Validation of Modeling Tools for Detection Design in High Air Flow Environments

Final Phase I Report

Prepared by:

Daniel Gottuk
Jason Floyd
Joshua Dinaburg
Justin Williamson

Hughes Associates, Inc.
Baltimore, MD

THE FIRE PROTECTION RESEARCH FOUNDATION

FIRE RESEARCH

THE FIRE PROTECTION RESEARCH FOUNDATION
ONE BATTERYMARCH PARK
QUINCY, MASSACHUSETTS, U.S.A. 02169-7471
E-MAIL: Foundation@NFPA.org
WEB: www.nfpa.org/Foundation

FOREWORD

Information-technology and telecommunications (IT/telecom) facilities provide critical services in today's world. From a risk standpoint, the indirect impact of fire loss due to business interruption and loss of critical operations, sometimes geographically very distant from the IT/telecom facility itself, can far outweigh the direct property loss.

In the past few years, there have been dramatic changes in the equipment housed in these facilities, which have placed increased demands on HVAC systems. As a result, airflow containment solutions are being introduced to increase energy efficiency. From a fire safety design perspective, the use of airflow containment creates a high airflow environment that dilutes the smoke, which poses challenges for providing adequate detection, and affects the dispersion of suppression agents.

Fire protection requirements for IT/telecom facilities are directly addressed by NFPA 75, *Protection of Information Technology Equipment*, and NFPA 76, *Fire Protection of Telecommunications Facilities*. Installation of detection systems are covered by NFPA 72, *National Fire Alarm and Signaling Code*, which is referenced by both NFPA 75 and NFPA 76. Annex Section B.4.5 of NFPA 72, *National Fire Alarm and Signaling Code*, states, "There currently are no quantitative methods for estimating either smoke dilution or airflow effects on locating smoke detectors." Although tools exist to model fire development, detection time, and suppression agent dispersion, they have not been validated for this application.

Accordingly, the Fire Protection Research Foundation initiated this project with an overall goal to develop a validated set of modeling tools that can be used for providing reliable analysis of detection performance in IT/telecom facilities. The goal of the first phase is to develop a full scale fire test research plan and a list of models and data inputs to be used in the validation study.

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The content, opinions and conclusions contained in this report are solely those of the authors.

PROJECT TECHNICAL PANEL

Thomas Fabian, Underwriters Laboratories

Steve Dryden, Poole Fire Protection Inc.

Ken Dungan, Risk Technologies, LLC

Ron Marts, Telcordia Technologies

Jonathan Hart, NFPA Staff Liaison

Jay Ierardi, AKF Group LLC

Chris Marrion, Marrion Fire & Risk Consulting

Kevin McGrattan, NIST

Dan O'Connor, Aon Fire Protection

Lee Richardson, NFPA Staff Liaison

Tom Wysocki, Guardian Services, Inc

PROJECT SPONSORS

Dupont Flouroproducts	Mark Robin
FM Global	Yi Wang
Honeywell/System Sensor	Scott Lang
Intel	Dan Aruda
ORR Protection Systems, Inc	Steve Carter
Schneider Electric	Kevin Lemke
	Stephen McCluer
	John Niemann
	Jim VanGilder
Siemens Industry, Inc	Daniel Finnegan
	Ronald Ouimette
SimplexGrinnell	Rodger Reiswig
UTC / Kidde-Fenwal, Inc	Jonathan Ingram
	Joseph Senecal
Verizon Wireless	David Quirk
Xtralis Inc	Wayne Aho
	Sue Sadler

PROJECT WORKSHOP PARTICIPANTS

Jeff Betz, AT&T

Dick Bukowski, RJA

Steve Carter, Orr Protection Systems

Steve Dryden, Poole Fire Protection

Jonathan Ingram, Kidde-Fenwal

Scott Lang, System Sensor

Kevin Lemke, Schneider Electric

Ron Marts, Telcordia

Stephen McCluer, Schneider Electric

Dave Quirk, Verizon Wireless

Rodger Reiswig, SimplexGrinnell

Mark Robin, Dupont Flouroproducts

Joe Senecal, Kidde-Fenwal

Jim VanGilder, Schneider Electric

Yi Wang, FM Global

HUGHES ASSOCIATES, INC.
FIRE SCIENCE & ENGINEERING

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Prepared for:

The Fire Protection Research Foundation
One Battery Park Plaza
Quincy, MA 02169

Prepared by:

Daniel Gottuk, Jason Floyd, Joshua Dinaburg, and Justin Williamson
Hughes Associates, Inc.
3610 Commerce Drive, Suite 817
Baltimore, MD 21227
Ph. 410-737-8677 FAX 410-737-8688
www.haifire.com

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EXECUTIVE SUMMARY

Modern information-technology and telecommunications (IT/telecom) facilities create challenges for the design of fire protection systems and for the development of code guidance for those systems. The high flow rates needed to provide adequate cooling impact the performance of detection and suppression systems (upwards of 100 ACH or more). This impact has not generally been quantified for those higher flow rates by experiment, and current modeling tools, while having the ability, have not been validated for the specific application of detection performance in high air flow rate conditions. To reach the end point of having modeling tools for design engineers and code guidance for fire detection system installation requires a multi-step process, including:

- Identifying the modeling requirements for evaluating the performance of detection and suppression in high air flow rate environments for IT/telecom facilities
- Identifying potential computer models
- Indentifying gaps in knowledge for either model capability or model validation
- Developing a program of research to address the gaps
- Executing the research program to address critical gaps in knowledge or validation data
- Validating models for use in high air flow rate environments for IT/telecom facilities
- Using the validated models to develop code guidance and to design systems

To begin addressing this, the Fire Protection Research Foundation has funded a project to address the first four items above for detection performance. This report documents the result of that project.

Seventeen model requirements were identified for evaluating the performance of detection in high airflow rate environments in IT/telecom facilities. These requirements include both software capabilities (geometry, heat transfer, fire physics, etc.) and software quality (validation, user support, etc.). Twenty-six models (one network model, two zone models, and twenty-three CFD models) were evaluated against these criteria. Eight models were identified as being candidates for use in predicting detection performance in IT/telecom facilities with high flow rates: ANSYS-CFX, ANSYS Fluent, FDS, FLOTHERM, FLOVENT, KAMELEON, PHOENICS, STAR-CCM+.

Following a review of available models, a gap analysis was performed. This analysis considered the ability to specify the necessary inputs for the models (geometry, material, heat loads, fire sources, etc.), the ability of the models to predict performance of detection (smoke transport, prediction of detector performance), and the ability to validate the usage of the models. The gap analysis identified four gaps:

1. Specification of the fire and smoke inputs: There is very limited data for representative sources in IT/telecom facilities that have been characterized in a way that it is usable as an input to a model.
2. Smoke Transport: There is a need to assess the importance of being able to predict smoke deposition and spatial particle size distributions (e.g. the adequacy of treating smoke as a gas verse particles) on the ability of models to adequately predict detection performance.

3. Smoke detector performance: There is no data to reliably predict detection performance at high flow rates. The ability to correlate conditions predicted by a model (e.g., smoke concentration) at the location of a smoke detector/ASD sampling port to an alarm condition within the detector is a significant gap.
4. The existence of large scale integral test data is limited. There is no work that completely validates the full process of imputing representative fire sources into a model and predicting a detection response for a high air flow environment.

To address the four gaps, a test plan was developed. The test plan consists of three phases of testing to be conducted in a future project:

1. Characterizing typical fire sources in IT/telecom facilities to develop smoke and fire source inputs for modeling.
2. Characterizing the performance of detectors against the selected fire sources at high air flow rates to develop detector response correlations.
3. Execution of large scale tests using the selected fire sources and characterized detection to generate validation data that is then used to validate a candidate model (or models).

The end of the test program will be one or more models suitable for use in predicting the performance of detection in high air flow IT/telecom facilities. The model(s) would then be available for use by engineers designing detection systems and by code committees to develop guidance and code requirements for detector selection and installation.

TABLE OF CONTENTS

VALIDATION OF MODELING TOOLS FOR DETECTION DESIGN IN HIGH AIR FLOW ENVIRONMENTS

1.0 OBJECTIVE

Information technology and telecommunication (IT/telecom) services are critical to daily life in the modern world. Loss of an IT/telecom facility due to fire can have far reaching consequences whose value can easily exceed the direct property loss of the facility itself. In recent years, the increase in power density of electronics, the increase in the size of facilities, and the desire to improve energy efficiency has resulted in facility designs with very high airflow rates. From a fire protection design viewpoint, these airflow rates pose challenges due to the dilution of smoke for detection, the impact of high flow speeds on detection, and the dispersion of suppression agents. Currently NFPA 75, *Protection of Information Technology Equipment*, and NFPA 76, *Fire Protection of Telecommunications Facilities* due not directly address the challenges of fire protection in these high airflow environments with detailed detection requirements.

One of the challenges for both the engineer doing the fire protection design and the code committees developing code requirements is the lack of quantitative methods for evaluating the impact of high airflow rates on detection and suppression. While tools exist with the capabilities of analyzing these facilities, specific validation for this application has not been performed.

This report is the first step in the process of addressing the issue of detection in high airflow rate environments. This effort is undertaken to examine the applicability of computer modeling tools for the purpose of modeling smoke detection system design in information-technology and telecommunication (IT/telecom) facilities with high air flow rate ventilation systems. Aspects of modeling tools that impact the evaluation of detection system design are discussed, and a range of potential software models are compared against these aspects. The impact of each of these model aspects on the accurate prediction of smoke detection design performance in IT/telecom facilities is assessed. The ultimate requirement is that the computer model supports the accurate prediction of the conditions present at a detector location (smoke concentration, velocity, temperature, and possibly smoke characteristics) in order to be able to determine the expected performance of a detector. This document describes the requirements for a fire model being used for IT/telecom simulations, provides a review of existing models against the requirements, and discusses the gaps in the use of models for these applications. Based on the gaps identified, a plan is developed to address the gaps that will have the greatest impact on improving the utility of models for detection prediction in IT/telecom facilities.

Beyond this effort will be the need to execute the test plan provided in this report and validate computer model(s) for use in predicting smoke detection performance in high airflow rate environments. This will then provide the engineer with a tool for design and the code committees with a tool that can support the development of code requirements.

