050
	Small binder open	0.143		SNL—Nowlen Test 9	0.017
			Vacuum	Vacuum closed	0.950
				Vacuum open	0.050
			Wood	Pallet flame	0.167
				Pallet panel	0.167
				Plank flame	0.167
				Plank panel	0.167
				Wood block flame	0.167
				Wood block panel	0.167

C.3 Voting Results for Transient Combustible Control Location

Table C-8 shows the results of voting for which test fuel packages to include in the transient combustible control location (TCCL) distribution by the members of the working group. The table contains the list of test fuel packages and the total number of votes for that package not being present in the distribution for both rounds of voting. Additionally, the table shows which packages were not included (indicated by an X).

Table C-8
Total number votes (max of 4 Round 1, max of 5 Round 2) that a fuel package is not in a TCCL

Fuel Package	Votes			Fuel Package	Votes		
	Round 1	Round 2	Final		Round 1	Round 2	Final
15.2 m coil 120 V cord	0	0		Oil bottle	1	0	
15.2 m coil chain	0	1		Oxy-acetylene hose	3	5	X
15.2 m coil large rope	1	1		Pad of paper	0	0	
15.2 m coil small rope	1	0		Pallet flame	3	5	X
15.2 m coil tubing	2	3		Pallet panel	3	5	X
3 m coil 120 V cord	0	0		Plank flame	2	5	X
Four cones	2	3	X	Plank panel	2	5	X
Four oil pads	4	5	X	Plastic chair	4	4	X
Four oil pads with oil	4	5	X	Plastic stanchion	1	0	
Five rags	1	1		Plastic tarp draped	4	5	X
Five rags with heptane	3	4	X	Plastic tarp folded	1	0	
7.6 m coil 120 V cord	0	0		Plastic trash full	3	5	X
7.6 m coil 250 V cord	0	0		Plastic trash half	3	5	X
7.6 m coil chain	0	0		Plastic trash quarter	3	5	X
7.6 m coil large rope	0	0		Power spider	0	0	
7.6 m coil small rope	0	0		Rags with oil	1	0	
7.6 m coil tubing	0	0		Scissor stand full	4	5	X
Alcohol bottle	2	1		Scissor stand half	4	5	X
Bag of rags	2	2		Scissor stand quarter	3	4	X
Blower duct	1	0		Short duct tape air	0	0	
Bucket with debris	1	0		Single cone	0	0	
Canvas tarp draped	4	5	X	Single oil pad	2	3	
Canvas tarp folded	1	0		Single oil pad with oil	3	3	
Cardstock air	1	1		Single PPE	1	0	

Table C-8 (continued)
Total number votes (max of 4 Round 1, max of 5 Round 2) that a fuel package is not in a TCCL

Fuel Package	Votes Round 1	Votes Round 2	Votes Final	Fuel Package	Votes Round 1	Votes Round 2	Votes Final
Cardstock wall	0	0		Single rag	0	0	
Debris pile	2	5	X	Single rag with heptane	1	0	
Duct tape roll	0	0		Small binder closed	0	0	
Duct tape wall	0	0		Small binder open	0	0	
Empty bucket	0	0		Small box empty	0	0	
First aid kit	0	0		Small box with paper	0	0	
Fire-retardant plastic tarp draped	4	5	X	Small box with peanuts	1	0	
Fire-retardant plastic tarp folded	1	0		SNL—Nowlen Tests 1, 2	1	0	
HVAC filter	1	0		SNL—Nowlen Tests 3, 4	1	0	
Laptop	2	2	X	SNL—Nowlen Tests 5, 6	2	2	
Laptop+cart	4	5	X	SNL—Nowlen Tests 7, 8	2	5	X
Large binder closed	0	0		SNL—Nowlen Test 9	4	5	X
Large binder open	0	0		Stack PPE	3	5	X
Large box empty	4	5	X	Tablet	2	1	
Large box with paper	4	5	X	Tablet+metal case	2	1	
Large box with peanuts	4	5	X	Tablet+plastic case	2	1	
Lawson Test 51	3	4	X	Tool bag	1	1	
Lawson Test 56	2	3		Uncoiled 120 V cord	1	0	
LBL—Volkinburg one airline bag	2	4	X	Uncoiled chain	1	0	
Lift slings	1	1		Uncoiled large rope	1	2	
Long duct tape air	0	0		Uncoiled small rope	1	2	
Medium box empty	1	0		Uncoiled tubing	1	0	
Medium box with paper	1	0		Vacuum closed	2	3	
Medium box with peanuts	1	0		Vacuum open	4	5	X
Metal chair*	3	4		Water hose	0	0	

Table C-8 (continued)
Total number votes (max of 4 Round 1, max of 5 Round 2) that a fuel package is not in a TCCL

Fuel Package	Votes			Fuel Package	Votes		
	Round 1	Round 2	Final		Round 1	Round 2	Final
Metal trash full	3	5	X	Welding blanket draped	2	4	X
Metal trash full lid	3	5	X	Welding blanket folded	0	1	
Metal trash half	3	5	X	Wood block flame	1	1	
Metal trash quarter	3	5	X	Wood block panel	1	1	
Mop+bucket	2	2		WPI half bag	4	5	X
NBS—Lee fabric	1	1		WPI quarter bag	3	5	X

*Note while the metal chair had four votes to eliminate it from the TCCL, the working decided to include it in the TCCL to be consistent with the Lawson Test 56 fuel package which was a similar chair.

D

WEIGHTED DATA HISTOGRAMS AND GAMMA DISTRIBUTION FITS

This appendix contains a triplet of plots for each of the distributions in Table 4-1 and Table 4-4.

The first plot in each triplet is a probability density function, the second plot is a cumulative probability distribution, and the third plot is a probability-probability plot. The empirical (test data) plot data originates from the empirical cumulative distribution density functions generated in R. Note that the density axis for each probability density function plot is shown as a log scale. For each quantity, it can be seen that the histogram density is significantly higher on the left side of the plots and the right side shows a long tail of relatively low density. These are classic hallmarks of data obeying a gamma distribution. The cumulative probability distribution plots contain a main plot and an inset plot. The main plot is plotted out to the maximum value in the test data. The inset plot is zoomed to show up to approximately the 98th percentile; the actual value varies slightly in order to obtain a round number for the independent axis of the plot.

D.1 Generic Transient Fire Distribution Plots

Figures D-1 through D-51 contain the plots for the distribution in Table 4-1.

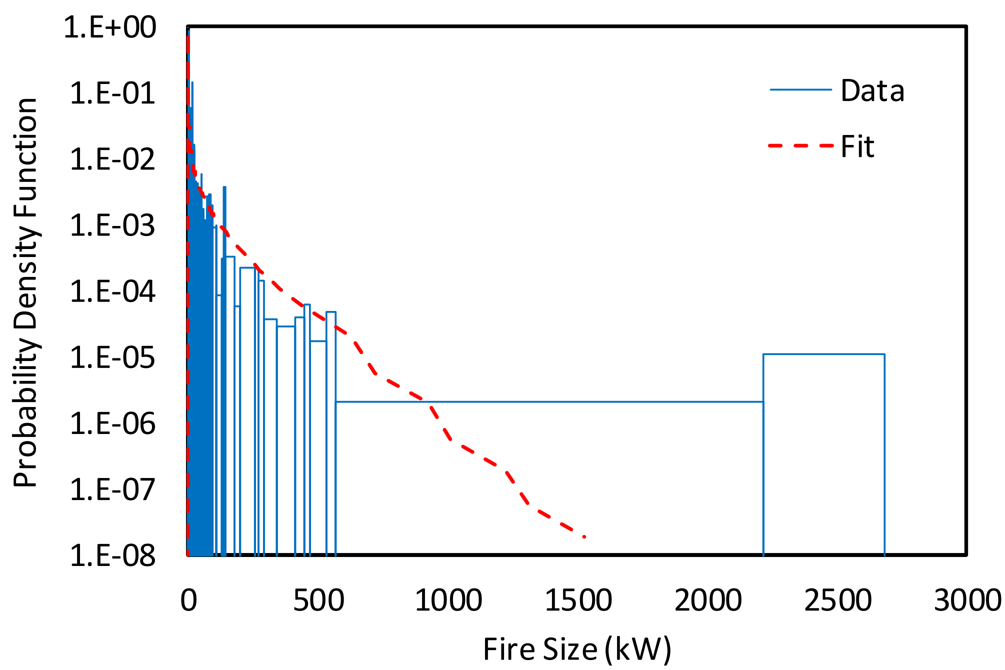

Figure D-1
Probability density function for peak heat release rate (HRR)

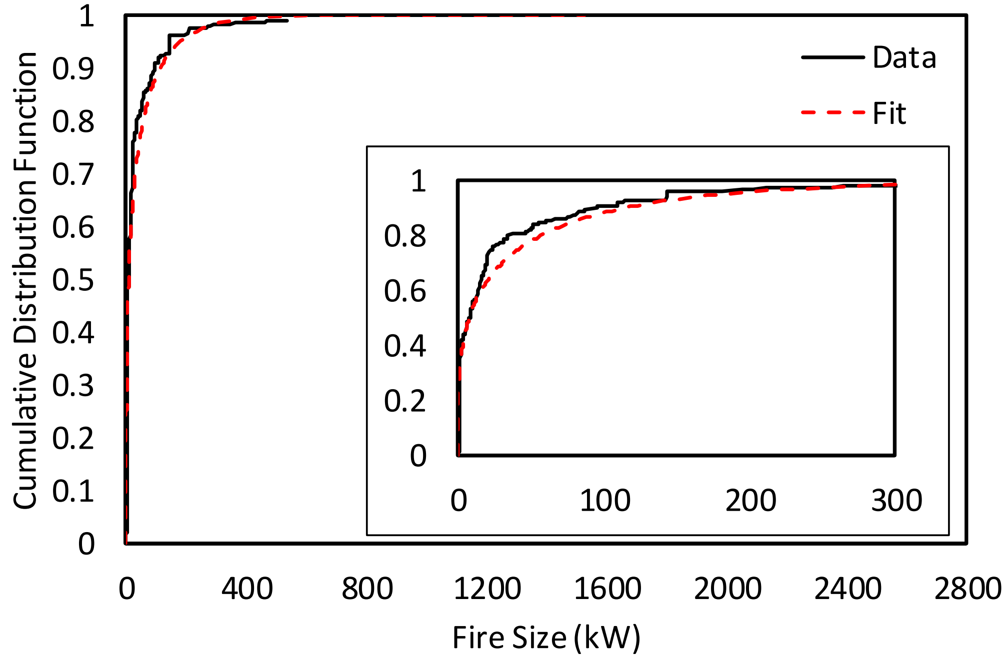

Figure D-2
Cumulative distribution function for peak HRR

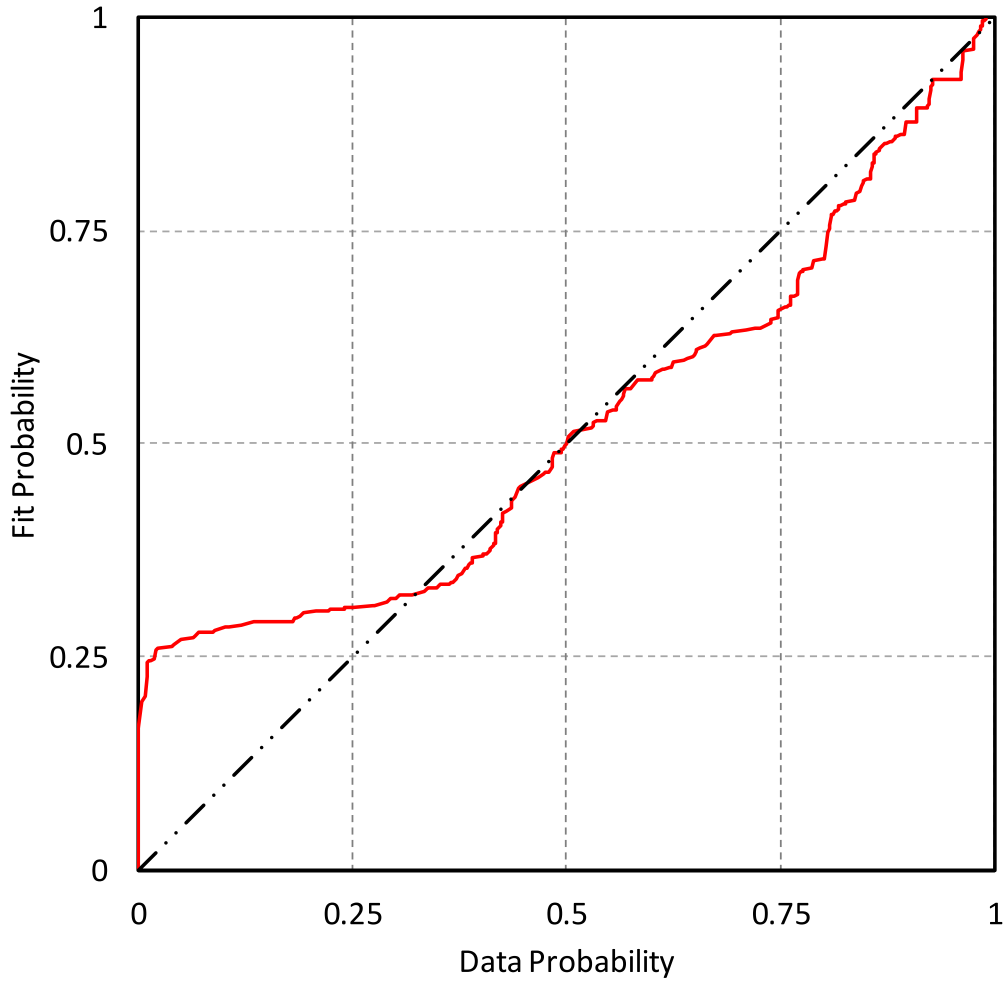

Figure D-3
Probability-probability plot for peak HRR

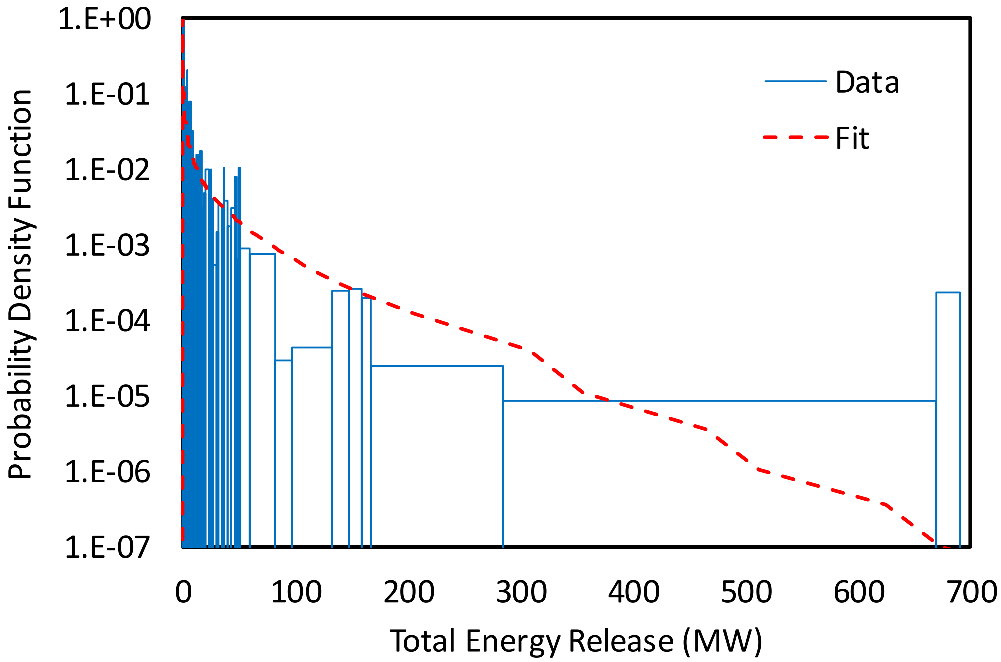

Figure D-4
Probability density function for total energy release (TER)

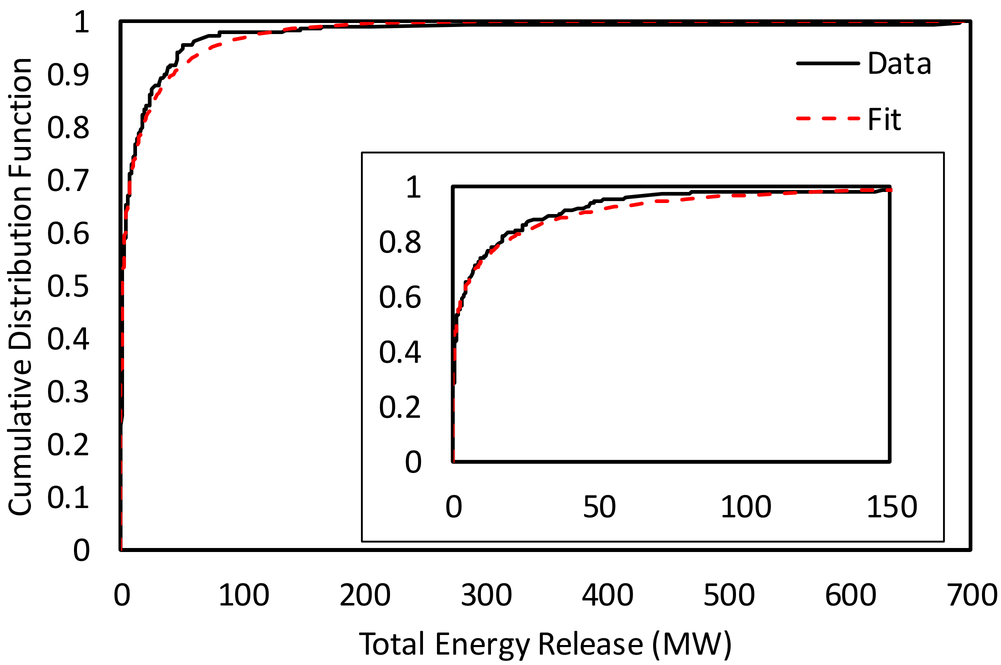

Figure D-5
Cumulative distribution function for TER

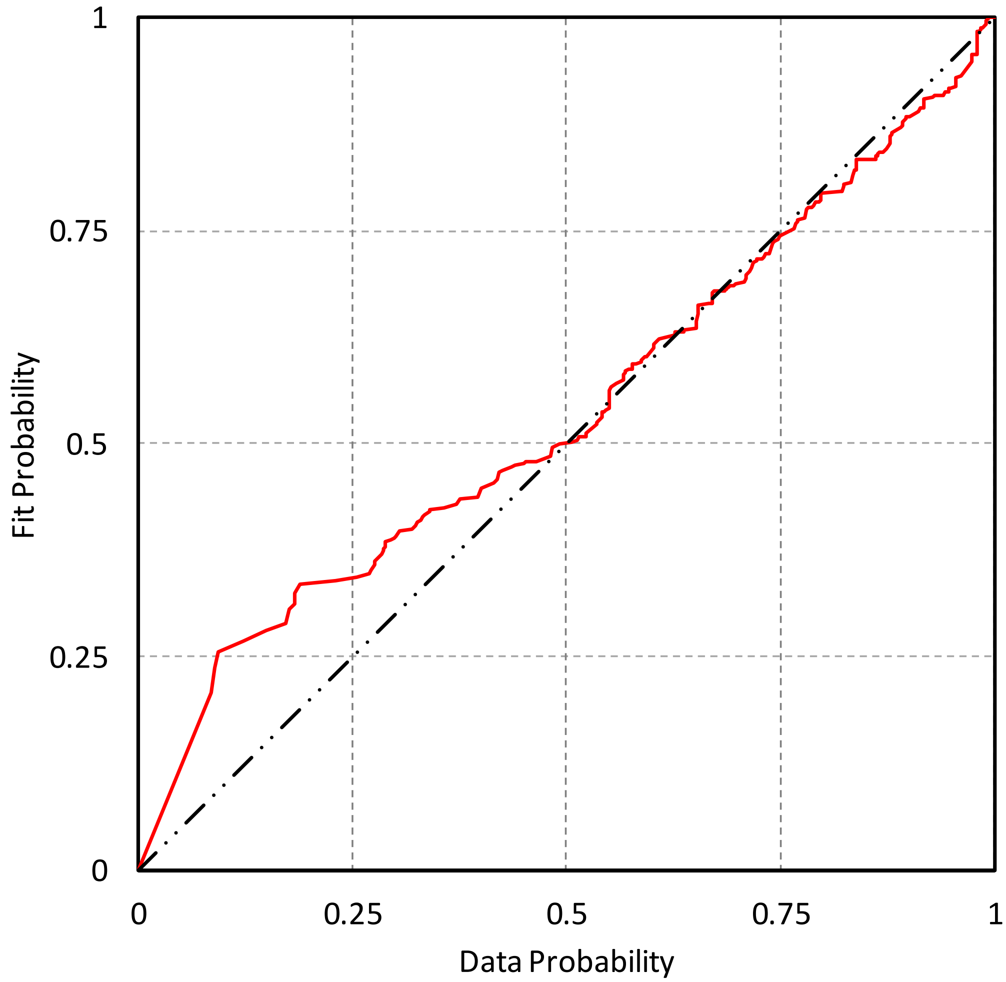

Figure D-6
Probability-probability plot for TER

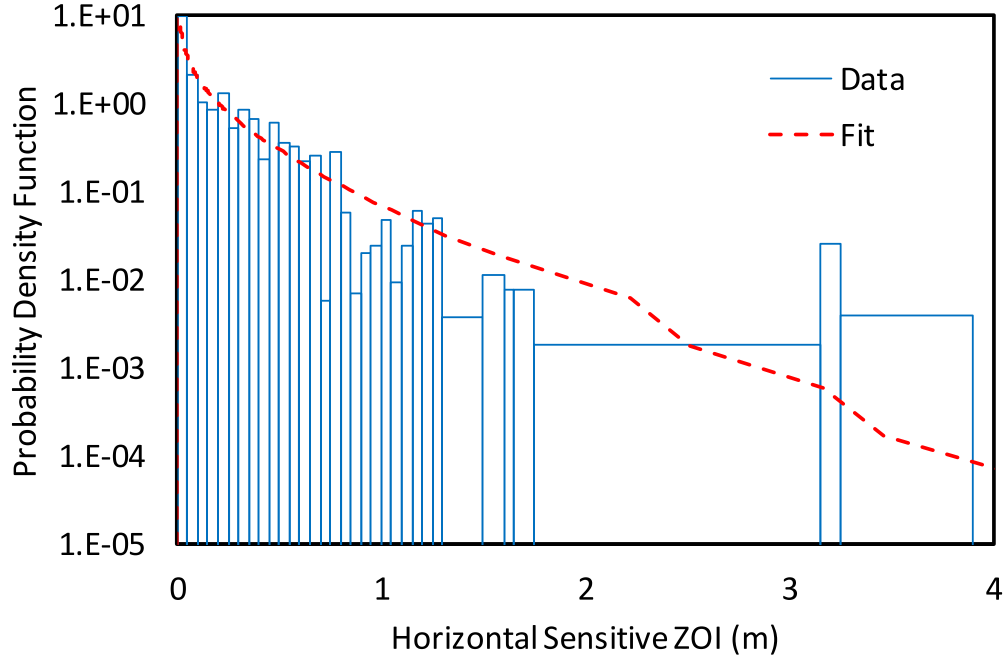

Figure D-7
Probability density function for horizontal zone of influence (ZOI) for sensitive electronics (SE)

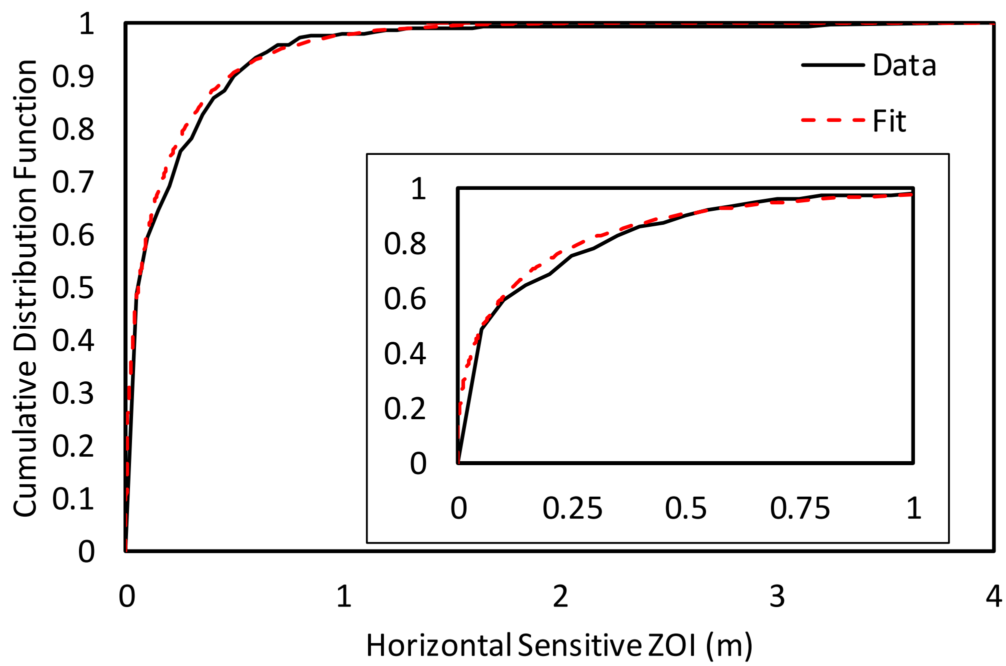

Figure D-8
Cumulative distribution function for horizontal ZOI for SE

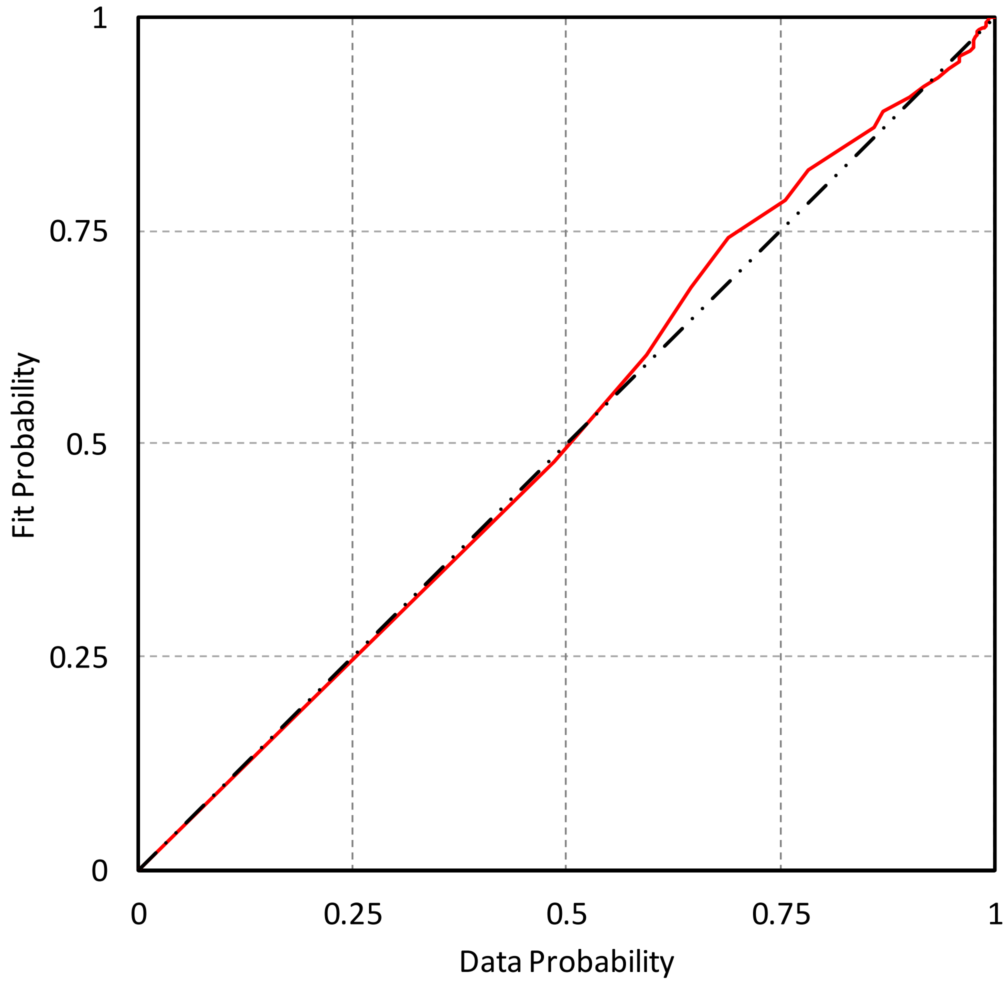

Figure D-9
Probability-probability plot for horizontal ZOI for SE

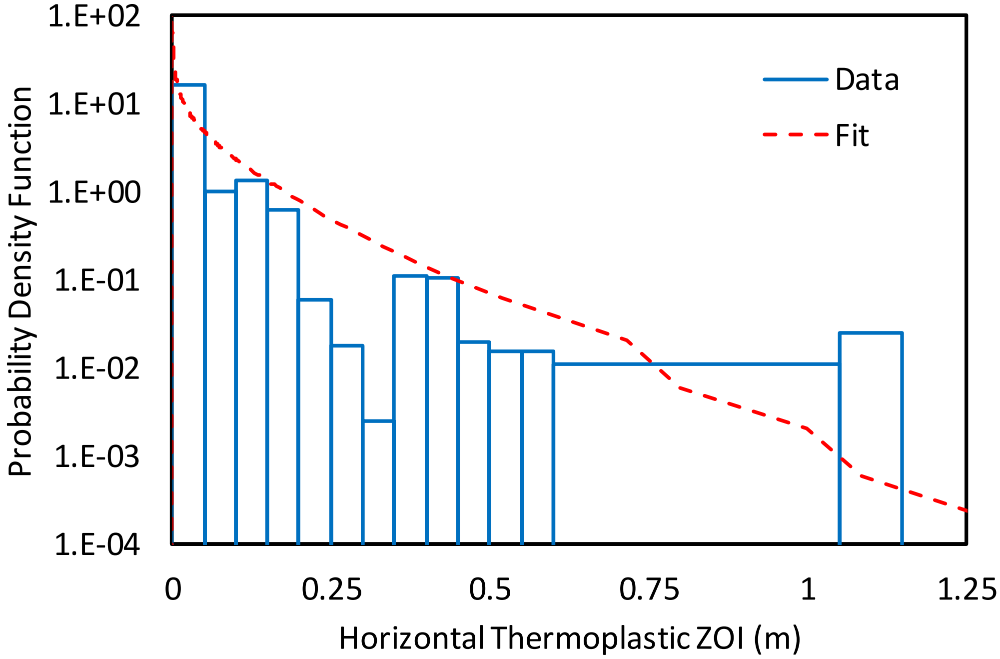

Figure D-10
Probability density function for horizontal ZOI for thermoplastic (TP) cable

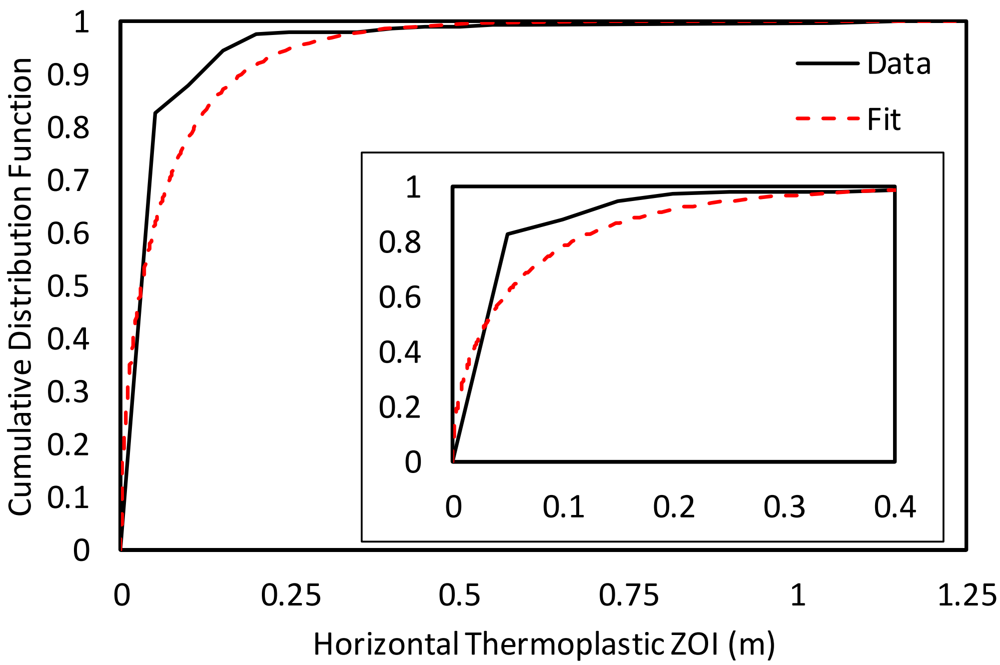

Figure D-11
Cumulative distribution function for horizontal ZOI for TP cable

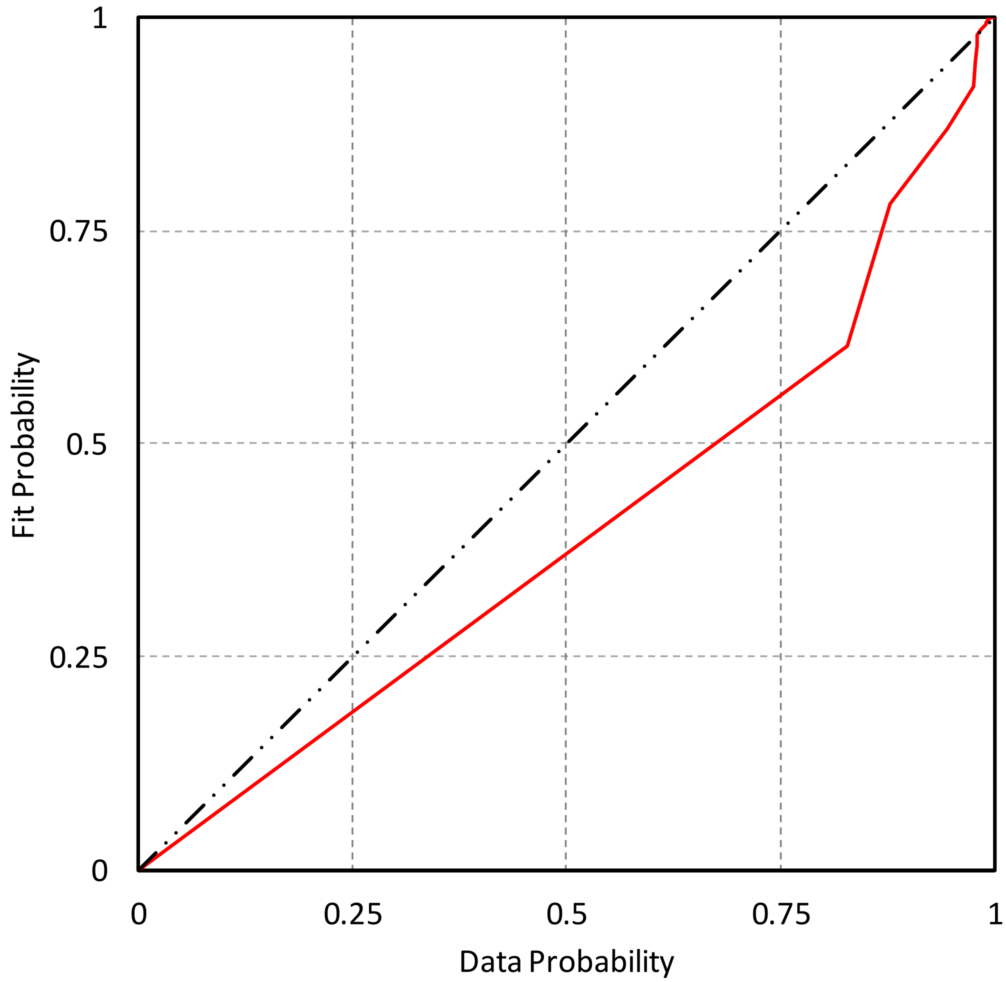

Figure D-12
Probability-probability plot for horizontal ZOI for TP cable

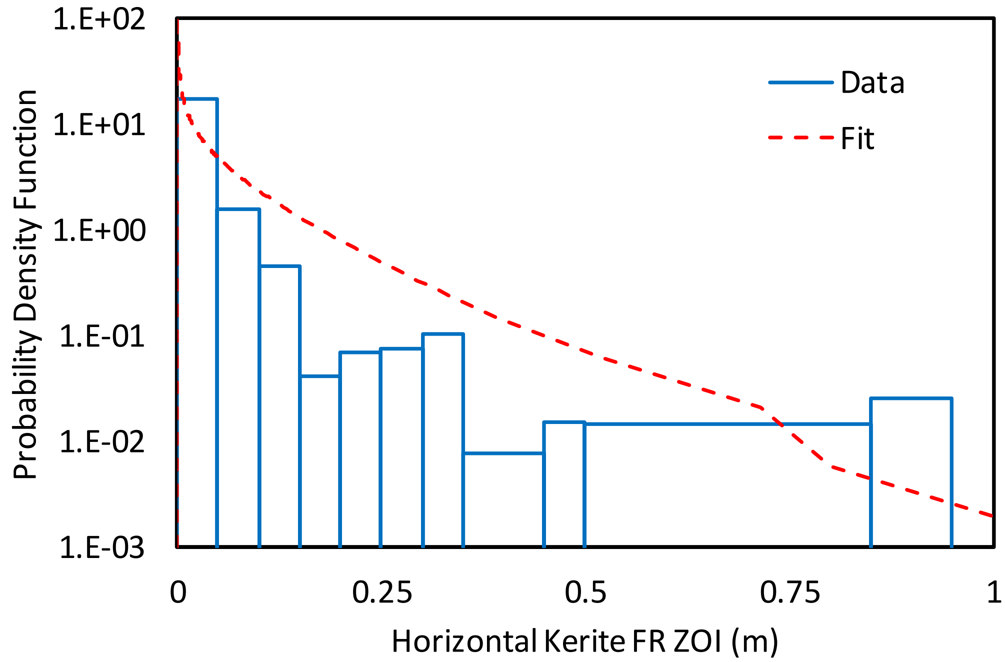

Figure D-13
Probability density function for horizontal ZOI for Kerite-FR cable (KC)

