

FIRE DEPARTMENT STAFFING LEVELS COMPARISON CHART

Apparatus Staffing	Engine	Aerial	Rescue
NFPA	4	4	4
Calgary	4	2	2
Edmonton	4	4	4
Vancouver	4	4	4
Toronto	5 (4)	5 (3)	6 (4)

SUMMARY OF CALLS TYPES

MEDICAL CALLS - NON MVC	NUMBER OF INCIDENTS	24965
	% OF TOTAL CALLS	41.99%
WORKING FIRES	NUMBER OF INCIDENTS	1817
	% OF TOTAL CALLS	3.06%
MEDICAL ASSIST - M.V.C.	NUMBER OF INCIDENTS	3859
	% OF TOTAL CALLS	6.49%
HAZARDOUS MATERIAL SITUATIONS	NUMBER OF INCIDENTS	9505
	% OF TOTAL CALLS	15.99%
SEVERE WEATHER	NUMBER OF INCIDENTS	665
*SEPTEMBER SNOW STORM	% OF TOTAL CALLS	1.12%
TOTAL INCIDENTS		59457

*CALL NUMBERS BASED ON 2014 CALGARY FIRE DEPARTMENT STATISTICS

THE ECONOMIC IMPACT OF SUCCESSFUL COMMERCIAL FIRE INTERVENTIONS

***PHOENIX FIRE DEPARTMENT
JUNE – AUGUST, 2012***



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L. WILLIAM SEIDMAN RESEARCH INSTITUTE

The L. William Seidman Research Institute serves as a link between the local, national, and international business communities and the W. P. Carey School of Business at Arizona State University (ASU).

First established in 1985 to serve as a center for applied business research alongside a consultancy resource for the Arizona business community, Seidman collects, analyzes and disseminates information about local economies, benchmarks industry practices, and identifies emerging business research issues that affect productivity and competitiveness.

Using tools that support sophisticated statistical modeling and planning, supplemented by an extensive understanding of the local, state and national economies, Seidman today offers a host of economic research and consulting services, including economic impact analyses, economic forecasting, general survey research, attitudinal and qualitative studies, and strategic analyses of economic development opportunities.

Working on behalf of government agencies, regulatory bodies, public or privately-owned firms, academic institutions, and non-profit organizations, Seidman specializes in consultancy at the city, county or state-wide level. Recent and current clients include:

- Arizona Commerce Authority (ACA)
- Arizona Corporation Commission (ACC)
- Arizona Department of Mines and Mineral Resources
- Arizona Hospital and Healthcare Association
- Arizona Investment Council (AIC)
- Arizona Mining Council
- Arizona Public Service Company (APS)
- Arizona School Boards Association
- Arizona Town Hall
- The Boeing Company
- City of Phoenix
- Excelsior Mining
- Executive Budget Office of the State of Arizona
- First Things First
- Freeport McMoran
- Glendale Community College
- Goodwill Industries
- Intel Corporation
- The Navajo Nation Division of Economic Development
- The Pat Tillman Foundation
- Phoenix Sky Harbor International Airport
- Pierce Eislen
- Public Service Company of New Mexico (PNM)
- Raytheon
- Rosemont Copper Mine
- Salt River Project (SRP)
- Science Foundation Arizona (SFAZ)
- Turf Paradise & Delaware North
- Valley METRO Light Rail
- The Vote Solar Initiative
- Waste Management

Executive Summary

- This study uses a REMI model to estimate the economic impact of the City of Phoenix Fire Department's successful intervention at eight fires, June 1 to August 31, 2012, affecting thirteen commercial businesses or organizations.
- Approximately 2,173 total private non-farm jobs could have been lost in the State of Arizona over the course of one year if the City of Phoenix Fire Department had not successfully intervened at the eight commercial fires studied.
- If government and farm sector employment is included, the total impact could increase to 2,322 jobs over the course of just one year in the State of Arizona.
- Maricopa County, as the host county, could suffer most of the estimated job losses, including 495 full-time direct jobs for at least one year.
- Gross state product could be lower by approximately \$196 million (2012 \$) throughout the State of Arizona, and real disposable personal income by \$94.6 million (2012 \$), without the City of Phoenix Fire Department's successful interventions at these eight commercial fires.
- State revenues could also fall by approximately \$10.6 million (2012 \$) throughout Arizona if the fires had not been extinguished.
- The City of Phoenix Fire Department is therefore estimated to exert a significant impact on the local economy at both a state and county level.

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1. Introduction

The City of Phoenix Fire Department is committed to providing the highest level of public safety service for the community, protecting lives and property through fire suppression, emergency medical and transportation services, disaster management, fire prevention and public education.

One of the busiest fire departments in the country, the City of Phoenix Fire Department is responsible for a 519.1 square mile area, and the safety/well-being of almost 1.5 million people. In FY2010-11, it attended 13,893 fires.¹

The City of Phoenix Fire Department currently implements a wide range of key performance indicators (KPIs) to demonstrate its value to City officials and the wider community. However, these methods all overlook the impact of the Fire Department's operations on the local economy.

In August 2011, the Seidman Research Institute conducted an exploratory case study for the City of Phoenix Fire Department, evaluating the economic impact of saving a furniture manufacturer from a major fire. The case study suggested that up to 203 jobs could have been lost in the State of Arizona if the property had not been saved, plus \$20 million gross state product and \$9 million real disposable personal income (2011 \$).

Surprised by the magnitude of these impacts, the Seidman Research Institute therefore agreed to further assess the economic impact of successful fire interventions at commercial establishments over a longer time horizon. The objectives of this study are to:

- Implement a three month aggregate analysis of commercial fire interventions, focusing exclusively on any organization that could have temporarily or permanently lost their production capability and/or operations without the successful intervention of the City of Phoenix Fire Department.
- Quantify the total employment, gross state product (GSP), real disposable personal income (RDPI) and adjusted state/local tax revenue losses in the State of Arizona and Maricopa County if the fires had not been successfully contained.

¹ This is the latest publically-available figure.

The interventions included in this analysis occurred between June 1 and August 31, 2012, and each fire was in a post-incipient phase.²

Estimated impacts include the direct combined effects of every commercial property benefitting from a successful Fire Department intervention, alongside the indirect and induced effects that arise when their incomes and expenditures are recycled within the state's and county's economy. The year of study for this analysis is 2012, and all impacts are expressed in 2012 dollars (2012 \$).

Section 2 summarizes the economic impact method and the primary data used in the calculations. Simulation results for the State of Arizona and Maricopa County are offered in Section 3. Conclusions and recommendations are provided in Section 4.

2. Economic Impact Analysis – Study Method and Scenario Examined

Commercial businesses and organizations exert direct, indirect and induced impacts on a state or county's economy.

The *direct* impacts are generally easy to understand and calculate. They include the initial capital investment when a business or organization is launched, and the people directly employed to supply their products or services.

The *indirect* and *induced* effects are additional, second round expenditures and jobs created as a result of the initial "injection" of capital expenditures and direct employment. Indirect effects arise when a company makes purchases from suppliers to support its operation. Induced effects occur when workers either directly or indirectly associated with commercial businesses or organizations spend their incomes in the local economy, when suppliers place upstream demands on other producers, and when state and local governments spend new tax revenues. The income that a company or employee spends in the

² This means that the fire had progressed beyond the incipient or ignition phase, and was either growing in intensity, or was fully developed (the hottest and most dangerous phase of any fire).

local economy therefore generates revenues/income for a variety of different businesses, which creates induced effects.