2.0 DESCRIPTION OF DESIGN FIRE MODELING REQUIREMENTS

This section discusses the types of fire models that could be applied and provides an overview of the desired attributes for the models. Those attributes include inputs, support, capabilities, and validation. The underlying assumption in this section is that the modeling focus is for non-trivial detector locations. For example, a cold aisle with an isolated return serving only that aisle with return air duct detection would not require detailed computer modeling. Simple hand calculations could yield smoke concentrations in the duct.

2.1 Model Types

There are three classes of computer fire models (ignoring hand/spreadsheet methods) applicable to modeling fire and smoke effects within a compartment with ventilation: field, zone, and network. These models are briefly discussed below.

2.1.1 Field Models

Field models, computational fluid dynamics (CFD) models, provide spatially resolved information about the fluid motion within the computational domain (the portion of the facility that has been input into the model) of the model. In brief, a room (the computational domain) is divided into many cells, and the model calculates the properties (i.e., species, temperature, and density) for each cell. Depending upon the model, this can be done as a steady-state or a time-dependent computation. The ability to perform a detailed simulation of a complicated geometry with complex boundary conditions (e.g., ventilation, equipment thermal loads, and fire sources), makes field models well suited to the simulation of IT/telecom facilities.

In general there are a couple of approaches for CFD models. The models can solve for the viscous forces acting on the fluid (which ultimately will result in turbulence if the flow speed is high enough) or the models can ignore the viscous forces (inviscid). An inviscid approach, such as potential flow models, result in a very simplified set of equations and results in very fast execution speed. However, these models cannot capture the effects of the turbulent mixing and dilution of species (such as smoke) and are therefore not considered further.

CFD models can be divided into two broad classes: direct numerical simulation (DNS) and non-DNS. Due to its requirement of very small grid cells (millimeter or less), for the foreseeable future, DNS is impractical for use in modeling detector performance in IT/telecom facilities. Non-DNS models themselves have two broad classes: Reynolds Averaged Navier Stokes (RANS), Large Eddy Simulation (LES). These refer to the method via which the model incorporates the effects of turbulence occurring at length scales smaller than the grid size. In greatly simplified terms, RANS models represent turbulence by averaging its effects over time and LES models represent turbulence by averaging its effects over distance. LES models are inherently time-dependent and RANS models can be either time-dependent or steady-state. Depending upon the specifics of detector type, detector location, and facility design, the prediction of time to detection could require a time-dependent model.

2.1.2 Zone Fire Models (Two Layer)

A zone fire model divides each compartment into two zones: an upper layer and a lower layer. A fire in a compartment creates a plume that entrains air from the lower layer and deposits it in the upper layer along with the energy from the fire. Each layer is treated as being homogeneous (e.g., well-mixed) with a uniform temperature and smoke concentration. Zone models are typically limited in their ability to specify complicated ventilation, and the high air flow rates violate the primary zone model assumption of two layers.

2.1.3 Network Models

A network model is a further simplification from a zone model. These models treat each compartment as a well-mixed space (e.g., as a single zone). Network models are commonly used in computational tools developed for determining indoor air quality and as such can contain the ability to model complex HVAC systems, which may be an important feature for IT/telecom facilities. The inherent simplicity of network models allows for highly efficient simulation of design scenarios, and would produce substantial computation cost savings compared to field models. This suggests that network models can be used as a preliminary screening tool for evaluating ventilation and detection designs that could then be evaluated in greater detail with a field model.

2.2 Model Inputs

Since the quality of model inputs are of such critical importance to the quality of the model outputs, this section discusses the most critical inputs required for the application of smoke detection design using CFD. The ability to specify the inputs to support the analysis are discussed in Section 4. A simple design flow chart that describes some of the critical inputs, outputs and processes is provided in Figure 1.

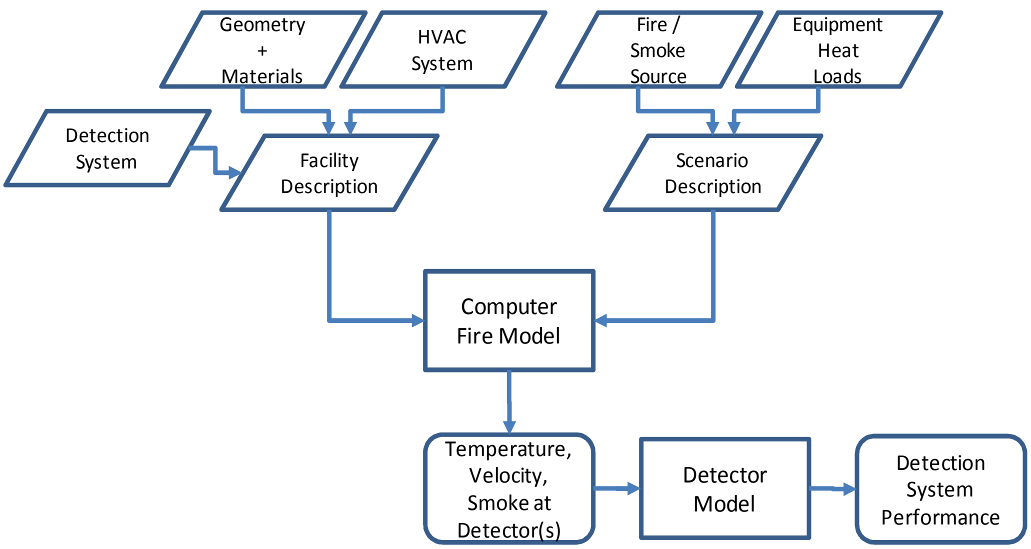

Figure 1: Flow chart for determining fire effects and smoke detector performance using computer modeling

2.2.1 Geometry

Geometry refers to all things that impact how air flows within the facility. This list includes, but is not limited to:

- External walls
- Internal walls
- Floors
- Ceilings

- Columns
- Doors
- Windows
- Equipment
- Containment boundaries (e.g., curtains, baffles, etc.)
- Porous/leakage boundaries (define the approximate porosity percentage)
- Ductwork
- Cable raceways (i.e., cable bundles, large conduits and cable trays)
- Any other geometric feature with the potential to substantially affect the flow of air
- Small isolated objects (e.g., individual cables) can usually be ignored

The level of detail will depend upon the type of model being used. A zone or network model would require a basic footprint, height and free air volume whereas a CFD model would require a description of the geometry at a level of detail commensurate with the computational grid being used. Simplifications in geometry can be made for a CFD model with the recognition that doing so may increase the uncertainty of the computation.

Some additional details may be necessary as follows:

- When defining the external boundaries of the domain, make note of unique geometric features such as curved or angled walls (a rare occurrence) and block outs like large structural columns and well-sealed rooms that block off a substantial portion of the facility internal volume from the overall air flow.

- When defining the location, size, and orientation of all major equipment and obstructions within the domain, make note of unique geometric features such as vent openings, fans, or thermal equipment.

- When defining the location, size, orientation, and flow characteristics (diffuser direction) of all ventilation pathways, make note of the presence of fans, filters, or thermal equipment (heating or cooling).

2.2.2 Material Properties

Material properties refer to the thermal properties of those items included in the geometry. These properties are needed to evaluate heat losses to boundaries and would include density, thermal conductivity, specific heat capacity, and emissivity. Given the high air flow rates and relatively low temperatures wall heat transfer is likely to be a minor contributor as compared to the electronic equipment heat addition. For materials likely to be present one should generally be able to locate room temperature properties for that material or a sufficiently similar material. This is likely to be adequate for most conditions being simulated as large changes in temperature would not be expected (in general one would expect to detect a fire before it is large enough to impact the temperature of a room's boundaries). Indeed for in many cases, the use fixed temperature surfaces may be justifiable.

2.2.3 Equipment Heat Loads

The reason for the high air flow rates in IT/telecom facilities is the need to remove large amounts of heat (10's of kW/m^2 of equipment footprint). This heat generation will likely outweigh the effects of the fire in many cases. That is, the size fires one wishes to detect are likely to be small compared to the heat being dissipated by the equipment. The rate of thermal energy released by all normally operating equipment within the computational domain must be defined. This definition should include how the heat is transferred from the equipment to the surrounding air. This may include a combination of heat transfer to air flowing through the equipment and heat transfer from the external surface of an equipment cabinet to the air surrounding it. It is likely that the internal heat transfer will not be modeled explicitly. Instead, a CFD model for example, might model the internal heat transfer as a specified heat source term at the air outflow locations of a cabinet. In other words, a rack of equipment may be treated as a thermal black box where air at a lower temperature enters the rack and exhausts at another area of the rack at an elevated temperature, some guidance on this approach is available from ASHRAE [1]. Some facilities may use chilled water cooling systems in combination with air systems. In these cases, the heat extracted by the water system must be excluded from the heat load that will impact the air flows and movement of smoke.

2.2.4 Flow Boundary Conditions (HVAC System)

Flow boundary conditions describe all of the vent openings that affect air flow within the CFD domain. This can include simple openings (e.g., open archways), CRACs, coolers, and other HVAC connections. Some of this information will have been captured in the geometry definition stage; however, certain specific information may complicate the definition of ventilation flows.

- Openings between rooms within the domain – If present, determine the size, location, and orientation of the opening.
- Openings to areas outside the domain – If present, determine the size, location, and orientation of the opening. This configuration may also require an extension of the computational domain to capture entrance and exit loss effects, pressure differentials, and wind effects.
- Ducted supply air – Determine the flow rate, temperature, and orientation of the diffuser.
- Ducted return air (typically CRACs) – Returns can be simpler than supply and usually only require an effective opening area that achieves an appropriate pressure differential in the domain and adequate flow balancing.
- Ducted air flow (typically coolers and perforated tiles) – Determine the size, location, flow rate (if fan driven), and temperature change in duct (if applicable). This would capture a return/supply pair that is internal to the computational domain where the separation between return and supply is large. Also, note if this ducted air flow is affected by equipment heating or internal fans in order to adequately specify the flow characteristics.

- Internal fans (e.g., inside equipment cabinets, ceiling mounted fans, etc.) – Characterize any source of forced air motion within the domain. Determine the size, location, orientation of flow, flow rate, and potentially a fan performance curve.