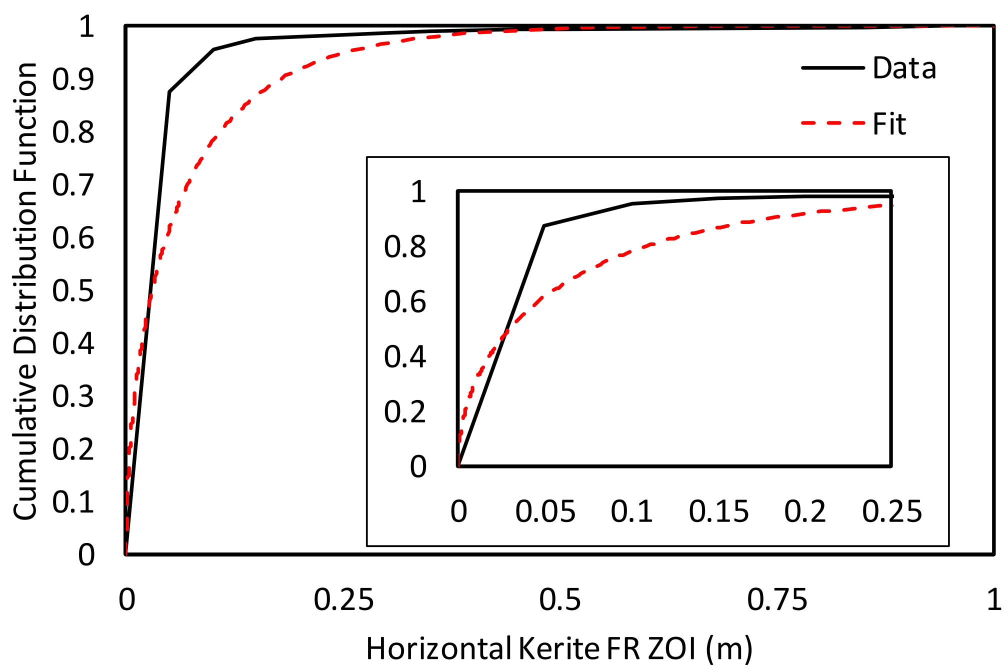

Figure D-14
Cumulative distribution function for horizontal ZOI for KC

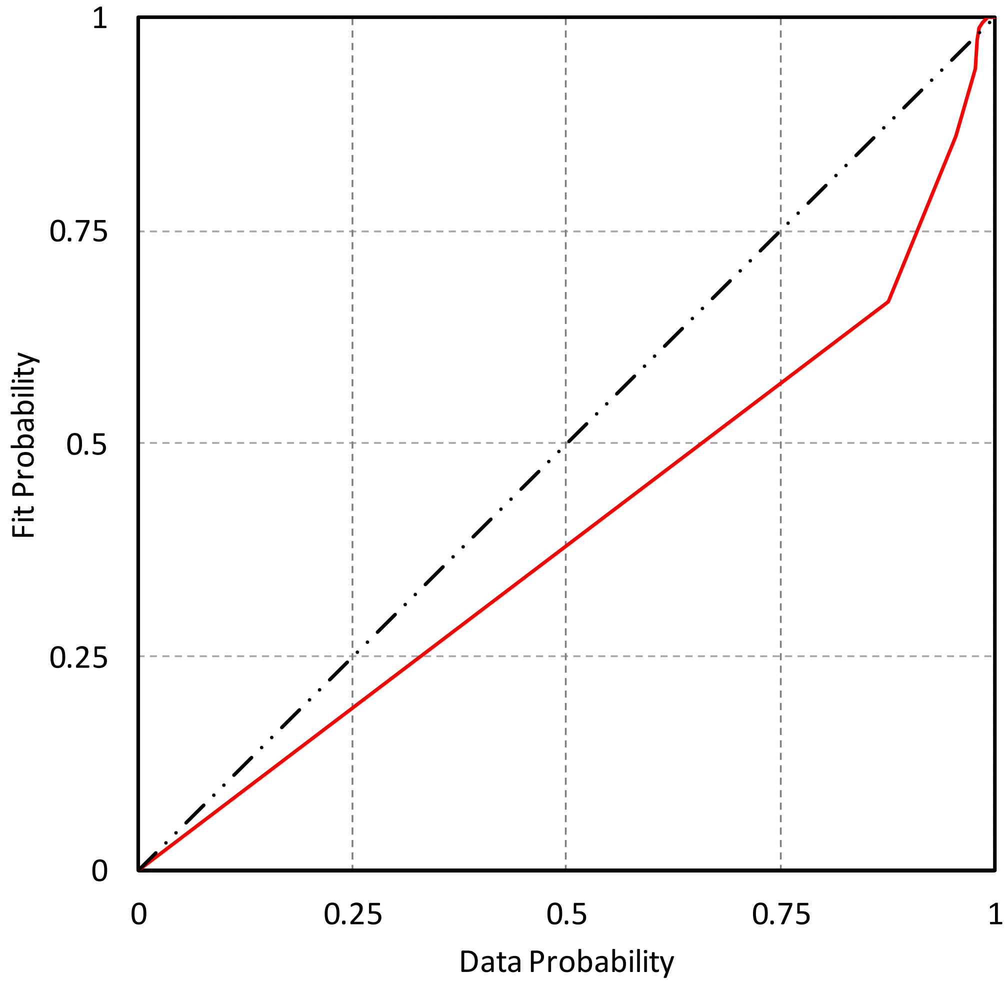

Figure D-15
Probability-probability plot for horizontal ZOI for KC

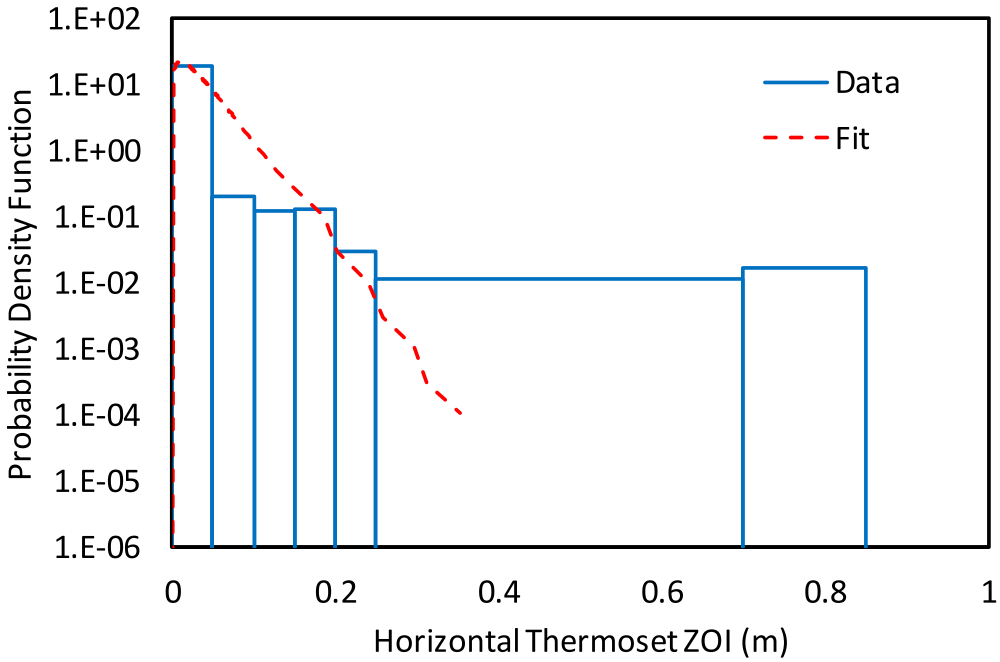

Figure D-16
Probability density function for horizontal ZOI for thermoset (TS) cable

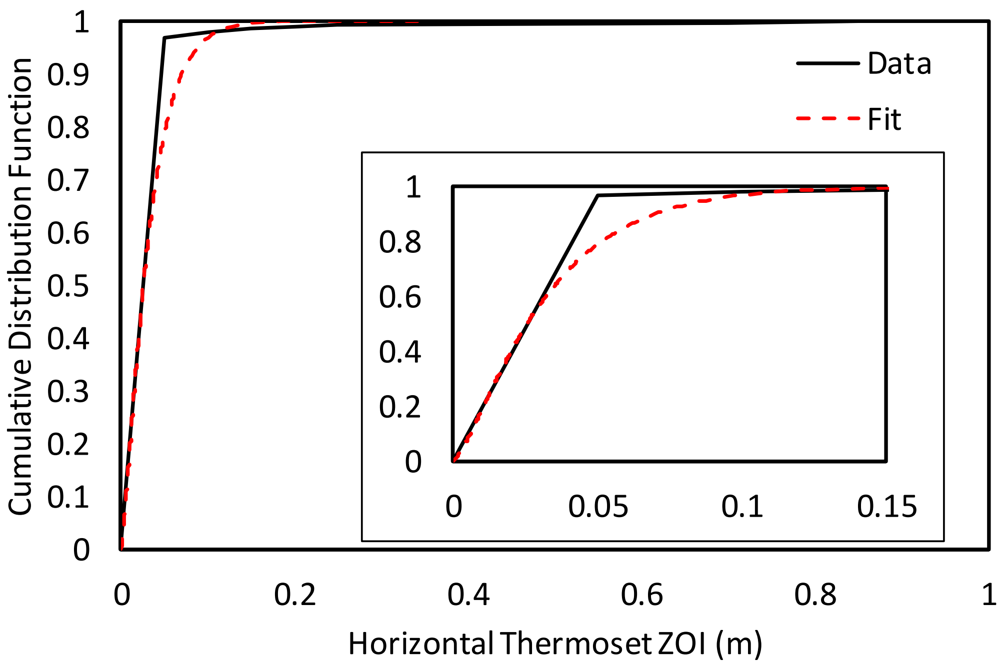

Figure D-17
Cumulative distribution function for horizontal ZOI for TS cable

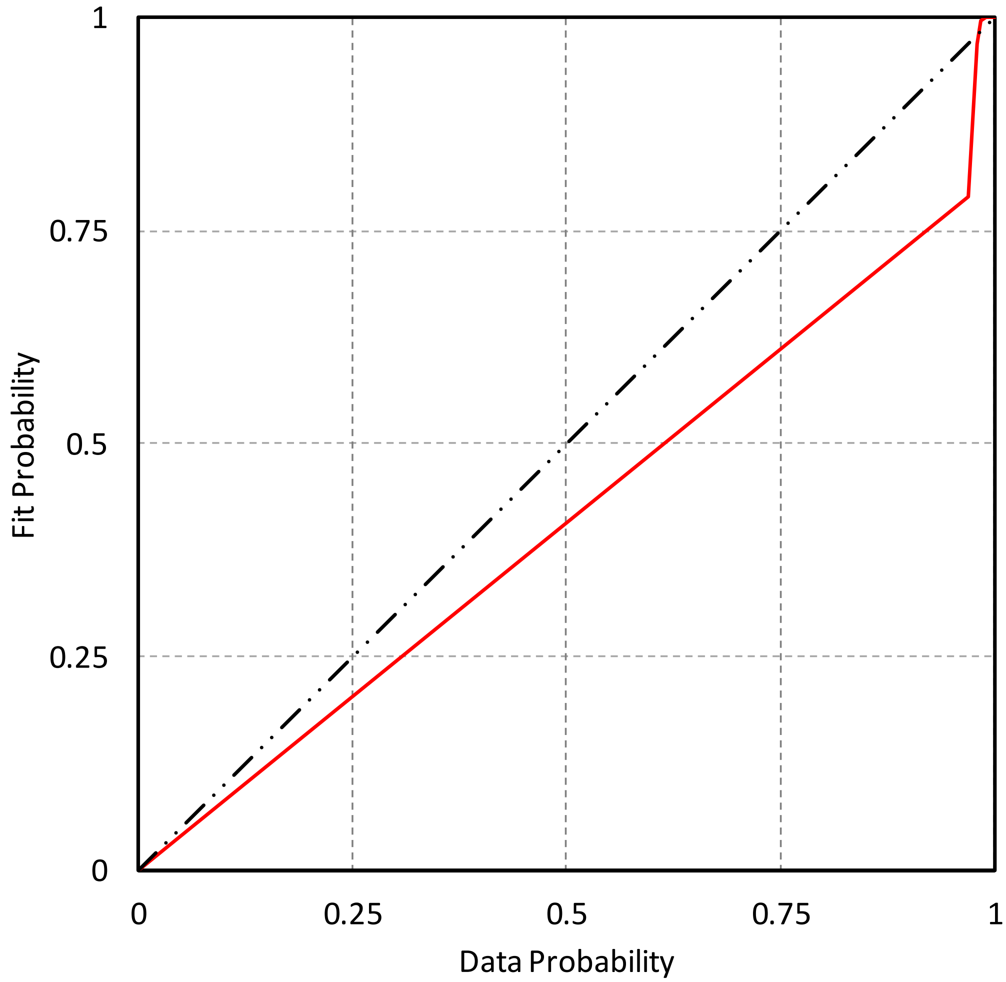

Figure D-18
Probability-probability plot for horizontal ZOI for TS cable

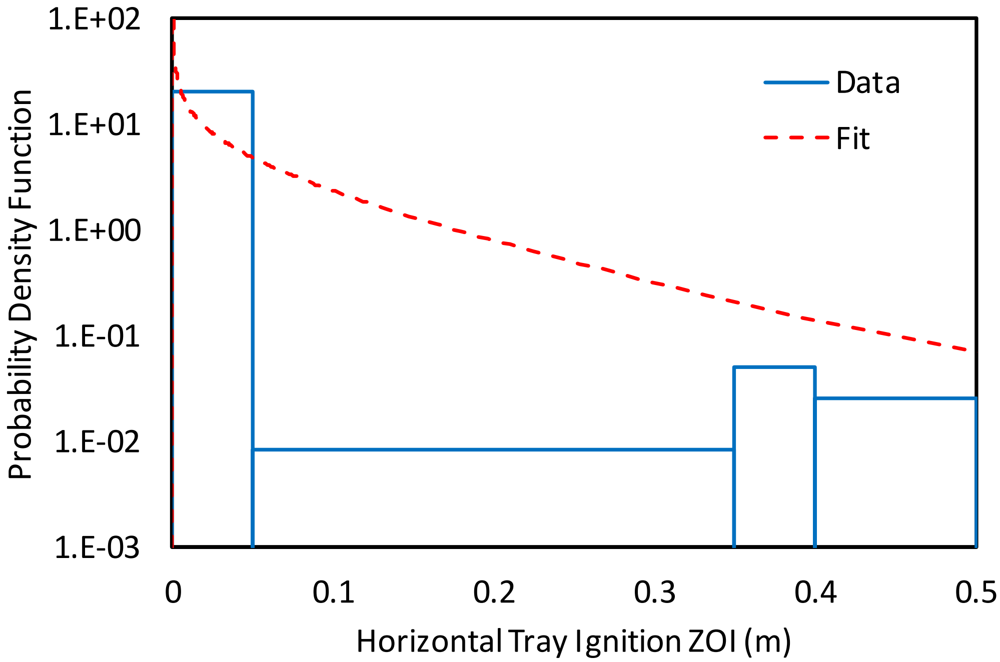

Figure D-19
Probability density function for horizontal ZOI for bulk cable tray ignition (TI)