The rounds of expenditures are not self-perpetuating in equal measure. Through time, they become smaller as more of the income/expenditures “leak” out of the local economy.³ The cumulative impacts of these rounds of expenditures or “ripple effects” are known as the multiplier effect in economics. Importantly, there is no one “magic” multiplier number for every conceivable scenario. Due to the inter-linked nature of the Arizona economy and its links to the rest of the U.S. (and the world), the eventual ripple effects depend on a variety of different factors.⁴

If a commercial business or organization is adversely affected by fire, causing a temporary or permanent cessation of trade or potentially even relocation, this will also affect the host state or county’s local economy. The potential impacts of fire damage include actual physical structure impairment, falls in sales output, or new production costs such as the purchase of replacement equipment and supplies. This will affect key economic variables such as employment, gross state product, disposable personal income and local/state tax revenues.

Therefore, a full understanding of the total impact that a successful fire intervention at a business will have on the Arizona economy is rather more complex than just an extrapolation of direct impacts.

Please note that this study only considers the potential economic losses if a commercial business or organization is forced to temporarily or permanently close down due to fire. No consideration is given to the potential construction impacts arising from unsuccessful interventions. Residential interventions are also excluded from the analysis.

³ For example, in the form of savings, or as payments for goods and services produced outside of a state.

⁴ In very simple terms, what matters is the size of the direct impact, where it occurs (that is, which county and which sector of the economy) and the duration of the impacts.

2.1. Study Method

This study makes use of an Arizona-specific version of the REMI regional forecasting model, updated at the Seidman Research Institute, to produce economic estimates of commercial businesses and organizations in the State of Arizona and Maricopa County.

Through its dynamic modeling, REMI takes account of variations in the economic impact of a business through time. These estimated impacts are the difference between the baseline economy and the baseline economy augmented with the new enterprise. As a result, the analysis measures the economy *with* and *without* the existence of the fire-stricken business in both the State of Arizona and Maricopa County. The use of a county level model also enables a more detailed disaggregation of results to occur, estimating the “leakage” of economic impacts into other counties in Arizona.

Seidman’s method for estimating the economic impacts involves four fundamental steps:

1. **Prepare a baseline forecast for the state and county economy:** This baseline scenario provides a forecast of the future path of the local economies in the State of Arizona and Maricopa County based on a combination of the extrapolation of historic economic conditions and an exogenous forecast of relevant national economic variables. This is often referred to as the Business as Usual (BAU) case, and assumes that the commercial businesses and organizations included in the analysis did not require successful fire interventions to continue operating.
2. **Develop policy scenario:** This describes the *direct* economic impacts generated by the loss of these commercial businesses and organizations for up to one year if the City of Phoenix Fire Department had been unable to successfully intervene.
3. **Compare the baseline and policy scenario forecasts**
4. **Produce delta results:** Differences between the future values of each variable in the forecast results estimate the magnitude of the loss of the businesses and organizations for the local economy, relative to the baseline.

The economic impacts measured in this study are:

- **Total Employment:** An estimate of the total number of full-time (or equivalent) jobs in the State of Arizona or Maricopa County, encompassing every sector and industry, including government and farm workers. Total employment therefore includes employees, sole proprietors and active partners, but excludes unpaid family workers and volunteers.
- **Total Private Non-Farm Employment:** An estimate of the total number of full-time (or equivalent) jobs in the State of Arizona or Maricopa County, encompassing all sectors and industries but excluding government and farm workers. This again includes employees, sole proprietors and active partners, but excludes unpaid family workers and volunteers.
- **Gross State Product (GSP):** This is the market value of goods and services produced by labor and property in the State of Arizona or Maricopa County. It represents the dollar value of all goods and services produced for the state or county's final demand, but excludes the value of intermediate goods and services purchased as inputs to final production. It can also be defined as the sum of employee compensation (wages, salaries and benefits, including employer contributions to health insurance and retirement pensions), proprietor income, property income, and indirect business taxes.
- **Real disposable personal income (RDPI):** This is an estimate of the total after-tax income received by any person residing in the state or county, deflated by the Personal Consumption Expenditure (PCE)-Price Index, but available for spending or saving. Technically speaking, real disposable personal income is the sum of wage and salary disbursements, supplements to wages and salaries, proprietors' income, rental income of persons, personal dividend income, personal interest income, and personal current transfer receipts, less personal taxes and contributions for government social insurance.
- **State Tax Revenue:** This is an estimate of general sales tax, selective sales tax, license taxes, individual and corporate income taxes, other taxes, miscellaneous general revenue, utility revenue, liquor store revenue, insurance trust revenue, intergovernmental revenue and current charges.

2.2. Data Inputs

Between June 1 and August 31, 2012, the City of Phoenix Fire Department successfully intervened at thirteen post-incipient commercial fires - that is, fires that were either growing in intensity or fully developed (the hottest and most dangerous phase of any fire).

Two of the interventions were at vacant commercial premises, and therefore excluded from the current analysis. The businesses and organizations at three commercial fire locations declined to participate in the study. The remaining eight interventions directly affected thirteen local businesses. Production capability and business operations could have been lost for at least one year at eleven of these local businesses without the successful intervention of the City of Phoenix Fire Department. Commercial activity at the remaining two local businesses could have been compromised for at least three months if their fires had not been successfully controlled.

Each commercial business or organization was asked to complete a brief survey as part of a follow-up fire incident investigation to supply the following data:

- Industry type
- Industry NAICS code/description
- Number of full-time (or equivalent) employees
- Annual total revenue/sales
- Average employee salary
- Extent of actual disruption to business operations
- Estimated extent of disruption without successful intervention

Anonymity was guaranteed in return for their sharing of commercially sensitive information. The industries directly benefiting from the City of Phoenix Fire Department interventions included construction, manufacturing, retail, finance, administrative and support services, and other services (except public administration).

Cumulatively accounting for 545 employees and annual salaries of almost \$19.6 million, the inputs supplied by each business or organization have been used to estimate the economic impact for the State of Arizona and Maricopa County for one entire year if the City of Phoenix Fire Department had been unable to successfully intervene and extinguish the fires.

3. Simulation Results

Table 1 illustrates the total employment and total private non-farm employment job impacts for one full calendar year if the City of Phoenix Fire Department had been unable to intervene at the eight commercial fires. The distinction between the two employment measures is important. Total employment refers to any job in the public or private sector, including government jobs and farm workers. Total private non-farm employment simply refers to the private sector, and therefore excludes government jobs, and any impacts associated with farming. The unit of measurement for each impact is job years.⁵

This table estimates that approximately 2,173 total private non-farm full-time (or equivalent) jobs could have been lost in the State of Arizona over the course of one year if the City of Phoenix Fire Department had not successfully intervened at the eight commercial fires. If the government and farm sectors are included, this could increase to 2,322 full-time (or equivalent) job losses over the course of one year in the State of Arizona. Approximately 98% of these full-time (or equivalent) job losses could have taken place in Maricopa County – the host county in which the commercial fires occurred.

Table 1: Employment Impacts of the 8 Commercial Fire Interventions for One Year

	Total Employment Losses (Job Years)	Total Private Non-Farm Employment Losses (Job Years)
Arizona	2,322	2,173
Maricopa County	2,280	2,137
Host County as Percentage of Arizona	98.2%	98.4%

Source: L. William Seidman Research Institute, W. P. Carey School of Business, Arizona State University

⁵ A job year is equivalent to one person having a full-time job for exactly one year.

The 2,173 private non-farm jobs saved by the City of Phoenix Fire Department's successful intervention at eight commercial fires consisted of 495 direct jobs ⁶ and 1,678 indirect or induced jobs.

Table 2 estimates the distribution of job losses for one year across the private non-farm employment sectors if the City of Phoenix Fire Department had been unable to successfully intervene, resulting in a loss of production or operational capability at the 13 commercial businesses or organizations. This table suggests that the five sectors that could lose the greatest number of jobs are retail trade, construction, manufacturing, administrative and waste services, and health care and social assistance.