2.2.5 Fire and Smoke Source

Depending upon the desired detection performance, fires may be incipient/smoldering fires or they may be flaming fires. In the former case, the amount of heat being generated is likely to be insignificant and the critical input is the rate of smoke generation. In the later case, the heat being generated may become large enough to impact the normal ambient air flow. In this case, the time-dependent heat release and smoke production are both important inputs. A fire is defined by specifying the heat of combustion, exposed surface area and configuration of the fuel, rate of mass release of fuel (heat release rate), rate of mass production of soot, and potentially the radiative fraction of the fire. In cases where the fire is contained within an enclosed equipment cabinet, the fire boundary condition in the model could be simplified to a rate of heat and combustion product formation applied to the air outflow from the cabinet. The cabinet design and fire source would likely dictate how to define where heat and smoke emanated from the cabinet. In this case, care must be taken to properly account for mass flow, temperature, and smoke production to ensure an accurate reproduction of the internal fire source, and an accurate evaluation of the smoke detection design.

2.3 Model Support

Dozens of fire models of various types have been developed over the years. Many models have seen limited periods of use or were released as the culmination of a graduate student or institutional research project and never revisited. A highly desirable attribute for a model, is that its developers still support the model. This includes adding features, fixing software bugs, and providing assistance to end users. A high level of support is generally indicative of a model that has a broad acceptance as a design tool based on the active participation of the user community. User support can be especially important for CFD models, which often contain a large number of features, which may or may not be appropriate for use in a given simulation.

2.4 Model Capabilities

Certain model capabilities are considered critical, or useful for the application of the software to IT/telecom facility smoke detection design. Not all of these capabilities should be considered necessary, but knowledge of the software capabilities is critical for designers to make informed decisions about the end application of the model. Some important capabilities are listed below with a brief description about the importance of that feature for IT/telecom facility smoke detection design.

- **Complex Geometry** – IT/telecom facility footprints, the layouts of equipment and HVAC equipment and the flow paths for cooling air flows can all be very complex. Given the nearly infinite combination of equipment design and layout, along with potential future design innovations, the ability to capture complex geometry is very important. The shape and layout of the rooms, equipment, and various internal features must be captured in order to accurately model the air flow for a given facility. Models with higher geometric fidelity (the ability to accurately represent this complexity) would be expected to have lower uncertainty in their predictions.

- **Species (Smoke) Transport –** Predicting the expected performance of a smoke detector requires being able to predict the conditions present at the detector location. The most important of these is the quantity of smoke that is present. A model which does not allow one to track separate species, will be less useful..
- **Thermal Fluid Flows –** This capability indicates the ability of the model to predict the space and time-dependent temperature of the air within a facility. The heat generated by the equipment within the facility, and the effects that it has on the air flow within the facility will have an impact on the dispersion of smoke as will the energy release of the fire if it is large enough. This thermal flow is the driving factor behind the design of effective cooling and ventilation configurations, and it has a correspondingly strong effect on the smoke detection design.
- **Conjugate Heat Transfer –** This capability indicates the ability of the model to accurately capture the effects of heat transfer between the air and the solid objects within the computational domain. This includes changes in the gas temperature and the changes in the solid temperature in the IT/telecom facility. Give the airflow rates and temperature gradients present in IT/telecom facilities, this is not likely to be a critical capability for evaluating detection design. However, uncertainty in validation could be impacted if this was not accounted for.
- **Fire Source Modeling –** In general, it is expected that fire sources will be specified rather than computed from first principles (i.e., one would not model the pyrolysis of the solid phase but rather just specify the rate at which fuel is produced). The ability to predict pyrolysis of real materials with current tools is greatly limited. In the case where an incipient fire is being modeled, the low levels of heat being produced do not warrant the additional expense of modeling combustion and specification of a soot production rate is all that is required. For flaming fires contained entirely within a cabinet, it may also not be necessary to model the combustion, but rather simply specify a rate of heat and products being added to the air flow exiting the cabinet. Combustion modeling would be necessary for large design fires where it is anticipated that there will be a visible flame outside of a piece of equipment. This requires the model to track the release of fuel, its burning rate in the air, and the soot production associated with this burning. Software packages that have flexible capabilities for modeling combustion, fire growth and fire spread to adjacent equipment will be indicated.
- **Air flow Leakage Through Porous Media –** Many facility ventilation designs utilize plenum spaces and isolation techniques that use materials (e.g. grating, perforated tiles), which allow the passage of air through the material. For a subfloor or ceiling plenum, the pressure drop resulting from flow through the porous media leads to non-uniform supply or exhaust flow over a hot or cold aisle which could impact the performance of detection. Assessing the specific performance of detection in subfloor or ceiling plenum spaces would benefit from being able to capture the effects of porous media.

- **Flow Boundary Conditions** – This capability would capture the methods used to supply, extract, and re-circulate air in an IT/telecom facility (see Section 2.2.4 Flow Boundary Conditions (HVAC)). It may also be used as the primary method to inject smoke and heat into the domain to represent a fire within a cabinet or piece of equipment. The clearest example of this application is for a small fire inside an enclosed cabinet. Here, the cabinet would be described by its air inflow, the fire size within the equipment (heat release rate, and smoke release rate), and then the air outflow would be prescribed based on these quantities. The air outflow would be slightly hotter than it normally would be, and it would contain the smoke produced by the fire. The flexibility in the software to choose between multiple flow boundary options is necessary.
- **HVAC Sub Model** – If the transport of smoke and heat through the HVAC system is critical for determining detector performance (e.g., in-duct detection or where recirculated smoke is being detected), then the model needs to be able to model the flows through the HVAC system including species and temperature. For many typical systems, this capability need not be very complex. However, the need to be able to model in a detailed fashion fans, the effects of filtration, the effects of cooling equipment, and potentially duct flow losses cannot be precluded.
- **Equipment Heat Generation** – This capability indicates the ability of the model to accurately represent all of the equipment heat generation described in the input section. The heat generated by the equipment within the facility will define the temperature of air circulating throughout the facility. The equipment thermal energy balance and the resulting thermal flow is the driving factor behind the design of effective cooling and ventilation configurations, and it has a correspondingly strong effect on the smoke detection design. Software packages that have flexible capabilities for modeling equipment heat generation and thermal energy balance through Flow Boundary Conditions, high temperature surfaces (see Conjugate Heat Transfer) and other effects are indicated in the review.
- **Output** – Any model must be able to produce output data that is appropriate for use in detector modeling. Critical parameters include air temperature, air velocity and species concentration, particularly smoke.
- **IT/Telecom Specific Features** – While this is not a requirement that would eliminate a model, the presence of features specifically related to IT/Telecom facilities (such as input databases for equipment) could greatly reduce the time and effort needed to model a facility.

2.5 Model Validation

Model validation is the process of determining the degree to which a model or simulation and its output data accurately represent the real world for a specific application. Model validation is critical to designers, owners, and authorities having jurisdiction for determining that a selected model is appropriate for use in a specific application. This is typically established by comparing model predictions to data collected by experiments or real world experience. The availability of model validation can vary considerably across models, and is further limited when exploring specific applications. Three important model validation categories are considered for the application of computer models to smoke detection modeling in IT/telecom facilities.

- **General** – The ability of the model to accurately predict the flow and mixing of air over a range of flow conditions and geometries.

- **Fire Specific** – The ability of the model to predict quantities of interest for fire hazards analyses including fire plume, ceiling jet, smoke layer height, compartment fire, pool fire, flame spread, and target exposure.

- **Facility Specific** – Model validation that specifically addresses the use of the model for simulating flows within IT/telecom facilities. If the model developers or end users indicate this specific application, it is noted.

3.0 MODEL REVIEW

Twenty-six candidate models have been examined and evaluated against the critical aspects detailed above. Twenty-three field models were selected based on input from the International Survey of Fire Models for Fire and Smoke (http://www.firemodelsurvey.com) and input from facility designers. An emphasis was placed on models that are generally available for use rather than vendor specific proprietary models as the latter complicate the use of model studies in the development of codes and standards. Additionally, two zone models and one network model were selected on the basis of their wide use as fire hazard analysis tools (CFAST, CONTAM, and FSSIM respectively). The remaining zone models listed in the International Survey of Fire Models for Fire and Smoke were not examined based on their limited current usage.

Table 1 has been generated to cross reference the model capabilities against the critical model aspects detailed above. In order for any of these models to accurately predict the performance of a smoke detection design, appropriate inputs for the fire source generation and flow boundary conditions must be established. Furthermore, IT/telecom specific validation studies are critical to improve the industry confidence in their application to smoke detection design in IT/telecom facilities. It should be noted that the evaluation of these model aspects is subjective as much of the background, verification and validation documentation for these models is either proprietary or spread across numerous research publications. Sources of information regarding the capability of these models have been reviewed from the references provided in the International Survey of Fire Models for Fire and Smoke, and commercially produced brochures and demonstrations found on the model websites.

Table 1: Review of Modeling Tools Against Requirements for IT/Telecom Facility Modeling

				Model Capabilities										Model Validation			
Model Name	**Model Type**	**Active V&V**	**Support + Usability**	**Complex Geometry**	**Smoke/ Species**	**Thermal Fluids**	**Heat Transfer**	**Fire Source**	**Leakage/ Porous Media**	**Flow Boundary Conditions**	**HVAC flows**	**Equipment Heating**	**Output**	**IT/Telecom Specific Features**	**General**	**Fire Specific**	**IT/ Telecom Specific**
AIRPAK (FLUENT)	Field	No	Some	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	???	Yes	Yes	Yes	???	???
ALOFT-FT	Field	No	No	No	Yes	Yes	No	Yes	No	No	No	No	Yes	No	No	Limited	No
ANSYS CFX	Field	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	???
ANSYS Fluent	Field	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	???
CFAST	Zone	Yes	Yes	No	Yes	Yes	Some	Yes	Some	Yes	Some	No	Yes	No	Yes	Yes	No
CONTAM	Network	Yes	Yes	No	Yes	No	No	Some	Yes	Yes	Yes	No	Yes	No	Some	Some	No
Coolsim (FLUENT)	Field	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes
FDS	Field	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
FIRE	Field	No	No	No	Yes	Yes	Some	Yes	No	Yes	No	No	Yes	No	No	Some	No
FIRE/OPEN FOAM	Field	Yes	Some	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Some	Some	???
FLOTHERM	Filed	Yes	Yes	Yes	Yes	Yes	Yes	???	???	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
FLOVENT	Field	Yes	Yes	Yes	Yes	Yes	Yes	???	???	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
FSSIM	Network	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No
JASMINE	Field	???	No	???	Yes	Yes	Yes	Yes	???	Yes	???	???	Yes	No	Yes	Yes	No
KAMELEON FireEx	Field	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	???	Yes	No	Yes	Yes	???
KOBRA-3D	Field	Yes	???											No			
MEFE	Field	No	No											No			
PHOENICS	Field	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
RMFIRE	Field	No	No	Limited	Yes	Yes	Yes	Yes	???	Yes	???	???	Yes	No	???	???	???
SMARTFIRE	Field	Yes	No	Yes	Yes	Yes	Yes	Yes	???	Yes	Yes	???	Yes	No	Yes	Yes	No
SOFIE	Field	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	Yes	No	Limited	Yes	No
SOLVENT	Field	Yes	Yes	No	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	No	No	Yes	No
SPLASH	Field	No	No	No	Yes	Yes	No	No	No	Limited	No	No	Yes	No	No	No	No
STAR-CCM+	Field	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	???
TileFlow	Field	Yes	Yes	Yes	No	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
UNDSAFE	Field	No	No											No			

The models are colored according to the review of their capabilities. Green models should be suitable for use without any significant caveats. Yellow models might be suitable but have potentially significant limitations in their usability. Red models have been deemed unsuitable for use. The one orange model (FSSIM) is potentially useful as a screening tool or for a tool to evaluate in-duct detection systems where highly-mixed conditions are expected (for example where hot and cold air flows are segregated in the facility design).