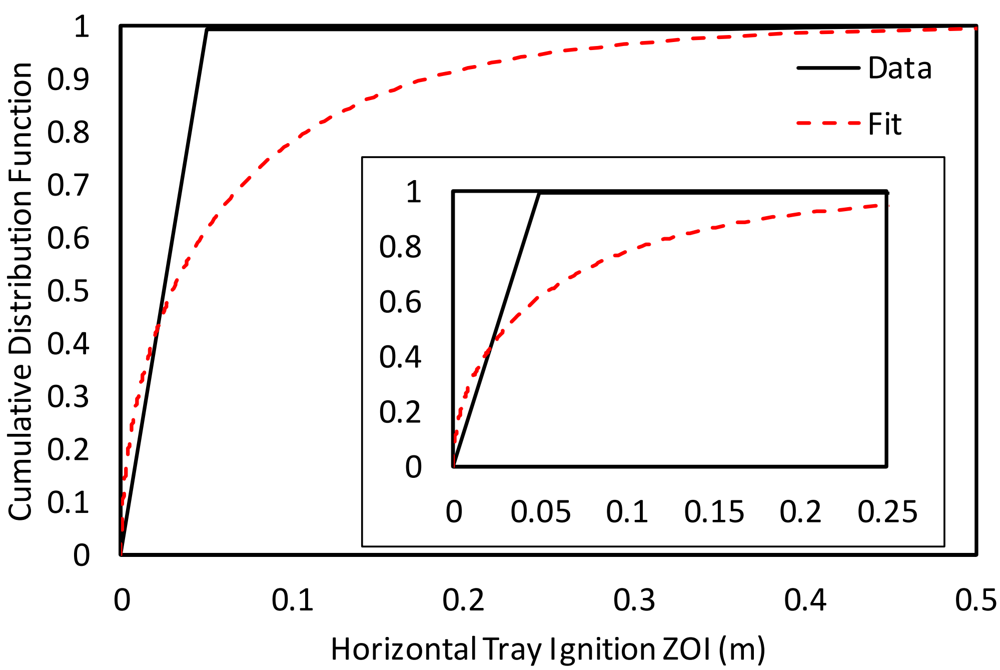

Figure D-20
Cumulative distribution function for horizontal ZOI for TI

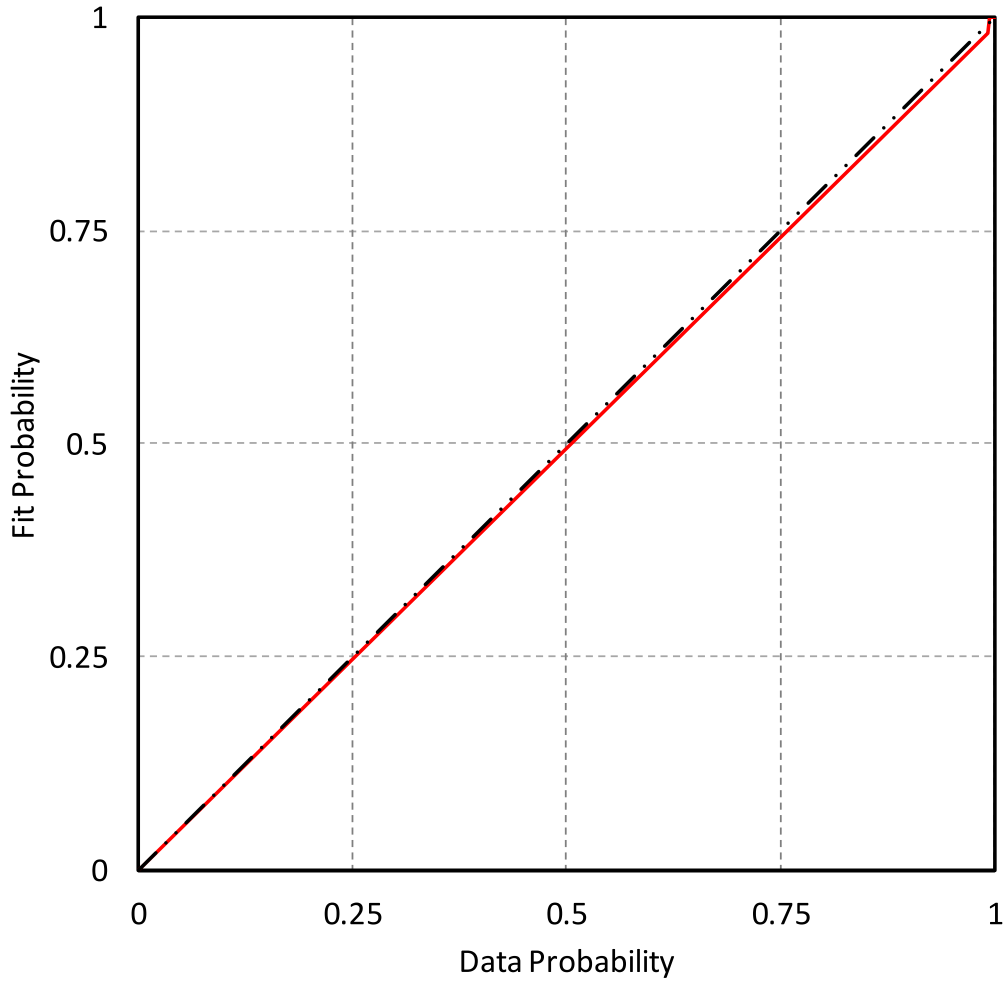

Figure D-21
Probability-probability plot for horizontal ZOI for TI

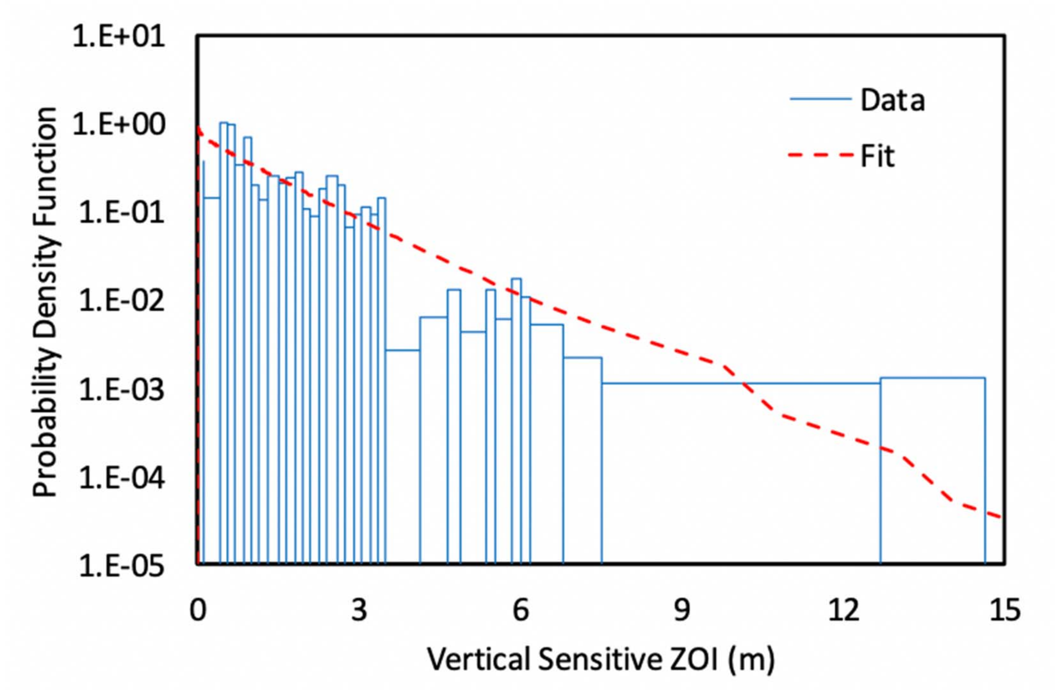

Figure D-22
Probability density function for vertical ZOI for SE

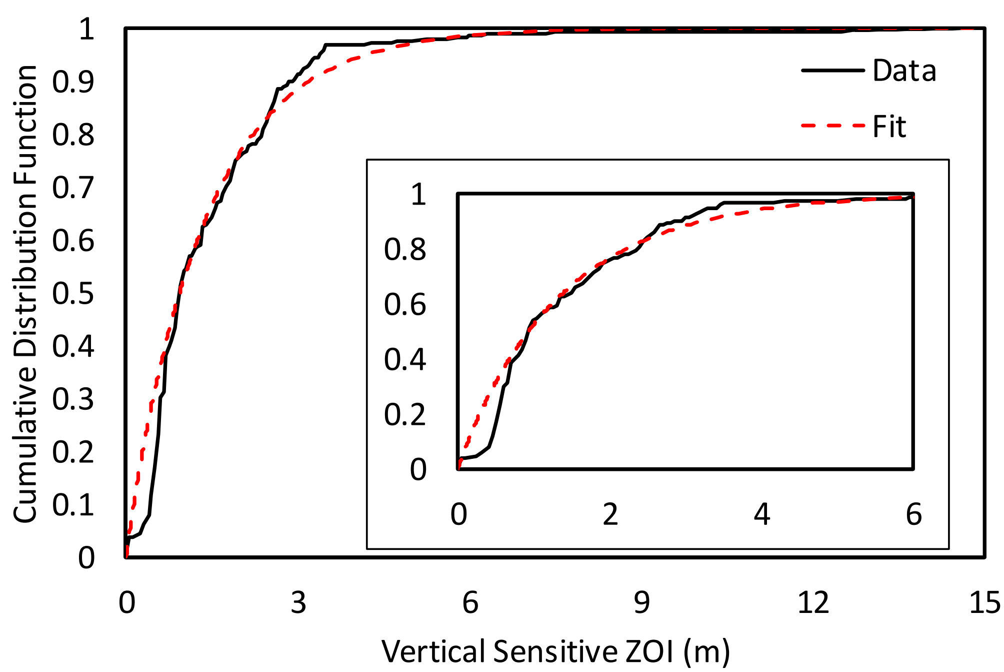

Figure D-23
Cumulative distribution function for vertical ZOI for SE

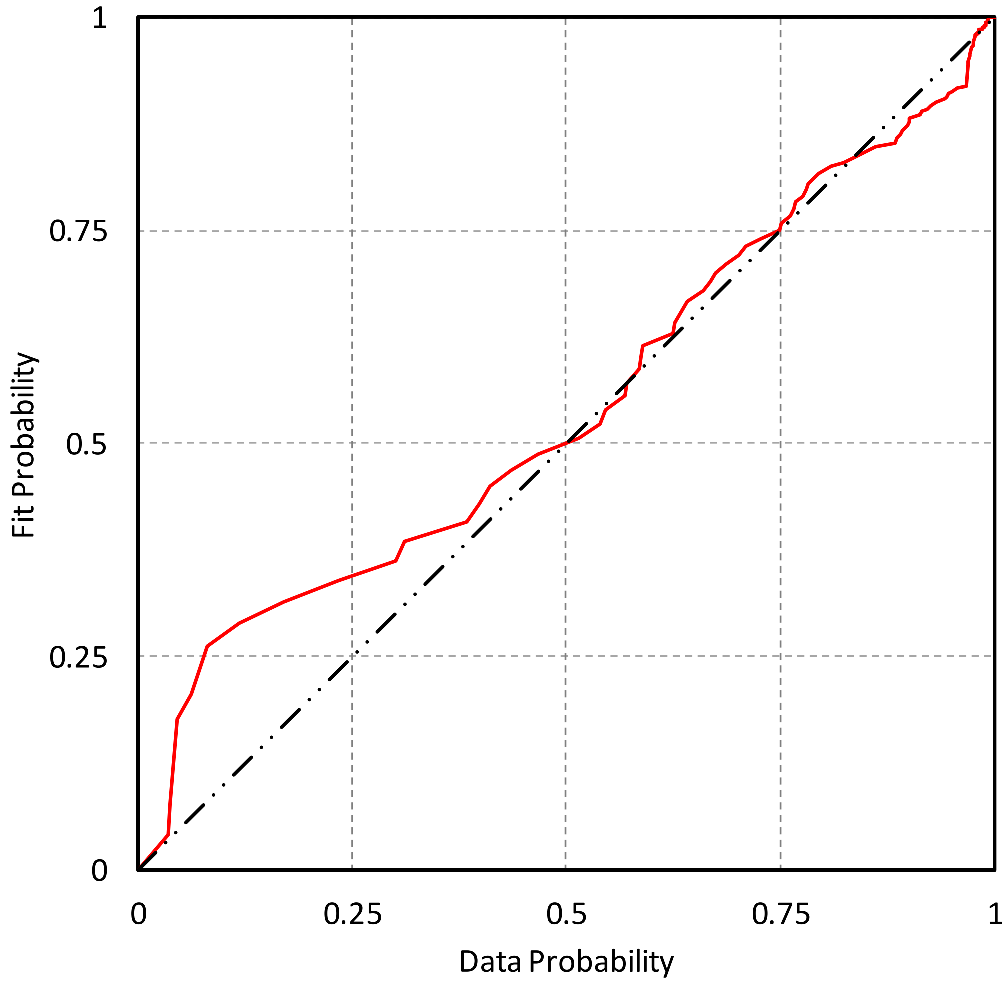

Figure D-24
Probability-probability plot for vertical ZOI for SE

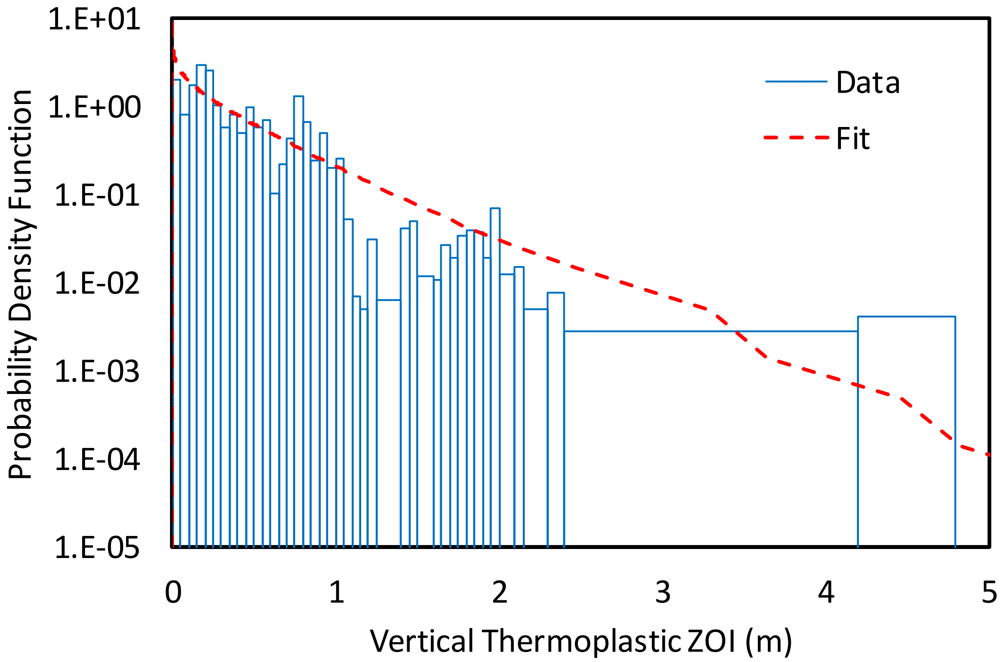

Figure D-25
Probability density function for vertical ZOI for TP cable

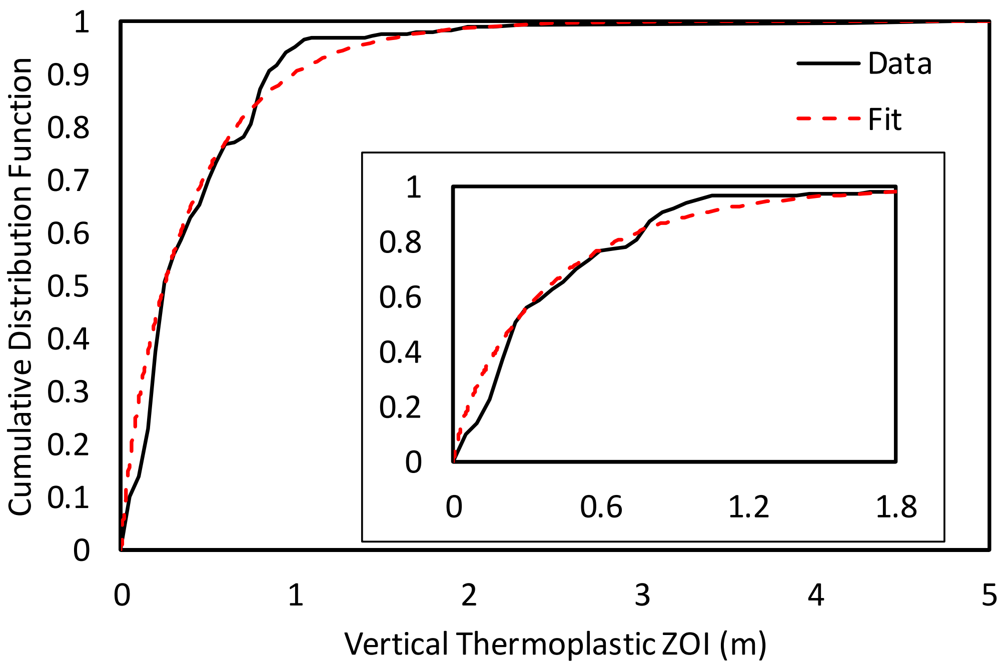

Figure D-26
Cumulative distribution function for vertical ZOI for TP cable

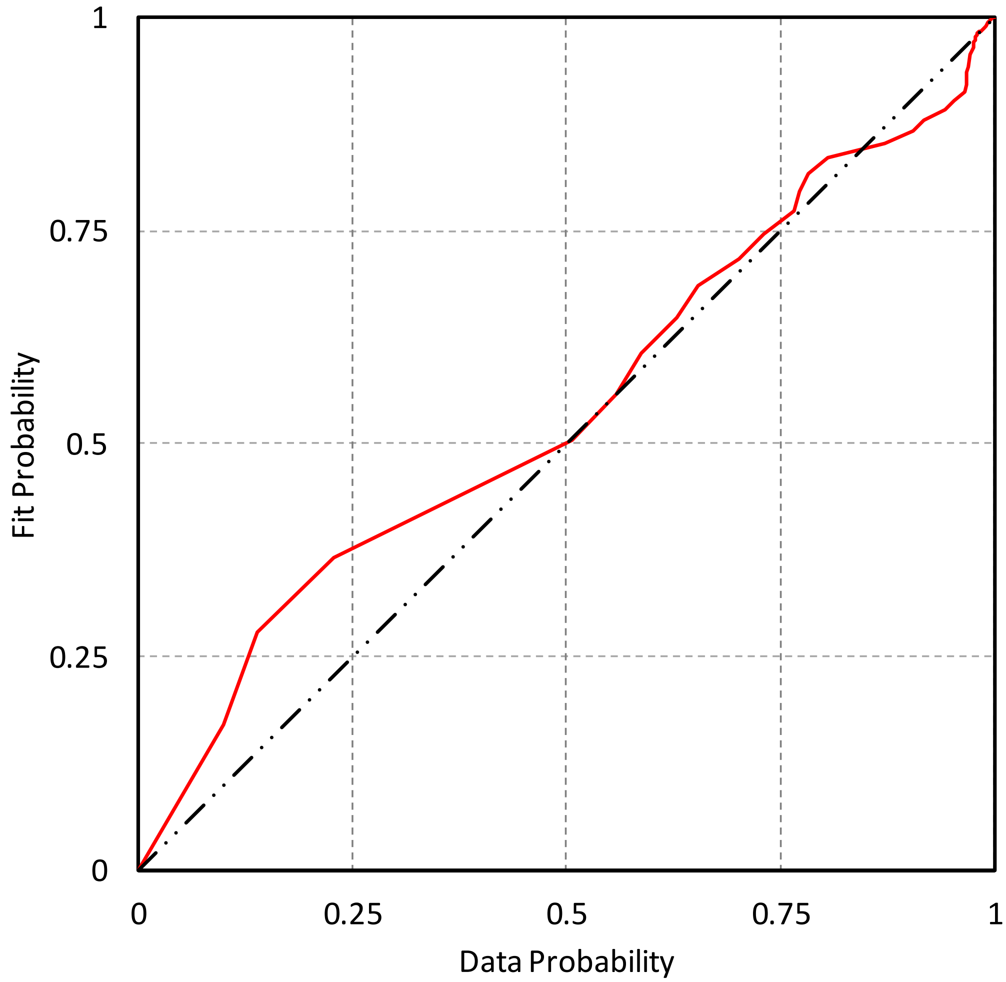

Figure D-27
Probability-probability plot for vertical ZOI for TP cable

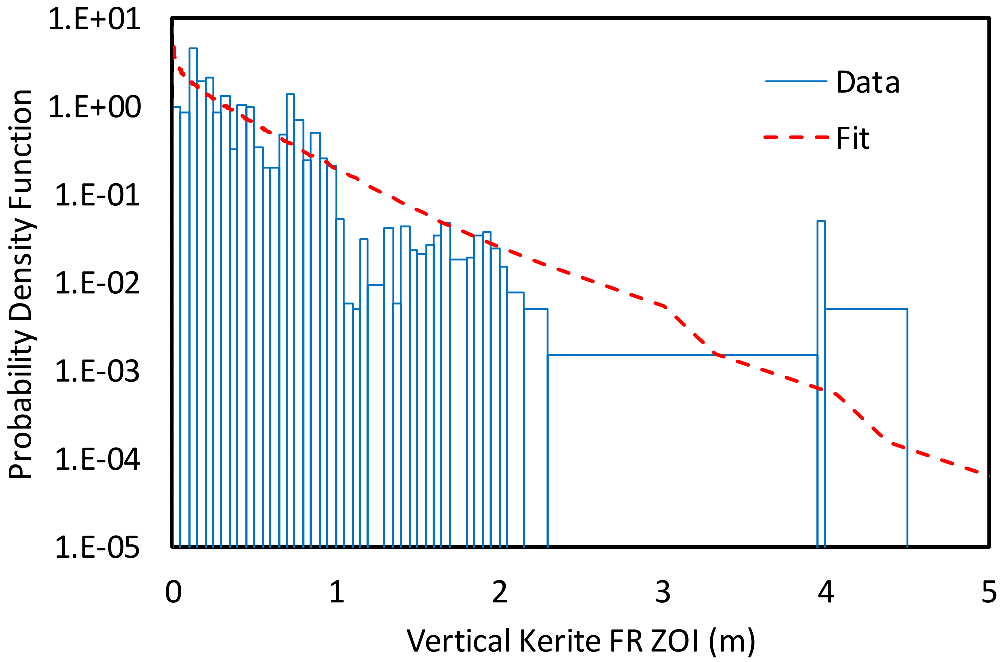

Figure D-28
Probability density function for vertical ZOI for KC

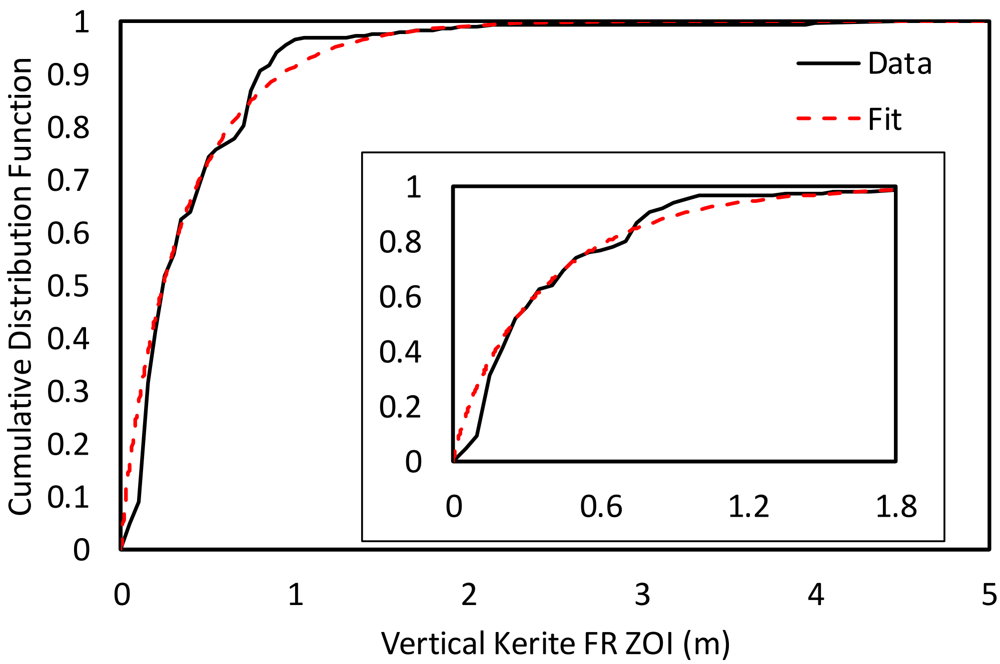

Figure D-29
Cumulative distribution function for vertical ZOI for KC

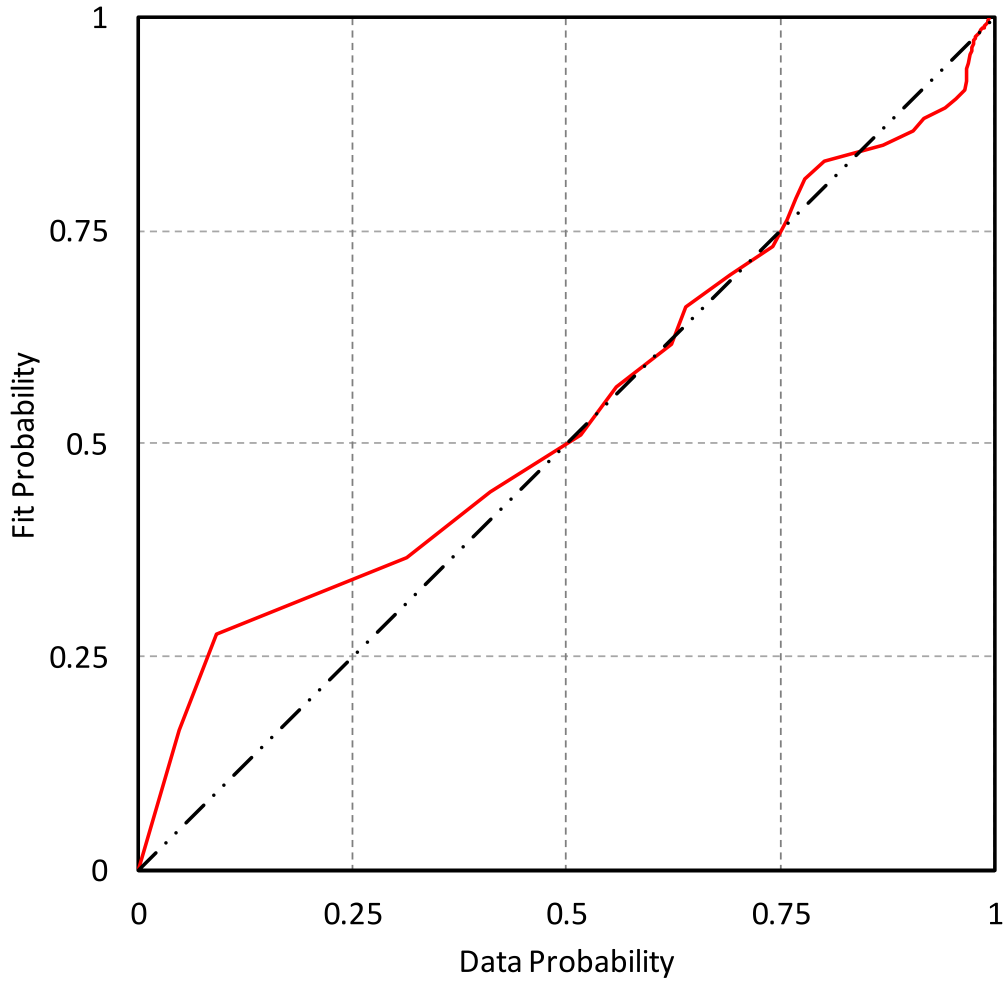

Figure D-30
Probability-probability plot for vertical ZOI for KC

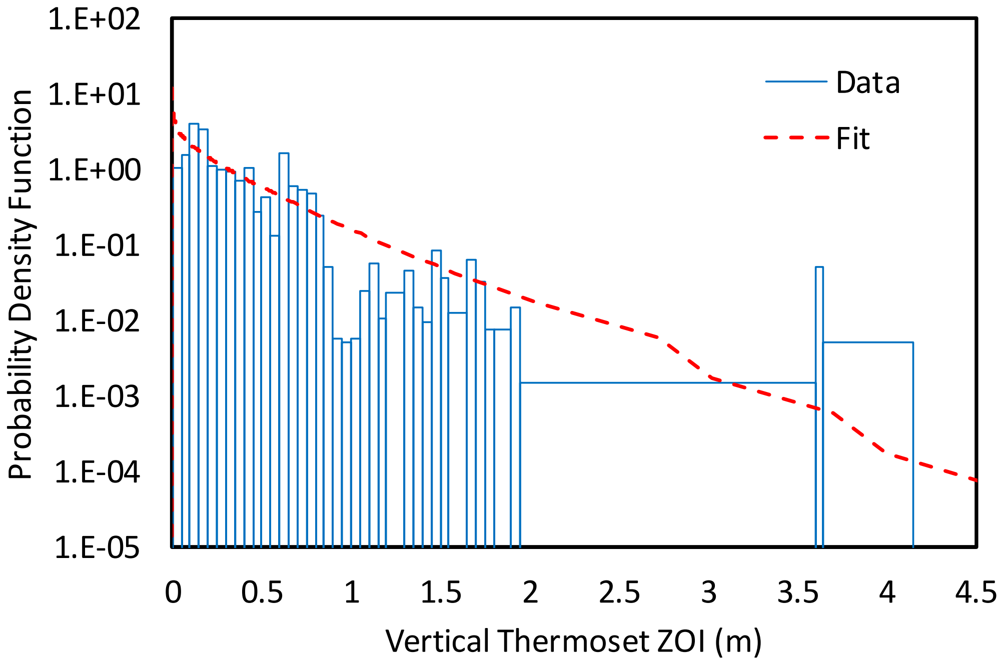

Figure D-31
Probability density function for vertical ZOI for TS cable

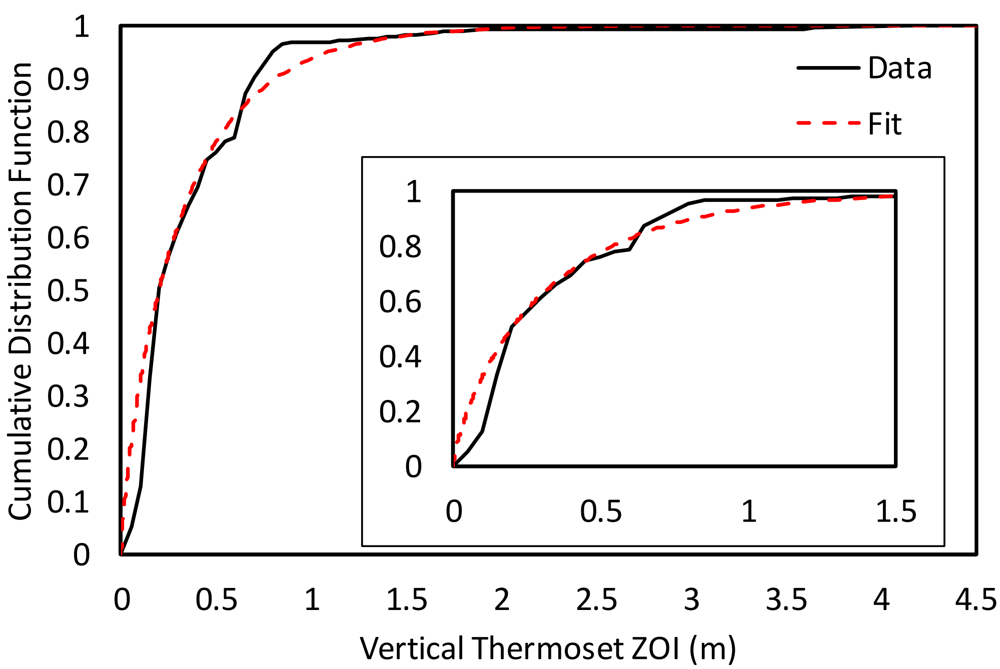

Figure D-32
Cumulative distribution function for vertical ZOI for TS cable

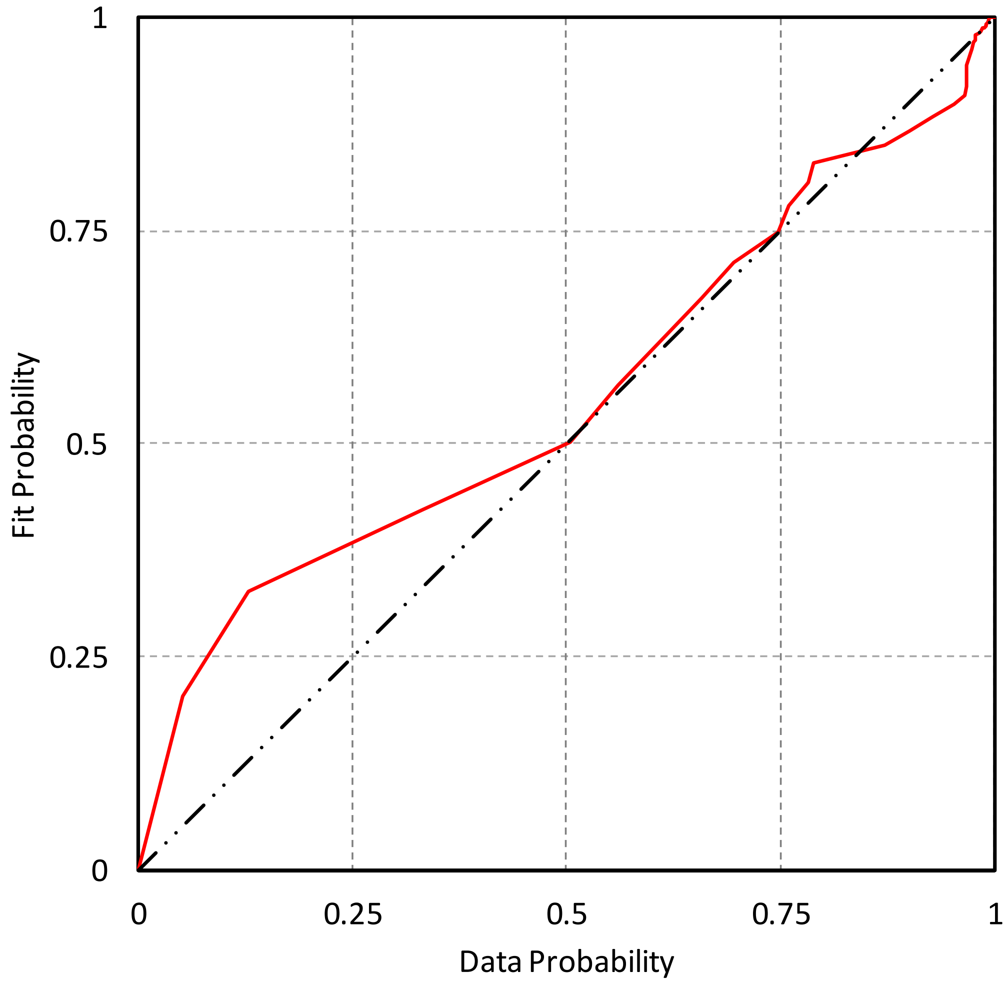

Figure D-33
Probability-probability plot for vertical ZOI for TS cable

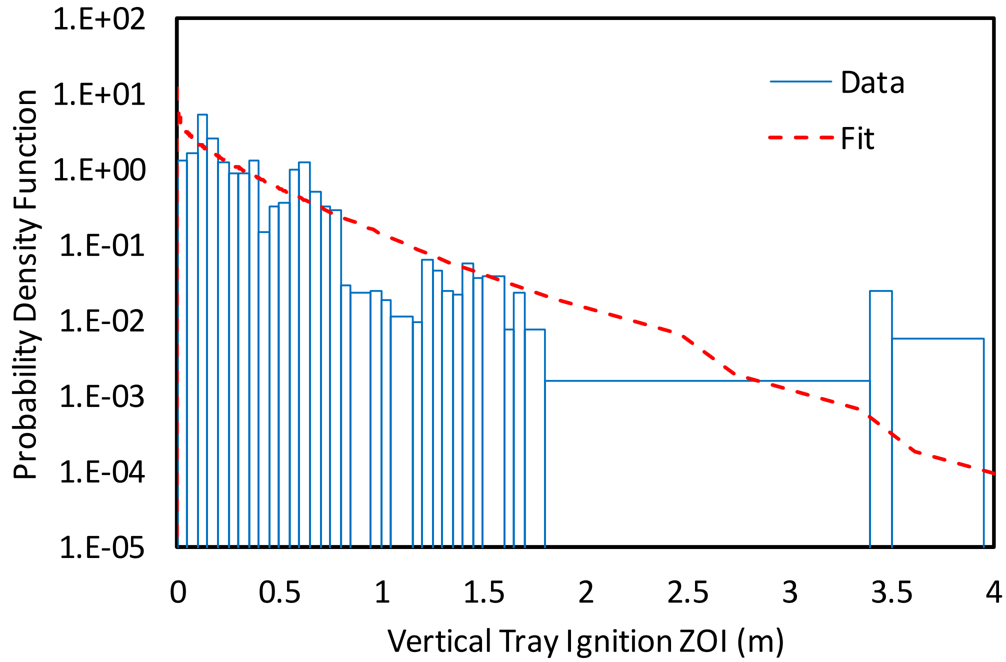

Figure D-34
Probability density function for vertical ZOI for TI

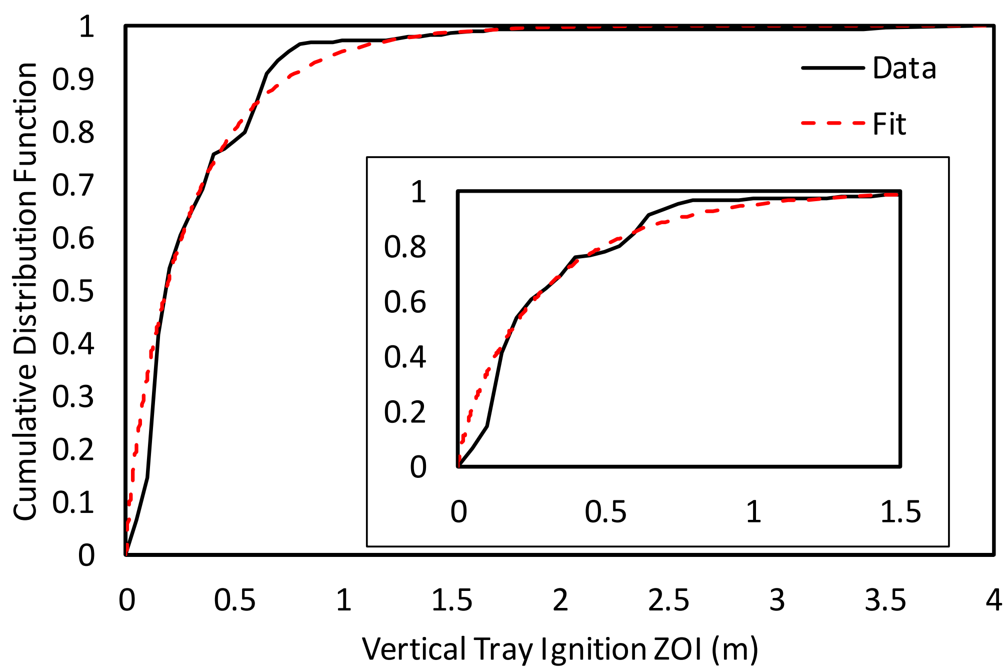

Figure D-35
Cumulative distribution function for vertical ZOI for TI

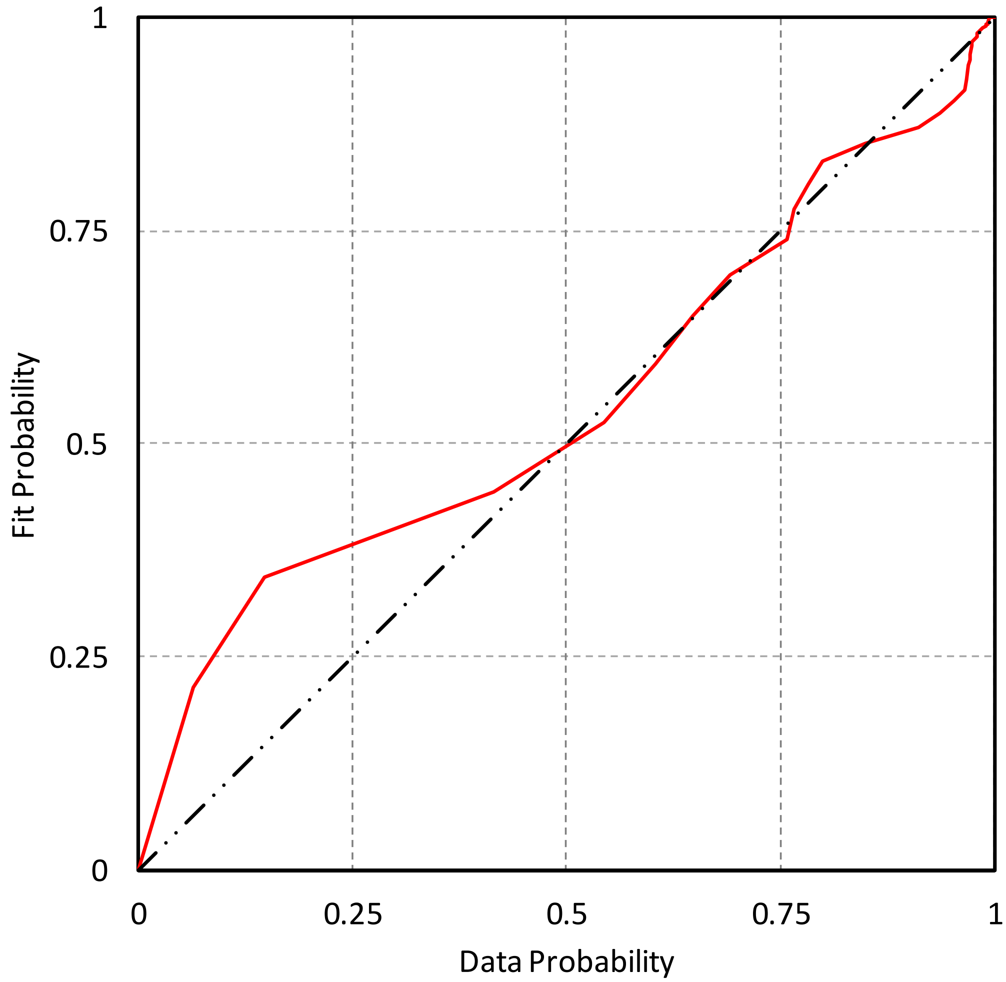

Figure D-36
Probability-probability plot for vertical ZOI for TI

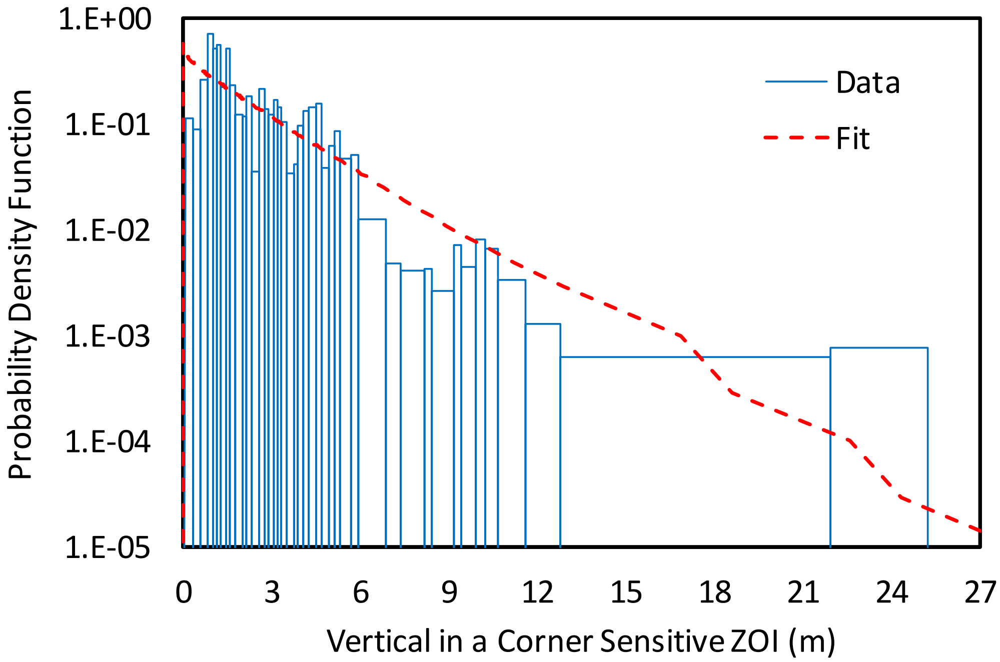

Figure D-37
Probability density function for vertical in a corner ZOI for SE

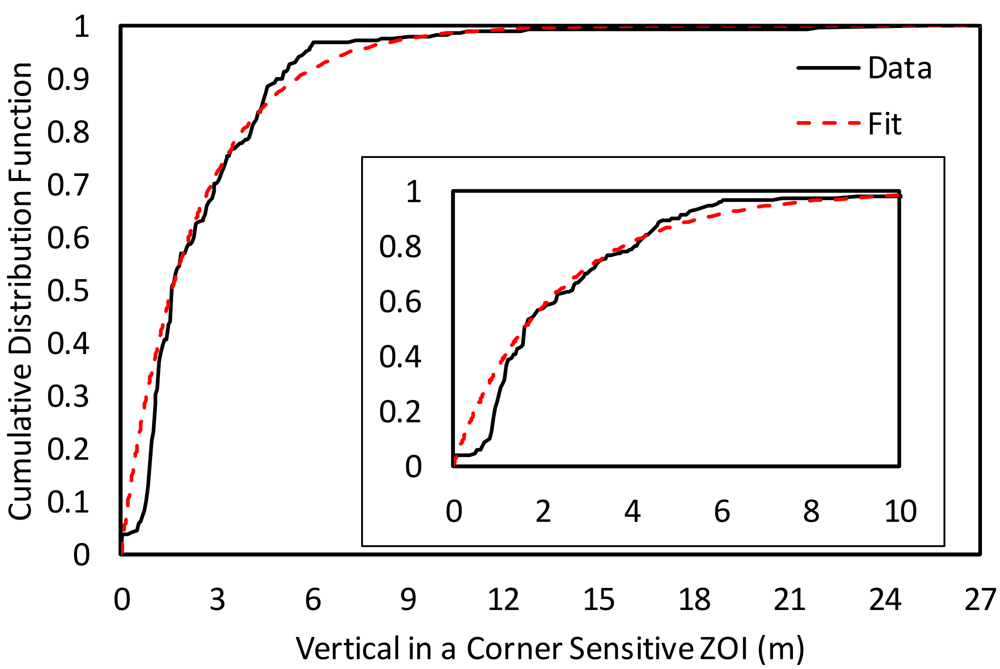

Figure D-38
Cumulative distribution function for vertical in a corner ZOI for SE

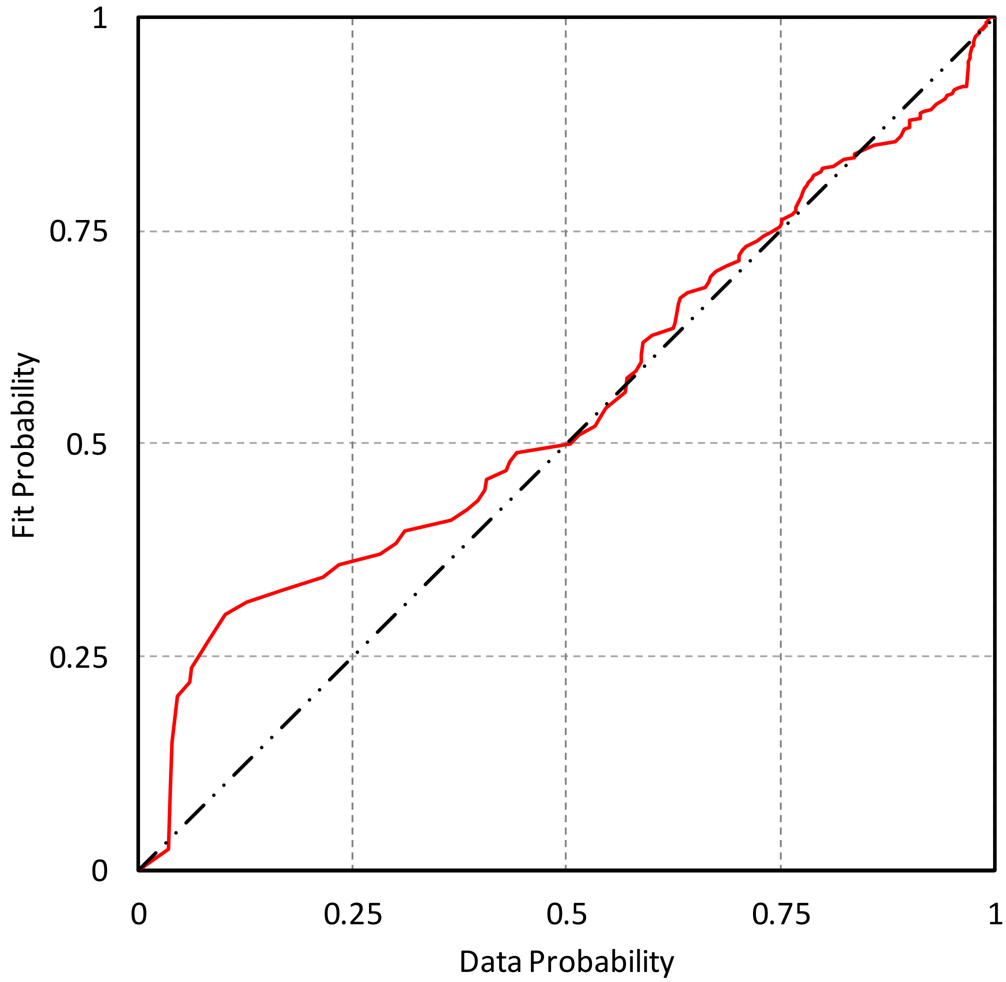

Figure D-39
Probability-probability plot for vertical in a corner ZOI for SE

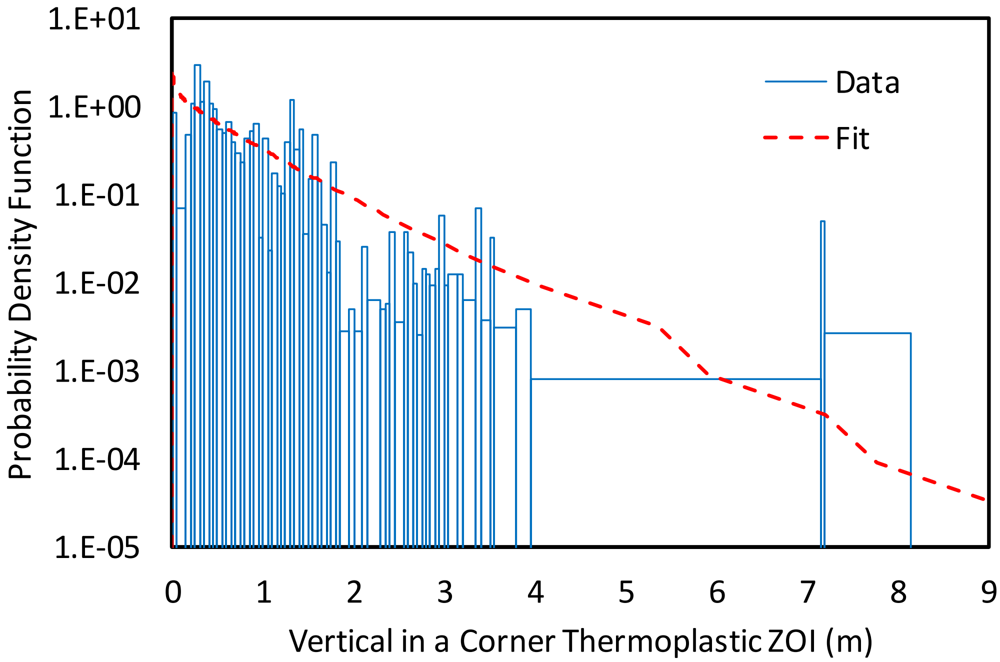

Figure D-40
Probability density function for vertical in a corner ZOI for TP cable

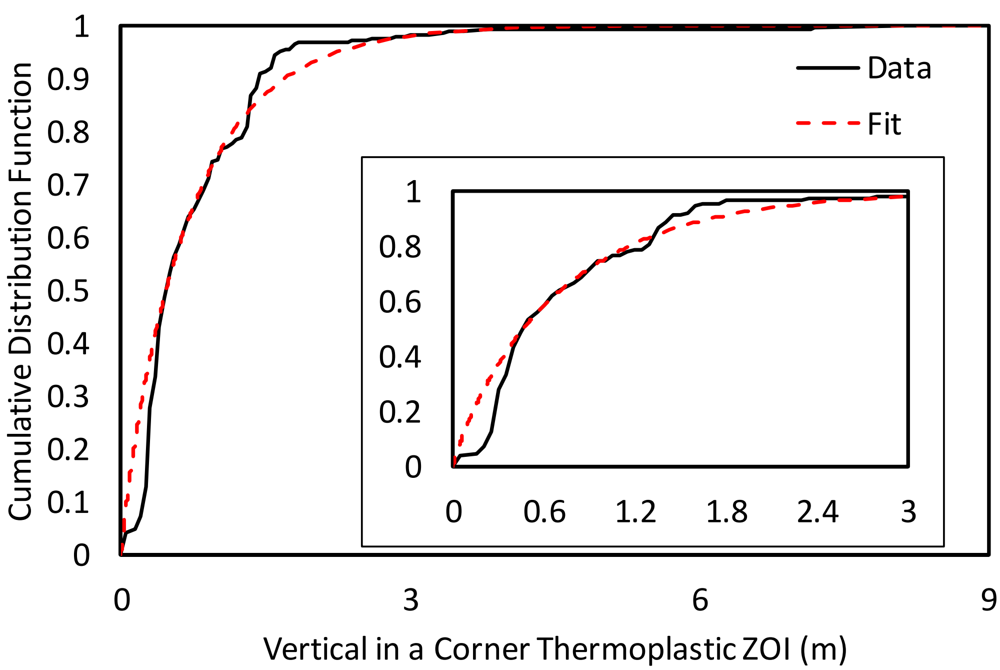

Figure D-41
Cumulative distribution function for vertical in a corner ZOI for TP cable

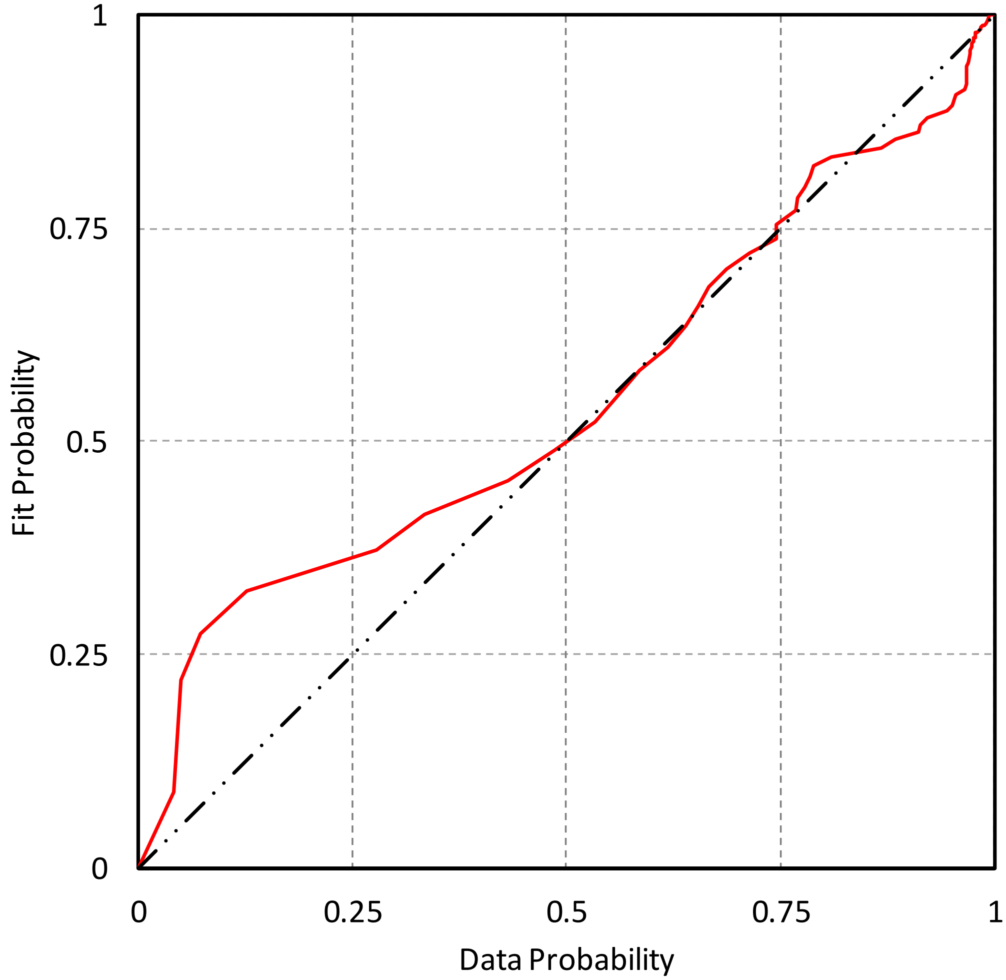

Figure D-42
Probability-probability plot for vertical in a corner ZOI for TP cable