Table 3 estimates the gross state product (GSP) and real disposable personal income (RDPI) losses potentially emanating from the non- or unsuccessful intervention of the City Phoenix Fire Department. The table estimates that the State of Arizona could have lost approximately \$196 million GSP (2012 \$) in just one year if the City of Phoenix Fire Department had failed to successfully intervene at the eight commercial fires. Approximately 98.4% of the loss could have taken place in Maricopa County.

Table 3 also estimates that RDPI in the State of Arizona could fall by \$94.6 million (2012 \$) without the successful fire interventions. Maricopa County again could suffer almost all of the loss (95.8%).

Table 4 estimates the adjusted state tax/revenue losses for one year if the City of Phoenix Fire Department had not successfully intervened at the commercial fires. The losses could amount to \$10.56 million in the State of Arizona – that is, 96% in Maricopa County, with the balance in Pinal and Pima Counties.

⁶ This direct job years figure is lower than the total annual direct employment (545 jobs) at the 13 commercial business or organizations saved, because 2 of the companies indicated that they would only close for 3 months. As a result, a pro-rata input for these 2 companies has been used in the total direct calculation for all 13 businesses or organizations.

Table 2: Distribution of Private Non-Farm Employment Losses across Industry Sectors for One Year

Sector	Jobs Lost in Arizona	Jobs Lost in Maricopa County
Forestry, Fishing, Related Activities, and Other	0.53	0.4
Mining	2.99	1.3
Utilities	6	5.9
Construction	486.77	485.2
Manufacturing	248.03	244.48
Wholesale Trade	70.43	69.76
Retail Trade	578.34	574.34
Transportation and Warehousing	26.01	24.77
Information	16.56	15.93
Finance and Insurance	69.09	67.23
Real Estate and Rental and Leasing	50.11	48.49
Professional and Technical Services	114.53	111.57
Management of Companies and Enterprises	10.77	10.53
Administrative and Waste Services	134.7	133.18
Educational Services	19.24	18.59
Health Care and Social Assistance	123.29	119.19
Arts, Entertainment, and Recreation	22.58	21.12
Accommodation and Food Services	70.56	68.27
Other Services, except Public Administration	122.12	116.97
Total	2,173	2,137

Source: L. William Seidman Research Institute, W. P. Carey School of Business, Arizona State University

Table 3: Summary of Gross State Product and Real Disposable Personal Income Impacts for One Year

Impact Type	Initial Year Impact
Gross State Product (Millions 2012 \$)	
Arizona	196.0
Maricopa County	193.0
Host County as Percentage of Arizona	98.4%
Real Disposable Personal Income (Millions 2012 \$)	
Arizona	94.6
Maricopa County	90.6
Host County as Percentage of Arizona	95.8%

Source: L. William Seidman Research Institute, W. P. Carey School of Business, Arizona State University

Table 4: Summary of Adjusted State Revenue Impacts for One Year

	Income Tax (Millions 2012 \$)	General Sales Tax (Millions 2012 \$)	Selective Sales Tax (Millions 2012 \$)	Corporate Income Tax (Millions 2012 \$)	Rest⁷ (Millions 2012 \$)	Total (Millions 2012 \$)
Arizona	1.94	3.50	0.99	0.42	3.71	10.56
Maricopa County	1.85	3.41	0.96	0.41	3.53	10.16

Source: L. William Seidman Research Institute, W. P. Carey School of Business, Arizona State University

4. Conclusions and Recommendations

The goal of this study has been to estimate the impact of the City of Phoenix Fire Department's successful commercial fire interventions on the local economy at a state and county level.

Focusing on eight fire interventions affecting at least thirteen commercial businesses from June 1 to August 31, 2012, the study has estimated the impacts for the local economy in terms of employment, gross state product, real disposable income, and adjusted state tax revenues.

If the City of Phoenix Fire Department had been unable to successfully intervene at these eight commercial fires, the State of Arizona could have lost up to 2,322 full-time (or equivalent) jobs - including government and farm workers - over the subsequent 12 months. The State of Arizona could also have lost approximately \$196 million GSP, \$94.6 million RDPI, and \$10.6 million in adjusted state tax revenues.

Maricopa County, as the host county, could have suffered the most. Estimated losses over the year could include up to 2,280 full-time (or equivalent) jobs for all sectors, including government and farm workers, approximately \$193 million GSP, \$90.6 million RDPI, and \$10.2 million in adjusted state tax revenues.

⁷ Rest includes license taxes, other taxes, miscellaneous general revenue, utility revenue, liquor store revenue, insurance trust revenue, intergovernmental revenue and current charges.

If this three month time horizon is representative of the number and type of City of Phoenix Fire Department commercial fire interventions for a full calendar year, it is reasonable to conclude that the Fire Department exerts a significant impact on the local economy at both a state and county level. Seidman therefore recommends additional economic analysis of commercial fire interventions for other three-month time horizons to ensure the representativeness of the study sample, prior to the inclusion of an economic KPI to further demonstrate the Fire Department's value to City officials and the wider community.

The City of Phoenix Fire Department also offers much more than commercial fire interventions. The sourcing of appropriate data inputs from successful single-family and multi-family residential fire interventions for economic analyses poses greater challenges than commercial interventions. However, if an appropriate solution or way forward can be found, the economic impact of the City of the Phoenix Fire Department's successful interventions could be even greater.

Appendix

A.1. Inputs Provided by Client

The following data was sourced by the City of Phoenix Fire Department's investigators after their successful commercial fire interventions. The responses from all thirteen businesses and organizations affected by the fires have been grouped by industry or sector. Four of the thirteen businesses and organizations failed to disclose their average salary. REMI's pre-programmed average salary for those types of company in Maricopa County has therefore been applied to enable quantification of the impacts.

Sector	Annual Direct Full-Time (or Equivalent) Employment	Average Salary per Employee (2012 \$)	Total Revenue/Sales (2012 \$)
Administrative and Support Services	<i>Not available for public disclosure due to the commercially sensitive nature of the data</i>		
Construction			
Food Manufacturing			
Membership Associations and Organizations			
Monetary Authorities			
Personal and Laundry Services			
Primary Metal Manufacturing			
Retail Trade			
Wood Product Manufacturing			
Total	545	\$35,978	\$179,827,000

Source: City of Phoenix Fire Department

A.2. The REMI Model

REMI is an economic-demographic forecasting and simulation model developed by Regional Economic Models, Inc. REMI is designed to forecast the impact of public policies and external events on an economy and its population. The REMI model is recognized by the business and academic community as the leading regional forecast/simulation tool available.

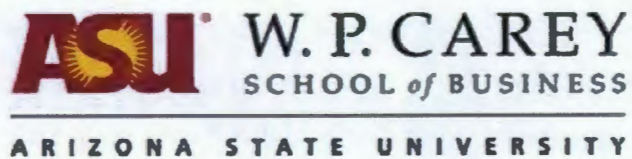
Unlike most other regional economic impact models, REMI is a dynamic model that produces integrated multi-year forecasts and accounts for dynamic feedbacks among its economic and demographic variables. The REMI model is also an "open" model in that it explicitly accounts for trade and migration flows in and out of the state. A complete explanation of the model and discussion of the empirical estimation of the parameters/equations can be found at www.remi.com.

The operation of the REMI model has been developed to facilitate the simulation of policy changes, such as a tax increase for example, or many other types of events – anything from the opening of a new business to closure of a military base to a natural disaster. The model's construction includes a large set of policy variables that are under the control of the model's operators. To simulate the impact of a policy change or other event, a change in one or more of the policy variables is entered into the model and a new forecast is generated. The REMI model then automatically produces a detailed set of simulation results showing the differences in the values of each economic variable between the control and the alternative forecast.