The suitable models include:

- ANSYS CFX – A widely used, well validated, general purpose, commercial CFD model. It supports all the necessary capabilities.
- ANSYS Fluent – A widely used, well validated, general purpose, commercial CFD model. It supports all the necessary capabilities.
- FDS – The most widely used CFD fire model. It is a well validated, public domain CFD model developed by the US Government. While it does not support as wide a set of features as the commercial models, it does possess the necessary capabilities.
- FLOTHERM/FLOVENT – CFD models used by the datacenter/telecom facility industry to evaluate facility designs. The models have the capability to track contaminants and input heat sources which should enable them to be used for modeling fire sources.
- KAMELEON (KFX) – While its primary focus is hazards analyses for the oil and gas industries, it appears to have the necessary capabilities for IT/telecom facility analysis.
- PHOENICS – A widely used, well validated, general purpose, commercial CFD model. It supports all the necessary capabilities and contains modeling options specific to HVAC analyses.
- STAR-CCM+ - A widely used, well-validated, general purpose, commercial CFD model. It supports all the necessary capabilities.

All of the above models should be capable of simulating fire scenarios within IT/telecom facilities.

Two models (AIRPAK by Fluent and FireFOAM/OpenFOAM) have the basic capabilities required but suffer from limitations in usability. Support for AIRPAK is being discontinued, an indication that the model will soon fade from existence as an available tool.

FireFOAM/OpenFOAM is a collection of open source CFD routines that can be compiled to create customized CFD applications. While it is feature rich, it is primarily a research tool and it not currently a commercial product. As a result, it is difficult to use, lacks user support, and its documented validation is immature in comparison to the commercially used model.

The remaining CFD models (ALOFT-FT, CoolSim, FIRE, JASMINE, KOBRA-3D, MEFE, RMFIRE, SMARTFIRE, SOFIE, SOLVENT, SPLASH, and TileFlow) are not considered suitable. They either lack critical features or are not suitable for use as a commercial tool due to their availability, support, and/or degree of maturity. CoolSim is a steady state RANS solver based on the FLUENT platform. It was designed specifically for data center air flow, but does not have the capacity to handle fire sources and smoke and species. While this capability could be added to the model, in its currently available state, CoolSim is unsuitable. TileFlow is a currently used CFD model for data center cooling, but it lacks the species and fire source capabilities needed for this effort. As with CoolSim, while this capability could potentially be added in the future, it does not currently exist.

The two zone models evaluated, CFAST and CONTAM, lack important features. CFAST contains the necessary fire features but does not support the required HVAC and equipment heat load capabilities. CONTAM supports the HVAC capabilities but does not support the required fire features. These models are considered unsuitable.

The network model FSSIM was designed to simulate fires in structures with complex ventilation. While it would not support a detailed analysis of spot detection within a facility, it could have usefulness as a scoping tool or a tool to evaluate in-duct detection or detection in circumstance where high levels of mixing are expected.

4.0 MODELING GAP ANALYSIS

The model review indicates that CFD models are best suited to IT/telecom facility analyses. This section discusses what gaps exist in being able to model these facilities. The discussion focuses on the application of CFD tools to the design of smoke detection systems in IT/telecom facilities; however, it is noted that the discussion is generally applicable to other types of models. These gaps are identified through analysis of each of the processes required to model smoke detection design.

4.1 Facility Specification

4.1.1 Geometry

If a facility design is mature enough to warrant designing a facility specific detection system, the specification of geometry is not going to be a modeling gap. While inputting the details of the geometry may present a challenge to the modeler, one would expect the details to be present in either design drawings or via direct measurement for an existing facility. The form of available information (CAD files, scanned blueprints, or hand measurements) may impact the ease with which the facility’s geometry can be input into the model; however, any of these forms should provide sufficient detail.

4.1.2 Material Properties

Specifying the properties of the materials used in the construction of the facility and its contents is not considered a modeling gap. Properties can be easily found for most common construction materials. For uncommon materials, properties of similar materials should suffice. Since heat losses to walls is likely a small component of the overall energy balance, errors in material property specification should not dramatically affect the smoke detection modeling results.

4.1.3 Equipment Heat Loads

The specification of the details of equipment heat loads within a facility is not considered a modeling gap. Numerous equipment manufacturers and technical and professional associations have published works focused on the application of CFD toward IT/telecom facility ventilation designs, including IBM [2], HP [3], ASHRAE, IEEE, and ASME. These studies focus on establishing cost effective cooling designs. These analyses require being able to specify the heat loads of equipment at similar levels of detail as would be necessary for smoke detection design. This industry experience indicates that equipment heat loads can be handled reasonably, and with a high level of confidence.

While it is recognized that most of the necessary information about equipment heat generation (heat dissipation rates, rack airflow rates, etc) likely exists, this data may not be readily available in forms easily used for modeling. This information must be made available to smoke detection system designers in order to assure a successful design strategy. The Coolsim (Fluent) software package was designed specifically to address optimized equipment cooling within a facility. In researching this software, it was found to have a limited database of equipment that is typically used in IT/telecom facilities. This database contains several key features of the equipment, such as size, shape, ventilation, and thermal heat generation. Such a database should be made available to smoke detection system designers. Otherwise, a smoke detection design modeling effort would require a detailed characterization of all of the equipment utilized in a facility, with substantial design cost implications.

4.1.4 Flow Boundary Conditions

The specification of ventilation details within a given facility design is not considered a modeling gap. Computer models are currently being used to design IT/telecom facility cooling systems. This practice is common enough to have resulted in the development of specialized modeling tools (e.g., CoolSim), and validation of CFD modeling of cooling air flows shows good agreement with measured flows in facilities [4].

4.1.5 Fire/Smoke Production

Specification of the rate of smoke production for incipient fires and the smoke production and heat release for flaming fires is considered a modeling gap. There are two aspects to this gap. The first is the existence of applicable measured data and the second is a methodology for specifying the inputs. Being able to predict the ignition and growth of fires of real world objects is still in the realm of academic research. Modeling aspects such as how complex materials and objects pyrolyze; how to best model those chemical processes and their associated heat transfer combined; and how to translate gas phase calculations on room scales to the micro-scales required for modeling materials are all areas of active research. Given this and the industry standard practice for design evaluation using CFD, the design fires will be prescribed. That means parameters such as the location of the fire, the fire heat release rate over time, and the fire smoke generation rate over time will be prescribed inputs to the CFD model.

There have been a number of efforts to quantify the heat release and smoke production from electrical equipment. The US Nuclear Regulatory Commission (NRC) [5] and VTT [6] have sponsored research that measured the heat release rate for electrical cabinet fires. The NRC cabinet fires, however, primarily addressed the types of electrical equipment found in nuclear power plants – breaker panels, high-voltage/high current switchgear, etc. While there will be some overlap and similarities with the equipment in IT/telecom facilities, much of the data is not directly applicable either due to size of equipment or the type of equipment. VTT tested cabinets with computing equipment; however, the vintage of the equipment (pre-1994) is dated. Other testing [7] has examined fires in telecom facilities; however, these fires were relative large (100-12,000 kW). Therefore, the fire size is not appropriate for design fires intended to be detected by very early warning equipment. Additionally, the testing program was for equipment in use prior to 2002, and there has been a rapid evolution in the design of communications and data processing equipment since that time.

Smoke production rates for incipient and small flaming fires have been measured for a variety of sources [8]; however, only a few electrical sources have been quantified. These measurements have also been made in the open, and the impact of an equipment enclosure on the production rate and on the amount of smoke that actually exits the cabinet (vs. being deposited) has not been quantified. Lastly, most experiments include measurements of smoke via obscuration and the mass production rate of smoke is obtained by assuming an extinction coefficient. This coefficient will vary depending upon the material and errors in the coefficient will result in errors in the smoke production rate. Gravimetric measurements, which physically measure the mass of smoke, are not often performed. Data sources of smoke production are generally quantified using obscuration methods. For low levels of smoke as would be expected for very early warning detection, standard smoke obscuration meters will not be sufficiently sensitive.

The second gap is in a methodology for specifying the inputs for heat release and smoke production. Attempting to model the details of flow through an equipment cabinet would be costly. The dimensions of flow paths through equipment are very small, and modeling those length scales would add considerable time and expense to an analysis. This suggests that the methodology should focus on specifying the addition of heat and smoke to the air exiting an equipment cabinet. However, it is not known what the most appropriate method of specifying that is (uniform over all outlets, present at only one outlet location, etc.). This likely will depend upon air flows through a cabinet and where the fire or smoke source is within the cabinet. For most equipment, it is anticipated that the general design details of the cabinet used for the cooling design should provided enough information for defining the geometric location of the heat and smoke source.

4.2 Smoke Transport

In a typical model evaluation of smoke transport, the smoke is treated like a gas with the model output being a mass fraction. It is noted that the common detection technologies have a sensitivity that is a function of particle number densities and size distributions. The underlying assumption is that the soot particle size is small enough, that it will quickly accelerate to match the local velocity field and that the effects of gravity on the particle are negligible. This assumption that soot is a gas; however, has its limitations. Some soot particles may be large enough that their transport will differ from the local velocity field due to drag and gravity. Also, soot particles will deposit onto surfaces. To the extent that size and deposition are important for an evaluation, this could impact the ability to predict the performance of a detection design. It is not clear how critical this is for high air flow applications. For large particles it is noted that while their settling speed near 0.5 cm/s is large in the quiescent environment of a room fire, the speed is small in comparison to the ambient velocities induced by the high air flow rates.