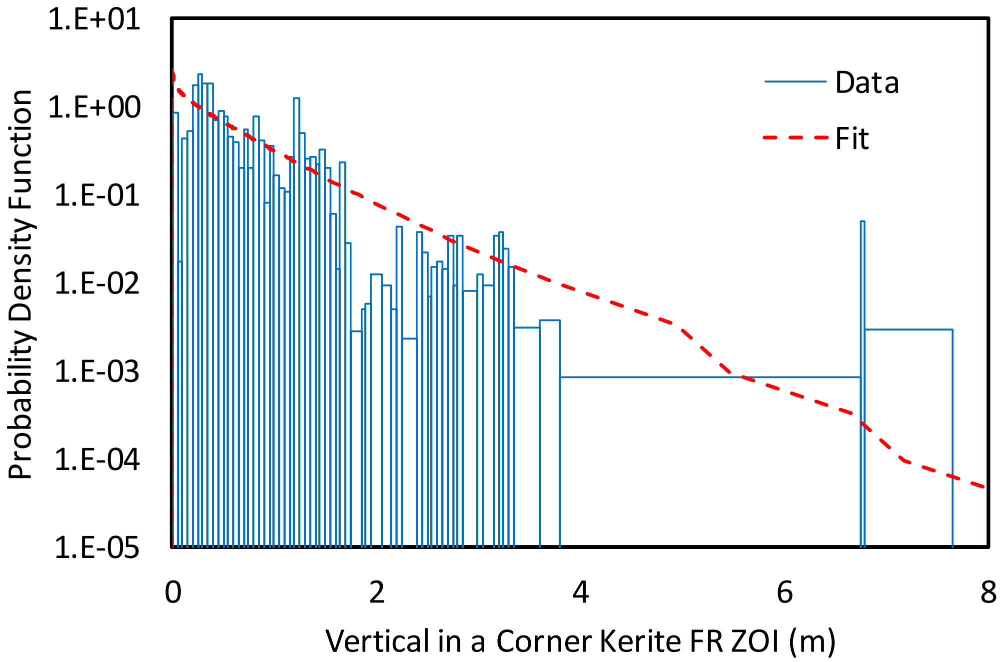

Figure D-43
Probability density function for vertical in a corner ZOI for KC

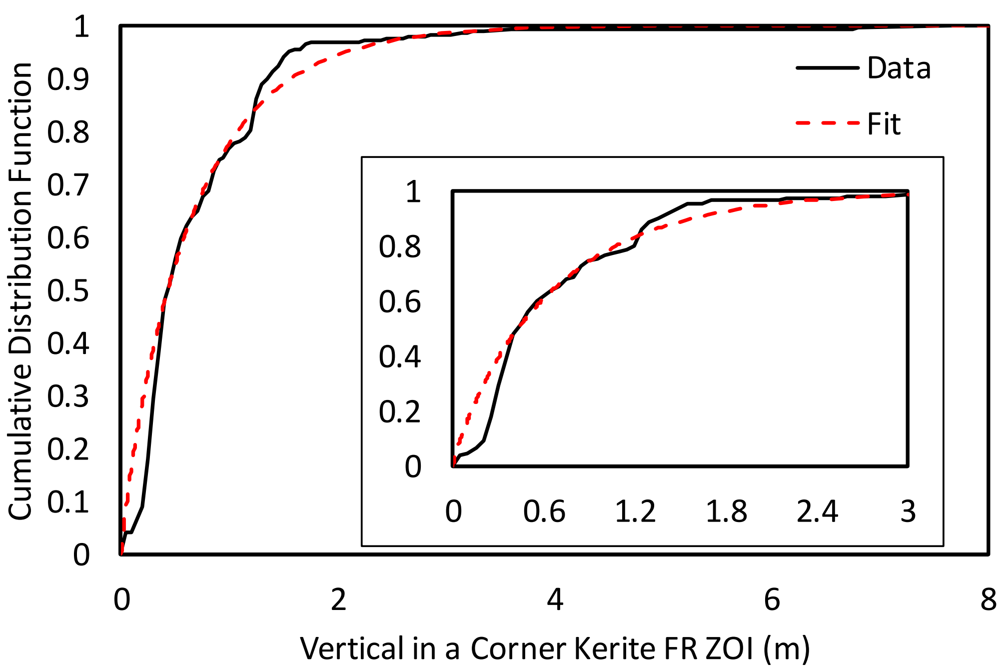

Figure D-44
Cumulative distribution function for vertical in a corner ZOI for KC

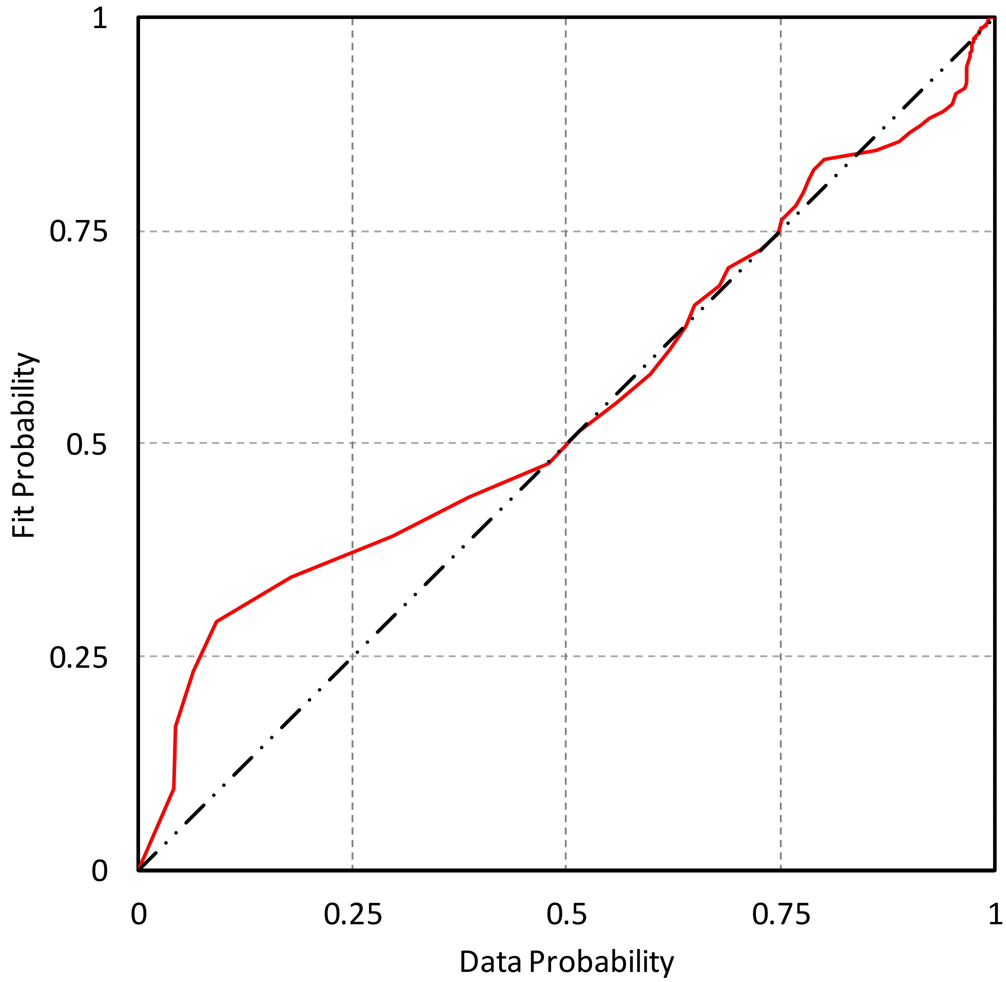

Figure D-45
Probability-probability plot for vertical in a corner ZOI for KC

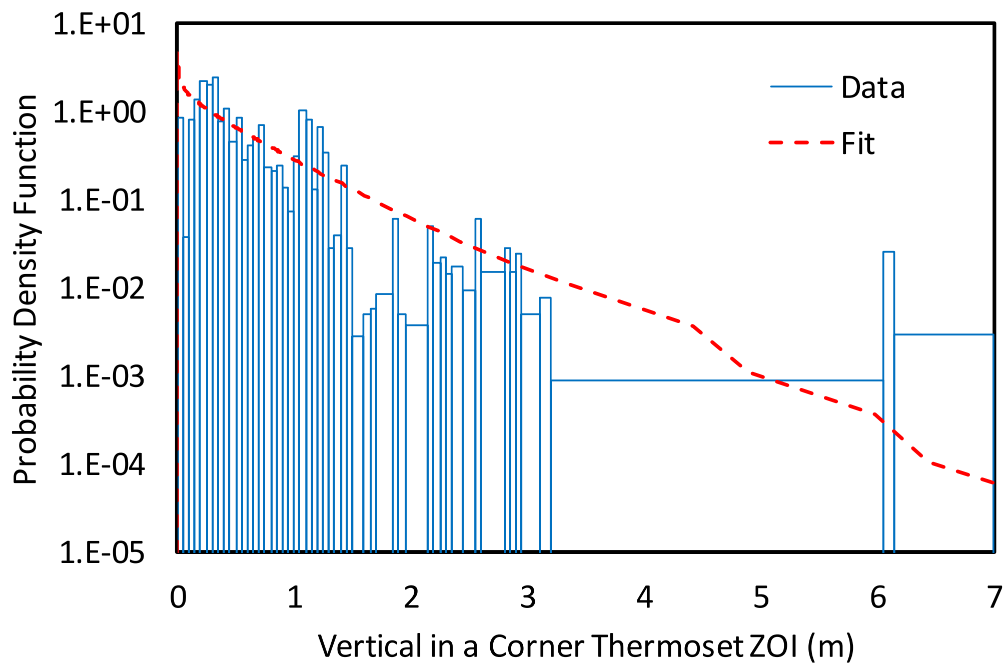

Figure D-46
Probability density function for vertical in a corner ZOI for TS cable

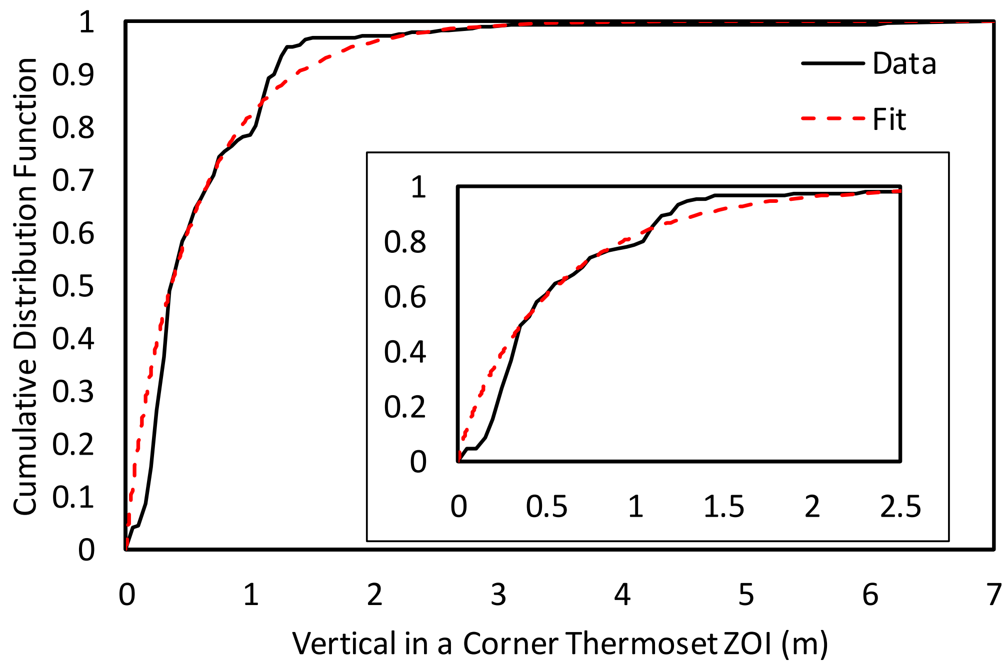

Figure D-47
Cumulative distribution function for vertical in a corner ZOI for TS cable

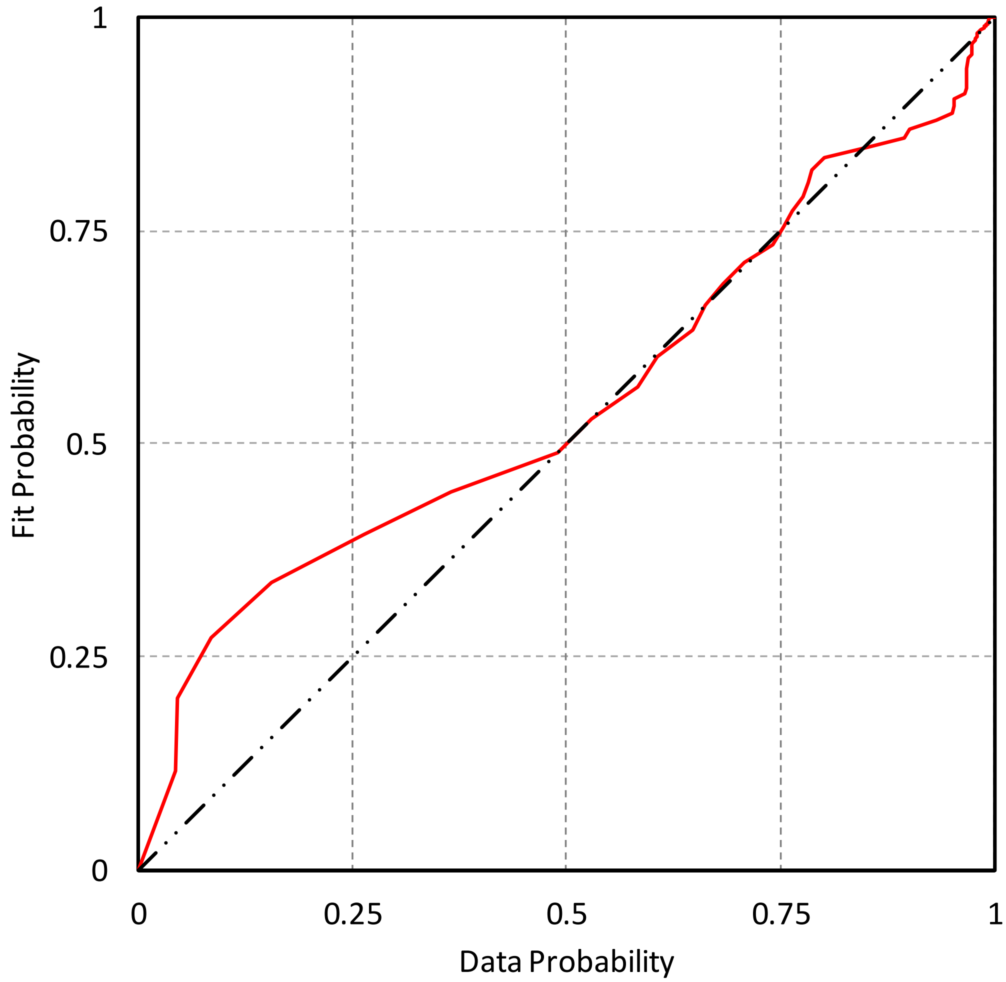

Figure D-48
Probability-probability plot for vertical in a corner ZOI for TS cable

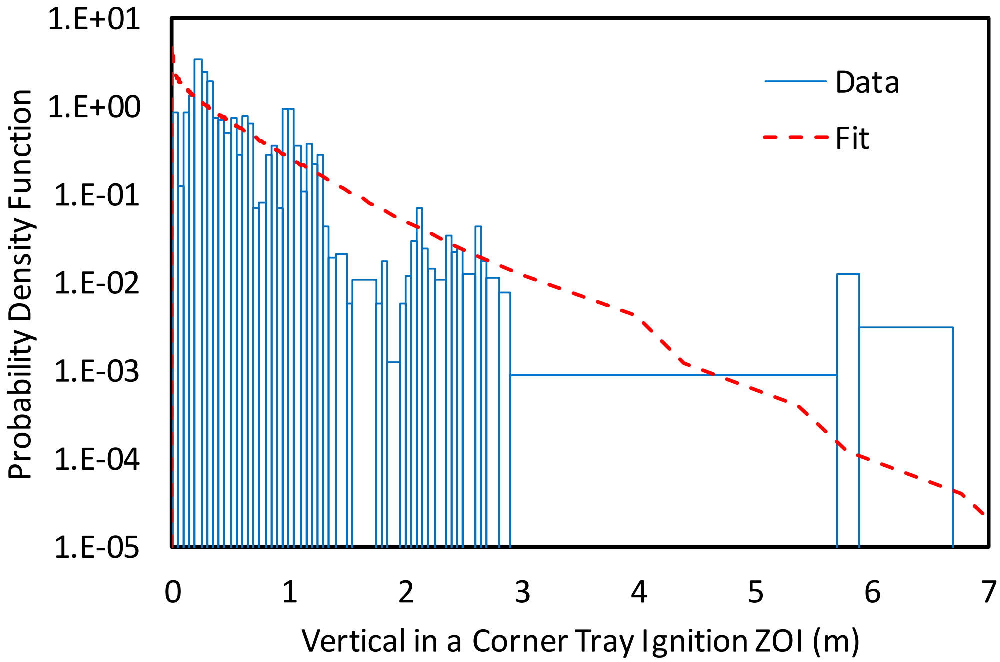

Figure D-49
Probability density function for vertical in a corner ZOI for TI

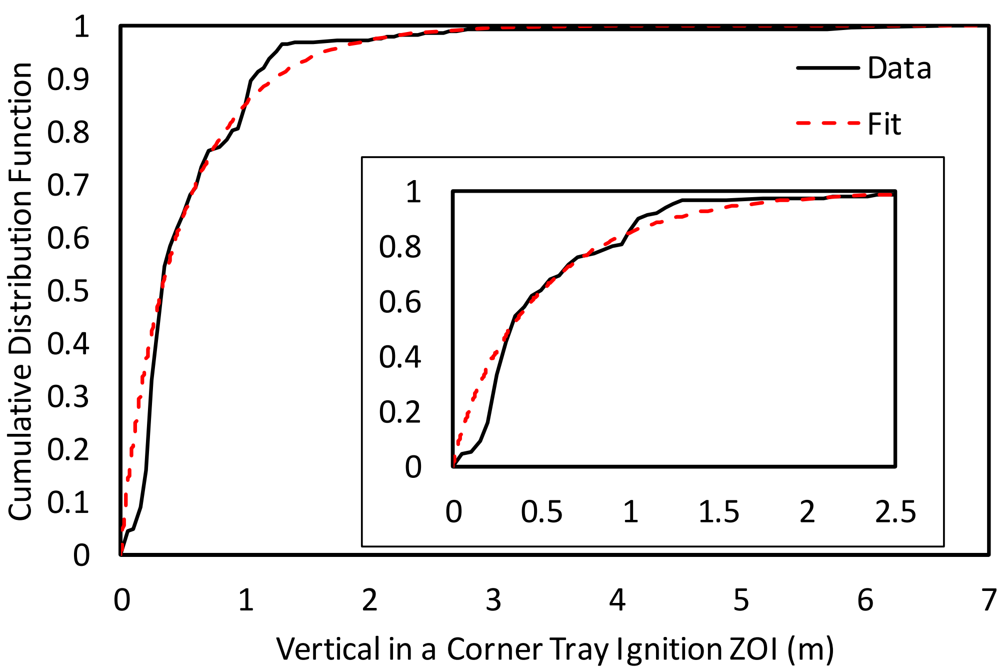

Figure D-50
Cumulative distribution function for vertical in a corner ZOI for TI

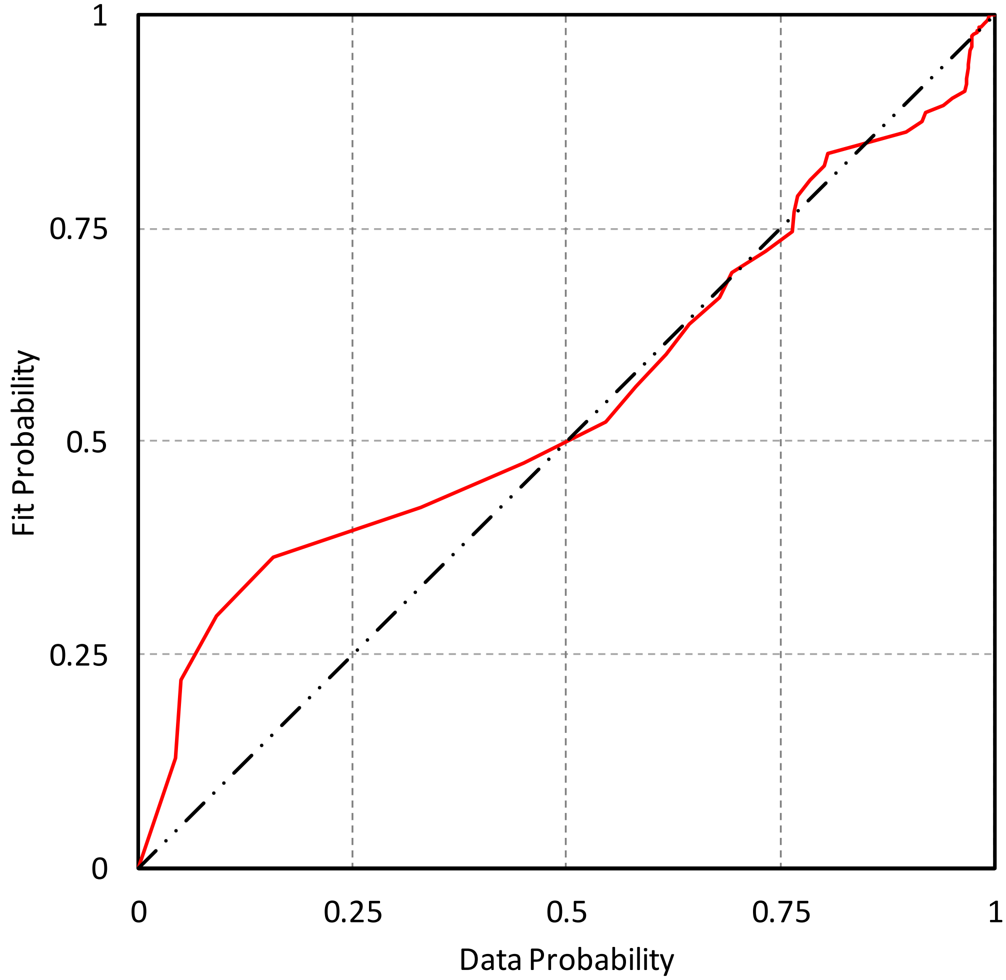

Figure D-51
Probability-probability plot for vertical in a corner ZOI for TI

D.2 Transient Combustible Control Location Transient Fire Distribution Plots

Figures D-52 through D-102 contain the plots for the distributions in Table 4-4.