The specific REMI model used for this analysis was Policy Insight Model Version PI⁺ version 1.3.13 of the Arizona economy (at the county level) leased from Regional Economic Models Inc. by a consortium of State agencies, including Arizona State University, for economic forecasting and policy analysis.

A.3. Effects Not Incorporated into the Analysis

No major commercial impacts were omitted.



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Landmark Residential Fire Study Shows How Crew Sizes and Arrival Times Influence Saving Lives and Property

Released April 28, 2010

Contact: [Evelyn Brown](#)
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Firefighting Study: Impacts of Crew Sizes and Arrival Times



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WASHINGTON D.C.--A **landmark study** issued today by the U.S. Department of Commerce's National Institute of Standards and Technology (NIST) shows that the size of firefighting crews has a substantial effect on the fire service's ability to protect lives and property in residential fires.

Performed by a broad coalition in the scientific, firefighting and public-safety communities, the study found that four-person firefighting crews were able to complete 22 essential firefighting and rescue tasks in a typical residential structure 30 percent faster than two-person crews and 25 percent faster than three-person crews.

The report is the first to quantify the effects of crew sizes and arrival times on the fire service's lifesaving and firefighting operations for residential fires. Until now, little scientific data have been available.

"The results from this rigorous scientific study on the most common and deadly fires in the country—those in single-family residences—provide quantitative data to fire chiefs and public officials responsible for determining safe staffing levels, station locations and appropriate funding for community and firefighter safety," said NIST's Jason Averill, one of the study's principal investigators.

The four-person crews were able to deliver water to a similar-sized fire 15 percent faster than the two-person crews and 6 percent faster than three-person crews, steps that help to reduce property damage and lower danger to the firefighters.

"Fire risks grow exponentially. Each minute of delay is critical to the safety of the occupants and firefighters, and is directly related to property damage," said Averill, who leads NIST's Engineered Fire Safety Group within its Building and Fire Research Laboratory.

"Our experiments directly address two primary objectives of the fire service: extinguishing the fire and rescuing occupants," said Lori Moore-Merrell of the International Association of Fire Fighters (IAFF) and a principal investigator on the study.

The four-person crews were able to complete search and rescue 30 percent faster than two-person crews and 5 percent faster than three-person crews, Moore-Merrell explained. Five-person crews were faster than four-person crews in several key tasks. The benefits of five-person crews have also been documented by other researchers for fires in medium- and high-hazard structures, such as high-rise buildings, commercial properties, factories and warehouses.

This study explored fires in a residential structure, where the vast majority of fatal fires occur. The researchers built a "low-hazard" structure as described in National Fire Protection Association Standard 1710 (NFPA 1710), a consensus standard that provides guidance on the deployment of career firefighters. The two-story, 2000-square-foot test facility was constructed at the Montgomery County Public Safety Training Academy in Rockville, Md. Fire crews from Montgomery County, Md., and Fairfax County, Va., responded to live fires within this facility.



A fire fighter conducts a second-story ventilation at a controlled fire during a fire fighter safety and resource deployment study funded by the U.S. Department of Homeland Security and led by the National Institute of Standards and Technology. Credit: International Association of Fire Fighters

NIST researchers and their collaborators conducted more than 60 controlled fire experiments to determine the relative effects of crew size, the arrival time of the first fire crews, and the "stagger," or spacing, between the arrivals of successive waves of fire-fighting apparatus (vehicles and equipment). The stagger time simulates the typically later arrival of crews from more distant stations as compared to crews from more nearby stations.

Crews of two, three, four and five firefighters were timed as they performed 22 standard firefighting and rescue tasks to extinguish a live fire in the test facility. Those standard tasks included occupant search and rescue, time to put water on fire, and laddering and ventilation. Apparatus arrival time, the stagger between apparatus, and crew sizes were varied.

The United States Fire Administration reported that 403,000 residential structure fires killed close to 3,000 people in 2008—accounting for approximately 84 percent of all fire deaths—and injured about 13,500. Direct costs from these fires were about \$8.5 billion. Annually, firefighter deaths have remained steady at around 100, while tens of

thousands more are injured.

Researchers also performed simulations using NIST's Fire Dynamic Simulator to examine how the interior conditions change for trapped occupants and the firefighters if the fire develops more slowly or more rapidly than observed in the actual experiments. The fire modeling simulations demonstrated that two-person, late-arriving crews can face a fire that is twice the intensity of the fire faced by five-person, early arriving crews. Additionally, the modeling demonstrated that trapped occupants receive less exposure to toxic combustion products—such as carbon monoxide and carbon dioxide—if the firefighters arrive earlier and involve three or more persons per crew.

"The results of the field experiments apply only to fires in low-hazard residential structures as described in the NFPA Standard 1710, but it provides a strong starting point," said Moore-Merrell. Future research could extend the findings of the report to quantify the effects of crew size and apparatus arrival times in medium- and high-hazard structures, she said.

The next step for this research team is to develop a training package for firefighters and public officials that would enable them to have both quantitative and qualitative understanding of the research, a project also funded by FEMA's Assistance to Firefighters Grant Program.

The study's principal investigators were Averill, Moore-Merrell and Kathy Notarianni of Worcester Polytechnic Institute. Other organizations participating in this research include the International Association of Fire Chiefs, the Commission on Fire Accreditation International-RISK and the Urban Institute.

The report was funded by the U.S. Department of Homeland Security, Federal Emergency Management Agency's (FEMA) Assistance to Firefighters Grant Program and released today in Washington, D.C., before the start of the annual Congressional Fire Services Institute meeting that draws top fire safety officials from across the nation.

The Report on Residential Fireground Field Experiments, NIST Technical Note 1661, can be downloaded here.

Founded in 1901, NIST is a nonregulatory agency of the Commerce Department that promotes U.S. innovation and industrial competitiveness by advancing measurement science, standards and technology in

ways that enhance economic security and improve our quality of life.

IAFF Contact: **Bill Glanz**, 202-824-1505

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Report on Residential Fireground Field Experiments



NIST Technical Note 1661

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Edited by Bill Robinson



U.S. Department of Commerce
Gary Locke, Secretary

National Institute of Standards and Technology
Patrick D. Gallagher, Director

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Abstract

Service expectations placed on the fire service, including Emergency Medical Services (EMS), response to natural disasters, hazardous materials incidents, and acts of terrorism, have steadily increased. However, local decision-makers are challenged to balance these community service expectations with finite resources without a solid technical foundation for evaluating the impact of staffing and deployment decisions on the safety of the public and firefighters.

For the first time, this study investigates the effect of varying crew size, first apparatus arrival time, and response time on firefighter safety, overall task completion, and interior residential tenability using realistic residential fires. This study is also unique because of the array of stakeholders and the caliber of technical experts involved. Additionally, the structure used in the field experiments included customized instrumentation; all related industry standards were followed; and robust research methods were used. The results and conclusions will directly inform the NPFA 1710 Technical Committee, who is responsible for developing consensus industry deployment standards.

This report presents the results of more than 60 laboratory and residential fireground experiments designed to quantify the effects of various fire department deployment configurations on the most common type of fire — a low hazard residential structure fire. For the fireground experiments, a 2,000 sq ft (186 m²), two-story residential structure was designed and built at the Montgomery County Public Safety Training Academy in Rockville, MD. Fire crews from Montgomery County, MD and Fairfax County, VA were deployed in response to live fires within this facility. In addition to systematically controlling for the arrival times of the first and subsequent fire apparatus, crew size was varied to consider two-, three-, four-, and five-person staffing. Each deployment performed a series of 22 tasks that were timed, while the thermal and toxic environment inside the structure was measured. Additional experiments with larger fuel loads as well as fire modeling produced additional insight. Report results quantify the effectiveness of crew size, first-due engine arrival time, and apparatus arrival stagger on the duration and time to completion of the key 22 fireground tasks and the effect on occupant and firefighter safety.