4.2.1 Transport of Large Particles

There are alternative approaches to treating soot as a gas. One obvious approach is to model soot using Lagrangian particles. Most modern, general-purpose CFD tools have the ability to inject and track Lagrangian particles. With this approach, instead of specifying a smoke source as a flow of gas at a temperature, one would specify the smoke source as a size distribution of hot particles along with a flow of gas representing the gaseous combustion products. This approach; however, is likely to be very costly. A typical simulation might involve 100's of thousands to millions of grid cells. A potentially much larger number of particles would have to be tracked in order to determine the smoke mass in a cell or the particle distribution in a cell (i.e., if the number of particles is on the order of the number of grid cells, how much certainty would there be in the prediction of smoke mass if there was only on average one particle per cell). Compared to just specifying a mass production rate of smoke for the fire input, tracking particles would require inputs of size and number distributions of the particles, which is more difficult to obtain and very limited data currently exists for such measurements. In addition (as will be discussed below), the use of size and number distributions introduces greater complexities in performing estimates of smoke detector response

A second approach is to still consider soot a gas, but add terms to the momentum and energy equations to account for the effect of gravity. This approach has been investigated for use in CFD models, but is not generally available as a validated model [9].

A combined approach might also be successful where soot is treated both as a gas and as particles. Changes in particle size distributions from the particle method could be used to correct the predictions of the gas approach. This approach, however, would require research and validation to develop.

4.2.2 Soot Deposition

Soot deposition upon walls and equipment is a known challenge related to smoke detection system designs and modeling [10]-[13]. Soot deposition is a relatively new area of research, and as such has a level of uncertainty, which may challenge model validation of IT/telecom facility smoke detection designs. Deposition of soot reduces the concentration of soot in the air and acts to delay detection response. The extent to which this phenomenon is critical to IT/telecom facility modeling is unclear. Soot deposition for these applications will primarily result from thermophoresis (deposition due to temperature gradients), electrophoresis (deposition due to the effect of electrical fields on soot particles which carry a slight charge), and impaction (deposition of soot where airstreams make sharp turns near obstructions). The high air flows mean that large temperature gradients will exist only within or very near the equipment, strong electrical fields exist only near the field generating electrical components, and sudden changes in the airstream occur primarily within the equipment. This all suggests that deposition may not be as significant outside the equipment as it is inside the equipment. This means that characterizing the soot that comes out of the cabinet from a source inside may be adequate for this application; however, this assumption needs to be verified.

Most general-purpose CFD models have the ability to predict the deposition of particles. Not all models; however, contain all the deposition mechanisms. If deposition outside of cabinets is critical to the prediction of detection performance, than further evaluation of model capabilities for deposition will be required.

4.3 Detector Performance

Evaluating detector performance requires two things: being able to predict the conditions present at a detector location, and being able to predict how a detector will respond to those conditions. There are gaps for both aspects.

Provided appropriate facility descriptions and fire sources are input, there is every expectation that a CFD model will be able to correctly predict the temperature and velocity conditions present at a detector location. If the assumptions that smoke can be treated as a gas and that deposition outside the equipment is negligible are true, then it is expected that CFD models will also correctly predict smoke mass concentration at a detector location. The certainty of that prediction will be reduced depending upon the validity of the assumptions. Prior work has demonstrated this for a range of smoke sources with ventilation up to 12 air changes per hour [14].

The response of a specific smoke detector is a very complicated phenomenon to model. First one must determine how smoke gets from the gas outside the detector to the location within the detector where detection occurs. Then one must determine how the sensor responds to the smoke. Finally, one must determine how the detector evaluates the output of the sensor (time-averaging, constant frequency polling, etc.) to determine when to alarm. All of these can be impacted by the local velocity and temperature as well as the specifics of the smoke concentration (e.g., the particle distribution and the optical properties of the smoke.).

Various approaches have been proposed to model the response of spot smoke detectors. One set of approaches [15]–[17] uses empirical constants to impose a smoke entry lag (a delay on the entry of smoke into the detector due to the design of the detector). However, despite being implemented in one model code (i.e., FDS), these detection response models have not gained widespread practical usage in large part due to the difficulty of obtaining the necessary model parameters needed for each specific detector. An alternate approach is to use a statistical smoke optical density threshold for activation. HAI researchers have developed a set of alarm thresholds for ionization and photoelectric spot-smoke detectors by characterizing a range of smoke optical density values (measured outside of a detector) associated with detector alarms based on experimental data from full-scale detection tests [18] and [19]. These smoke concentration thresholds can be used directly in CFD models that calculate smoke concentration; however, they are limited to spot detectors. There is a general lack of specific validation studies for the prediction of aspiration system performance.

Prediction of detection performance is further hampered by the typical conditions under which existing data has been collected. Existing performance data has generally been collected in either a smoke tunnel or for detectors exposed to the conditions produced by a small fire (i.e., low induced gas velocities). A recent study [20] did examine the effects of room ventilation on smoke detection, which showed reduction in the smoke concentration threshold at alarm. That study, however, only tested air flow rates of 6 and 12 air changes per hour, an order of magnitude below air flow rates in high flow IT/telecom facilities. In both of these cases, flow speeds are low. The impact of these higher flow speeds on detector response has not been evaluated and is considered a gap.

4.4 Model Validation

The six computer models identified in Section 3 can all be considered well validated in terms of general and fire specific validation. They all have general validation demonstrating their ability to model species and energy transport for a wide range of geometries and flow conditions. The flow speeds of concern for IT/telecom facilities, all incompressible, are also within the range of validation for the models. They all have validation demonstrating the ability to model fires and heat sources over a range of sizes that includes those under consideration. In terms of facility specific validation, the geometric parameters of materials and the physical layout of IT/telecom facilities, is not radically different from the other types of buildings for which specific validation has been performed. A strong argument could be made that the range of existing validation encompasses the conditions found in IT/telecom facilities. Additionally there is the commercial usage of models such as CoolSim and PHOENICS along with the widespread usage of CFD for ventilation design by companies such as IBM and HP. However, it is recognized, that there is a lack of integral test data. That is, a test where a fire/smokes source is introduced in to a facility containing prototypical equipment and heat loads with a prototypical cooling system (e.g., very high air flow rates) and the details of smoke transport have been measured at a variety of locations within the facility. This lack of data is considered a gap, and an IT/telecom specific set of validation data would most clearly allow one to demonstrate the suitability of a computer model. This type of validation would also address the suitability of the assumption that smoke can be represented as a gas in the CFD models rather than as particles (see Section 4.2).

5.0 MODELING GAP SUMMARY

Four modeling gaps have been identified:

1. Specification of the fire and smoke inputs: There is very limited data for representative sources in IT/telecom facilities that have been characterized in a way that it is usable as an input to a model. For a source located outside of a cabinet, this would include the heat release rate (for a flaming fire), smoke production rate (potentially with the inclusion of particle size data), and physical size of the source. For a source internal to a cabinet, the actual source size is replaced by the location of where smoke and heat is emitted from the cabinet. Source size and location is not expected to be a significant gap; however, novel cabinet designs might require additional analysis.
2. Smoke transport: It is believed that the assumption of treating the smoke as a gas will be sufficient for this application; however, it is noted that little quantitative data exists on smoke deposition in real environments. It is anticipated that addressing the other

gaps will provide insight to the importance of the aerosol behavior of smoke, and thus the adequacy of the assumption that smoke can be modeled as a gas.

3. Smoke detector performance: The ability to correlate conditions predicted by a model (e.g., smoke concentration) at the location of a smoke detector/ASD sampling port to an alarm condition within the detector is a significant gap for IT/telecom facility applications. Existing correlations for spot detectors in low air flow environments have a high degree of uncertainty, particularly from one detector model to another (i.e., manufacturer dependent). There is a lack of data on how the higher ambient air velocities will affect detector sensitivity, but the limited data trends at low air flows that does exist indicates that the low velocity correlations are not adequate as velocity increases. There are no established correlations for predicting alarm response for ASD systems at either low or high air flow environments. ASD test data indicates that correlations will be highly dependent on the specific detector model. Lastly, past research on detection performance has not focused specifically on the smoke sources likely to be present in IT/telecom facilities.

4. Large scale, integral test data: There is limited data available on HVAC flows and cooling effectiveness of IT/telecom facilities. Addressing the other gaps identified in combination with existing data will provide data on fire source and detection performance. The various pieces required for successful modeling of a fire in an IT/telecom facility will exist; however, not as an integral test with all phenomena present. An IT/telecom facility specific set of large-scale tests would serve as a validation benchmark for determining the suitability of a specific model. Additionally, it would serve to identify the degree to which the currently identified gaps have been addressed.

6.0 MODELING GAP TEST PLAN

Based on the gaps identified in the modeling assessment, a set of tasks have been identified to improve the utility of CFD models for the prediction of smoke detector response in high air flow environments. A series of small scale and full scale experiments are proposed to quantify the information gaps required for proper computer modeling of smoke detection in IT/telecom facilities. The results of these experiments will provide critical model input values and realistic output data for model validation. In many cases, some additional research will be necessary to determine the appropriate parameters of the conducted experiments. A summary of the primary tasks, including objectives, measured variables, and design rationale is provided in Table 2.

Table 2: Modeling gap primary tasks including description of investigated variables and outcome of investigation

Task		Objective	Variables	Outcome
1	**Fire Source Characterization**	To produce a set of fire data applicable as modeling inputs representative of fire sources in IT/telecom	• Materials • Ignition and Burning Regimes • Air Flow Rates • Soot Deposition	• Heat and Smoke Production Rates • Smoke Characteristics
2	**Detector Response Characterization**	To produce a set of correlations capable of predicting the response of smoke detectors to measured smoke properties in high air flow environments	• Fire Source • Air Velocity • Detector Technology • Detector/sample port orientation • Alarm sensitivity	Detector response correlation to mass concentration Or Detector response correlation to smoke properties (number density, size distribution) Or Detection response for multi-criteria or gas detectors to measured concentrations
3	**Full scale validation testing**	To produce a set of full scale fire test data replicating an IT/telecom facility for direct comparison to modeled data	• Fire Source • Detector Technologies • Air Velocity • Facility design	Validation of: • Smoke source input • Smoke Transport Model (gas vs. particle) • Detection Response Correlation

6.1 Task 1: Fire Source Characterization

In order to accurately prescribe the fires as inputs to CFD models, fire data representative of the types of materials, likely ignition scenarios, and burning environments must be developed experimentally. The completion of this analysis will require several sub-tasks summarized in Table 3 and discussed below.