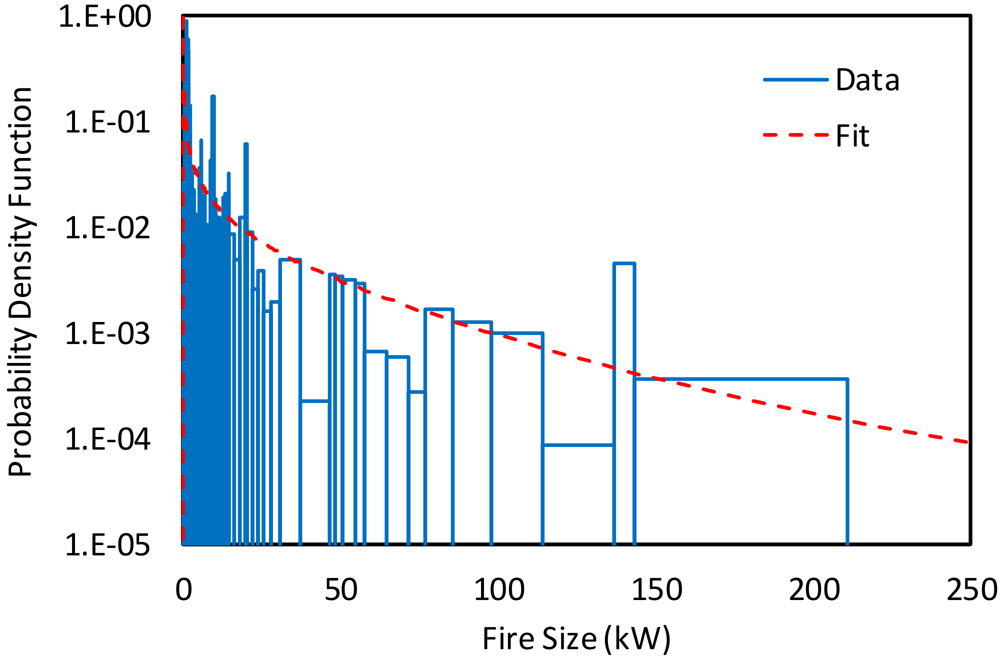

Figure D-52
Probability density function for peak HRR

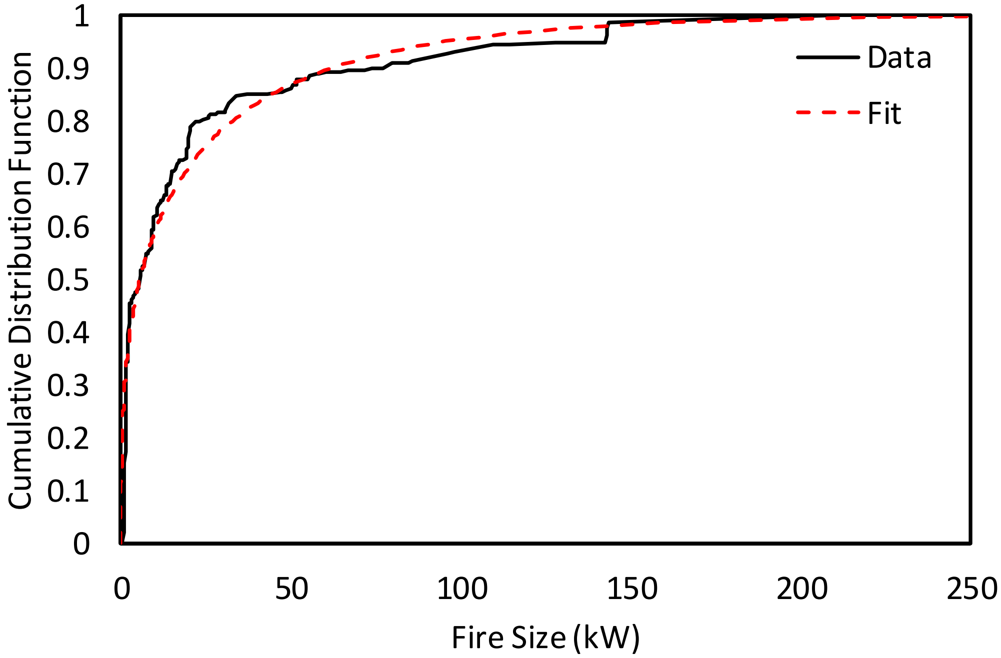

Figure D-53
Cumulative distribution function for peak HRR

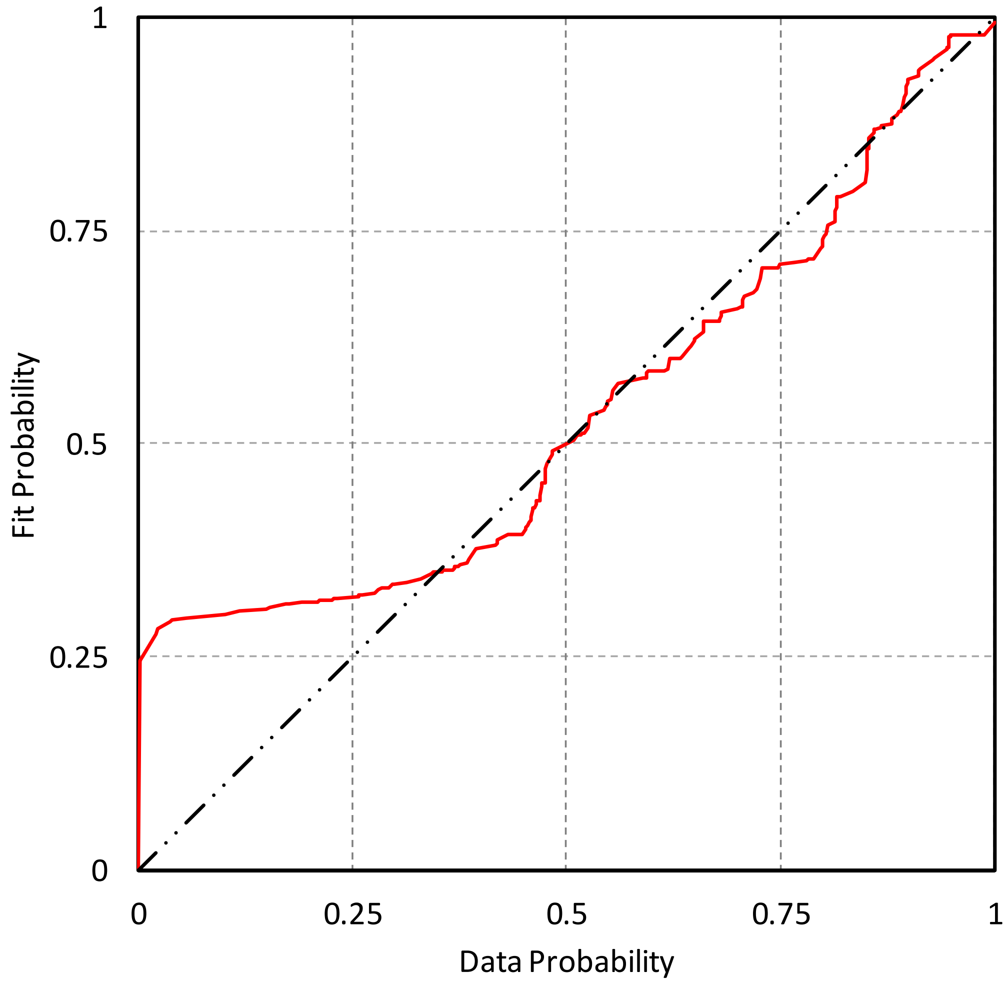

Figure D-54
Probability-probability plot for peak HRR

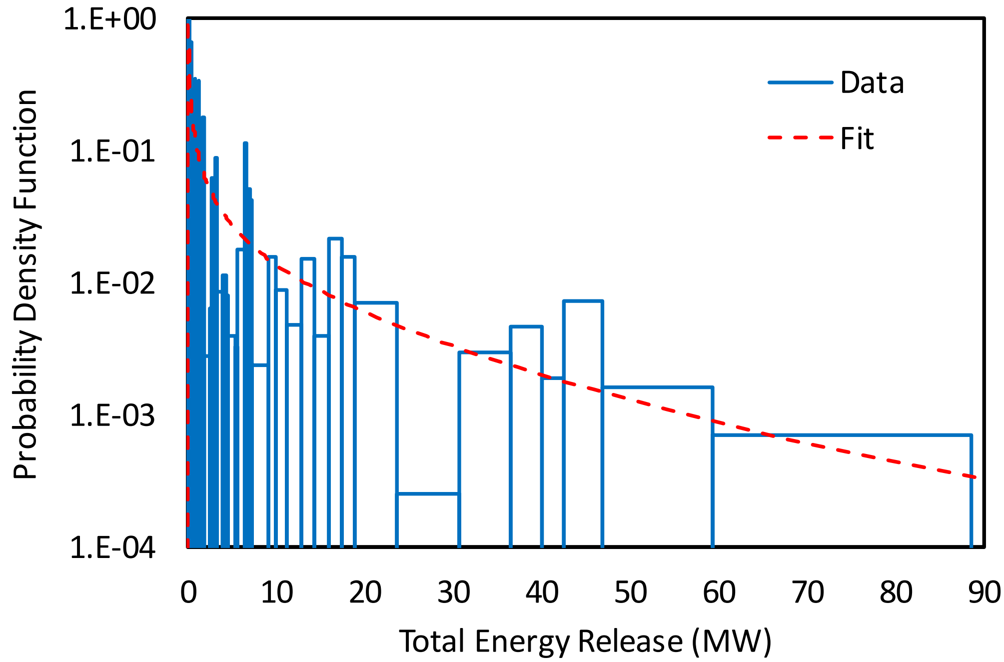

Figure D-55
Probability density function for TER

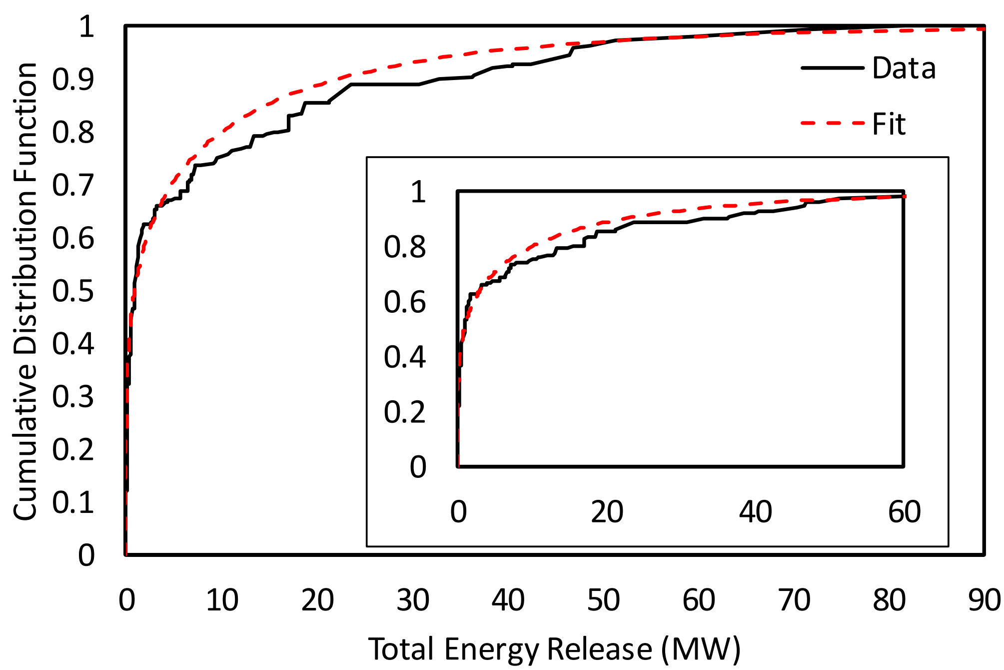

Figure D-56
Cumulative distribution function for TER

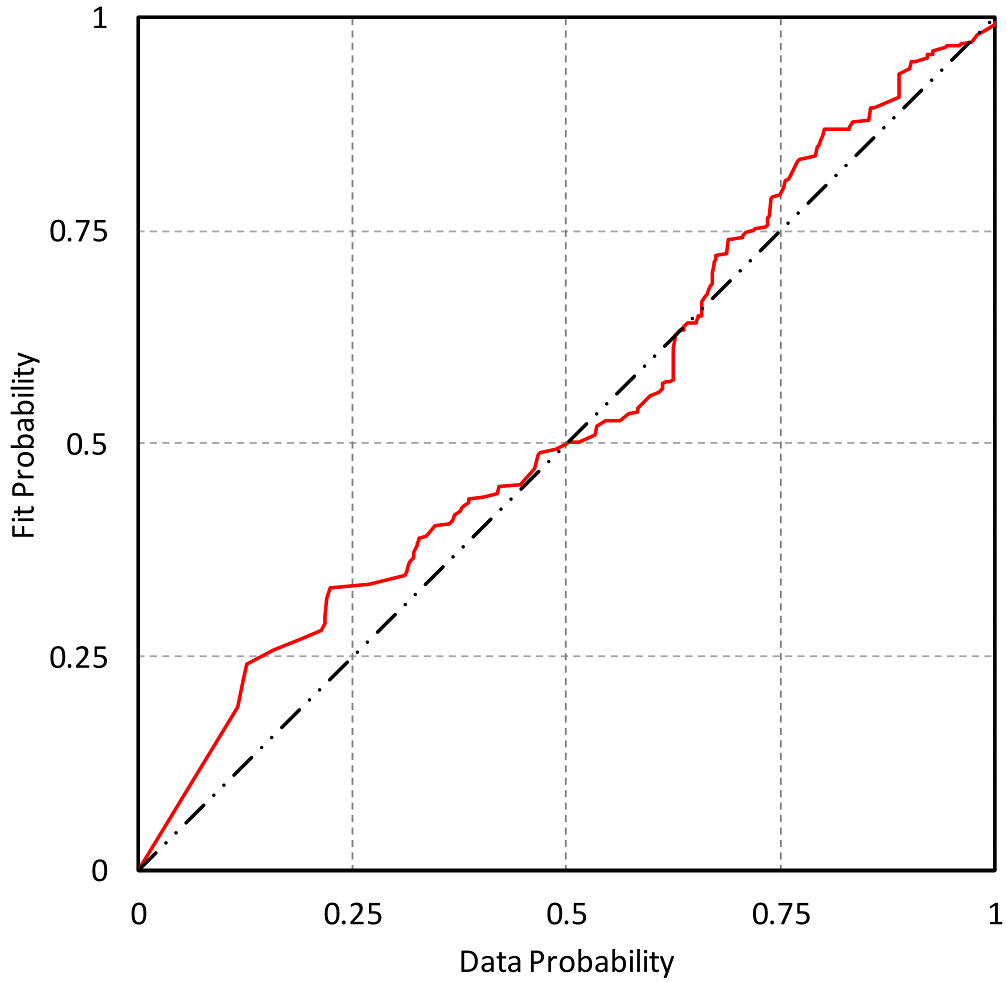

Figure D-57
Probability-probability plot for TER

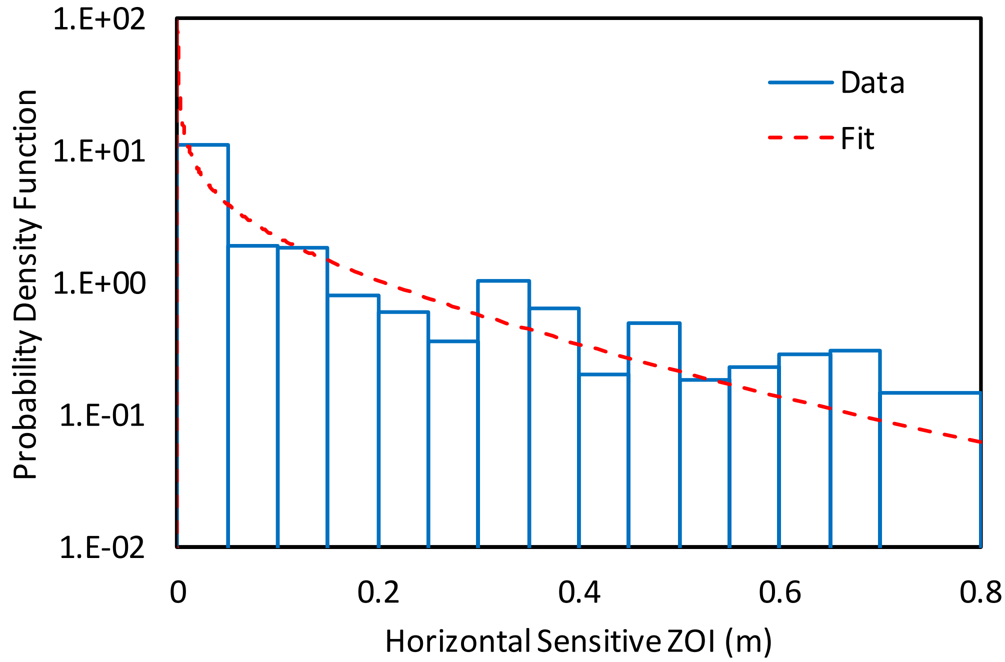

Figure D-58
Probability density function for horizontal ZOI for SE

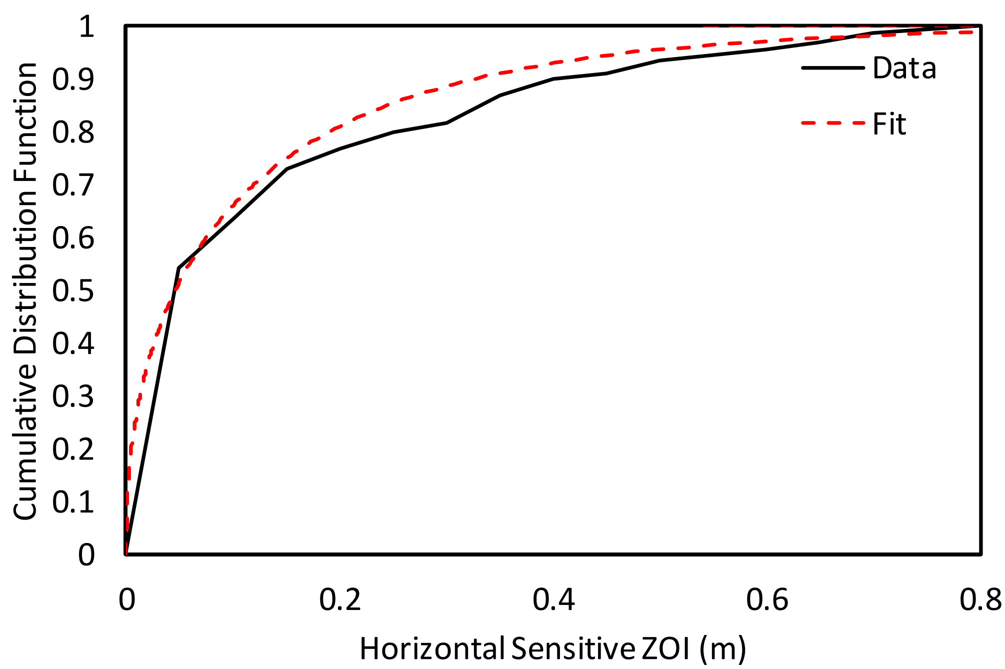

Figure D-59
Cumulative distribution function for horizontal ZOI for SE

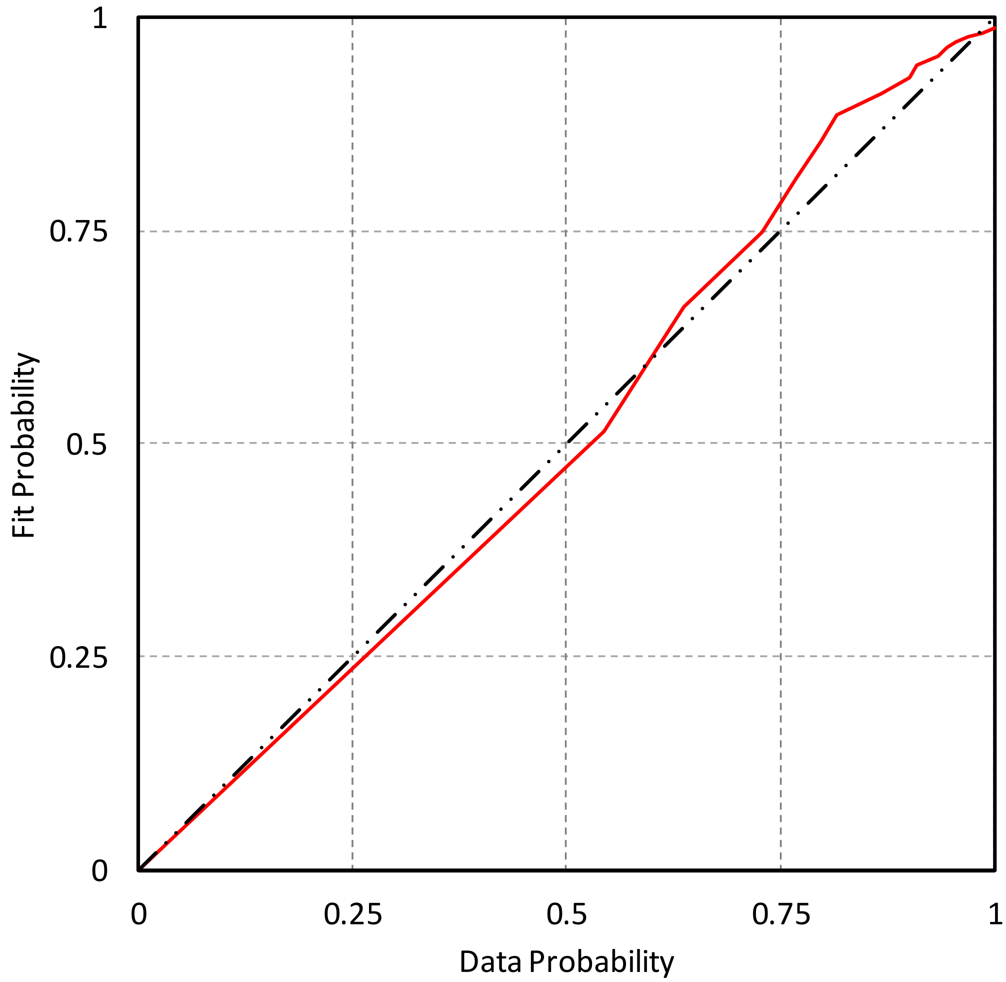

Figure D-60
Probability-probability plot for horizontal ZOI for SE

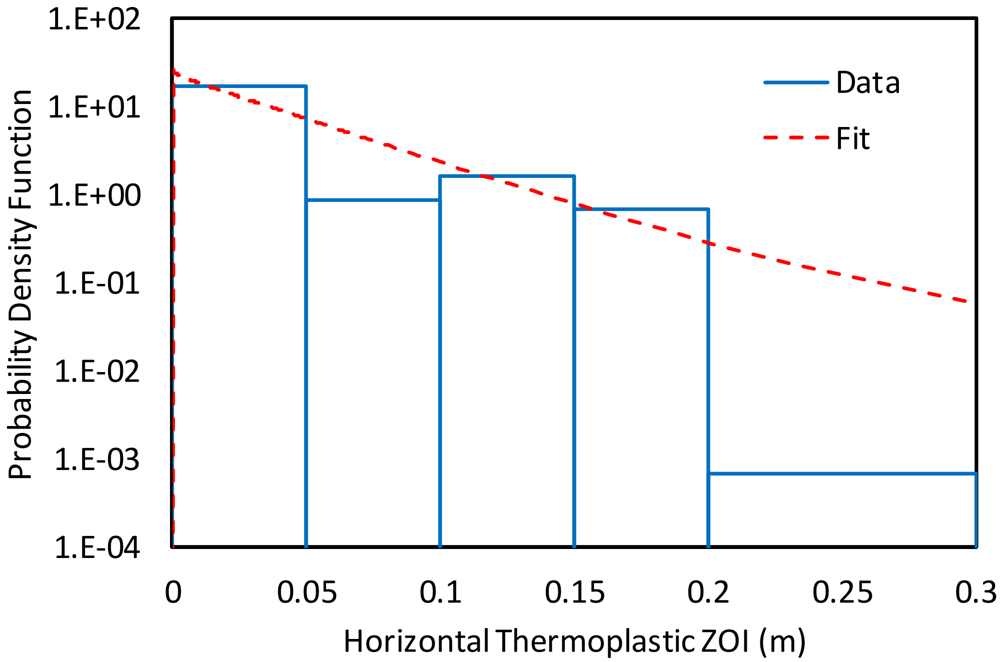

Figure D-61
Probability density function for horizontal ZOI for TP cable

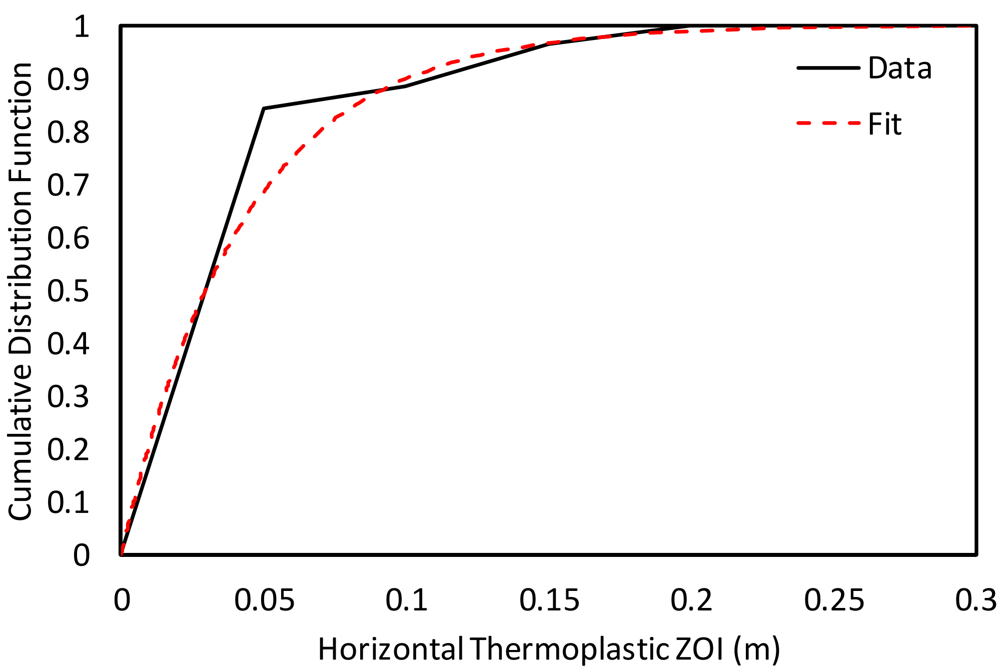

Figure D-62
Cumulative distribution function for horizontal ZOI for TP cable

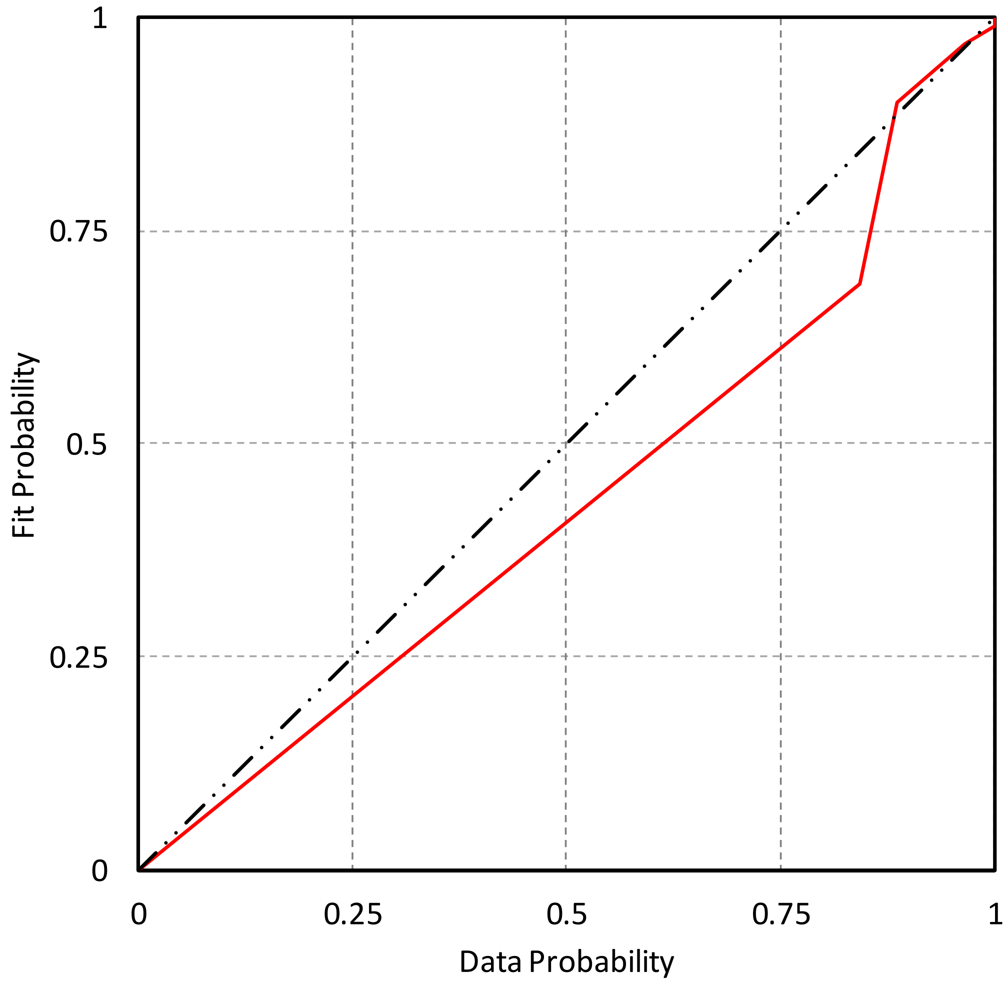

Figure D-63
Probability-probability plot for horizontal ZOI for TP cable

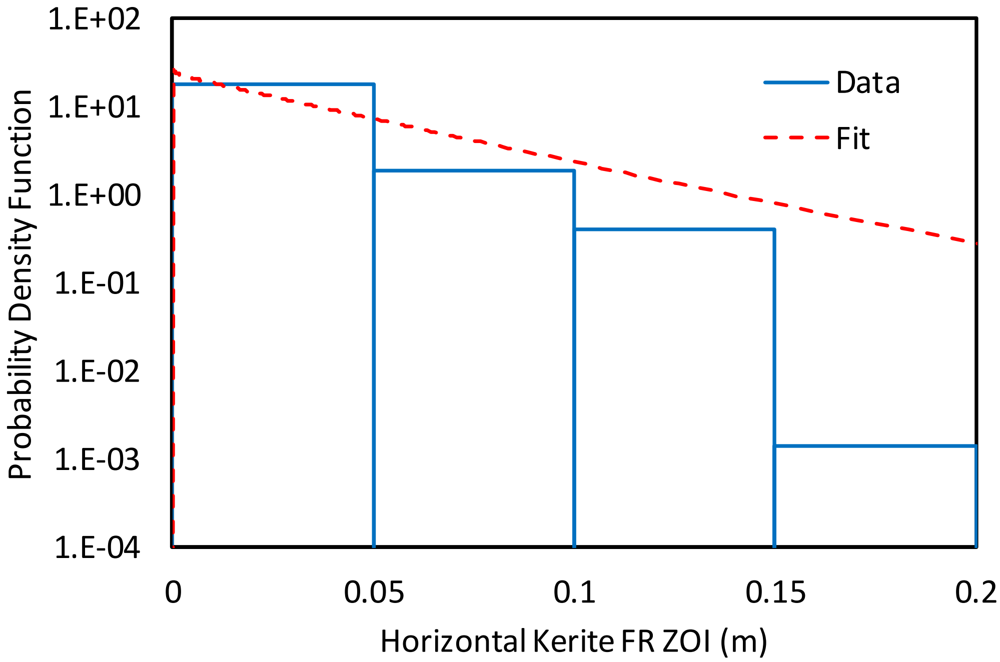

Figure D-64
Probability density function for horizontal ZOI for KC

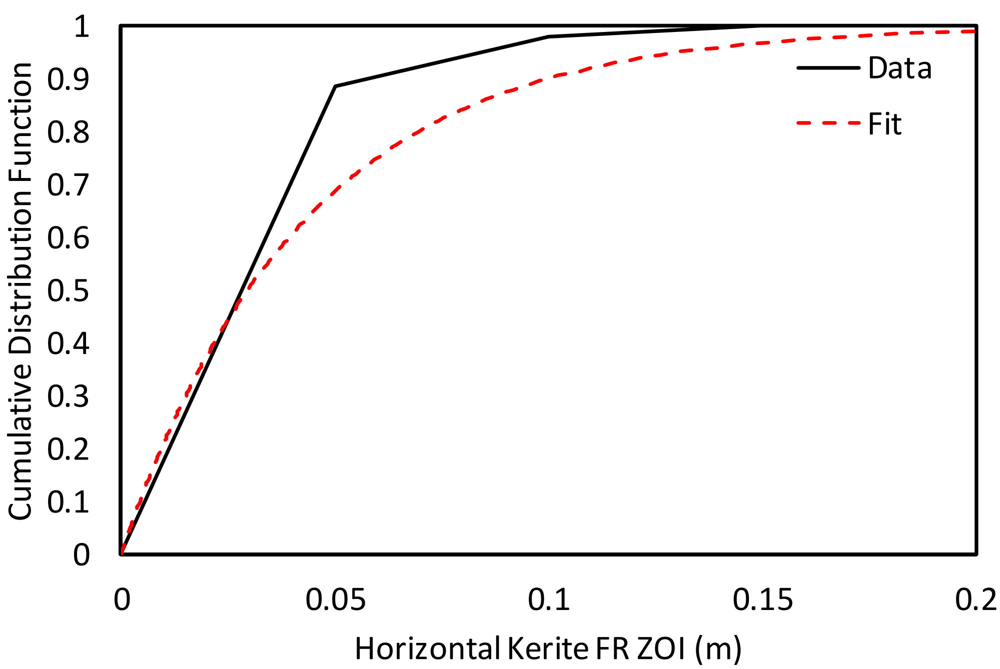

Figure D-65
Cumulative distribution function for horizontal ZOI for KC

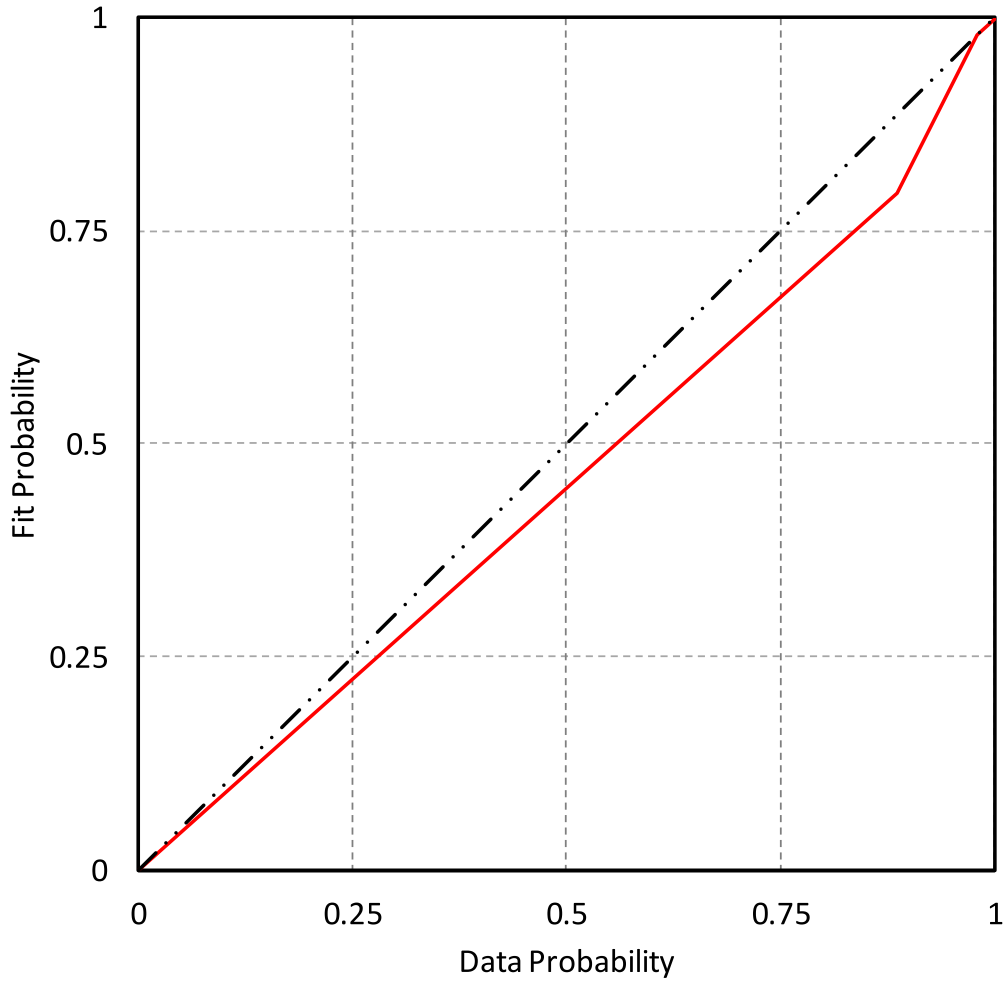

Figure D-66
Probability-probability plot for horizontal ZOI for KC

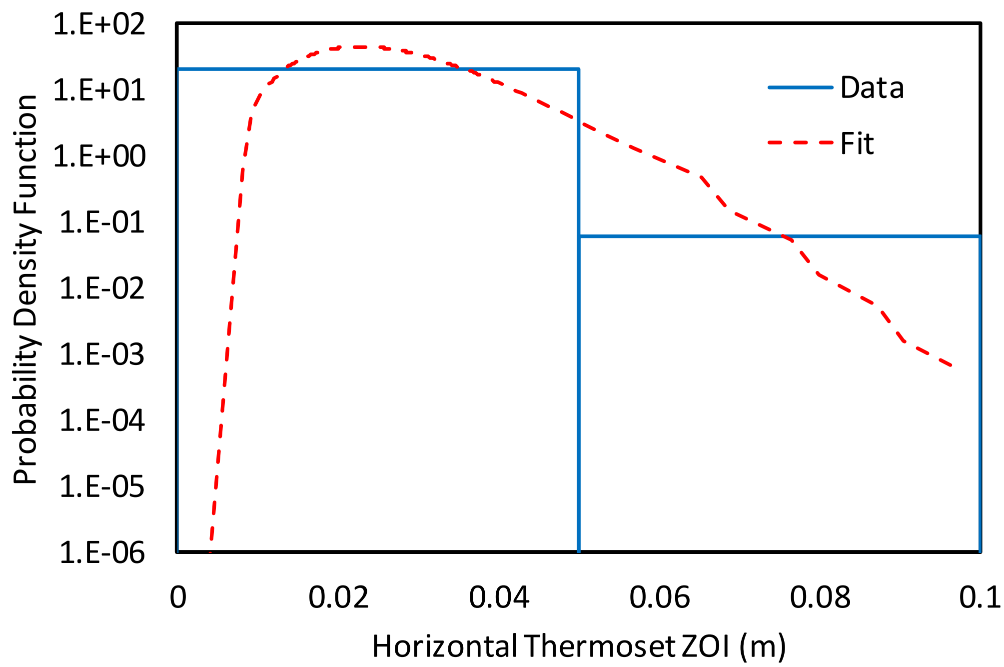

Figure D-67
Probability density function for horizontal ZOI for TS cable

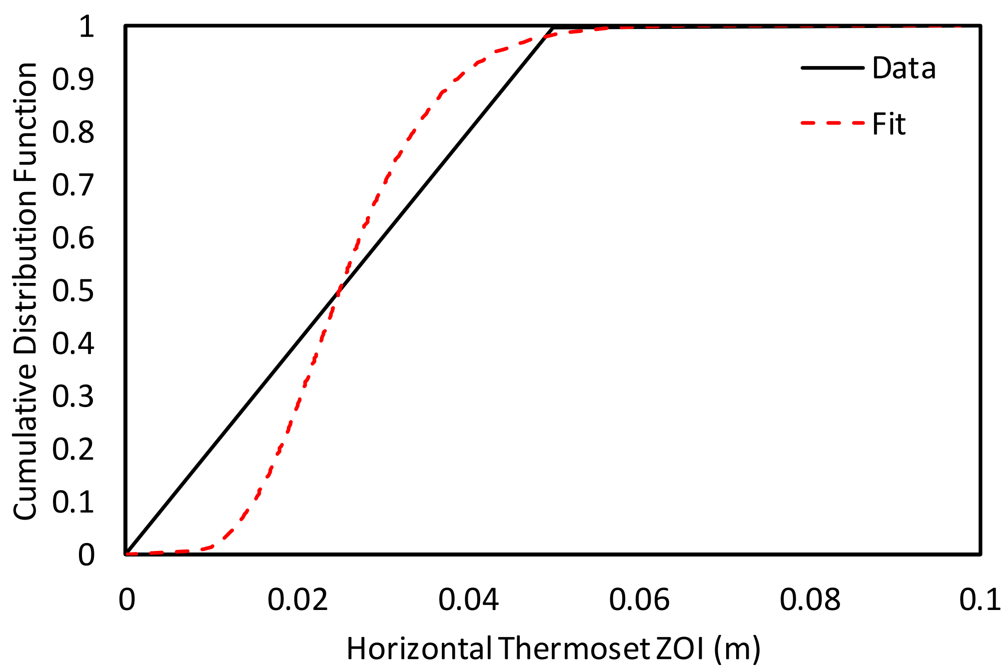

Figure D-68
Cumulative distribution function for horizontal ZOI for TS cable

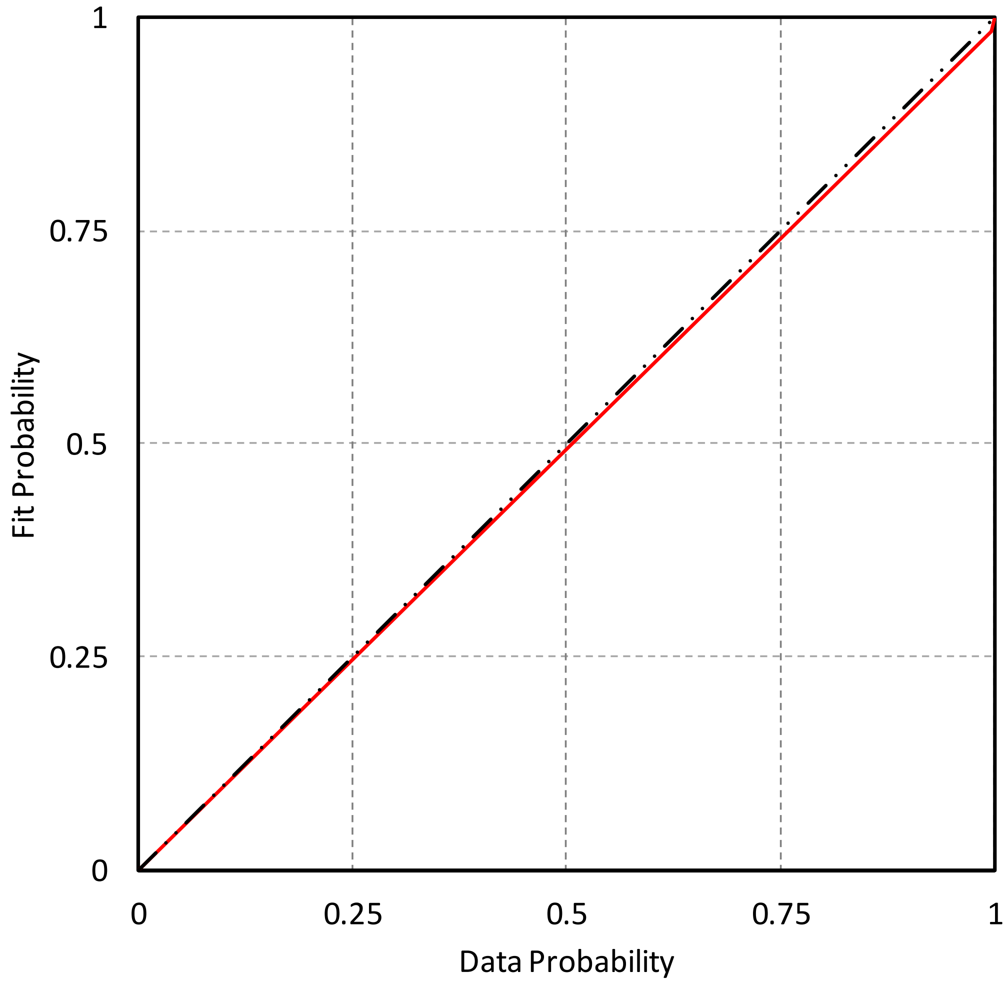

Figure D-69
Probability-probability plot for horizontal ZOI for TS cable

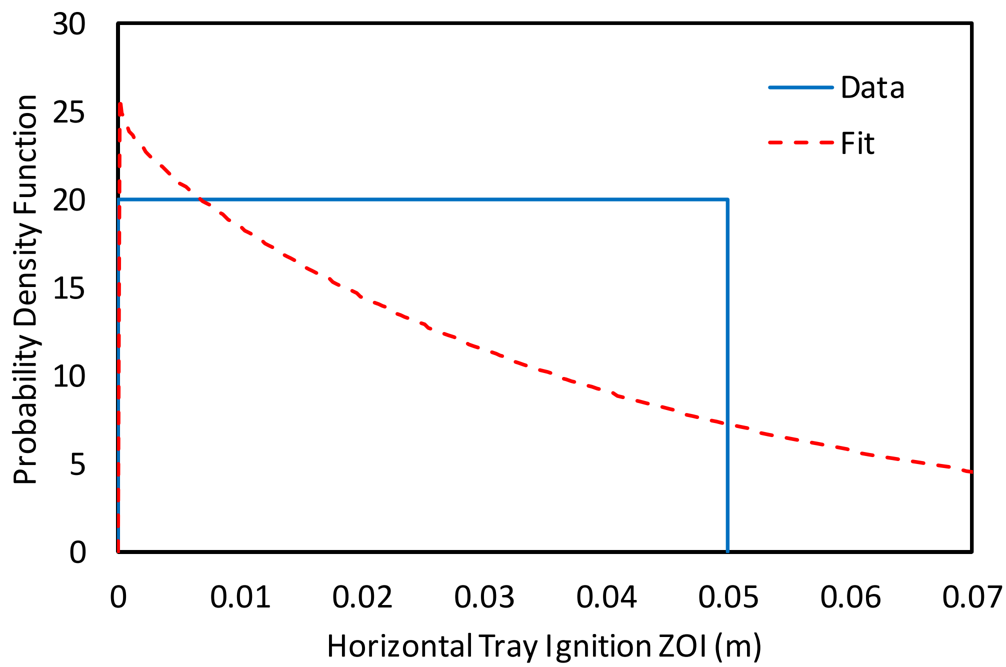

Figure D-70
Probability density function for horizontal ZOI for TI

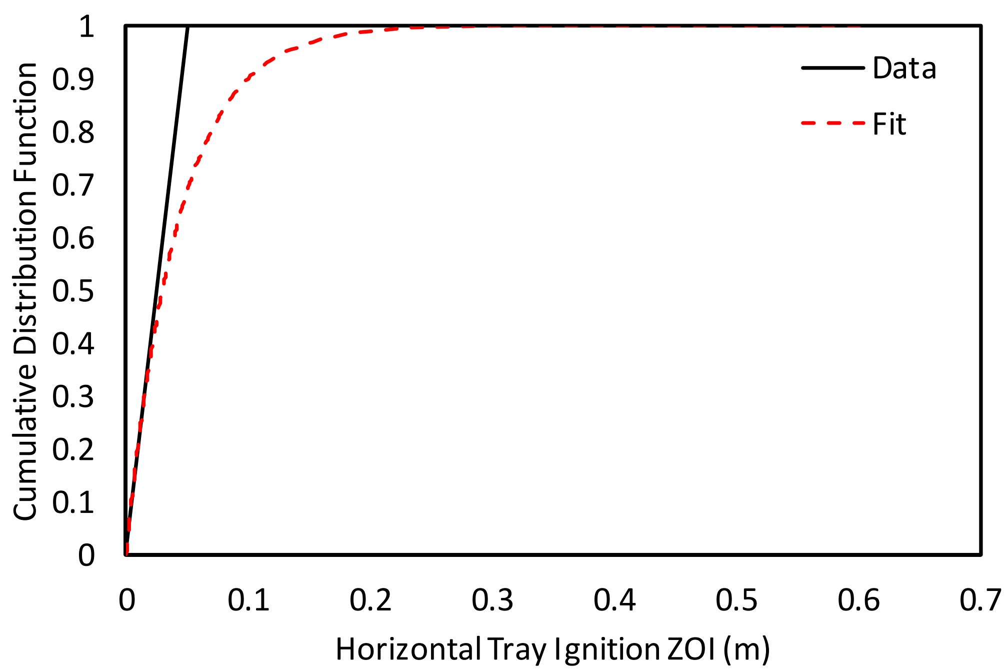

Figure D-71
Cumulative distribution function for horizontal ZOI for TI

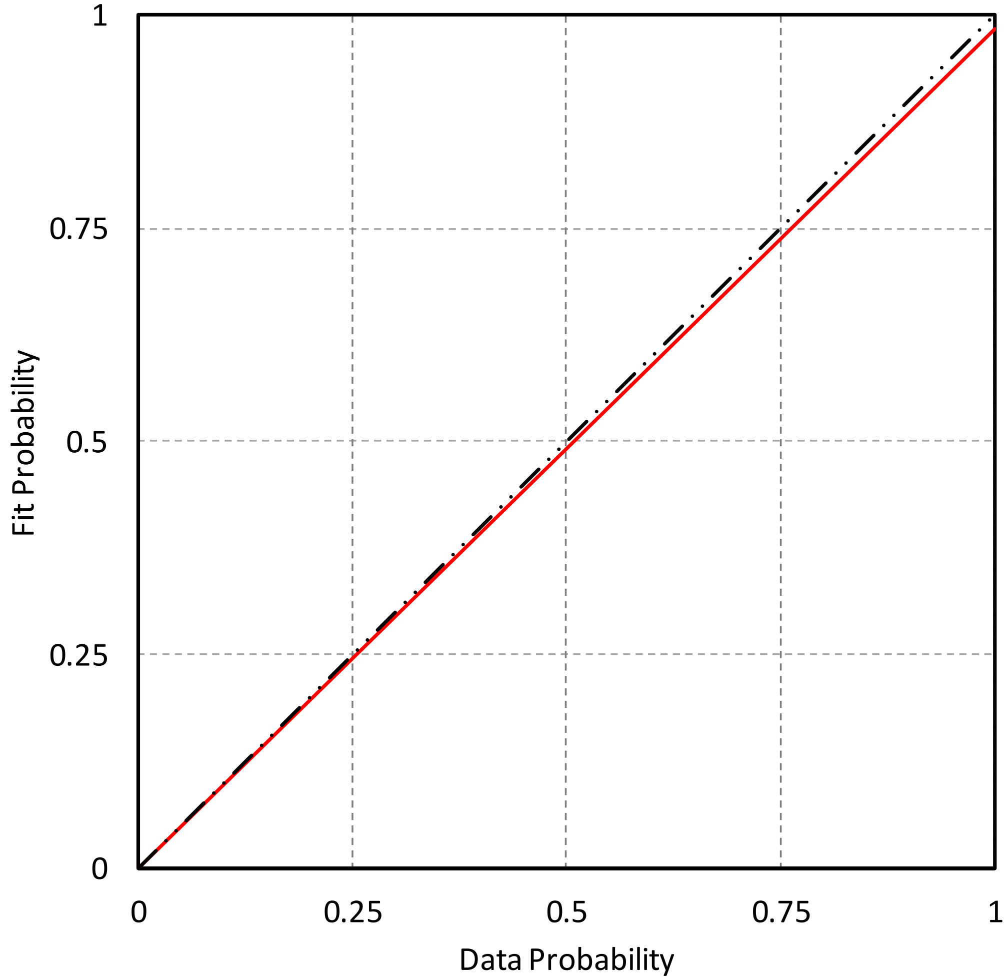

Figure D-72
Probability-probability plot for horizontal ZOI for TI

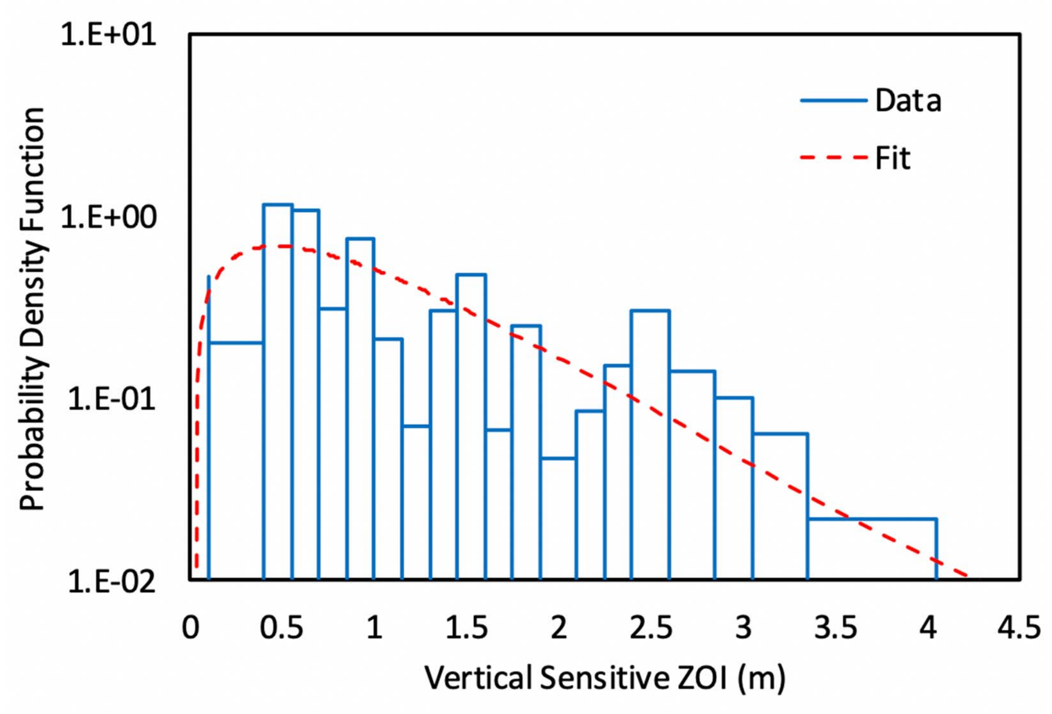