Executive Summary

Both the increasing demands on the fire service - such as the growing number of Emergency Medical Services (EMS) responses, challenges from natural disasters, hazardous materials incidents, and acts of terrorism — and previous research point to the need for scientifically based studies of the effect of different crew sizes and firefighter arrival times on the effectiveness of the fire service to protect lives and property. To meet this need, a research partnership of the Commission on Fire Accreditation International (CFAI), International Association of Fire Chiefs (IAFC), International Association of Firefighters (IAFF), National Institute of Standards and Technology (NIST), and Worcester Polytechnic Institute (WPI) was formed to conduct a multiphase study of the deployment of resources as it affects firefighter and occupant safety. Starting in FY 2005, funding was provided through the Department of Homeland Security (DHS) / Federal Emergency Management Agency (FEMA) Grant Program Directorate for Assistance to Firefighters Grant Program — Fire Prevention and Safety Grants. In addition to the low-hazard residential fireground experiments described in this report, the multiple phases of the overall research effort include development of a conceptual model for community risk assessment and deployment of resources, implementation of a generalizable department incident survey, and delivery of a software tool to quantify the effects of deployment decisions on resultant firefighter and civilian injuries and on property losses.

The first phase of the project was an extensive survey of more than 400 career and combination (both career and volunteer) fire departments in the United States with the objective of optimizing a fire service leader's capability to deploy resources to prevent or mitigate adverse events that occur in risk- and hazard-filled environments. The results of this survey are not documented in this report, which is limited to the experimental phase of the project. The survey results will constitute significant input into the development of a future software tool to quantify the effects of community risks and associated deployment decisions on resultant firefighter and civilian injuries and property losses.

The following research questions guided the experimental design of the low-hazard residential fireground experiments documented in this report:

1. How do crew size and stagger affect overall start-to-completion response timing?
2. How do crew size and stagger affect the timings of task initiation, task duration, and task completion for each of the 22 critical fireground tasks?
3. How does crew size affect elapsed times to achieve three critical events that are known to change fire behavior or tenability within the structure:
 - a. Entry into structure?
 - b. Water on fire?
 - c. Ventilation through windows (three upstairs and one back downstairs window and the burn room window).

4. How does the elapsed time to achieve the national standard of assembling 15 firefighters at the scene vary between crew sizes of four and five?

In order to address the primary research questions, the research was divided into four distinct, yet interconnected parts:

- Part 1 — Laboratory experiments to design appropriate fuel load
- Part 2 — Experiments to measure the time for various crew sizes and apparatus stagger (interval between arrival of various apparatus) to accomplish key tasks in rescuing occupants, extinguishing a fire, and protecting property
- Part 3 — Additional experiments with enhanced fuel load that prohibited firefighter entry into the burn prop — a building constructed for the fire experiments
- Part 4 — Fire modeling to correlate time-to-task completion by crew size and stagger to the increase in toxicity of the atmosphere in the burn prop for a range of fire growth rates.

The experiments were conducted in a burn prop designed to simulate a low-hazard¹ fire in a residential structure described as typical in NFPA 1710® *Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*. NFPA 1710 is the consensus standard for career firefighter deployment, including requirements for fire department arrival time, staffing levels, and fireground responsibilities.

Limitations of the study include firefighters' advance knowledge of the burn prop, invariable number of apparatus, and lack of experiments in elevated outdoor temperatures or at night. Further, the applicability of the conclusions from this report to commercial structure fires, high-rise fires, outside fires, terrorism/natural disaster response, HAZMAT or other technical responses has not been assessed and should not be extrapolated from this report.

Primary Findings

Of the 22 fireground tasks measured during the experiments, results indicated that the following factors had the most significant impact on the success of fire fighting operations. All differential outcomes described below are statistically significant at the 95 % confidence level or better.

Overall Scene Time:

The four-person crews operating on a low-hazard structure fire completed all the tasks on the fireground (on average) seven minutes faster — nearly 30 % — than the two-person crews. The four-person crews completed the same number of fireground tasks (on average) 5.1 minutes faster — nearly 25 % — than the three-person crews. On the low-hazard residential structure fire, adding a fifth person to the crews did not decrease overall fireground task times. However, it should be noted that the

¹ A low-hazard occupancy is defined in the NFPA Handbook as a one-, two-, or three-family dwelling and some small businesses. Medium hazards occupancies include apartments, offices, mercantile and industrial occupancies not normally requiring extensive rescue or firefighting forces. High-hazard occupancies include schools, hospitals, nursing homes, explosive plants, refineries, high-rise buildings, and other highlife hazard or large fire potential occupancies.

benefit of five-person crews has been documented in other evaluations to be significant for medium- and high-hazard structures, particularly in urban settings, and is recognized in industry standards.²

Time to Water on Fire:

There was a 10% difference in the "water on fire" time between the two- and three-person crews. There was an additional 6% difference in the "water on fire" time between the three- and four-person crews. (i.e., four-person crews put water on the fire 16% faster than two person crews). There was an additional 6% difference in the "water on fire" time between the four- and five-person crews (i.e. five-person crews put water on the fire 22% faster than two-person crews).

Ground Ladders and Ventilation:

The four-person crews operating on a low-hazard structure fire completed laddering and ventilation (for life safety and rescue) 30 % faster than the two-person crews and 25 % faster than the three-person crews.

Primary Search:

The three-person crews started and completed a primary search and rescue 25 % faster than the two-person crews. The four- and five-person crews started and completed a primary search 6 % faster than the three-person crews and 30 % faster than the two-person crew. A 10 % difference was equivalent to just over one minute.

Hose Stretch Time:

In comparing four- and five-person crews to two- and three-person crews collectively, the time difference to stretch a line was 76 seconds. In conducting more specific analysis comparing all crew sizes to the two-person crews the differences are more distinct. Two-person crews took 57 seconds longer than three-person crews to stretch a line. Two-person crews took 87 seconds longer than four-person crews to complete the same tasks. Finally, the most notable comparison was between two-person crews and five-person crews — more than 2 minutes (122 seconds) difference in task completion time.

Industry Standard Achieved:

As defined by NFPA 1710, the "industry standard achieved" time started from the first engine arrival at the hydrant and ended when 15 firefighters were assembled on scene.³ An effective response force was assembled by the five-person crews three minutes faster than the four-person crews. Based on the study protocols, modeled after a typical fire department apparatus deployment strategy, the total number of firefighters on scene in the two- and three-person crew scenarios never equaled 15 and therefore the two- and three-person crews were unable to assemble enough personnel to meet this standard.

Occupant Rescue:

Three different "standard" fires were simulated using the Fire Dynamics Simulator (FDS) model. Characterized in the *Handbook of the Society of Fire Protection Engineers* as slow-,

medium-, and fast-growth rate⁴, the fires grew exponentially with time. The rescue scenario was based on a non-ambulatory occupant in an upstairs bedroom with the bedroom door open.

Independent of fire size, there was a significant difference between the toxicity, expressed as fractional effective dose (FED), for occupants at the time of rescue depending on arrival times for all crew sizes. Occupants rescued by early-arriving crews had less exposure to combustion products than occupants rescued by late-arriving crews. The fire modeling showed clearly that two-person crews cannot complete essential fireground tasks in time to rescue occupants without subjecting them to an increasingly toxic atmosphere. For a slow-growth rate fire with two-person crews, the FED was approaching the level at which sensitive populations, such as children and the elderly are threatened. For a medium-growth rate fire with two-person crews, the FED was far above that threshold and approached the level affecting the general population. For a fast-growth rate fire with two-person crews, the FED was well above the median level at which 50 % of the general population would be incapacitated. Larger crews responding to slow-growth rate fires can rescue most occupants prior to incapacitation along with early-arriving larger crews responding to medium-growth rate fires. The result for late-arriving (two minutes later than early-arriving) larger crews may result in a threat to sensitive populations for medium-growth rate fires. Statistical averages should not, however, mask the fact that there is no FED level so low that every occupant in every situation is safe.