Table 3: Task 1 Subtasks including description of investigated variables and outcome of investigation

Task		Objective	Variables	Outcome
1.1	**Develop Candidate Sources**	To identify specific common materials within IT/telecom facilities that bound the fire problem within each of the major types of materials	• Chemical Composition • Total Combustible content • Existing fire test data • Applicable fire standard ratings • Installation location and configuration • Local air velocity	List of specific materials including: • Circuit boards • Electrical cables • Power supplies and batteries • Class A materials Candidate fire scenarios for fire testing: • Material • Configuration • Ignition Source
1.2	**Candidate Source Fire Testing**	To identify bounding fire sources and quantify the heat and smoke release characteristics	• Candidate fire sources • Air velocity	• Heat and Smoke Production Rates • Smoke Characteristics
1.3	**Model Input Design Fire Sources**	Synthesize results of Task 1.2 to produce a set of standardized model inputs	• Heat and Smoke Production Rates • Smoke Characteristics	• Select bounding design sources from candidate sources • Define model inputs

6.1.1 Task 1.1: Develop Candidate Sources

Prior to any fire testing, it is necessary to develop a set of candidate fire sources to evaluate. The candidate fire sources must be representative of the range of materials expected in IT/telecom facilities, the potential ignition scenarios, and the burning configurations and associated local air flow velocities.

6.1.1.1 Identify Materials

In order to develop models that accurately predict the smoke conditions present for detection, it is first necessary to accurately identify the range of materials that may burn within the environment. Well-characterized material combustion properties are an essential first step toward production of accurate fire detection models. A thorough review of the materials that may become involved in IT/telecom facility fires is necessary to complete this task.

Previous fire hazard analysis of telecom facilities [7] have determined that the primary fire hazards consist of electronic equipment, electrical cabling, battery racks, as well as regular Class A materials in administrative/technical support areas, such as papers and cardboard boxes. A more recent analysis of fire sources in data centers [21] also identifies the primary hazards to be electronic equipment, cable arrays, battery racks and ordinary office materials. In addition, the primary ignition source was identified to be power supplies. The identification of such general material groups provides an excellent basis for the classification of materials, but additional levels of specification are necessary.

The combustion properties of materials used for IT applications are constantly changing due to the rapid advancements in computing manufacturing and changing standards in fire resistance. It is likely that the combustion properties of an electrical circuit board manufactured and installed as few as 5–10 years ago is not comparable with current installations. For this reason, it is important to identify specific types of electrical circuit boards, batteries, power supplies, and cabling used in IT/telecom applications and how such materials have changed with time. It is also important to identify the fire standards and resistance ratings applicable to such materials, such as UL 94 [22] or UL 60950 [23]/

A wide range of representative materials will be burned within each of the recommended material groups. The materials selected will be representative of the materials currently being installed within new and updated IT/telecom centers. Combustion data obtained for the various materials, including the heat and smoke production rates, will be compared and two materials of each group will be selected for further testing and evaluation. These two sources will represent both the best and worst case scenarios for combustion in order to bound all other potential materials within the produced test data. Bounding materials for each applicable fire source group is necessary such that fire detection modelers can be confident that a designed detection system will operate for almost any potential fire source, not just one used in the model. Application of a single source does not provide modelers with sufficient input to design a robust and reliable detection system.

Characterization of the combustion scenarios involves the identification of the likely ignition modes and burning regimes for the materials identified in Task 1.1. In addition, an analysis of the effects of IT/telecom environments on the heat and smoke production rates of various fires sources will also be conducted.

6.1.1.2 Ignition and Burning Regimes

Once the specific materials posing a fire risk in IT/telecom facilities have been identified, it is necessary to determine the likely ignition scenarios and the type of combustion expected. In addition to bounding the material combustion properties, it is also necessary to bound the ignition scenarios.

Materials may pyrolyze (gasification due to thermal degradation), smolder (non-flaming combustion) or burn as a flaming fire. Typical incipient fire scenarios include an initial pyrolysis phase followed by a transition to smoldering or flaming. True self-sustaining smolder will not occur for many of the materials of interest in IT/telecom facilities (Class A packaging being the primary potential exception). However, due to the high heat loads in electrical equipment, materials may gasify when subjected to abnormally high temperatures (i.e., pyrolysis). This can lead to the evolution of smoke that is short-lived or sustained over a long period of time. The duration and amount of smoke released will be dependent on the size of the heat source, the orientation of the material with respect to the heat source, and the amount of material exposed. A review of existing fire data (if obtainable) for representative components would be of great value. Alternatively, an experimental evaluation to determine possible ignition and fire growth scenarios would provide a technical basis for assessing smoke production rates. The simple default approach is to place each candidate material on a hot plate set to a specified temperature(s). The selection of the exposure temperature can drastically affect the smoke profile and properties. In addition, the general scenario of flat exposure heating on a hot plate may not be representative of realistic scenarios.

Significant fire development occurs when pyrolysis/smoldering combustion transitions to flaming. Although it is generally a goal in IT/telecom facilities to detect fires prior to flaming conditions, there are practical issues that can prevent successful intervention at this early stage. A sensitive smoke detection system can detect incipient fires. However, particularly in the high air flow environment, smoke levels may not be visible to site personnel and, thus, the source can be very difficult to find. Consequently, the fire continues to grow beyond the time of smoke detection to the point that personnel can locate the source or electronic equipment monitoring is able to flag an abnormal condition at a specific location. Alternately, some fires occur due to events that are highly energetic and result in relatively fast growth right from the start. A risk analysis of the facility will establish a balance between a smoke detection system design with high sensitivity alarms for early notification of pyrolysis events where it may be difficult to define an effective personnel response and a system with less sensitive alarm settings to detect larger fires that may be small but growing flaming events.

Consequently, there is a need to define design fires that range from pyrolysis to small flaming fires. Design fires should be representative of the ignition scenarios and burning regimes expected for the common materials located in typical installations. Previous evaluations of design fires for telecom conducted by Budnick et al. [7] focused upon worst-case fire scenarios. These fires were intended to replicate the most destructive realistic scenarios. Fire scenarios for electronic equipment in cabinets were evaluated based upon Network Equipment and Building Systems Standard (NEBS) design fires and criteria. Electronic equipment was separated into Non-NEBS and pre-1990 NEBS, 1990-1998 NEBS compliant, and post 1998 NEBS compliant devices. The NEBS testing consists of a propane burner located within a cabinet shelf. These design fires were prescribed t-squared growth profiles with the same growth rate, but steady state peak HRR of 400, 200, and 100 kW, respectively. Similar design fires have been recommended by Bukowski and Transue [21]. No design smoke production rates for detection were proposed by either design fire evaluation.

In addition to modeling of electronic cabinet fires, the Budnick report [7] also develops several models for full-scale flaming cable tray design fires. The design fires include several arrangements of cables and range from peak HRR of 260-12,670 kW. Similar design fire sizes were developed for battery racks (380-1700 kW), and Class A materials (100 kW). All fires were modeled with t-squared growth phases followed by steady state burning. The design fires developed for this evaluation were intended to replicate fully involved flaming combustion of large cable trays and entire battery racks and trashcans.

It should be noted, however, that the aim of this work is to provide design fires for detection, and not for suppression activation or material flame spread or property destruction analysis. For this reason, even applicable flaming design fires are expected to be relatively small, with peak heat release rates ranging from 10-30 kW. Consequently, the fires used in the cited studies are deemed excessively large. In addition to being of a relatively small size, candidate fire sources should also be representative of realistic conditions and encompass both pyrolyzing and flaming sources. There is little data available to clearly identify electrical equipment and wire fires that transition from pyrolysis to flaming. Scenarios have been evaluated in the past for overheated cables and electrically over-powered circuit boards that arc and form a small propagating flame [24]. However, these test scenarios utilized printed circuit board material that is not in use today. In fact, many of the materials in use in IT/telecom facilities today are designed to resist ignition and fire growth.

6.1.1.3 Environmental Effects on Sources

Within an IT/telecom facility, it is likely that the existing geometric or environmental conditions could impact the burning characteristics of the identified source materials. For example, high air flow rates may increase the rate of smoldering ignition, increase the likelihood of transition to flaming combustion, or alter the type or rate of smoke production. In addition, the presence of adjacent materials and large temperature gradients between cooling systems and energized equipment can impact the deposition of soot and change the smoke concentrations at detector/sampling locations. Assessing the impact of these environmental parameters is necessary to provide an accurate representation of the fire sources (and model inputs) in IT/telecom facilities.

Air flow rates expected in IT/telecom facilities can range up to 100 ACH. Of more importance are the associated velocities in subfloors, electrical cabinets, main space aisles, overhead plenums, and at return air vents. Based upon typical sizes of equipment and equipment spacing in IT/telecom facilities it has been estimated that air flow speeds range from from 0-500 fpm in subfloors, 50-1500 fpm in aisles and ducts, and 0-100 fpm in open room spaces. These represent air speeds at which detection performance should be evaluated. Higher air speeds are not anticipated as heat dissipation requirements beyond the above air speeds would likely be handled by other cooling technologies (liquid cooling for example) [28]. The effect on the ignition, heat release rate, and smoke production of these high air velocity flows across the candidate sources need to be evaluated.

The geometric and thermal properties of the IT/telecom facilities may also impact the production of smoke used for modeling analyses. For example, within an electrical cabinet, the smoke produced from an incipient circuit board fire may impact several other circuit boards and pieces of electrical equipment before being enveloped into the primary air flow. In this scenario, deposition of soot on the impacted equipment may reduce the overall smoke concentration that is transported to a detection site compared to the same source in the open. For modeling purposes, the source term will generally be simplified by estimating the amount of soot leaving the electrical cabinet, thus, an understanding of the reduction in smoke production compared to the open source model may be necessary. Similar effects may be observed for cable fires in subfloor plenums where adjacent cable arrays, cable trays and obstructions may reduce the amount of smoke migrating away from the source. Based on previous testing [12],[13], large fractions of the soot from the fire may be deposited out on these adjacent surfaces. If a model input does not adequately account for smoke reduction, the model will overestimate the performance of a smoke detection system, which could lead to erroneously large detector spacings or use of insufficiently low sensitivity alarm settings. In other words, the installed system may not detect actual fires as intended.