Figure D-73
Probability density function for vertical ZOI for SE

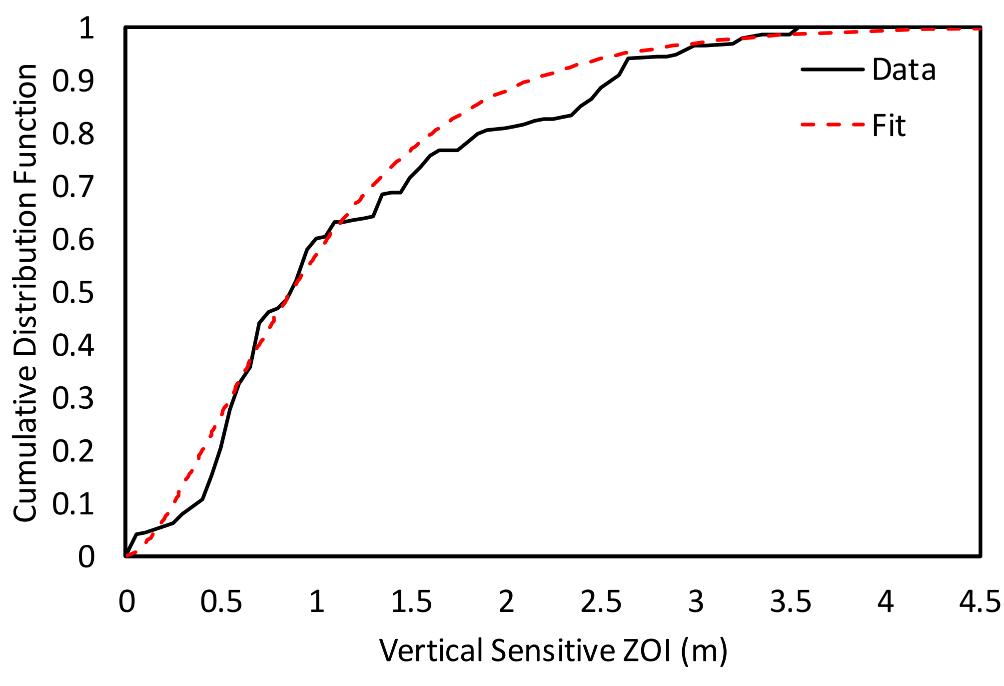

Figure D-74
Cumulative distribution function for vertical ZOI for SE

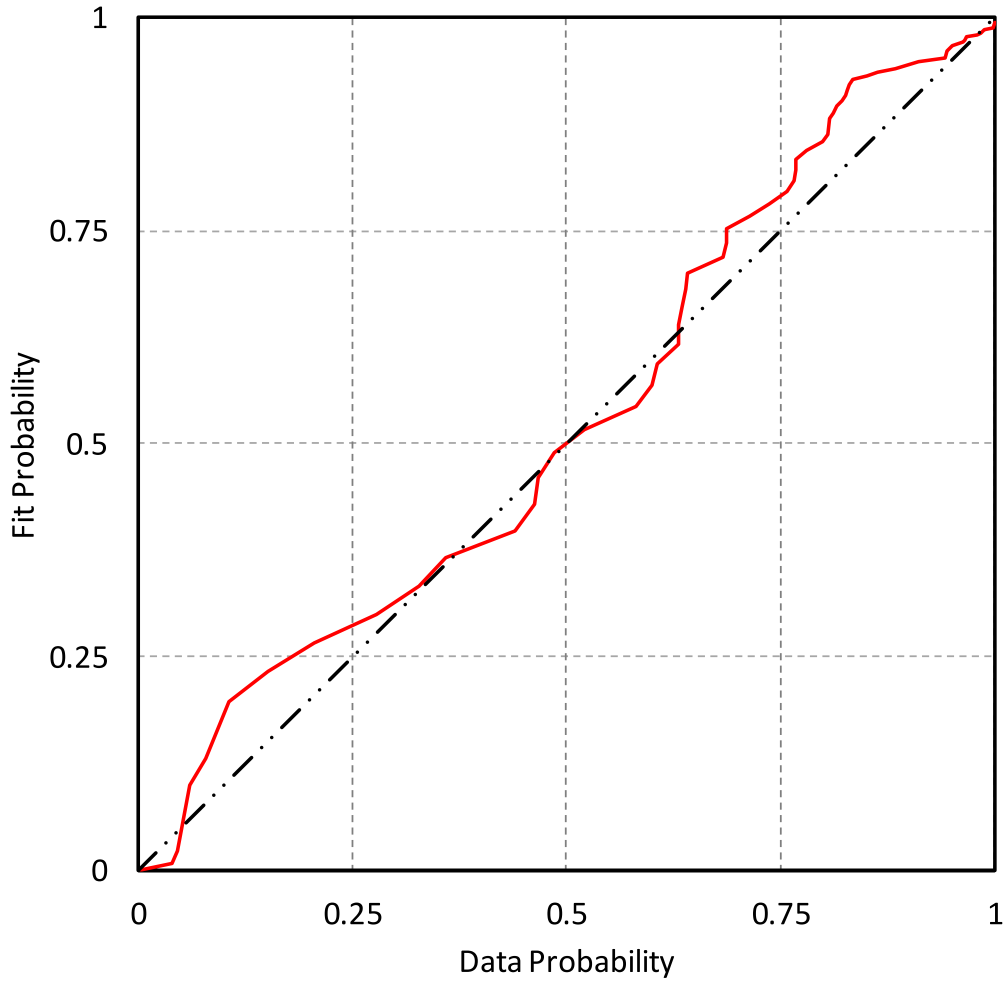

Figure D-75
Probability-probability plot for vertical ZOI for SE

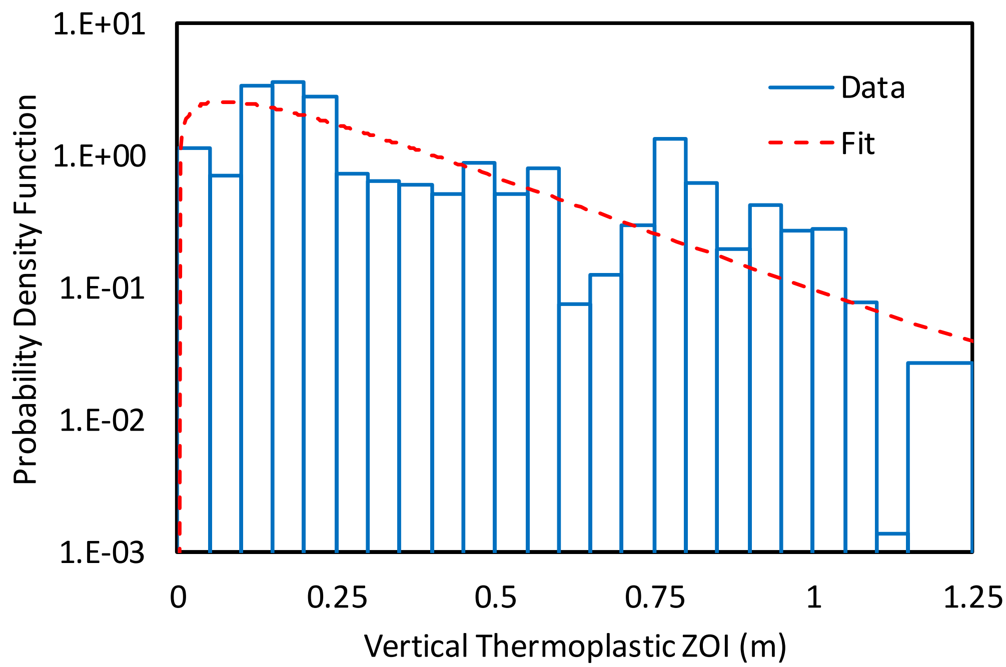

Figure D-76
Probability density function for vertical ZOI for TP cable

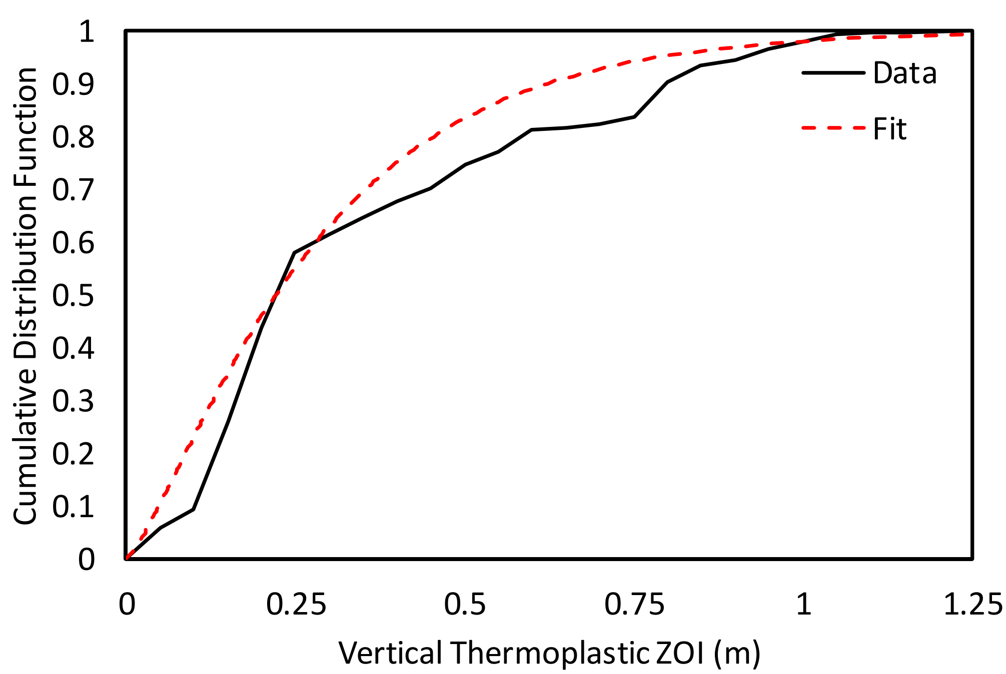

Figure D-77
Cumulative distribution function for vertical ZOI for TP cable

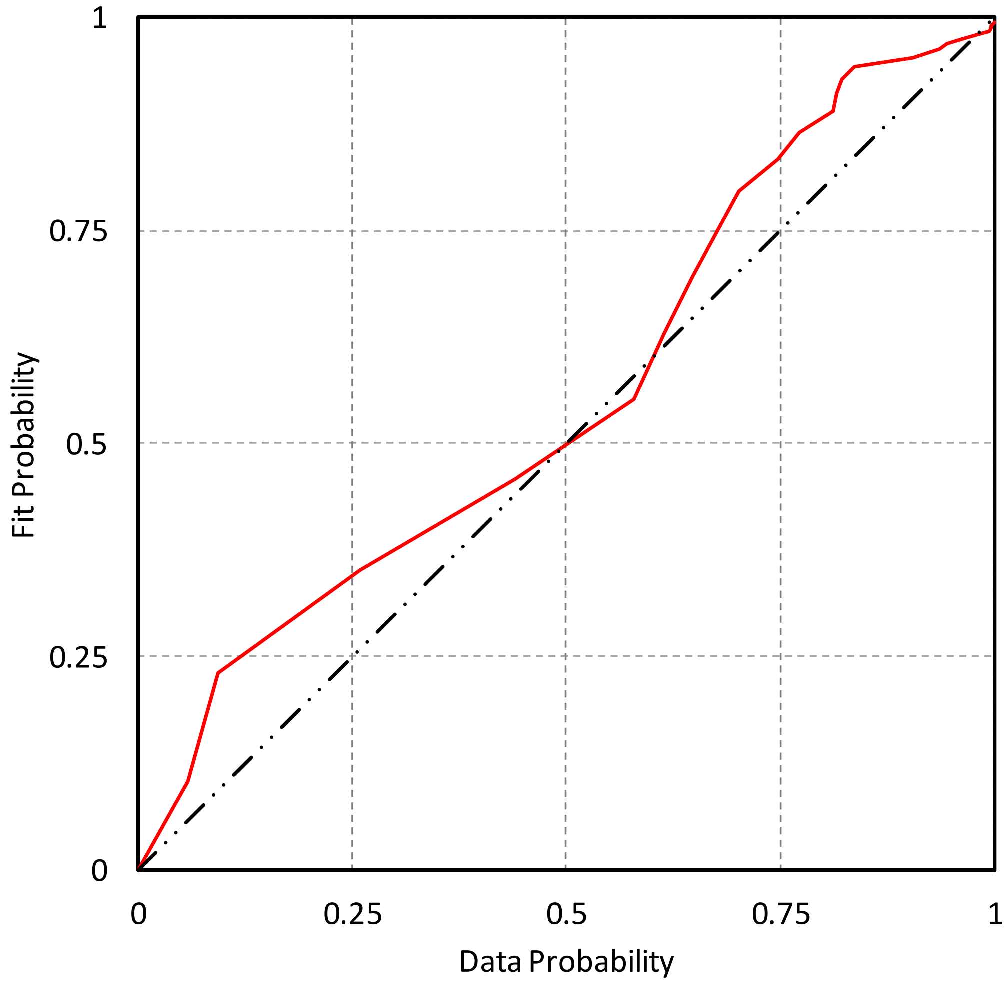

Figure D-78
Probability-probability plot for vertical ZOI for TP cable

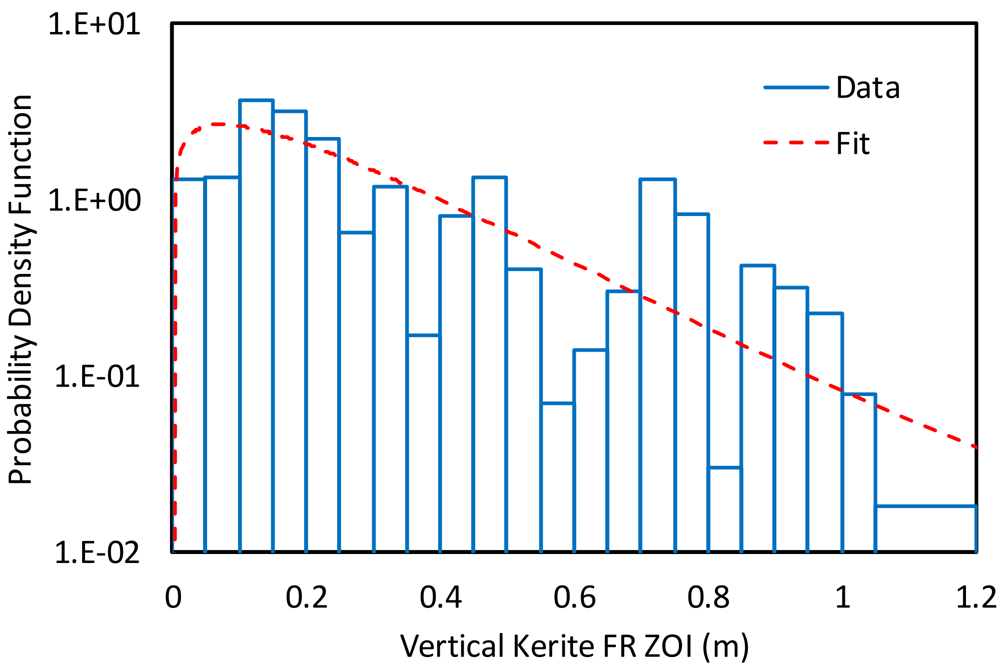

Figure D-79
Probability density function for vertical ZOI for KC

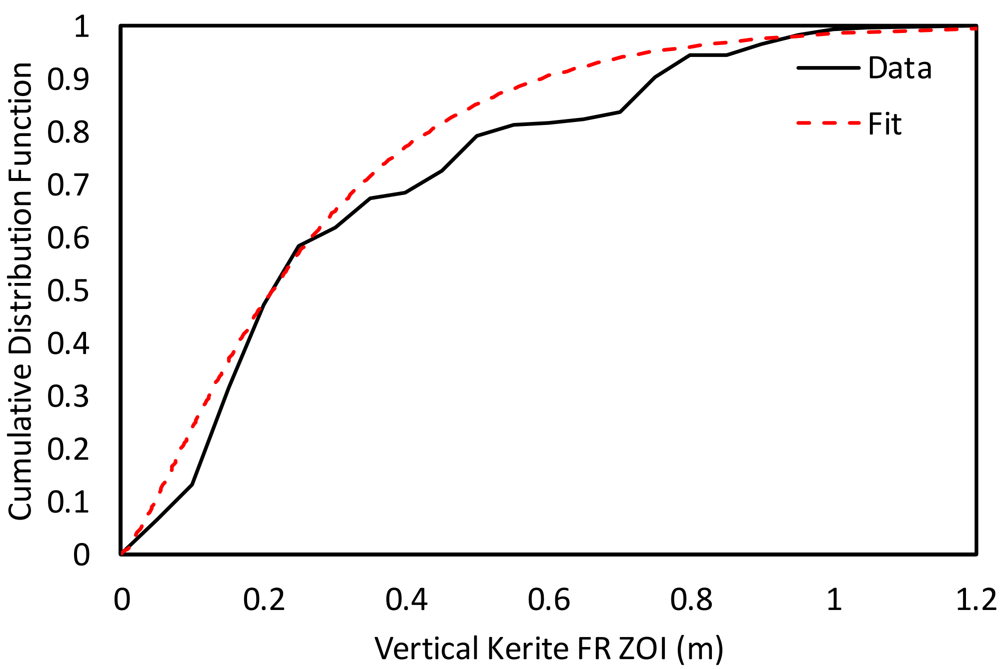

Figure D-80
Cumulative distribution function for vertical ZOI for KC

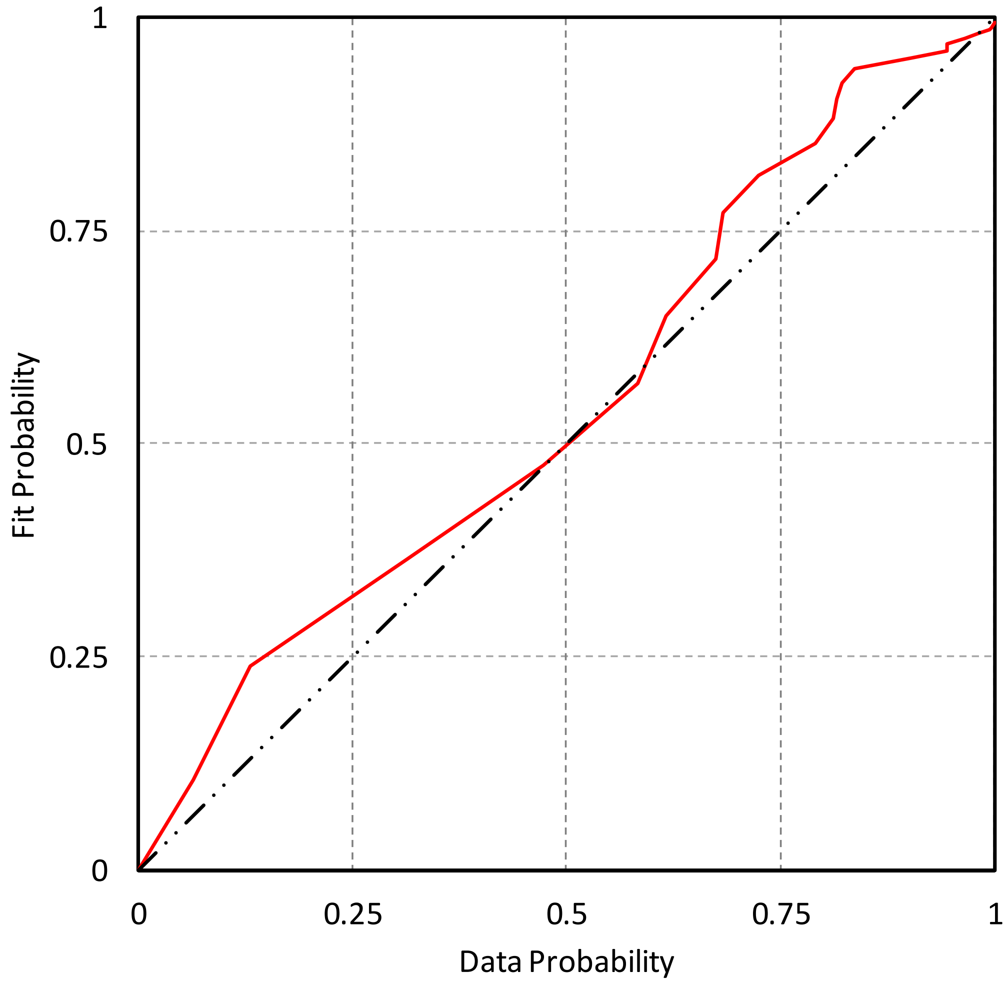

Figure D-81
Probability-probability plot for vertical ZOI for KC

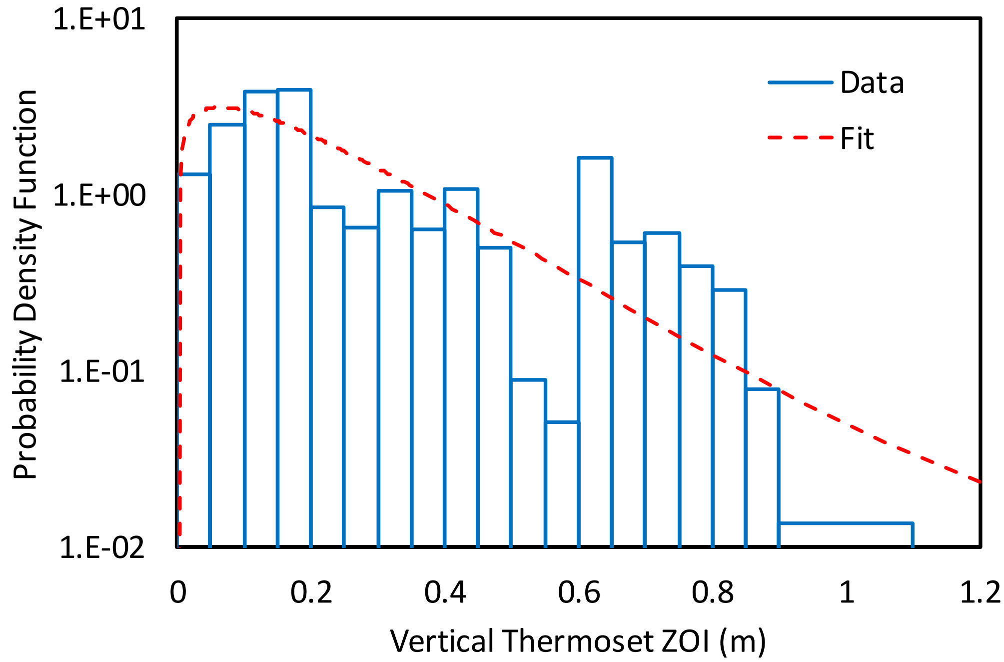

Figure D-82
Probability density function for vertical ZOI for TS cable

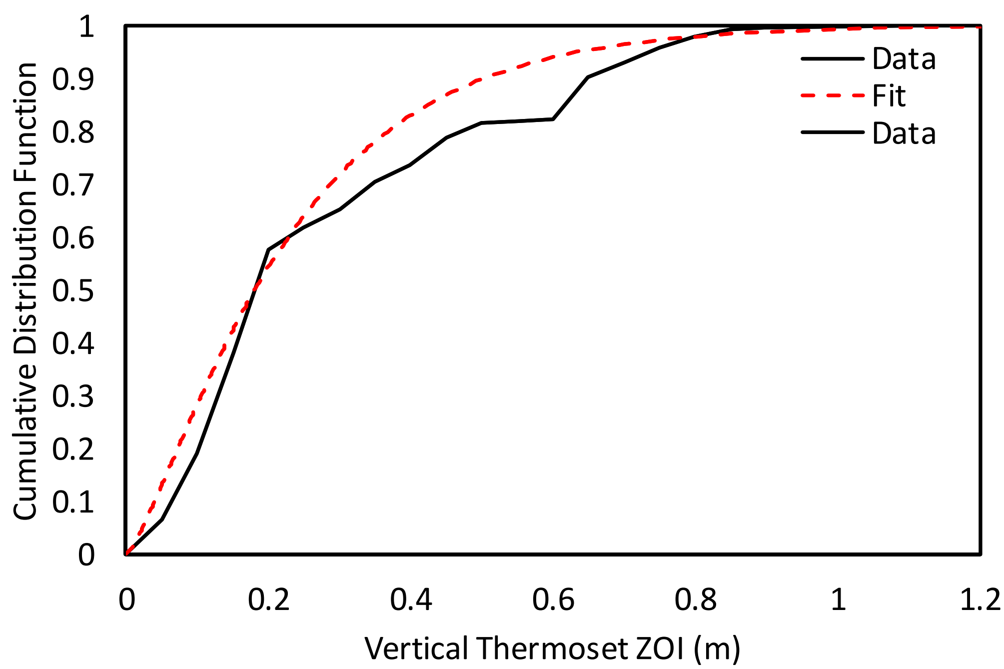

Figure D-83
Cumulative distribution function for vertical ZOI for TS cable

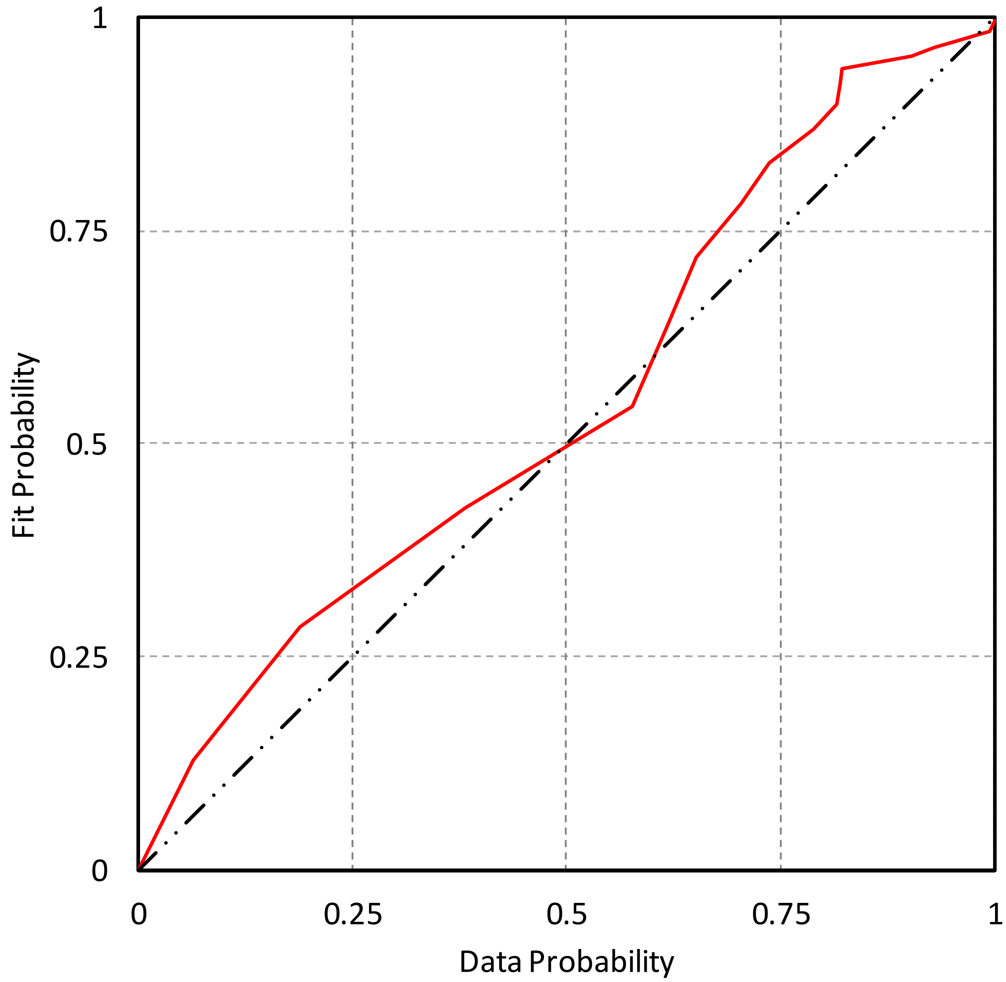

Figure D-84
Probability-probability plot for vertical ZOI for TS cable

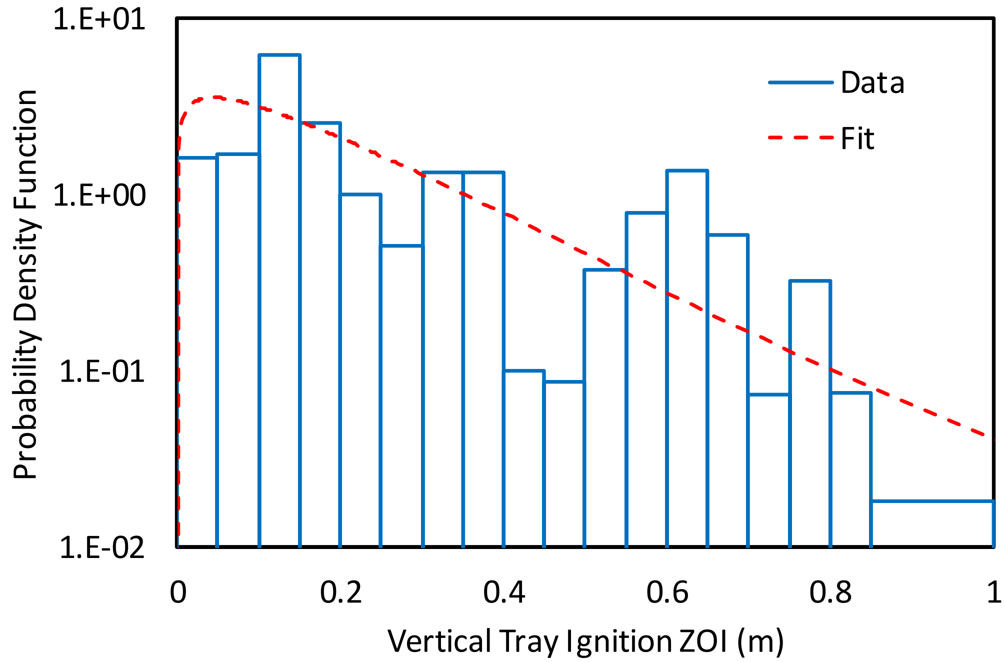

Figure D-85
Probability density function for vertical ZOI for TI

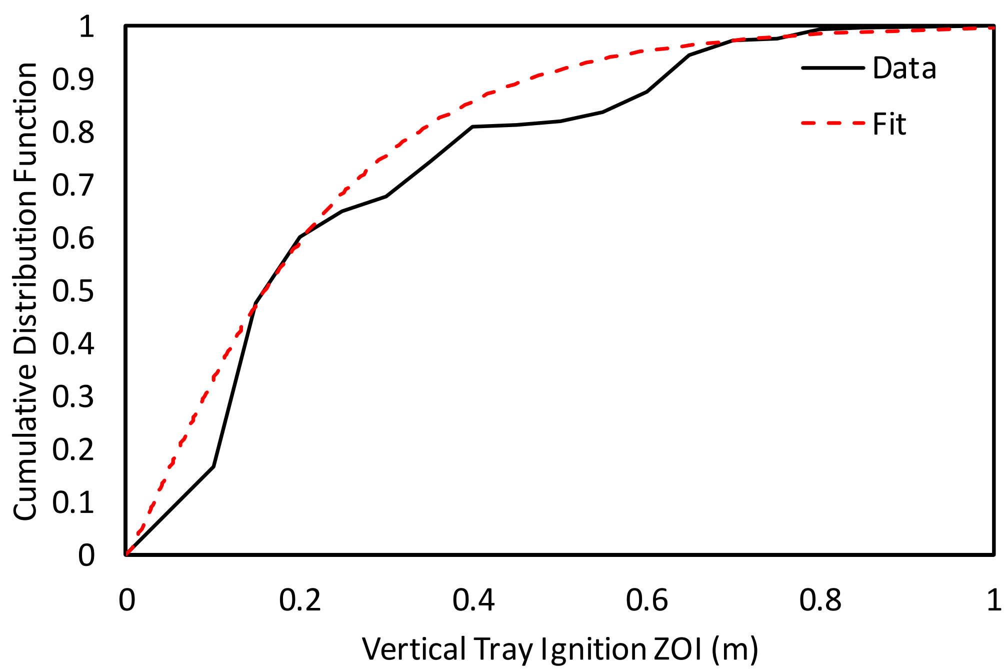

Figure D-86
Cumulative distribution function for vertical ZOI for TI

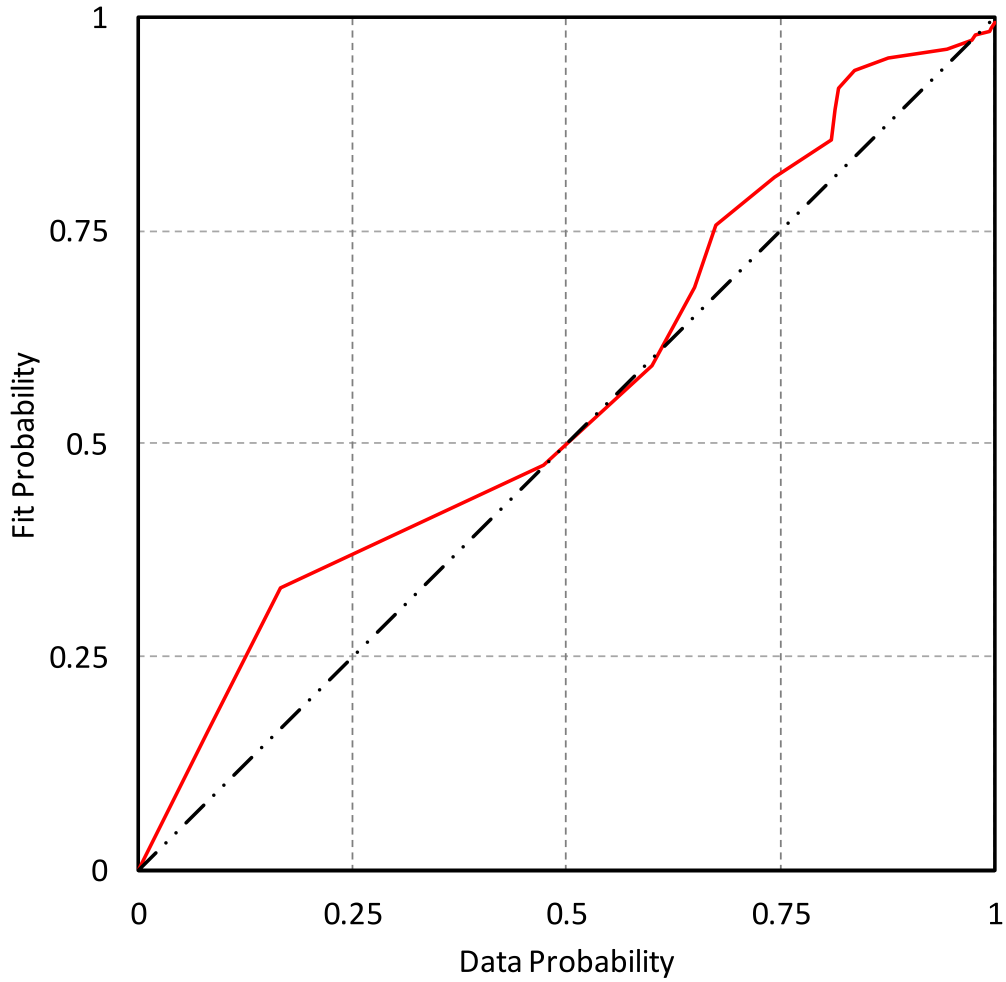

Figure D-87
Probability-probability plot for vertical ZOI for TI

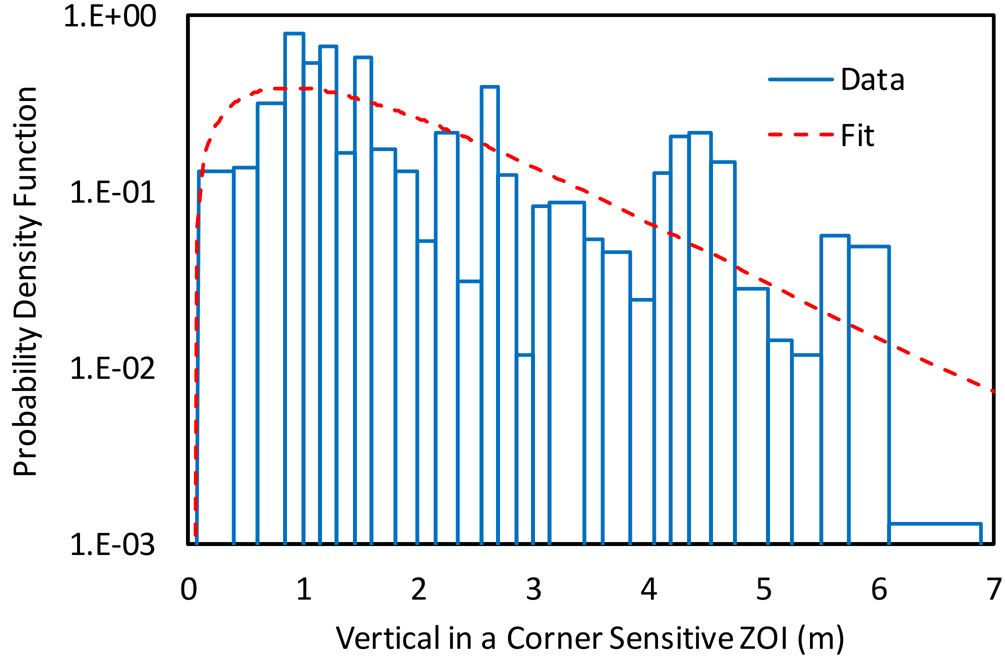

Figure D-88
Probability density function for vertical in a corner ZOI for SE

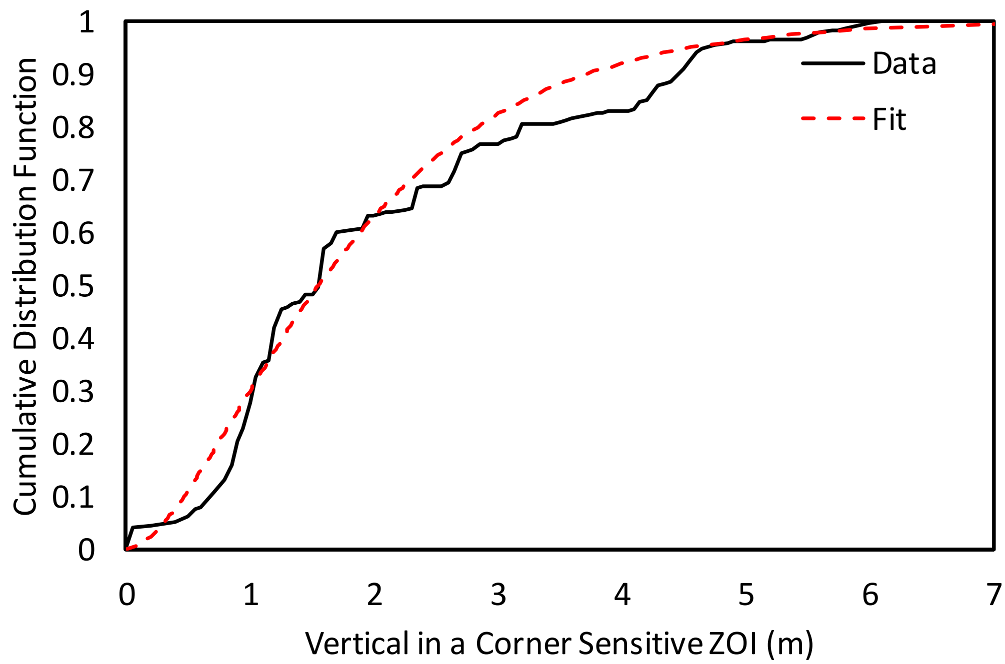

Figure D-89
Cumulative distribution function for vertical in a corner ZOI for SE

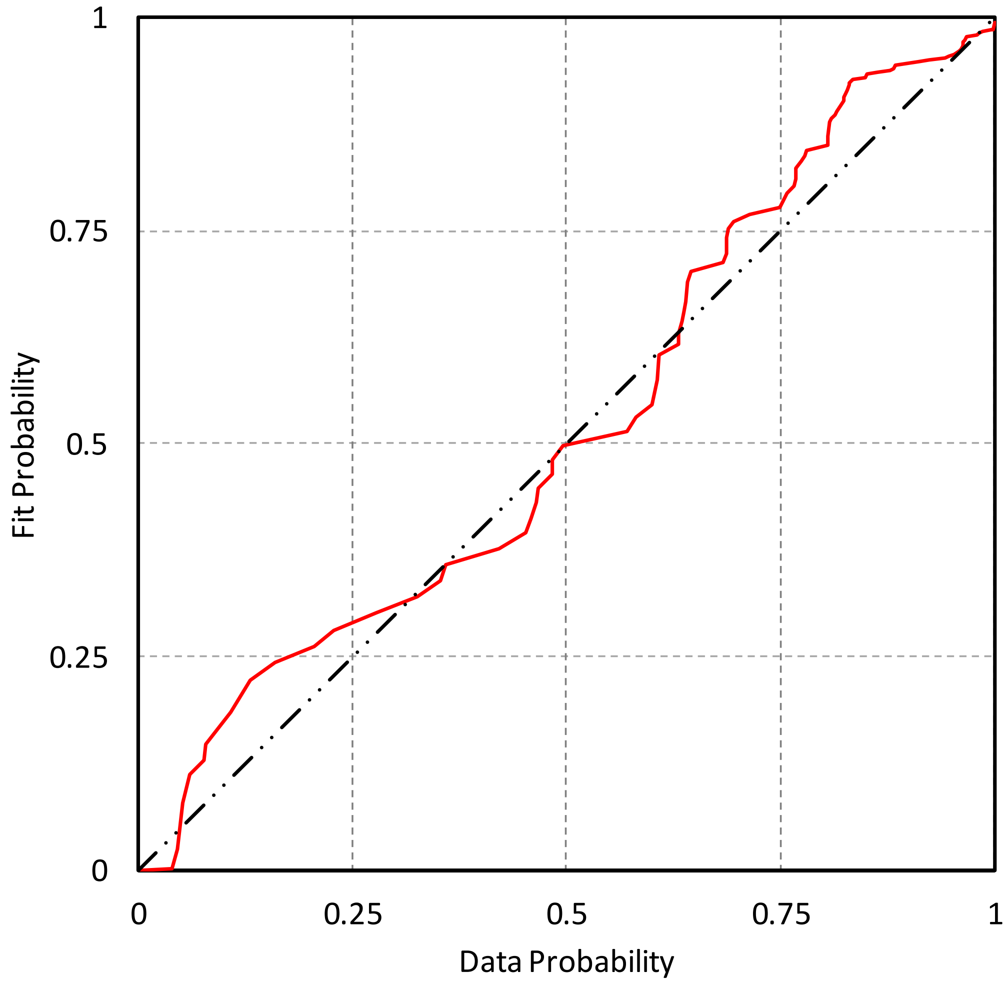

Figure D-90
Probability-probability plot for vertical in a corner ZOI for SE

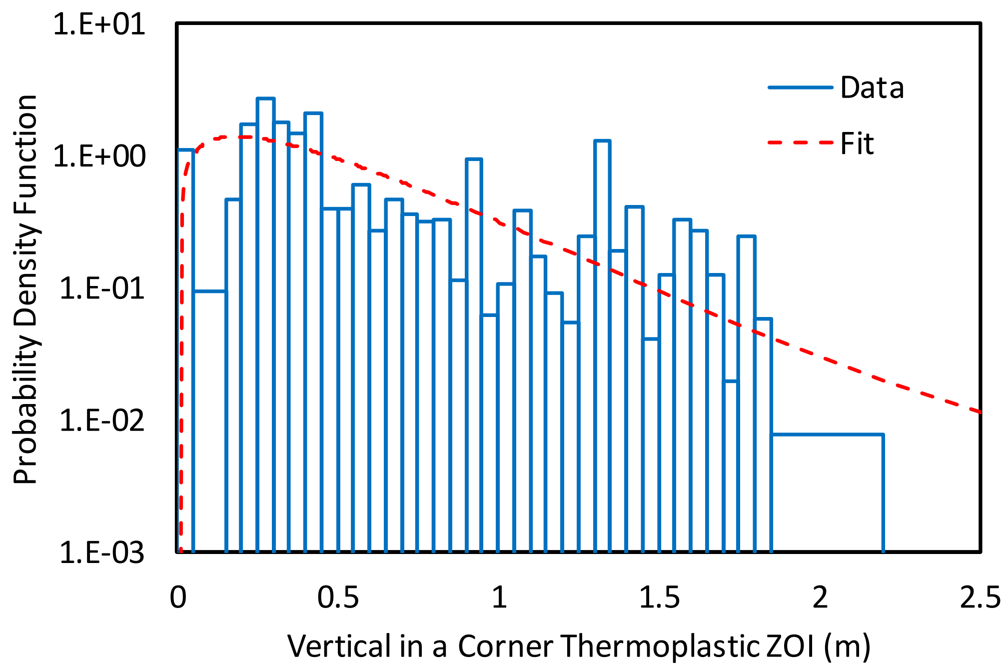

Figure D-91
Probability density function for vertical in a corner ZOI for TP cable

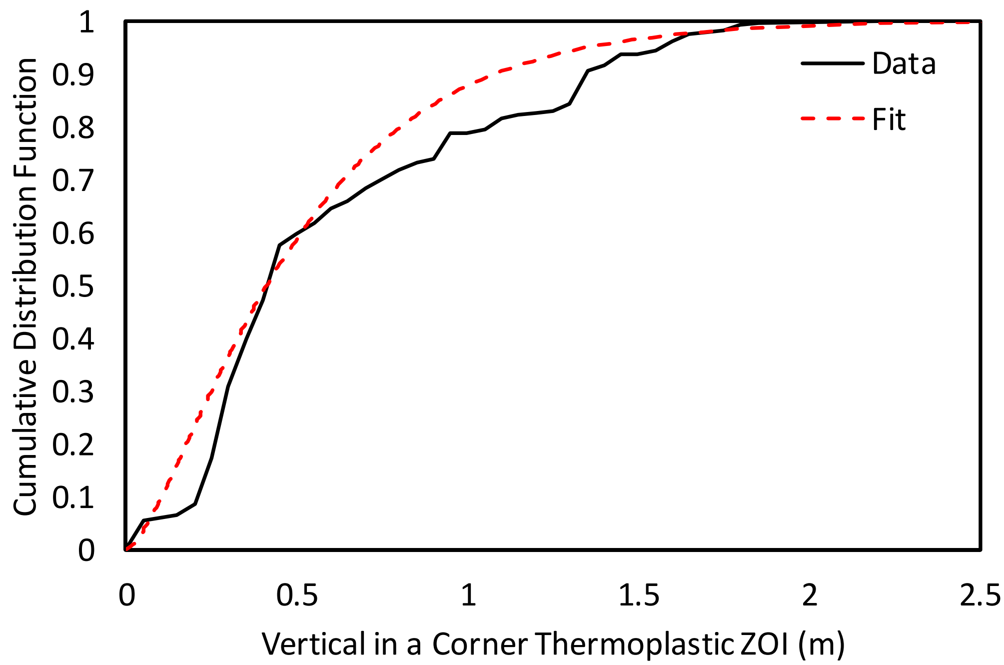

Figure D-92
Cumulative distribution function for vertical in a corner ZOI for TP cable

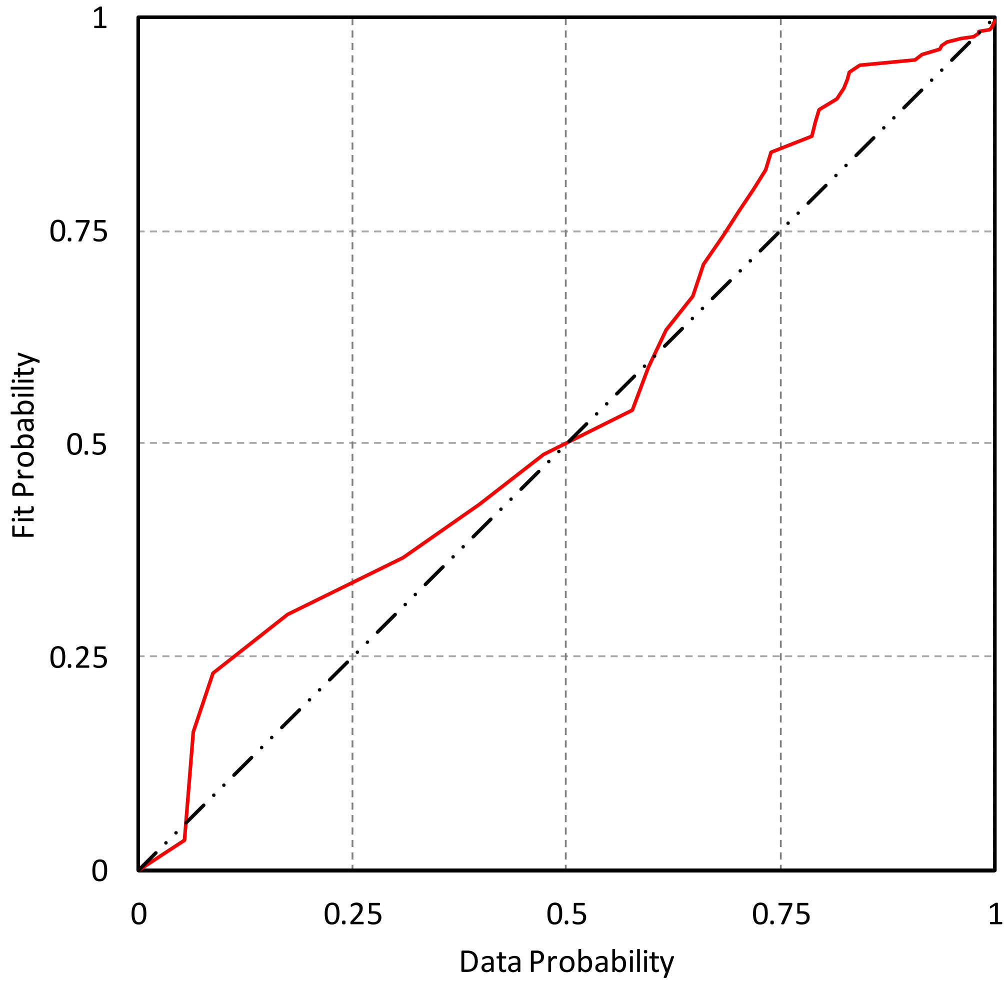

Figure D-93