Conclusion:

More than 60 full-scale fire experiments were conducted to determine the impact of crew size, first-due engine arrival time, and subsequent apparatus arrival times on firefighter safety and effectiveness at a low-hazard residential structure fire. This report quantifies the effects of changes to staffing and arrival times for residential firefighting operations. While resource deployment is addressed in the context of a single structure type and risk level, it is recognized that public policy decisions regarding the cost-benefit of specific deployment decisions are a function of many other factors including geography, local risks and hazards, available resources, as well as community expectations. This report does not specifically address these other factors.

The results of these field experiments contribute significant knowledge to the fire service industry. First, the results provide a quantitative basis for the effectiveness of four-person crews for low-hazard response in *NFPA 1710*. The results also provide valid measures of total effective response force assembly on scene for fireground operations, as well as the expected performance time-to-critical-task measures for low-hazard structure fires. Additionally, the results provide tenability measures associated with a range of modeled fires.

Future research should extend the findings of this report in order to quantify the effects of crew size and apparatus arrival times for moderate- and high-hazard events, such as fires in high-rise buildings, commercial properties, certain factories, or warehouse facilities, responses to large-scale non-fire incidents, or technical rescue operations.

2 NFPA Standard 1710 - A.5.2.4.2.1 ... Other occupancies and structures in the community that present greater hazards should be addressed by additional fire fighter functions and additional responding personnel on the initial full alarm assignment.

3 NFPA 1710 Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments. Section 5.2.1 - Fire Suppression Capability and Section 5.2.2 Staffing.

4 As defined in the handbook, a fast fire grows exponentially to 1.0 MW in 150 seconds. A medium fire grows exponentially to 1 MW in 300 seconds. A slow fire grows exponentially to 1 MW in 600 seconds. A 1 MW fire can be thought-of as a typical upholstered chair burning at its peak. A large sofa might be 2 to 3 MWs.

Background

The fire service in the United States has a deservedly proud tradition of service to community and country dating back hundreds of years. As technology advances and the scope of service grows (e.g., more EMS obligations and growing response to natural disasters, hazardous materials incidents, and acts of terrorism), the fire service remains committed to a core mission of protecting lives and property from the effects of fire.

Firefighting is a dangerous business with substantial financial implications. In 2007, U.S. municipal fire departments responded to an estimated 1,557,500 fires. These fires killed 3,430 civilians (non-firefighters) and contributed to 17,675 reported civilian fire injuries. Direct property damage was estimated at \$14.6 billion dollars (Karter, 2008). In spite of the vigorous nationwide efforts

to promote firefighter safety, the number of firefighter deaths has consistently remained tragically high. In both 2007 and 2008, the U.S. Fire Administration reported 118 firefighter fatalities (USFA 2008).

Although not all firefighter deaths occur on the fireground — accidents in vehicles and training fatalities add to the numbers — every statistical analysis of the fire problem in the United States identifies residential structure fires as a key component in firefighter and civilian deaths, as well as direct property loss. Consequently, community planners and decision-makers need tools for optimally aligning resources with the service commitments needed for adequate protection of citizens.

Problem

Despite the magnitude of the fire problem in the United States, there are no scientifically based tools available to community and fire service leaders to assess the effects of prevention, fixed sprinkler systems, fire fighting equipment, or deployment and staffing decisions. Presently, community and fire service leaders have a qualitative understanding of the effect of certain resource allocation decisions. For example, a decision to double the number of firehouses, apparatus, and firefighters would likely result in a decrease in community fire losses, while cutting the number of firehouses, apparatus, and firefighters would likely yield an increase in the community fire losses, both human and property. However, decision-makers lack a sound

basis for quantifying the total impact of enhanced fire resources on the number of firefighter and civilian lives saved and injuries prevented.

Studies on adequate deployment of resources are needed to enable fire departments, cities, counties, and fire districts to design an acceptable level of resource deployment based upon community risks and service provision commitment. These studies will assist with strategic planning and municipal and state budget processes. Additionally, as resource studies refine data collection methods and measures, both subsequent research and improvements to resource deployment models will have a sound scientific basis.

Review of Literature

Research to date has documented a consistent relationship between resources deployed and firefighter and civilian safety. Studies documenting engine and ladder crew performance in diverse simulated environments as well as actual responses show a basic relationship between apparatus staffing levels and a range of important performance variables and outcome measurements such as mean on-scene time, time-to-task completion, incidence of injury among fire service personnel, and costs incurred as a result of on-scene injuries (Cushman 1981, McManis 1984, Morrison 1990, Ontario 1991, Phoenix 1991, Roberts 1993).

Reports by fire service officials and consulting associates reviewing fire suppression and emergency response by fire crews in U.S. cities were the first publications to describe the relationship between adequate staffing levels and response time, time to completion of various fireground tasks, overall effectiveness of fire suppression, and estimated value of property loss for a wide range of real and simulated environments. In 1980, the Columbus Fire Division's report on firefighter effectiveness showed that for a predetermined number of personnel initially deployed to the scene of a fire, the proportion of incidents in which property loss exceeded \$5,000 and horizontal fire spread of more than 25 sq ft (2.3 m²) was significantly greater for crews whose numbers fell below the set thresholds of 15 total fireground personnel at residential fires and 23 at large-risk fires (Backoff 1980). The following year, repeated live experiments at a one-family residential site using modern apparatus and equipment demonstrated that larger units performed tasks and accomplished knockdown more quickly, ultimately resulting in a lower percentage of loss attributable to factors controlled by the fire department. The authors of this article highlighted that the fire company is the fire department's basic working unit and further emphasized the importance of establishing accurate and up-to-date performance measurements to help collect data and develop conclusive strategies to improve staffing and equipment utilization (Gerard 1981).

Subsequent reports from the United States Fire Administration (USFA) and several consulting firms continued to provide evidence for the effects of staffing on fire crews' ability to complete tasks involved in fire suppression efficiently and effectively. Citing a series of tests conducted in 1977 by the Dallas Fire Department that measured the time it took three-, four-, and five-person teams to advance a line and put water on a simulated fire at the rear of the third floor of an old school, officials from the USFA underscored that time-to-task completion and final level of physical exhaustion for crews markedly improved not after any one threshold, but with the addition of each new team member. This report went on to outline the manner in which simulated tests exemplify a clear-cut means to record and analyze the resources initially deployed and finally utilized at fire scenes (NFA 1981). A later publication detailing more Dallas Fire Department simulations — ninety-one runs each for a private residential fire, high-rise office fire, and apartment house fire — showed again that increased staffing levels greatly enhanced the coordination and effectiveness of crews' fire suppression efforts during a finite time span (McManis Associates 1984). Numerous studies of local departments have supported this conclusion using a diverse collection of data, including a report by the National Fire

Academy (NFA) on fire department staffing in smaller communities, which showed that a company crew staffed with four firefighters could perform rescue of potential victims approximately 80 % faster than a crew staffed with three firefighters (Morrison 1990).