Quantifying the potential for smoke reduction will include tests designed to replicate the two examples presented above. The test design will use representative materials and take into account actual operating conditions, such as component and air temperatures and air flow rates. Generally, since deposition is highly driven by thermophoretic effects (temperature gradients), capturing component and air temperatures are important. Chilled water-cooling systems may have an even larger effect on soot deposition due to more concentrated lower temperature surfaces. Given the range of cabinet and ventilation configurations, it may be necessary to evaluate several potential configurations with sources at different locations within a cabinet. For example, the total soot deposition may be significantly different for:

- A source in the bottom of a cabinet that has continuous vertical ventilation openings exposed to cold and hot aisles (smoke flows quickly out the back), compared to
- A source in the bottom of a cabinet with a single exhaust opening at the top of the cabinet (smoke must flow up through rack of equipment).

Cable fires in a subfloor plenum can be simulated using a duct arrangement in which air flow rates can be controlled. The height of cable fires relative to the underside of raised floor panels would be investigated to discern what fire size to vertical height ratios pose a soot loss issue relative to air velocity. Additional tests will include placement of obstructions downstream from the source to determine if the obstructions will result in appreciable soot deposition to affect smoke concentrations further downstream at a smoke detector location/sampling point. Obstructions would consist of cable arrays, cable trays, piping, and solid barriers, such as air dam materials.

6.1.2 Task 1.2: Candidate Source Fire Testing

Once candidate representative materials, ignition scenarios, fuel configurations, and local air flow conditions have been selected, the combustion properties, including heat release rate (HRR) and smoke production should be determined through fire testing. Fire testing will be conducted in two phases. The first phase of testing will be conducted in open burning configurations in quiescent air. These tests will evaluate the various materials and ignition scenarios developed in Task 1.1 (Section 6.1.1.1 and 6.1.1.2). The results of the initial tests will be used to identify the bounding candidate sources that will be used in the phase 2 testing. The second fire test phase will investigate the effects of environmental conditions identified in Section 6.1.1.3. The purpose of the second phase of the analysis will be to develop complete descriptions of fire sources for application to IT/telecom modeling inputs.

In order to produce modeling inputs, the products of combustion for the candidate fire sources must be measured. Such measurements have been previously conducted [8] ,[25] for numerous materials and the general methods are well defined. Typical combustion characterization measurements have included:

- Heat release rate (HRR) through oxygen consumption calorimetry;
- Smoke production through
    - Visible obscuration for smoke release rate (SRR)
    - Gravimetric analysis through collection of soot particulate
    - Particle concentration density analysis (number distribution)
    - Particle size distribution analysis;
- Gas species production through CO and CO_2 analysis, as well as other species;
- Exhaust air temperature; and,
- Ignition characteristics.

The UL smoke characterization project [25]quantified the HRR, SRR, smoke particle density and size distribution, and CO and CO_2 gas production for a wide range of materials. However, the materials evaluated were focused on residential type applications and included various foams, mattresses, appliances, flammable liquids, and wood sources.

The joint UL and UMD evaluation [8] of incipient fire sources for detection response modeling also measured the HRR, SRR, smoke particle density and size distribution, and CO and CO_2 gas production for a wide range of materials. The goal of this project was to develop detection response and modeling validation data for incipient fire conditions. While this analysis was primarily developed for commercial applications, several of the incipient fire sources may be applicable to IT/telecom environments, including flaming shredded paper, a flaming electrical circuit board, and an overheated PVC cable.

In order to develop complete fire source inputs for modeling, certain parameters are needed. Models will require inputs that specify a HRR (kW) (for flaming fires only) and a geometric boundary size, shape, and orientation for introducing the heat and smoke produced. Defining the requirements for the input of smoke can become significantly more complex, however, depending upon the assumptions of the model.

Mixture fraction models for smoke production link the production of smoke to the production of heat using a constant soot yield and heat of combustion. This type of model would only require determination of these two constants to specify the smoke production of a design fire. Previous design fire validation testing conducted by UL and UMD [8] determined that the mixture fraction model was not sufficient for modeling of detector response. A Species ID model, where the smoke and heat production in design input fires could be decoupled for modeling and a more accurate representation of smoke production could be applied was developed for further analysis.

The use of a decoupled heat and smoke production model requires the input of the smoke on a mass production rate basis (g/s). If the computer model simplifies the motion of smoke particulate by representing smoke as a gas that is not subject to drag or gravitational effects, this level of smoke input should be sufficient for transport modeling. In addition, if smoke detector response is well correlated to the mass concentration at the point of detection, then mass production rates should provide sufficient input for modeling of smoke.

If the correlation of the smoke detection response requires more complete smoke descriptions, such as smoke particle density or particle size distribution, then additional information must be provided for the smoke model input. In this case it will be necessary to specify more advanced parameters of the smoke and to adjust model transport calculations to account for the properties of the particulate (LaGrangian modeling). The necessary level of specification for the smoke input will be dictated by the results of the smoke detection testing conducted as part of this evaluation (see Section 6.2.2).

The intent of the fire testing is to produce representative data of candidate fire sources to develop source terms for detection modeling. The initial analysis will focus upon the burning characteristics of representative materials in open burning conditions. These results will identify the bounding representative materials within the general material groups. The second phase of testing will evaluate these bounding materials in realistic IT/telecom environments, including air flow velocities and soot deposition scenarios. The results of the second test phase will be used to develop standardized model inputs for computer simulation.

6.1.3 Task 1.3: Model Input Design Fire Sources

Utilizing the fire test results of Task 1.2, a range of design fire source model inputs will be developed. These models will identify the rate of heat and smoke production from realistic IT/telecom fires with representative air flow and soot deposition models. The fire test data will be evaluated to determine bounding fire scenarios and to develop a set of standardized fire model inputs.

The source models should provide a bounded range of representative fire conditions within the general material groups, including circuit boards, electrical cables, power supplies and batteries, and Class A materials. Specific materials bounding the fire problem will be identified from initial fire test data. The actual materials, methods of ignition, and burning characteristics of fire occurring in IT/telecom facilities will vary greatly, and it is desired that the provided source models will encompass a wide range of potential fire scenarios.

The final goal of this project will be to develop modeling of detection response. The evaluation of detection response through computer modeling will require the progression of data through multiple calculations, and the production of an accurately representative source term provides the initial basis for any further investigation and modeling. Some previous potential data center models for HRR only have been proposed by Bukowski and Transue [27]. At a minimum, the source models developed from this analysis should include a HRR and a smoke mass production rate, but must provide sufficient detail of smoke characteristics for the estimation of detector response. Depending upon the correlations developed for smoke detection (see Section 6.2.2), it may be necessary to provide smoke production with total particle count or particle size data.

6.2 Task 2: Detector Response Characterization

As discussed in Section 4.3, the alarm response characteristics of specific detectors are difficult to accurately model. While the computer model will predict the temperature, velocity, and smoke concentration properties at a detector/sample port location, the ability to correlate a specific detector response to a specific fire source in a high airflow environment is highly uncertain. In order to use computer modeling to predict the ability of a proposed detection system to respond to simulated fire conditions, a relationship between the environmental conditions and the detector response must be developed. In order to develop these correlations applicable to IT/telecom installations, several sub-tasks must be completed and are summarized in Table 4.

Table 4: Task 2 Subtasks including description of investigated variables and outcome of investigation

Task		Objective	Variables	Outcome

2.1	**Develop Detection Scenarios**	To identify and obtain applicable smoke (or gas) detection devices and define detailed test parameters	• Detectors:
			  • Technology
			  • Manufacturer/ Model
			  • Alarm Sensitivity
			• Detector/Sample port orientation
			• Candidate fire sources
			• Air velocity
				• Select and obtain detectors for evaluation
				• Detection test scenarios (detailed test matrix)

2.2	**Detection Scenario Testing**	To quantify local smoke and/or gas properties and detection response in representative IT/telecom environments	• Candidate fire sources • Detection test scenarios	• Local Smoke/Gas Properties • Detection response
2.3	**Model Detection Response Correlations**	Synthesize results of Task 2.2 to produce a set of correlations relating detector response to local smoke properties	• Local Smoke Properties • Detection response	• Identify properties of smoke that correlate well to detection response • Develop correlations for detector response for model application

In the development of detection response correlations, the causes of variability among response will be investigated. The parameters potentially having an impact upon the variability of the detection response include:

- Fire source and burning conditions
- Air flow rate
- Detection type/operating principle
- Detector manufacturer, model, or individual unit
- Detector installation location and orientation

6.2.1 Task 2.1: Develop Detection Scenarios

6.2.1.1 Representative Detection Devices

Aspirated smoke detectors (ASD) and photoelectric spot detectors (standard and high sensitivity) are the most common detection equipment to be used in IT/telecom facilities. The application of multicriteria type detection, including combination smoke and CO or other gas detection, has also gained influence for these facilities. As there is a significant variation in detector response among different technologies, different manufacturers, and different models by a manufacturer, there is a need to select a range of detector models from leading manufacturers. Ideally, the detectors should have confirmed sensitivity settings that represent the midpoint of their production range. This will make the results more generally applicable as opposed to a unit that is operating at the limit of the production range.

6.2.1.2 Identify Range of Operating Conditions

Detector or ASD sampling port orientations with respect to the direction of air flow and the alarm threshold settings of evaluated detectors must all be considered. In the case of high air flow environments, the orientation of a detector/sampling port with respect to the prevailing air flow direction can be a primary concern. With regard to spot detection, the orientation of the device may prevent or facilitate smoke or gas entrance into the sensor chamber. For example, one manufacturer recommends that devices be angled when located in front of a return vent. With regard to ASD, the sample hole may be oriented perpendicular to, pointed toward, or pointed away from the prevailing air flow. Since high air flow environments can create significant turbulence, the actual air flow orientation to a detector/sample point may be highly variable compared to the expected bulk air flow configuration. For instance, an ASD sample port may be positioned away from the bulk flow but due to obstructions and turbulence, the local flow of air is directed toward the sample port. Consequently, it is important to evaluate the impact of high air flow rates on detection response at various detector/sample port orientations.

Although it may seem obvious, the alarm response of a detector is directly influenced by the alarm threshold setting. Many advanced spot detectors and nearly all ASD systems allow the installer to specify a level of sensitivity and the threshold for producing alarms. In general, IT/telecom installations utilize high sensitivity (low alarm threshold) settings in order to provide a very early response. However, depending on the facility and the response plan, a range of alarm sensitivities are utilized. Some may be very sensitive at levels below 0.1 % obscuration/ft to an order of magnitude higher. Whether correlations between detector response and smoke properties are dependent on the range of alarm sensitivities must be assessed.