Probability-probability plot for vertical in a corner ZOI for TP cable

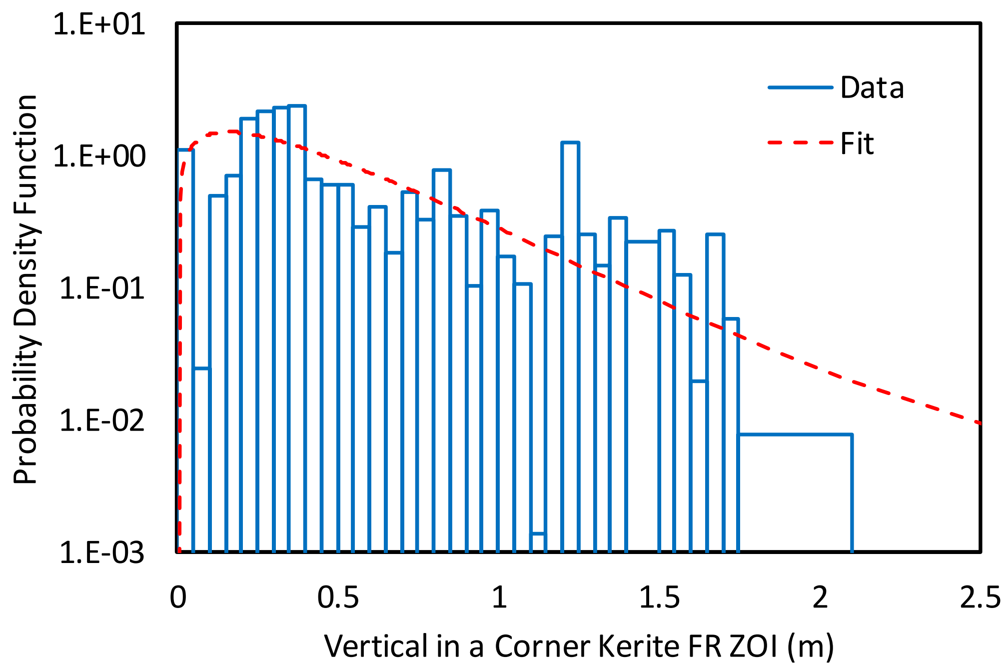

Figure D-94
Probability density function for vertical in a corner ZOI for KC

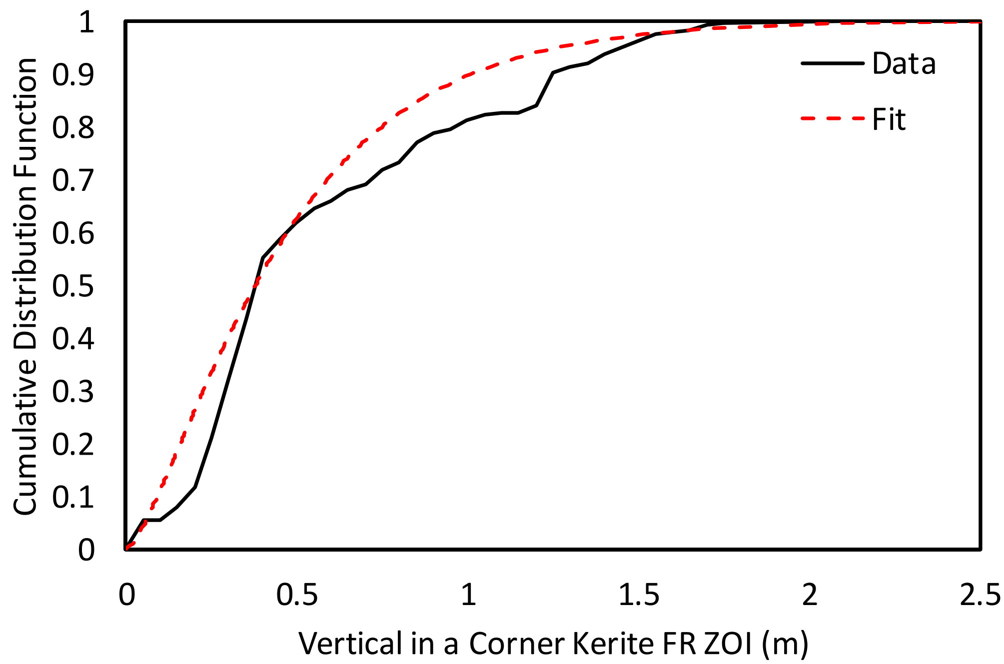

Figure D-95
Cumulative distribution function for vertical in a corner ZOI for KC

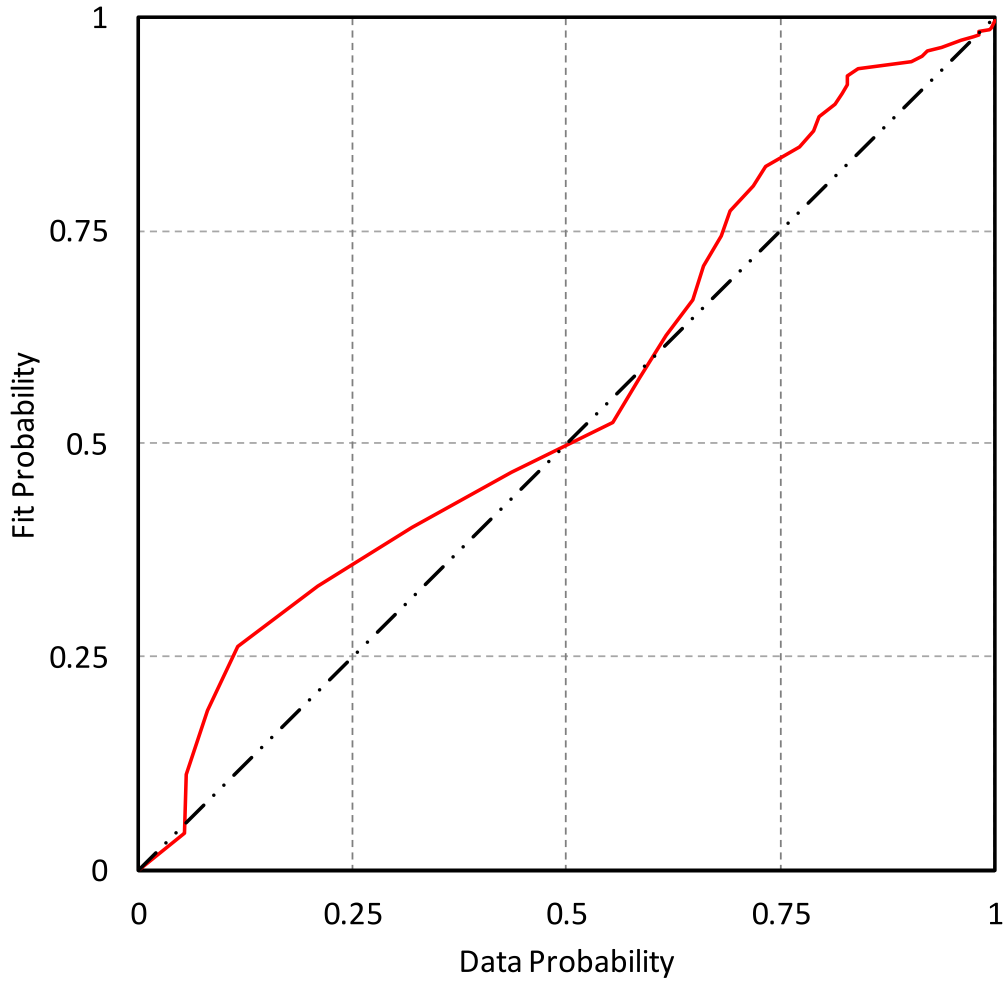

Figure D-96
Probability-probability plot for vertical in a corner ZOI for KC

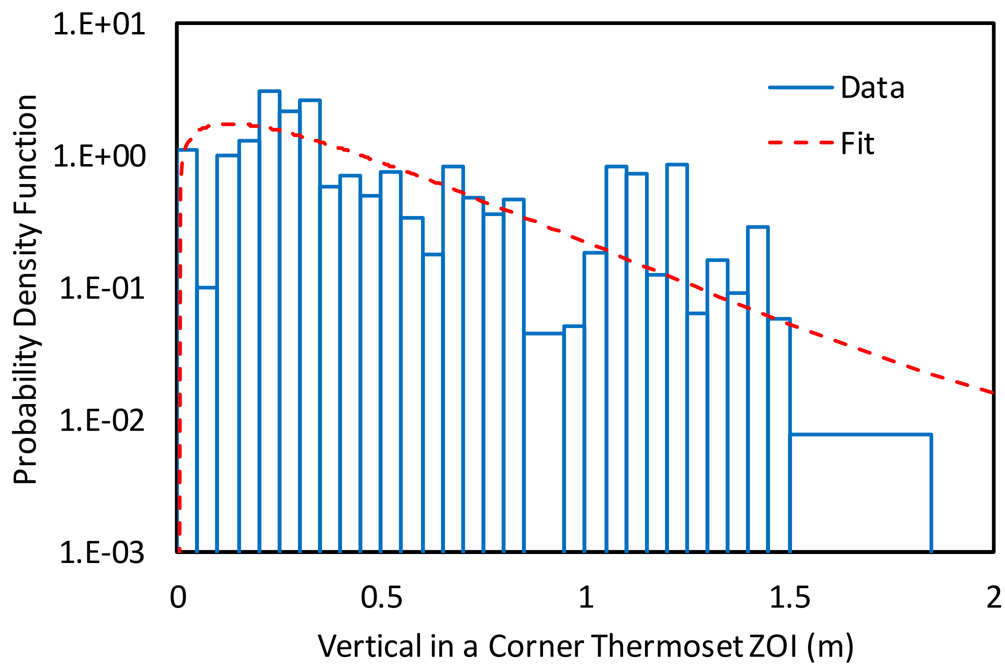

Figure D-97
Probability density function for vertical in a corner ZOI for TS cable

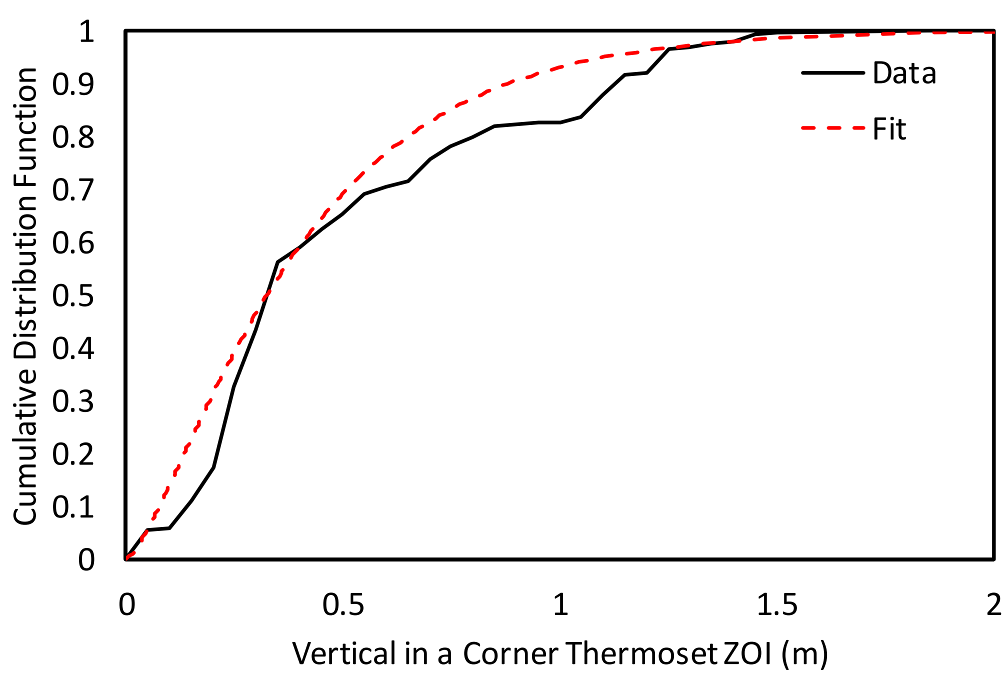

Figure D-98
Cumulative distribution function for vertical in a corner ZOI for TS cable

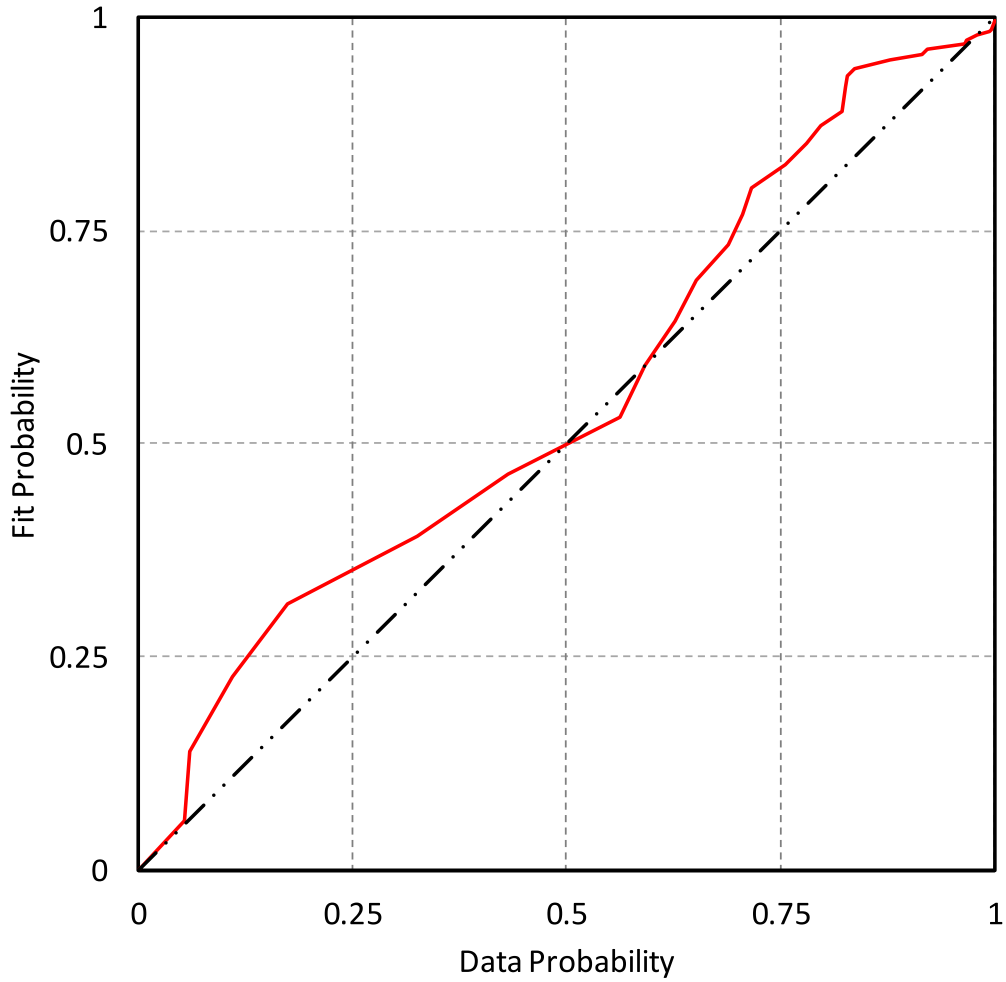

Figure D-99
Probability-probability plot for vertical in a corner ZOI for TS cable

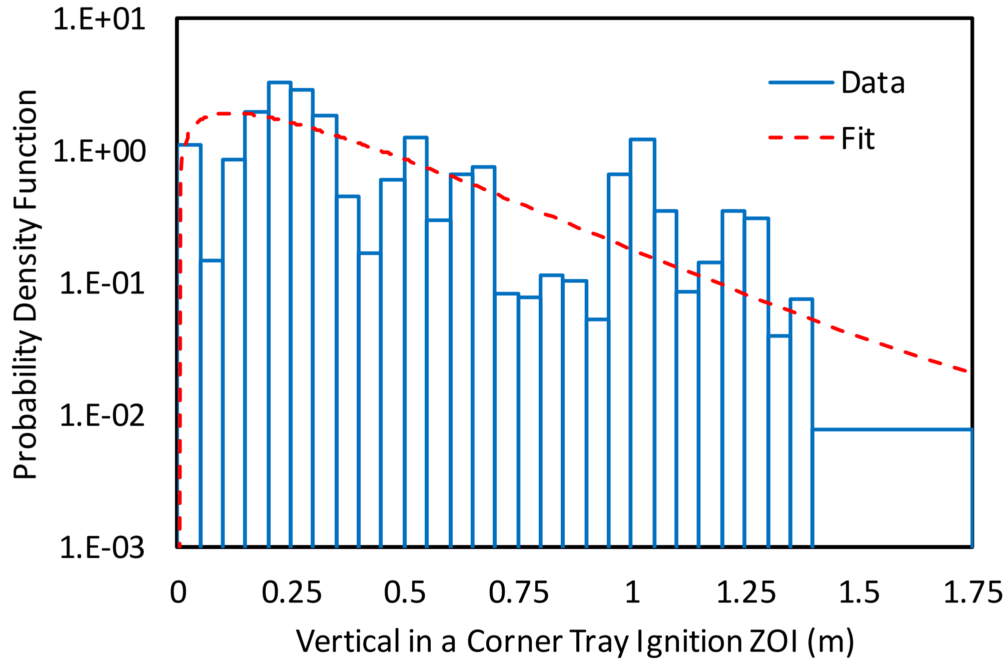

Figure D-100
Probability density function for vertical in a corner ZOI for TI

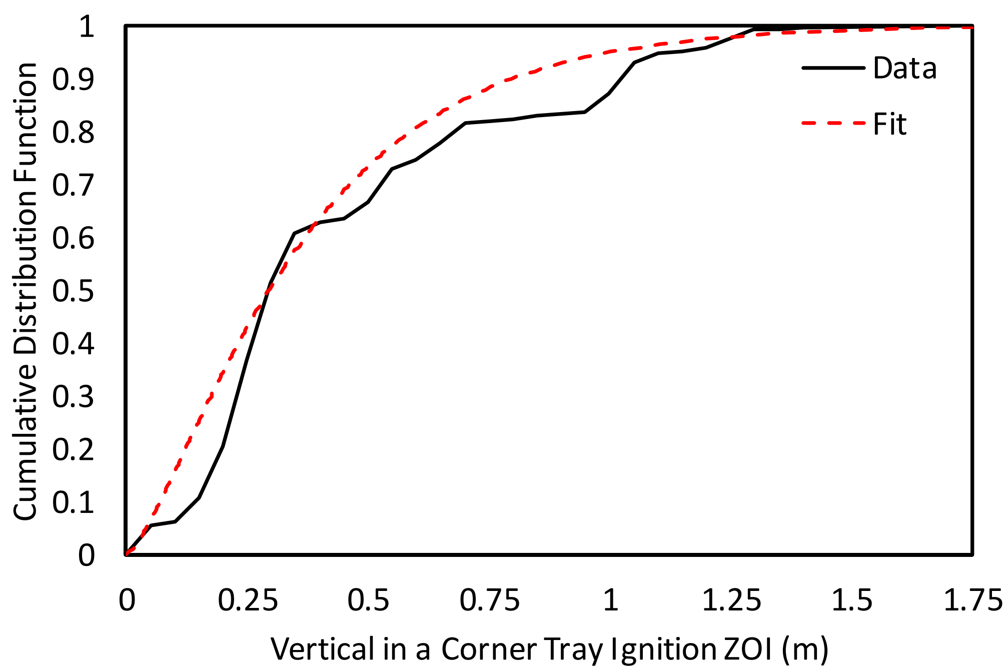

Figure D-101
Cumulative distribution function for vertical in a corner ZOI for TI

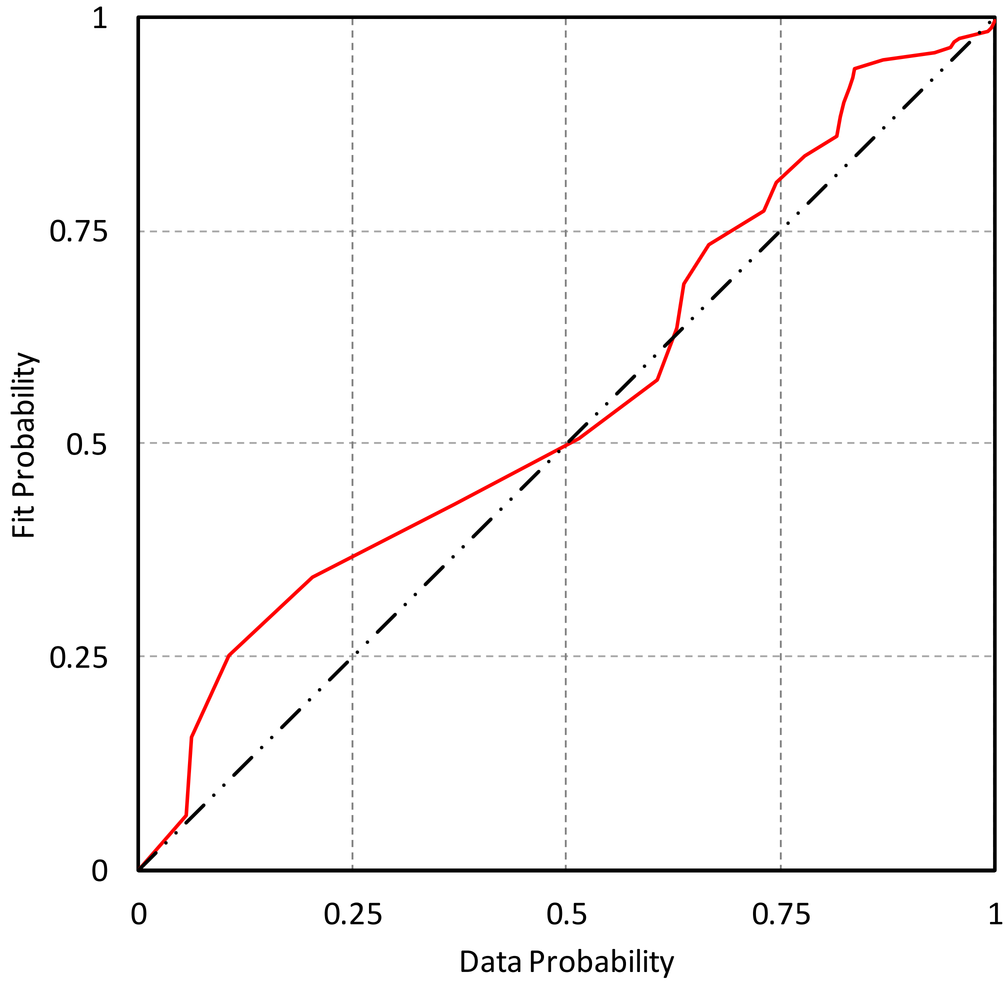

Figure D-102
Probability-probability plot for vertical in a corner ZOI for TI

E
INSPECTION FINDINGS ANALYSIS

The analysis performed in this report used the set of challenging or potentially challenging events contained in the EPRI fire events database [16]. This implicitly contains the assumption that events that have occurred to date have a distribution of severity that matches the distribution that would exist if there were many more years of data collection. One check on this is to consider violations of transient material procedures found during U.S. Nuclear Regulatory Commission inspections over the period from 2000 to 2010. It is noted that such inspection findings are not fire events. The findings are only the discovery of some quantity of transient materials in a location where such materials and/or quantities should not exist. Transient materials also require a potential ignition source to ultimately result in a fire event. It is additionally noted that inspection findings tend to bias toward significant violations—that is, a 55 gallon drum of lube oil in a combustible free zone would almost certainly result in a violation but a few sheets of paper fallen from a notebook would likely not.