During the same time period that the impact of staffing levels on fire operations was gaining attention, investigators began to question whether staffing levels could also be associated with the risk of firefighter injuries and the cost incurred as a result of such injuries at the fire scene. Initial results from the Columbus Fire Division showed that "firefighter injuries occurred more often when the total number of personnel on the fireground was less than 15 at residential fires and 23 at large-risk fires" (Backoff 1980), and mounting evidence has indicated that staffing levels are a fundamental health and safety issue for firefighters in addition to being a key determinant of immediate response capacity. One early analysis by the Seattle Fire Department for that city's Executive Board reviewed the average severity of injuries suffered by three-, four-, and five-person engine companies, with the finding that "the rate of firefighter injuries expressed as total hours of disability per hours of fireground exposure were 54 % greater for engine companies staffed with 3 personnel when compared to those staffed with 4 firefighters, while companies staffed with 5 personnel had an injury rate that was only one-third that associated with four-person companies" (Cushman 1981). A joint report from the International Association of Fire Fighters (IAFF) and Johns Hopkins University concluded, after a comprehensive analysis of the minimum staffing levels and firefighter injury rates in U.S. cities with populations of 150,000 or more, that jurisdictions operating with crews of less than four firefighters had injury rates nearly twice the percentage of jurisdictions operating with crews of four-person crews or more (IAFF, JHU 1991).

More recent studies have continued to support the finding that staffing per piece of apparatus integrally affects the efficacy and safety of fire department personnel during emergency response and fire suppression. Two studies in particular demonstrate the consistency of these conclusions and the increasing level of detail and accuracy present in the most recent literature, by looking closely at the discrete tasks that could be safely and effectively performed by three- and four-person fire companies. After testing drills comprised of a series of common fireground tasks at several fire simulation sites, investigators from the Austin Fire Department assessed the physiological impact and injury rates among the variably staffed fire crews. In these simulations, an increase from a three- to four-person crew resulted in marked improvements in time-to-task completion or efficiency for the two-story residential fire drill, aerial ladder evolution, and high-rise fire drill, leading the researchers to conclude that loss of life and property increases when a sufficient number of personnel are not available to conduct the required tasks efficiently, independent of firefighter experience, preparation, or training. Reviews of injury reports by the Austin Fire Department furthermore revealed that the injury rate for three-person companies in the four years preceding the study was nearly one-and-a-half that of crews staffed with four or more personnel (Roberts 1993). In a sequence of similar tests, the Office of the Fire Marshal of Ontario, Canada likewise found that three-person

fire companies were unable to safely perform deployment of backup protection lines, interior suppression or rescue operations, ventilation operations that required access to the roof of the involved structure, use of large hand-held hose lines, or establish a water supply from a static source without additional assistance and within the time limits of the study. Following these data, Fire Marshal officials noted that three-person crews were also at increased risk for exhaustion due to insufficient relief at fire scenes and made recommendations for the minimum staffing levels per apparatus necessary for suppression and rescue related tasks (Office of the Fire Marshal of Ontario 1993).

The most comprehensive contemporary studies on the implications of fire crew staffing now include much more accurate performance measures for tasks at the fireground, in addition to the basic metric of response time. They include environmental measures of performance, such as total water supply, which expand the potential for assessing the cost-effectiveness of staffing not only in terms of fireground personnel injury rates but also comparative resource expenditure required for fire suppression. Several examples from the early 1990s show investigators and independent fire departments beginning to gather the kind of specific, comprehensive data on staffing and fireground tasks such as those suggested and outlined in concurrent local government publications that dealt with management of fire services (Coleman 1988). A report by the Phoenix Fire Department laid out clear protocols for responding to structure fires and response evaluation in terms of staffing, objectives, task breakdowns, and times in addition to outlining the responsibilities of responding fire department members and the order in which they should be accomplished for a full-scale simulation activity (Phoenix 1991). One attempt to devise a prediction model for the effectiveness of manual fire suppression similarly reached beyond response time benchmarks to describe fire operations and the step-by-step actions of firefighters at incident scenes by delineating the time-to-task breakdowns for size-up, water supply, equipment selection, entry, locating the fire, and advancing hose lines, while also comparing the predicted time-to-task values with the actual times and total resources (Menker 1994). Two separate studies of local fire department performance, one from Taoyuan County in Taiwan and another from the London Fire Brigade, have drawn ties between fire crews' staffing levels and total water demand as the consequence of both response time and fire severity. Field data from Taoyuan County for cases of fire in commercial, business, hospital, and educational properties showed that the type of land use as well as response time had a significant impact on the water volume necessary for

fire suppression, with the notable quantitative finding that the water supply required on-scene doubled when the fire department response increased by ten minutes (Chang 2005).

Response time as a predictor of residential fire outcomes has received less study than the effect of crew size. A Rand Institute study demonstrated a relationship between the distance the responding companies traveled and the physical property damage. This study showed that the fire severity increased with response distance, and therefore the magnitude of loss increased proportionally (Rand 1978). Using records from 307 fires in nonresidential buildings over a three-year period, investigators in the United Kingdom correspondingly found response time to have a significant impact on final fire area, which in turn was proportional to total water demand (Sardqvist 2000).

Recent government and professional literature continues to demonstrate the need for more data that would quantify in depth and illustrate the required tasks, event sequences, and necessary response times for effective fire suppression in order to determine with accuracy the full effects of either a reduction or increase in fire company staffing (Karter 2008). A report prepared for National Institute of Standards and Technology (NIST) stressed the ongoing need to elucidate the relationship between staffing and personnel injury rates, stating that "a scientific study on the relationship between the number of firefighters per engine and the incidence of injuries would resolve a long-standing question concerning staffing and safety" (TriData 2005). While not addressing staffing levels as a central focus, an annual review of fire department calls and false alarms by the National Fire Protection Association (NFPA) exemplified the need to capture not only the number of personnel per apparatus for effective fire suppression but also to clarify the demands on individual fire departments with resolution at the station level (NFPA 2008).

In light of the existing literature, there remain unanswered questions about the relationships between fire service resource deployment levels and associated risks. For the first time this study investigates the effect of varying crew size, first apparatus arrival time, and response time on firefighter safety, overall task completion and interior residential tenability using realistic residential fires. This study is also unique because of the array of stakeholders and the caliber of technical advisors involved. Additionally, the structure used in the field experiments included customized instrumentation for the experiments; all related industry standards were followed; robust research methods were used; and the results and conclusions will directly inform the NFPA 1710 Technical Committee, as well as public officials and fire chiefs.⁵

5 NFPA is a registered trademark of the National Fire Protection Association, Quincy, Massachusetts. NFPA 1710 defines minimum requirements relating to the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by substantially all career fire departments. The requirements address functions and objectives of fire department emergency service delivery, response capabilities, and resources. The purpose of this standard is to specify the minimum criteria addressing the effectiveness and efficiency of the career public fire suppression operations, emergency medical service, and special operations delivery in protecting the citizens of the jurisdiction and the occupational safety and health of fire department employees. At the time of the experiments, the 2004 edition of NFPA 1710 was the current edition.

Purpose and Scope of the Study

This project systematically studies deployment of fire fighting resources and the subsequent effect on both firefighter safety and the ability to protect civilians and their property. It is intended to enable fire departments and city/county managers to make sound decisions regarding optimal resource allocation to meet service commitments using the results of scientifically based research. Specifically, the residential fireground experiments provide quantitative data on the effect of crew size, first-due engine arrival time, and subsequent apparatus stagger on time-to-task for critical steps in response and fire fighting.

The first phase of the multiphase project was an extensive survey of more than 400 career and combination fire departments in the United States with the objective of optimizing a fire service leader's capability to deploy resources to prevent or mitigate adverse events that occur in risk- and hazard-filled environments. The results of this survey are not documented in this report, which is limited to the experimental phase of the project, but they will constitute significant input into future applications of the data presented in this document.

This report describes the second phase of the project, divided into four parts:

- Part 1 — Laboratory experiments to design the appropriate fuel packages to be used in the burn facility specially constructed for the research project
- Part 2 — Field tests for critical time-to-task completion of key tasks in fire suppression
- Part 3 — Field tests with real furniture (room and contents experiments)
- Part 4 — Fire modeling to apply data gathered to slow-, medium-, and fast-growth rate fires

The scope of this study is limited to understanding the relative influence of deployment variables on low-hazard, residential structure fires, similar in magnitude to the hazards described in NFPA® 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*. The standard uses as a typical residential structure a 2,000 sq ft (186 m²) two-story, single-family dwelling with no basement and no exposures (nearby buildings or hazards such as stacked flammable material).