In addition to alarm threshold settings, several detection devices utilize complex algorithms that continuously monitor ambient conditions and adjust detection levels accordingly. An understanding of the operation of such software, the optional and default settings, and the manufacturer recommendations for IT/telecom applications will be necessary prior to any evaluation.

Some advanced spot detectors and many ASD systems allow for continuous monitoring and recording of the measured concentrations (smoke and/or gas) at the detectors. Any devices having this capability provide a wealth of additional information beyond the alarm response, and continuous comparisons between measured air properties and the detector measured concentrations can be made. This may allow for estimation of alarm response for any threshold setting up to the peak measured concentration.

6.2.2 Task 2.2: Candidate Detection Scenario Testing

Once the detection options and operating conditions have been identified, a complete bench scale analysis of the various detection options can be conducted. The purpose of such an analysis would be to identify the detection response of the detectors:

- To representative fire source materials and burning scenarios
- At a range of air flow rates at the detector location
- For a wide range of potential detection technologies, makes, and models
- For a range of detector orientations
- At a range of alarm threshold settings

It would be necessary during such testing to install various detectors in an air flow path co-located with smoke measurement instrumentation. In this way, the detection response can be correlated with the measured smoke/gas properties at the time of alarm. Measured properties may include:

- Obscuration
- Smoke mass concentration
- Smoke particulate density
- Smoke particle size
- Gas concentrations (CO, CO_2, H_2S, etc.)
- Air temperature
- Air flow velocity

The intent of this work will be to develop a correlation between the local smoke/gas properties at the detector/sample port and the detector response. Detector response to smoke is a function of the particle size distribution, the number of particles, and the extinction coefficient of the particles. As discussed in Section 4.2, computer modeling of smoke transport requires use of either simplified gas transport or more complex particle transport equations. Simplified gas transport models are expected to be capable of accurately predicting the motion of smoke throughout the model environments, but would not include estimates of the smoke particle density or size. In order to simplify model development and processing time for smoke detection, initial evaluations will focus upon developing correlations between the detector response and the smoke obscuration and mass concentration. These values can be predicted and quantified through use of the gas transport model at the detector/sample port location, and thus a correlation would allow for simpler detection modeling. If correlations cannot be developed for these values, the use of more complex smoke transport models and measurements of smoke particle properties will be considered. Detector response to gases is a function of either the volume or mass concentration of the gas in the air. The transport of gases for detection does not require an advanced particle transport model, and will only require the use of gas transport modeling tools.

Similar work has been conducted to correlate the measurable properties of smoke at the time of detector alarm response [14, 18, 25, 26, 27]. While the methods developed for these tests are applicable, these tests primarily focused on residential and commercial applications of spot photoelectric and ionization smoke detection in low air flow with much lower sensitivity than is required for most IT/telecom application. While detection experiments conducted as part of the UL/UMD project [14] did include the installation of ASD detection, the response characteristics were not analyzed within the report.

Detection response should be evaluated for the representative smoke sources and burning conditions identified in Tasks 1.2. Characterization of detector response to a single smoke source may not capture the impacts of advanced smoke properties on detection, such as the mass concentration, particle size, chemical composition, or even color. Although not all of these parameters may be measured during testing, the use of several different types of smoke sources may identify the impact of additional variables. In order to more completely describe the response characteristics of detectors, testing should be conducted using the full range of fire sources evaluated in Task 1.2. It may be possible to incorporate detection testing with the fire source characterization testing of Task 1.2 in order to reduce testing time and cost.

For ASD (or spot detectors) that continuously report and/or record measured smoke values, detector response can be continuously correlated to measured smoke properties. This would allow use of the data beyond the predetermined alarm threshold and would provide applicability to any alarm threshold.

6.2.3 Task 2.3: Model Detection Response Correlations

Utilizing the detection test results of Task 2.2, a set of correlations relating detection response to local smoke/gas properties will be developed. If such correlations cannot be determined, specifying response characteristics within a measured range may be required. Correlations must be made to properties that models are capable of calculating. For example, a model using a simple gas transport model cannot estimate the particle size of smoke, and either a different correlation must be applied or the model redeveloped to utilize particle transport methods.

The development of the detection correlations will be a key element in determining the fire source terms developed for modeling in Task 1.3. The fire source input must identify the properties of smoke required to correlate detection response.

6.3 Task 3: Full Scale Model Verification and Validation

The model inputs for fire sources from Task 1 and the response characteristics for detectors from Task 3 combined with facility design information represent all the inputs needed to model an IT/telecom facility with a suitable model. However, that model suitability must be demonstrated through verification and validation. Such verification will allow for the use of models to simulate a range of possible scenarios and thus be used to develop prescriptive requirements for code development. An important component of that is comparison of model predictions to full scale test data from experiment representing the conditions being modeled. To this end, the final model development task will be to conduct full scale testing for direct comparison with model predictions. Completion of this task will require several steps as summarized in Table 5.

Table 5: Task 3 Subtasks including description of investigated variables and outcome of investigation

Task		Objective	Variables	Outcome
3.1	**Mock IT/telecom facility**	Identify a functional IT/telecom facility Or create a full scale mockup facility and conduct fire detection testing	• Facility • Geometry • HVAC • Fire Sources • Detection Scenarios	Produce a set of full scale test data to compare to model outputs: • Heat and smoke production • smoke transport • Smoke transport • Detection Response
3.2	**IT/telecom Computer Model**	To develop a computer model identical to the full scale mock facility and simulate fire detection testing	• Fire model inputs • Detection response correlations	Produce a set of model outputs to compare to full scale test data: • Heat and smoke production • smoke transport • Smoke transport • Detection Response
3.3	**Validate Model Response**	Synthesize results of Tasks 3.1 and 3.2 to validate the model	• Full Scale Test Data • Model Outputs	• Confirm that modeling gaps have been satisfied • Validate future use of IT/telecom detection modeling • Identify remaining or new gaps

6.3.1 Task 3.1: Mock IT/telecom Facility

Either a functional IT/telecom facility should be identified or a full-scale mockup of a typical IT/telecom space should be constructed for conducting of fire testing. This facility would be used to validate the fire source and soot production estimations, the transport models for the products of combustion through high air flow environments, and the response of detection systems to measured smoke conditions.

The full-scale test facility would not require a complete building size structure, but should at a minimum incorporate each of the major components of a typical IT/telecom facility. Such components include a subfloor, electrical cabinets, main space aisles, overhead plenum, and return air grille. A typical facility for evaluation would likely include the use of a partially ducted hot/cold/hot or cold/hot/cold aisle configuration. Several cabinets would be installed in three total rows to allow for either a common hot or cold aisle. Typical cabinets to install may include air flows from front to back, side to side, bottom to top, front to top, side to top, or back to front.

The facility should also incorporate typical air flow rates and pathways, cooling and heat producing equipment, and air flow obstructions for soot deposition. Air flow rates ranging as high as 1500 fpm within the ducts or cabinets should be evaluated. There is a need to be able to evaluate the different types of cooling airflow distributions, including CRAC with raised floors, or close coupled cooling placed among the rows of IT equipment. In addition, representative detection installation locations and settings should be utilized.

The space should be instrumented, at a minimum in the vicinity of detection devices, to measure the air flow speed, gas temperature, and applicable smoke properties such as smoke and gas concentrations. Design fire sources will be used. The transport of the products of combustion will be tracked throughout the space, and the detection response characteristics recorded. This data can then be compared and used to verify the results of a computer simulation of the test facility and conditions.

6.3.2 Task 3.2: IT/telecom Computer Model

A simulation of the mock IT/telecom facility should be developed for computer modeling evaluation. The simulation should represent the facility geometry, fire source terms, instrumentation, and detection devices. An evaluation of input sensitivity (e.g. grid size, fire source, ventilation, etc.) should be performed as part of the modeling.

6.3.3 Task 3.3: Validate Model Response

The data produced during full scale testing and the outputs obtained through full-scale modeling will be compared and evaluated. These comparisons will validate the use of the computer model for IT/telecom detection applications and verify whether the modeling gaps summarized in Section 5 have been sufficiently satisfied.

Variations between data sets may serve to identify the existence of additional information gaps, limitations in modeling due to simplifications or assumptions, or excessive variability in fire source production rates or smoke detection response. The data obtained during this final task will identify whether the computer model is sufficient for widespread application or requires additional analysis.

6.4 Summary

A series of experimental tests will be developed in order to eliminate information gaps required for modeling of smoke detection in IT/telecom applications. The primary investigated parameters include the characterization of the fire sources, the smoke detector alarm response model, and the production of full-scale test data for model validation.

Representative combustible materials, ignition scenarios, and environmental conditions must be identified that are typical within IT/telecom environments. A range of potential materials and scenarios should be developed and burned in an initial investigation to determine the materials that bound the heat and smoke production rates. It is likely that a wide variation in the composition and total combustible mass may be present in outdated and modern electrical and computer equipment, and the testing should attempt to bound this range. The use of a best and worst case material will provide a level of confidence that the results can be applied to the combustion of any potential IT/telecom material. Typical sources will include electrical circuit boards, cabling and wires, power supplies and batteries, and class A materials (i.e., cardboard packaging).

Fire sources should be characterized both in open burning and realistic burning conditions. The heat and smoke production from various fires should be quantified such that it can be input as a computer model source term. The representative fire sources may be impacted by the total air flow rate and/or the deposition of soot on adjacent materials. The potential impacts of these parameters on fire sources should be investigated.

The response characteristics of high sensitivity spot detectors, aspirating smoke detectors, and multicriteria and gas detectors operating in high air flow environments have not been previously quantified or evaluated to establish detector response model. . Such detectors should be subjected to the representative IT/telecom design fire scenarios and the smoke properties at the time of alarm should be measured. Correlations will then be sought between detector response and the smoke properties to establish detector response models. Detectors should be evaluated for numerous installation options, including detector or sampling hole orientation relative to air flow. .

Finally, full-scale fire tests will be necessary to verify and validate the predictions of computer models. A representative IT/telecom facility or mockup should be instrumented to measure the transport of air, smoke and heat throughout the facility as well as detection for multiple design fire sources. The results of the full-scale study will be compared to modeled results for the simulated facility. These comparisons will validate the use of the computer model for IT/telecom detection applications and verify whether the modeling gaps have been sufficiently satisfied.

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