A list of inspection findings where large amounts of transient combustibles were present is given in Table E-1. The table is not all violations. The table provides the date of the inspection and plant status, the plant area, a description of the materials, and a disposition of the inspection report. Test numbers in the table refer to the tests in the test report [9]. In general, the findings are dispositioned by one or more of the following basic responses:

- The plant was not at power and the scope of this report is at-power probabilistic risk assessment.
- There is no credible ignition source that would ignite the fuel package.
- The combustible materials were tested during this project either directly or with a closely matching experiment.

A review of the table shows that the most severe violations in terms of quantity were associated with items with no credible transient ignition source or occurred during an outage. Remaining events are fuel items contained in the test database directly or through a reasonable surrogate.

Table E-1
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
6/9/2000 100% power	Battery rooms	Rubber matting on the floors and vinyl aprons hanging in the rooms	Inspectors performed walkdowns of four battery rooms and observed rubber matting on the floors and vinyl aprons hanging in the rooms. The licensee determined that, although the vinyl aprons would not support combustion, the rubber mats would and should be controlled as transient combustibles. The matting, in most cases greater than 100 lb., had been in the rooms for years.	Rubber floor matting is likely not an intensely burning substance. Testing of rubber hose (Test030, Test082, and Test083) showed that sustained ignition was unlikely (one of three tests). Overall burning rates were low (peak burning rate near 2 kW/kg of hose).
9/3/2000 Defueled	Containment	Tarp	The primary cause of the fire was failure to properly evaluate and control transient combustibles during welding, cutting, and grinding evolutions. Specifically, sparks from a grinding evolution landed on a combustible foreign material exclusion tarp.	The following tarps were tested: • Plastic tarp draped (Test017, Test018, Test019, Test020) • FR plastic tarp draped (Test050, Test051) and folded (Test052) • Plastic tarp folded (08_29_001, 08_29_002, 08_29_003)
3/7/2001 (55 gallon drum) 3/8/2001 (oily rags) Both at 100% power	Auxiliary building	55 gal drum lube oil half full unsealed, oily rags	During walkdowns of the Unit 1 primary auxiliary building, the inspectors identified the following combustible material control deficiencies: a 55 gallon drum of lube oil approximately half full of lube oil was not sealed and was left unattended near the Unit 1 high head safety injection pump area, and several oily rags were found stored in an open plastic bag near the Unit 1 high head safety injection pump area. Transient combustible materials (lube oil in the 55 gal drum) in the primary auxiliary building was approximately five times the amount assumed in the fire hazard analysis.	Igniting lube oil would require an event that heats the volume of oil to its flashpoint and an event to fail the drum, allowing the heated oil to be exposed to air. A 55 gal drum of lube oil would require on the order of 50 MJ of net energy input to heat from room temperature to its flashpoint. There are no credible transient ignition sources that contain that amount of energy. Several oily rags were tested: 07_16_004, 07_16_005, 07_16_006, 07_23_001, Test003, Test005, Test006, Test064, and Test066.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
3/14/2002 100% power	Turbine building	530 lb of Class A material	The inspectors identified that the licensee placed transient combustible materials in excess of procedure requirements in the turbine building approximately 15 ft from the auxiliary building.	The violation was not due to the amount being a hazard for the turbine building, but for the amount being over 100 lb within 20 ft of a safety-related structure. As a safety-related structure, the exterior wall should have at least a 1-hour fire-resistant (FR) rating. A fire involving class materials, even against the wall, would be a less severe exposure than used during the ASTM E119 tests. Although a violation of procedure, the risk significance of this is negligible.
3/16/2002 Refueling outage	Auxiliary building	330 gal (six 55 gal drums) of flammable lubricating oil	With the unit in Mode 5, inspectors identified that the licensee had staged approximately 330 gal (six 55 gal drums) of flammable lubricating oil in a room to be used for the reactor coolant pumps (RCPs).	Lube oil is not a flammable liquid. The flashpoint of lube oil (typically over 200°C) is too high to meet either National Fire Protection Association or Department of Transportation thresholds for a flammable liquid (under 100°C). See Event 3/7/2001 for a further discussion on drums containing lube oil.
9/19/2002 100% power	HPCI pump room	55 gal drum of oil	The inspector identified a 55 gal drum of oil in the HPCI pump room that was not controlled in accordance with the transient combustible control requirements.	See Event 3/7/2001 for a further discussion on drums containing lube oil.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
10/16/2003 One unit at power and one unit defueled	Auxiliary building	Multiple assorted amounts	• In the heating, ventilation, and air conditioning equipment (HVAC) room, staging area having combustible materials including two coils of plastic hoses, storage barrel (55 gal drum), plastic bucket, and an open large tool chest. • Also, several large storage cabinets, some of which were labeled as containing flammable materials. • In a motor control center room (a separate fire zone than the preceding items), anti-contamination clothing container and a large waste can; these materials were located approximately 10 ft below cable trays. • In the component cooling water room (a third unique fire zone), anti-contamination clothing container; the container was located approximately 7 ft below cable trays.	• Hoses were tested (Test030, Test082, and Test083), plastic bucket was tested (07_31_002, 07_31_003, and 07_31_004), and a canvas tool bag with tools (likely an easier source to ignite than a tool chest) was tested (09_19_001 and 09_19_002). If the barrel was being used for trash, large metal trash cans were tested (09_05_007, 09_06_001, and 09_06_002). If the barrel contained lube oil, see Event 3/7/2001 for a further discussion on drums containing lube oil. • Ignition of combustibles within a storage cabinet would require a substantial ignition source. • PPE storage was tested (WPI PPE bags), and full, large trash cans were tested (Test 059, Test 069, Test072, 09_05_007, 09_06_001, and 9_06_002). • PPE storage was tested (WPI PPE bags).

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
11/13/2003 One unit at power and one unit defueled	Auxiliary building	Welding equipment and miscellaneous supplies	• In the HVAC equipment room, welding equipment, including electrical cables and rope. • In the HVAC equipment room, staging area with combustible materials including equipment cart with two coils of plastic hose and a coil of rubber hose, vacuum cleaner, and two canvas bags.	• Welding equipment would be bounded by either the 250 V power cord tests (Test034, Test035, and Test036) or the closed vacuum tests (Test047 and Test048), power cords were tested (08_02_001, 08_02_002, 08_03_001, 08_03_002, 08_03_003, 08_03_004, 08_03_005, Test031, Test032, and Test033), and rope was tested (Test079, Test080, and Test081). • Hoses were tested (Test030, Test031, and Test032), vacuum cleaners were tested (Test046, Test047, Test048, and Test049), and canvas tools bag were tested (09_19_001 and 09_19_002).

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
1/27/2004 100% power	Auxiliary building (two different fire areas)	Assorted combustibles	Many of the combustibles had been permanently staged in the area for ease of use to support maintenance and operations activities. The inspectors identified the following materials: • Three laundry carts partially filled with anti-contamination clothing (two of the carts were located next to each other.) • Numerous rolls of plastic bagging material • Nine open plastic containers filled with cloth and plastic materials One metal trash can filled with cloth rags • Several non-fire-rated metal cabinets containing cloth and plastic materials	• Inspection report estimates the heat release rate (HRR) of the laundry carts as 1200 kW, which is less than the plastic carts (Test102, Test0105, and Test0106). • Size of rolls is not specified. Likely total mass is less than the plastic carts. • Containers and not trash cans suggests smaller containers. Because the laundry carts were identified as the most severe violation, this is likely approximated by the full plastic trash can (Test059, Test069, and Test072). • Metal trash can with paper and plastic was tested (09_05_007, 09_06_001, and 09_06_002), and more severe than rags, which char. • Even though non-fire-rated, materials in them would be protected against most typical ignition sources associated with transient events.
2/5/2004 100% power	Waste storage station	330 gal of lubricating oil	The transient fire loading of the 330 gal of combustible liquid was analyzed by the inspector to be an increase of a factor of 100 over the normal combustible fire loading.	See Event 3/7/2001 for a further discussion on drums containing lube oil.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
2/24/2004 100% power	Auxiliary building	4 55 gal barrels filled with RCP motor oil	Inspectors observed four 55 gal barrels filled with RCP motor oil that were stored inside the radiological drumming station on the 55 ft elevation of the primary auxiliary building. Labels attached to the barrels indicated that they had been stored inside the area for ~11 months.	See Event 3/7/2001 for a further discussion on drums containing lube oil.
3/4/2004 100% power	Reactor building	55 gal drum of oil	During a walkdown of the reactor building, the inspectors observed that a 55 gal drum of oil was stored in the A core spray pump room.	See Event 3/7/2001 for a further discussion on drums containing lube oil.
5/10/2004 through 5/14/2004 and 5/24/2004 through 5/28/2004 Unit 1 came out of outage 5/9/2004	Electrical room	Large quantities of health physics materials	Inspectors noted large quantities of health physics materials and equipment for outage use stored inside a chain-link fence enclosure in the north end of the Unit 1 West electrical room.	Inspection findings note that the area did not contain cabinets or trays. There is no indication that a potential ignition source was present in the vicinity of the materials.
7/28/2004 100% power	Hallways adjacent to material storage area	Three plastic trash cans and a coat rack	The team identified that materials were stacked on top of shelving in the materials storage area. The materials were stacked high enough so that a fire in the materials would neither be detected by the detectors for the automatic deluge system nor extinguished by the deluge system. The team noted that there were cables important to safety located directly above the materials.	Plastic trash cans were tested: • Plastic trash quarter (Test057, Test067, Test070) • Plastic trash half (Test058, Test068, Test071) • Plastic trash full (Test059, Test069, Test072)

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
8/20/2004 Coastdown to refueling outage	Screenwell house	1600 lb of resin	During a walkdown, the inspectors observed approximately 1600 lb (dry weight) of resin stored on the 272 ft elevation. The resin was contained primarily in 5 gal plastic buckets with some buckets located immediately adjacent to a building structural column. The material procurement and control department had delivered two shipments of resin to the screenwell house during a seven-day period and did not recognize following the second shipment that the transient combustible weight was exceeded.	Ion exchange resin is typically in a moist state and will not support a fire unless fully dried out. It would require a substantial heat source to do this for which no credible ignition source exists.
10/1/2005 through 12/31/05	Reactor building	250 lb of wood	The transient combustibles consisted of wood planking located on scaffolding in the southeastern corner room of the reactor building.	Testing showed that scaffolding is not easily ignited with the types of ignition sources associated with transient fires (Test087, Test088, Test089, Test098, Test099, and Test100).
10/18/2004 Refueling outage	Near, but not in, the emergency diesel generator (EDG) room	Nine 55 gal drums	Inspectors observed maintenance personnel changing out the lube oil for the 1A EDG. At the time of the inspector's observations, the used lubricating oil had been removed from the EDG and transferred out of the room.	See Event 3/7/2001 for a further discussion on drums containing lube oil.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
10/19/2004 Refueling outage	Working material storage	Two cardboard boxes and a plastic bucket	Inspectors identified two cardboard boxes and a plastic bucket that were stacked on top of shelving in the working materials storage area.	Cardboard boxes and plastic buckets were tested: • Empty bucket (07_31_001, 07_31_002, 07_31_003, 07_31_004) • Medium box with paper (08_06_004, 08_06_005, 08_06_006) • Medium box with peanuts (08_06_007, 08_06_008, 08_06_009) • Large box with peanuts (Test008, Test011, Test015) • Large box with paper (Test009, Test012, Test016)
10/20/2004 Refueling outage	Materials storage area	Two cardboard boxes labeled as containing paper towels and a third cardboard box labeled as containing reinforced wipes	Inspectors identified materials stacked on top of a metal cabinet.	Cardboard boxes with paper were tested: • Medium box with paper (08_06_004, 08_06_005, 08_06_006) • Large box with paper (Test009, Test012, Test016)
1/26/2006 100% power	Auxiliary building	Four drums of charcoal	The inspectors observed four drums of charcoal stored on the auxiliary building operating floor near a Class 1E bus and a motor control center.	Items in a sealed metal can are not credibly ignited with the types of ignition sources associated with transient fires. Charcoal requires a relatively long-duration, intense source to obtain sustained ignition.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
4/10/2006 Refueling outage	Dry spent-fuel storage pad	Sealand container/hydraulic fluid truck	Sealand containers containing combustible materials within 50 ft of the horizontal storage module (in regard to spent-fuel dry storage pad) and a truck trailer, located on the storage pad, which had hydraulic fluid stored on it.	Items in a metal shipping container do not pose a significant hazard. They are protected from ignition sources by the metal walls of the container and a closed container limits available oxygen for a large fire. This also appears to be outside and not within the scope of a fire probabilistic risk assessment.
4/11/2006 100% power	Reactor building	Plastic chair, portable yellow plastic signs, and ~60 ft of rubber hose	During a fire protection walkdown, the inspectors identified a number of transient combustible items including a plastic chair, portable yellow plastic signs, and approximately 60 ft of rubber hose temporarily installed in an area of the building.	Similar items were tested: • Plastic chair (Test084, Test085, and Test086) • Stack of four cones (08_14_002, 08_15_001, and 08_15_002) • Water hose (Test030, Test082, and Test083) Furthermore, if the hose was charged, there is no credible event that would result in a fire.
5/15/2006 92% power	Residual heat removal (RHR) complex	Office chair and a plastic trash bin half full of paper	Specifically, the inspectors identified an office chair and a plastic trash bin approximately half full of paper secured approximately 1 ft from a safety-related electrical panel for EDG room ventilation and associated cable raceway. Licensee personnel performed a walkdown of the RHR complex and identified three additional trash bins and two chairs in other switchgear rooms within the RHR complex.	Similar items were tested: • Plastic chair (Test084, Test085, and Test086) • Plastic trash quarter bin (Test057, Test067, and Test070) • Plastic trash half bin (Test058, Test068 and Test071)

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
6/8/2006 100% power	RHR heat exchanger room	500 lb wood scaffolding	During a plant tour, the inspectors observed scaffolding in the RHR heat exchanger room, which had a large number of wooden scaffolding planks.	See event 10/1/2005 for a discussion on scaffolding planks.
6/15/2006 100% power	Auxiliary building	Trash/nylon fall gear/radiation protection supplies	The inspectors identified unattended transient combustibles placed on a stainless-steel table set next to vertical cable risers in the Unit 2 auxiliary building. The transient combustibles included a plastic trash bag containing six nylon fall protection harnesses and three polypropylene plastic bins (approximately 0.2 m (8 in.) by 0.38 m (15 in.) by 0.18m (7 in.)) containing minor radiation protection supplies (including eight pairs of cotton gloves and six pairs of nitrile gloves). The inspectors noted that some of the materials, such as the plastic bag containing fall protection harnesses, were located approximately (0.2m) 8 in. from vertical cable risers, which was within the zone of influence (ZOI) for a 70 kW fire for thermoset cables. The inspectors also noted that there was a sign attached to one of the vertical cable risers which stated, “No combustible materials allowed. Please store in combustible storage.”	Description of materials suggests a fuel package similar in overall hazard to the full plastic trash can tests (Test059, Test069, and Test072).

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
8/16/2006 100% power	Cable vault	Plastic tarp sheeting		Plastic tarp in several configurations were tested: • Plastic tarp folded (08_29_001, 08_29_002, 08_29_003) • Plastic tarp draped (Test017, Test018, Test019, Test020) • Fire-retardant plastic tarp draped (Test050, Test051) and folded (Test052)
3/7/2007 100% power	Turbine building	21 55 gal oil drums—and later, nine 55 gal oil drums	The licensee identified that 21 55 gal oil drums were located on turbine building 620 East elevation and that nine drums were within the turbine lube oil room. And on 4/9/2007, the licensee personnel identified that nine 55 gal oil drums were located in the turbine lube oil storage area and that this exceeded permitted levels.	See Event 3/7/2001 for a further discussion on drums containing lube oil.
5/7/2007 Refueling outage	Turbine building	Three acetylene cylinders and one oxygen cylinder	During a routine plant walkdown, the inspectors identified that there were three acetylene cylinders and one oxygen cylinder in the turbine building east room.	Gas cylinders require a substantial fire event to cause them to over pressurize and fail. No credible ignition source exists for this. Also, this occurred during an outage.
5/10/2007 Refueling outage	Turbine building	Three acetylene cylinders and one oxygen cylinder in close proximity to several 55 gal drums of oil	The licensee identified that the three acetylene cylinders and one oxygen cylinder were located in the turbine building 620 east room and in close proximity to several 55 gal drums of oil.	See Event 5/7/2007 for a further discussion on gas cylinders. See Event 3/7/2001 for a further discussion on drums containing lube oil.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
5/16/2007 Refueling outage	Turbine building	Two acetylene cylinders, a large amount of cloth rags scattered on the floor, and several empty wooden crates	Inspectors identified that there were two acetylene cylinders, a large amount of cloth rags scattered on the floor, and several empty wooden crates located in the turbine building 620 east room.	See Event 5/7/2007 for a further discussion on gas cylinders. Scattered indicates discontinuous piles. Small piles of rags were tested (07_16_001, 07_16_002, 07_16_003, and 07_23_003). Empty wood crates are not easily ignited given typical transient ignition sources (Test093, Test094, and Test097 are surrogates). Event occurred during an outage.
8/23/2007 At power	EDG room	Flame-retardant treated wood scaffolding	During a walkdown, the inspectors noted that temporary scaffolding installed in the EDG rooms contained a large amount of wood. The inspectors identified that the scaffold did not have a transient combustible materials permit but was constructed of flame-retardant treated wood. Using industry standards, the inspectors estimated the wood to be approximately 500 lb., by multiplying the apparent board-feet of wood by 4.0 lb. By multiplying the estimated weight of the wood by 8000 BTU per pound, the inspectors estimated the heat of combustion of the wood at 4.0 MBTU.	See event 10/1/2005 for a discussion on scaffolding planks. Additionally, these were treated planks, which would further increase the difficulty of obtaining sustained ignition.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
9/19/2007 At power	Control building	Three combustible chairs	The unattended transient combustible material was three combustible chairs. The team noted that one of the chairs was located beneath some of the cable trays in the room which contained Train B safety-related safe shutdown cables. The team noted that there were no other sources of heat or electrical energy in the room that would cause the chairs to ignite.	Fire size likely bounded by the plastic chair test (Test084, Test085, and Test086) or plastic cart test (Test102, Test0105, and Test0106) depending upon the specific construction of the chairs. Finding notes no ignition sources present.
9/28/2007 100% power	Auxiliary building	Trash/carts	During a plant tour, the inspectors identified a concern with two nonmetallic carts containing what appeared to be trash stored on elevation 354' in the Unit 1 auxiliary building. The inspectors noted the carts and their contents appeared to exceed the allowed transient Class A combustible limit for the area of 100 lb.	The laptop+cart tests (Test102, Test0105, Test0106) are surrogates for this.
10/11/2007 One unit in outage, one unit at 100% power	Cable spreading room	Wooden box, a fiberboard table, a plastic chair, a small trash can containing paper trash, a large plastic bag containing air filters, plastic wrap around electrical gear, a computer including power supply cables,	Inspectors found unapproved transient combustible materials stored in the cable spreading room. The inspectors observed a wooden box, a fiberboard table, a plastic chair, a small trash can containing paper trash, a large plastic bag containing air filters, plastic wrap around electrical gear, a computer including power supply cables, two plastic computer storage cases, a lamp, and assorted papers and documents. The materials were largely outage related and had been left after outage activities were completed.	Individual items in this group were tested. Overall, the fuel mass and hazard are similar to that of the plastic cart (Test102, Test0105, andTest0106).

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
10/11/2007 One unit in outage, one unit at 100% power (continued)	Cable spreading room	two plastic computer storage cases, a lamp, and assorted papers and documents		
11/29/2007 95% power (coastdown to refueling outage)	Control building	Cardboard boxes containing fluorescent light bulbs	Inspectors observed transient combustible items (cardboard boxes containing fluorescent light bulbs) in a combustible free zone.	Quantity of boxes is not specified. A single box of T8 bulbs would have a surface area on the order of the medium box. The large box would be equivalent to three boxes. The finding only notes boxes and not a large quantity of boxes. This was likely a similar hazard to the large box (Test007, Test010, Test014, and Test0104).
12/3/2007 97% power (coastdown to refueling outage)	Control building	Rubber hoses and plastic bucket	Inspectors noted transient combustible items (rubber hoses and plastic bucket) in the transient combustible free zone.	Tested similar items such as the water hose (Test030, Test082, Test083) and plastic buckets: • Mop+bucket (Test024, Test025) • Bucket with debris (07_24_001, 07_24_002, 07_24_003) • Empty bucket (07_31_001, 07_31_002, 07_31_003, 07_31_004)

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
1/15/2008 100% power	Auxiliary building	Plastic bin filled with glove liners and three-ring binder		Cotton gloves are not a significant hazard as shown by testing of cotton rags (07_17_001, 07_17_002, 07_17_003). A three-ring binder is also not a significant hazard as shown by testing of three-ring binders (07_18_011, 07_18_012, and 07_18_003). The plastic bin size is not noted; however, it is likely bounded by other plastic storage containers tested—that is, bounded by the 2 gal bucket (07_31_001, 07_31_002, 07_31_003, and 07_31_004) and the full plastic trash can (Test059, Test069, Test072).
3/6/2008 96% power	Control building	Plastic tool cart containing a plastic toolbox, absorbent pads, and other plastic/rubber items	The inspectors observed unattended transient combustible items (plastic tool cart containing a plastic toolbox, absorbent pads, and other plastic/rubber items) staged on the control building 781 elevation.	Similar to laptop+cart tests (Test102, Test0105, Test0106).
4/4/2008 100% power	Turbine building	Six buckets of resin (that is, 12 lb. of resin per bucket)	In response to an inspector’s question, the licensee identified six buckets of resin–that is, 12 lb. of resin per bucket) in the turbine building. This amount of resin (72 lb.) exceeded the licensee's fire protection program’s limit (that is, 280,000 BTUs, the equivalent of 2 gal of general purpose solvent) for transient combustible material. The additional combustible loading from the resin (styrene and resin in aqueous mixture) was 1,296,000 BTUs.	Finding states resin was aqueous—that is, contained water. See Event 8/20/2004 for a discussion on ion exchange resins.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
Between 6/26/2008 and 8/11/2008	Multiple buildings	Multiple materials	• Wood pallets in the safeguards building hallway • Plastic sheets on top of the Unit 2 Train B batteries • Empty resin barrels and wood pallets in the safeguards building hallway • Hoses and other material in auxiliary building • Ropes, harnesses, and other material in the service water intake structure	• Wood pallets are not easily ignited with the types of ignition sources associated with transient fires. • Plastic sheets were tested in the following configurations: – Plastic tarp folded (08_29_001, 08_29_002, 08_29_003) – Plastic tarp draped (Test017, Test018, Test019, Test020) – Fire-retardant plastic tarp draped (Test050, Test051) and folded (Test052) • Empty resin barrels and wood pallets—if a large quantity of resin had just swapped out, this was likely an outage event. • Hoses were tested in Test030, Test082, and Test083. • Ropes (Test079, Test080, Test081, 08_16_001, 08_16_002, 08_16_003, 08_16_004, 08_20_001, 08_20_002, 08_20_003, 08_20_004, 08_20_005, 08_21_001, 08_21_002, 08_21_003, 08_21_005, 08_21_006, and 08_21_007) and harnesses (08_24_001, 08_24_002, and 08_24_003) were tested.
9/11/2008	Not specified	Nine temporary power cables	In preparation for a refueling outage, nine temporary power cables were strung through a combustible control zone without an engineering evaluation that assessed risk and established compensatory measures.	Power cabling shown in testing to not readily support fires such as in Tests031 through 036, and 08_02_002 through 08_03_005.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
10/22/2008 100% power	Auxiliary building	Plastic chair	Inspectors identified a plastic chair staged adjacent to cable risers in the auxiliary building. Specifically, the plastic chair was located between two cable risers and was less than 2 ft from cable risers containing safety-related cables.	Plastic chair was tested (Test084, Test085, Test086).
10/24/2008 Coastdown to refueling outage	Auxiliary building	Resin/laundry	Seven barrels of resin and a laundry cart left outside of the designated storage location on the elevation 354 in the Unit 1 auxiliary building. (The inspectors noted that the barrels and the laundry cart appeared to exceed the allowable transient Class A combustible limit for the area of 100 lb.).	Laundry cart is likely represented by the laptop+cart tests (Test102, Test0105, Test0106). Ion exchange resins are typically packed moist and do not readily support a fire until the water is driven out. This would require a large heat source well beyond the types of ignition sources seen in operational experience.
11/4/2008 100% power	Unknown	Fiberglass cart with rags and tools	The inspectors identified an unattended fiberglass cart with rags and tools in the upper tray adjacent to a cable riser containing emergency shutdown system cables.	Plastic cart tested (Test102, Test0105, Test0106) was more severe than a fiberglass cart.
11/6/2008 100% power	Unknown	Black foam sheet of insulation material	A black foam sheet of insulation material, approximately 0.19m^2 (2 ft^2), was left behind and adjacent to a cable riser containing reactor protection system cables.	Two square feet of foam insulation is a small quantity of material and bounded by many items tested.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
11/25/2008 97% power	Control building	25 ft coiled rubber drain hose with a paper tag and a 4 ft x 6 ft x 1 in. roll of foam insulation	A 7.6m (25 ft) coiled rubber drain hose with a paper tag and a 1.2 m (4 ft) x 1.83 m (6 ft) x 0.025 m (1 in.) roll of foam insulation was found by inspectors on top of ventilation filter units on the control building 751 elevation. The area in which these transient combustible items were found contained highly visible red stripes on the floor and markings indicating the area to be a combustible free zone.	Tested similar items such as the water hose (Test030, Test082, Test083); the paper tag is similar to the cardstock tests (07_18_001 through 07_18_004) with a max HRR of 7.7 kW. The roll of foam insulation is bounded by the WPI quarter or half bag PPE tests.
6/24/2009 100% power	Reactor building	Cabinet containing oil absorbing pads	Inspectors found a cabinet containing oil absorbing pads that was staged adjacent to safety-related cable risers in the 761 ft elevation of the Unit 2 reactor building.	Items in a metal cabinet are protected from the types of ignition source associated with transient fires. Additional absorbing pads were tested (for example, 08_23_001, 08_23_002, 08_23_003).
6/24/2009 100% power	Reactor building	Cart with absorbent pads, anti-contamination clothing, and mop heads	The inspectors identified a cart with oil absorbing pads, anti-contamination clothing, and mop heads in the 761 ft elevation of the Unit 1 reactor building. The cart was staged less than 2 ft from the safety-related cable risers.	Plastic cart was tested in Test102, Test0105, Test0106 (unclear what type of cart was in the finding). The other materials would be insignificant compared with the plastic cart.
6/24/2009 100% power	Reactor building	Cart with welding equipment	Inspectors identified a maintenance cart containing welding equipment staged near a safety-related cable riser. The cart was staged less than 2 ft from the safety-related cable risers.	Plastic cart was tested in Test102, Test0105, Test0106 (Unclear what type of cart was in the finding). The other materials would be insignificant compared with the plastic cart.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
9/29/2009 96% power	Diesel generator building	1 qt motor oil, 1 pt. lubricating oil, and plastic debris items	A plastic container with about 0.95 liters (1 quart) of motor oil, a plastic container with about 0.47 liters (1 pint) of lubricating oil, an empty collapsible plastic container, a plastic bottle half-filled with what appeared to be a soap-bubble and water solution used for leak detection on pipe fittings, two paper towels, and other assorted small debris items underneath two air receiver tanks in the diesel generator ventilation fan room. The area in which these transient combustible items were found contained highly visible red striped paint on the floor and markings indicating the area to be a combustible free zone.	The description suggests that these were individual items located near one another. The only items that are easily ignitable are the paper towels and debris. Based on the testing of plastic containers filled with oil, it is unlikely that either the paper towels or small amounts of debris would be capable of heating the oil containers to failure and then also heating any spilling high flashpoint liquids to ignition.
12/30/2009 91% power (coastdown to refueling outage)	Auxiliary building personnel hatch area	Compressed gas cylinders containing flammable gasses (oxygen and propylene)	Inspectors identified two unattended compressed gas cylinders containing flammable gasses (oxygen and propylene) in the auxiliary building.	See Event 5/7/2007 for a further discussion on gas cylinders.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
1/22/2010 100% power	Control room heating and ventilation equipment room	200 lb. of lumber	During a fire protection inspection activity, the inspectors discovered scaffolding erected in the control room heating and ventilation equipment room. Transient combustibles totaling less than 100 lb. of lumber may be introduced into a Level 2 control area without performing a transient combustible evaluation. However, because the scaffolding appeared to use more than 100 lb. of lumber, the inspector requested to view the transient combustible evaluation for the area. No transient combustible evaluation had been performed. When a transient combustible evaluation was performed, it was discovered that the room contained over 200 lb. of lumber.	Testing showed that untreated dimensional lumber exposed to typical transient ignition sources will not sustain a fire.
Date not specified	High-pressure coolant injection pump room	Three fiberglass extension ladders, approximately 100 ft of rubber hose, a plastic bucket, and two work boxes with unknown contents	The combustibles noted were not controlled in accordance with the plant transient combustible control requirements.	Fiberglass does not readily support combustion. Similar items were tested: • Water hose (Test030, Test082, Test083) • Bucket with debris (07_24_001, 07_24_002, 07_24_003) • Empty bucket (07_31_001, 07_31_002, 07_31_003, 07_31_004) • Medium box with paper (08_06_004, 08_06_005, 08_06_006)

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
Date not specified (continued)				• Medium box with peanuts (08_06_007, 08_06_008, 08_06_009) • Large box with peanuts (Test008, Test011, Test015) • Large box with paper (Test009, Test012, Test016)
Date not specified	Auxiliary building	Seven 55 gal drums of waste lubrication oil	Seven 55 gal drums of waste lubrication oil stored in the common electrical access area adjacent to the four EDG rooms.	See Event 3/7/2001 for a further discussion on drums containing lube oil.
Date not specified	Main steam valve enclosure building	Two piles of plywood	The inspectors discussed the existing permit with a fire protection engineer with respect to the total fire loading for the area because two piles of plywood in the area appeared to be in excess of the assumed fire loading on the permit. The fire severity classification for the building is stated as *insignificant* based on a total fire loading of less than 6500 BTU/ft^2. Based on the fire loading added by the two piles of plywood, the final calculated total fire loading increased to approximately 7100 BTU/ft^2.	Given that the permissible loading in this area was 6500 BTU/ft^2 and the actual loading was 7100 BTU/ft^2 (10% excess), this does not appear to be a significant finding because calculations for permissible loading are generally conservative in nature.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
Date not specified	Not specified in report	Welding cables, rubber hoses, cotton storage bags, and an oxygen-acetylene gas welding rig	The inspectors performed a walkdown of the standby liquid control area. The inspectors identified that a room located within the area and adjacent to safety-related switchgear contained a significant amount of combustible materials. Specifically, welding cables, rubber hoses, cotton storage bags, and an oxygen-acetylene gas welding rig were found in the room.	The only easily ignited item identified was cotton storage bags (similar to bag of rags: 07_17_001, 07_17_002, and 07_17_003), which would have low HRRs. Rubber hose (Test030, Test082, and Test083) and welding cables (Test034, Test035, and Test036) are not easily ignited, and testing shows low HRRs. Unlikely this material would fail a compressed gas cylinder.
Date not specified, but occurred during refueling outage	Containment	11 drums of lubricating oil and storage shelves of radiation protection materials	The material in the containment building included 11 drums of lubricating oil and storage shelves of radiation protection materials (clothing and plastic contamination control clothing and supplies).	See Event 3/7/2001 for a further discussion on drums containing lube oil. PPE storage was tested (WPI PPE bags).
Date not specified, but occurred during refueling outage	Turbine building	Eight drums of waste oil	Inspector identified eight drums of waste oil in the turbine building adjacent to auxiliary feedwater pump and EDG rooms.	Event occurred during a refueling outage.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
Date not specified, but occurred during refueling outage	Reactor building	Six 55 gal barrels of lubricating oil, storage shelves and racks of radiation protection materials, bags of accumulated waste, temporary cables and hoses, and plastic shipping containers	The materials in the reactor building included six 55 gal barrels of lubricating oil, storage shelves and racks of radiation protection materials (cloth, paper, and plastic contamination control supplies), bags of accumulated waste (cloth, paper, and plastic), temporary cables and hoses, and plastic shipping containers. Permits did not exist for the storage of these materials. Several potential ignition sources were identified including welding, grinding, and use of portable or temporary electrical equipment.	Event occurred during a refueling outage. See Event 3/7/2001 for a further discussion on drums containing lube oil.
Date not specified	Diesel generator control room	Wooden tables with computer, monitor, and printers	Each room had a wooden table with a computer, monitor, and a printer set on them. The inspectors identified electrical relay panels that supported diesel generator operation were located across equipment aisles approximately 3.5 ft from the edge of the tables.	Solid dimensional wood is not easily ignited with the types of ignition source associated with transient events. The overall fuel package of a table plus computer hardware, if fully involved would be similar to the plastic work cart (Test102, Test0105, and Test0106).

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
Date not specified	Spent-fuel pool building	Can of spray paint and a can of an adhesive chemical	Flammable chemicals (that is, a can of spray paint and a can of an adhesive chemical) were stored on an open workbench located on the 100 elevation of the building. The inspector also observed other transient combustible materials including a pile of unused temporary cables that were located on the 130 elevation of the spent-fuel pool building.	Flammable mass of cans on the order of the flammable liquids tested (Test056, Test060, and Test061). Chemicals in a spray can would require a severe ignition source to fail the can and ignite the contents.
Date not specified	Relay room	Three chairs, two wooden brooms, a filing cabinet, a printer, and various electrical components	Specifically, the team identified three chairs, two wooden brooms, a filing cabinet, a computer printer, and various electrical components that were not analyzed for combustible loading.	Items in a metal filing cabinet are not a significant hazard. Overall, this is likely less severe than the plastic cart test (Test102, Test0105, and Test0106).
Date not specified	Containment	Propane to be approximately 33.5 lb. of liquid and calculated the combustible loading to be approximately 772,000 BTU.	During a walkdown, the inspectors noted that a temporary propane cylinder for a generator contained a large amount of propane. The inspectors identified that the propane cylinder did not have a transient combustible materials permit. Using industry standards, the inspectors estimated the propane to be approximately 33.5 lb. of liquid and calculated the combustible loading to be approximately 772,000 BTU.	Highly unlikely that the ignition sources seen in operational experience would result in the failure of a propane cylinder.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
Date not specified but appears either in or just after an outage	Auxiliary building (electrical penetration room)	27 charcoal filter trays	Specifically, licensee personnel staged unattended transient combustible materials underneath horizontal cable trays in the auxiliary building in a manner contrary to the licensee's procedure for control of combustible materials. The transient combustibles had been previously removed from the containment charcoal filter unit. Mechanical maintenance moved the filters from their permitted temporary storage location to an unauthorized location due to poor interdepartmental communication and lack of knowledge of plant procedures.	It appears that the combustible material was improperly moved either in or just coming out of a refueling outage.
Date not specified	Electrical penetration room	Large amount of heavy canvas cloth, two large coils of rubber water hose and about 1.36 m^3 (48 ft^3) of plastic flexible vacuum hose	During a walkdown of the Unit 2 560 level electrical penetration room, the inspectors observed a housekeeping area established adjacent to a safety-related 600 V pressurizer heater breaker panel and safety-related containment pressure transmitters. The area contained a large amount of heavy canvas cloth, two large coils of rubber water hose, and about 48 ft^3 of plastic flexible vacuum hose. The heavy canvas cloth was considered fire-retardant but not fireproof.	Testing shows that folded non-fire-retardant canvas cloth has low HRRs (Test055). The outer layers char and prevent combustion of the inner layers. Water hose was tested (Test030, Test082, and Test083), and HRRs for a 50-ft coil peaked at under 25 kW. 48 ft^3 of vacuum hose is on the order of 100 ft of hose. The mass of this would likely be less than the mass of the plastic cart (Test102, Test0105, and Test0106). Fire size of this should be bounded by the hazard of the plastic carts.

Table E-1 (continued)
Summary of notable inspection findings related to transient materials

Date (If Available) and Plant Status	Plant Area	Combustible Type	Description	Response
Unknown	Unknown	At least 100 lb. of rubber diaphragms and hoses	Not available.	See event 6/9/2000 for a discussion of quantities of rubber material.
Unknown	Turbine building	Multiple cans of unknown combustible materials	Not available.	Items in a sealed metal can are not easily ignited with the types of ignition sources associated with transient fires.

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