The limitations of the study, such as firefighters' advance knowledge of the facility constructed for this experiment, invariable number of apparatus, and lack of experiments in extreme temperatures or at night, will be discussed in the Limitations section of this report. It should be noted that the applicability of the conclusions from this report to commercial structure fires, high-rise fires, outside fires, and response to hazardous material incidents, acts of terrorism, and natural disasters or other technical responses has not been assessed and should not be extrapolated from this report.

A Brief Overview of the Fireground Operations

Regardless of the size of a structure on fire, firefighting crews identify four priorities: life safety of occupants and firefighters, confinement of the fire, property conservation, and reduction of adverse environmental impact. Interdependent and coordinated activities of all fire fighting personnel are required to meet the priority objectives.

NFPA 1710 specifies that the number of on-duty fire suppression personnel must be sufficient to carry out the necessary fire fighting operations given the expected fire fighting conditions. During each fireground experiment, the following were dispatched to the test fire building:

- three engine companies
- one truck company
- a command vehicle with a battalion chief and a command aide

Staffing numbers for the engine and truck crews and response times were varied for the purposes of the tests. Additional personnel available to ensure safety will be described later in this report.

The following narrative account describes the general sequence of activities in part 2 of the experiments (time-to-task), when the fuel load permitted firefighter entry:

The first arriving engine company conducts a size-up or initial life safety assessment of the building to include signs of occupants in the home, construction features, and location of the original fire and any extension to other parts of the structure. This crew lays a supply line from a hydrant close to the building for a continuous water supply.

The truck company usually arrives in close proximity to the first engine company. The truck company is responsible for gaining access or forcing entry into the building so that the engine company can advance the first hose line into the building to locate and extinguish the fire. Usually, they assist the engine company in finding the fire. The NFPA and OSHA 2 In/2 Out⁶ crew is also assembled prior to anyone entering an atmosphere that is immediately dangerous to life or health (IDLH). This important safety requirement will have a large impact on availability of firefighters to enter the building when small crews are deployed.

Once a door is opened, the engine crew advances a hose line (attack line) toward the location of the fire. At the same time, members from the truck crew accompany the engine crew and

assist in ventilating the building to provide a more tenable atmosphere for occupants and firefighters. Ventilation also helps by improving visibility in an otherwise "pitch black" environment, but it must be coordinated with the attack line crew to ensure it helps control the fire and does not contribute to fire growth. The truck crew performs a systematic rapid search of the entire structure starting in the area where occupants would be in the most danger. The most dangerous area is proximate to the fire and the areas directly above the fire.

Depending upon the travel distance, the battalion chief and command aide will have arrived on the scene and have taken command of the incident and established a command post. The role of the incident commander is to develop the action plan to mitigate the incident and see that those actions are carried out in a safe, efficient, and effective manner. The command aide is responsible for situational assessment and communications, including communications with crew officers to ensure personnel accountability.

Depending on response time or station location, the second (engine 2) and possibly the third engine company (engine 3) arrive. The second arriving engine (engine 2) connects to the fire hydrant where the first engine (engine 1) laid their supply line. Engine 2 pumps water from the hydrant through the supply line to the first engine for fire fighting operations. According to *NFPA 1710*, water should be flowing from the supply line to the attack engine prior to the attack crew's entry into the structure.

The crew from the second engine advances a second hand line as a backup line to protect firefighters operating on the inside and to prevent fire from spreading to other parts of the structure.

The third engine crew is responsible for establishing a Rapid Intervention Team (RIT), a rescue team staged at or near the command post or as designated by the Incident Commander (in the front of the building) with all necessary equipment needed to locate and/or rescue firefighters that become trapped or incapacitated. The RIT plans entry/exit portals and removes hazards, if found, to assist interior crews.

As the fire fighting, search and rescue, and ventilation operations are continuing, two members of the truck company are tasked with placing ground ladders to windows and the roof to provide a means of egress for occupants or firefighters. The truck crew is responsible for controlling interior utilities such as gas and electric after their ventilation, search, and rescue duties are completed.

Once the fire is located and extinguished and occupants are

⁶ The "2 In/2 Out" policy is part of paragraph (g)(4) of OSHA's revised respiratory protection standard, 29 CFR 1910.134. This paragraph applies to private sector workers engaged in interior structural fire fighting and to Federal employees covered under Section 19 of the Occupational Safety and Health Act. States that have chosen to operate OSHA-approved occupational safety and health state plans are required to extend their jurisdiction to include employees of their state and local governments. These states are required to adopt a standard at least as effective as the Federal standard within six months.

OSHA's interpretation on requirements for the number of workers required to be present when conducting operations in atmospheres that are immediately dangerous to life and health (IDLH) covers the number of persons who must be on the scene before fire fighting personnel may initiate an attack on a structural fire. An interior structural fire (an advanced fire that has spread inside of the building where high temperatures, "heat" and dense smoke are normally occurring) would present an IDLH atmosphere and therefore, require the use of respirators. In those cases, at least two standby persons, in addition to the minimum of two persons inside needed to fight the fire, must be present before fire fighters may enter the building.

Letter to Thomas N. Cooper, Purdue University, from Paula O. White, Director of Federal-State Operations, U.S. Department of Labor, Occupational Safety & Health Administration, November 1, 1995.

removed, the incident commander reassesses the situation and provides direction to conduct a very thorough secondary search of the building to verify that the fire has not extended into void spaces and that it is fully extinguished. (In a nonexperimental fire situation, salvageable property would be covered or removed to minimize damage.)

Throughout the entire incident, each crew officer is responsible for the safety and accountability of his or her personnel along with air management. The location and wellness of crews is tracked by the command aide through a system of personal accountability checks conducted at 20-minute intervals.

Following extinguishment of the fire, an onsite review is conducted to identify actions for improvement. Crews are monitored, hydrated and rested before returning to work in the fire building.

The Relation of Time-to-Task Completion and Risk

Delayed response, particularly in conjunction with the deployment of inadequate resources, reduces the likelihood of controlling the fire in time to prevent major damage and possible loss of life and increases the danger to firefighters.

Figure 1 illustrates a hypothetical sequence of events for response to a structure fire. During fire growth, the temperature of a typical compartment fire can rise to over 1,000° F (538° C). When a fire in part of a compartment reaches flashover, the rapid transition between the growth and the fully developed fire stage, flame breaks out almost at once over the surface of all objects in

the compartment, with results for occupants, even firefighters in full gear, that are frequently deadly.

Successful containment and control of a fire require the coordination of many separate tasks. Fire suppression must be coordinated with rescue operations, forcible entry, and utilities control. Ventilation typically occurs only after an attack line is in place and crews are ready to move in and attack the fire. The incident commander needs up-to-the-minute knowledge of crew activities and the status of task assignments which could result in a decision to change from an offensive to a defensive strategy.

Standards of Response Cover

Developing a standard of response cover — the policies and procedures that determine the distribution, concentration, and reliability of fixed and mobile resources for response to fire (as well as other kinds of technical response) — related to service commitments to the community is a complex task. Fire and rescue departments must evaluate existing (or proposed) resources against identified risk levels in the community and against the tasks necessary to conduct safe, efficient and effective fire suppression at structures identified in these various risk levels. Leaders must also evaluate geographic distribution and depth or concentration of resources deployed based on time parameters.

Recognition and reporting of a fire sets off a chain of events before firefighters arrive at the scene: call receipt and processing, dispatch of resources, donning protective gear, and travel to the scene. *NFPA 1710* defines the overall time from dispatch to scene arrival as the *total response time*. The standard divides total

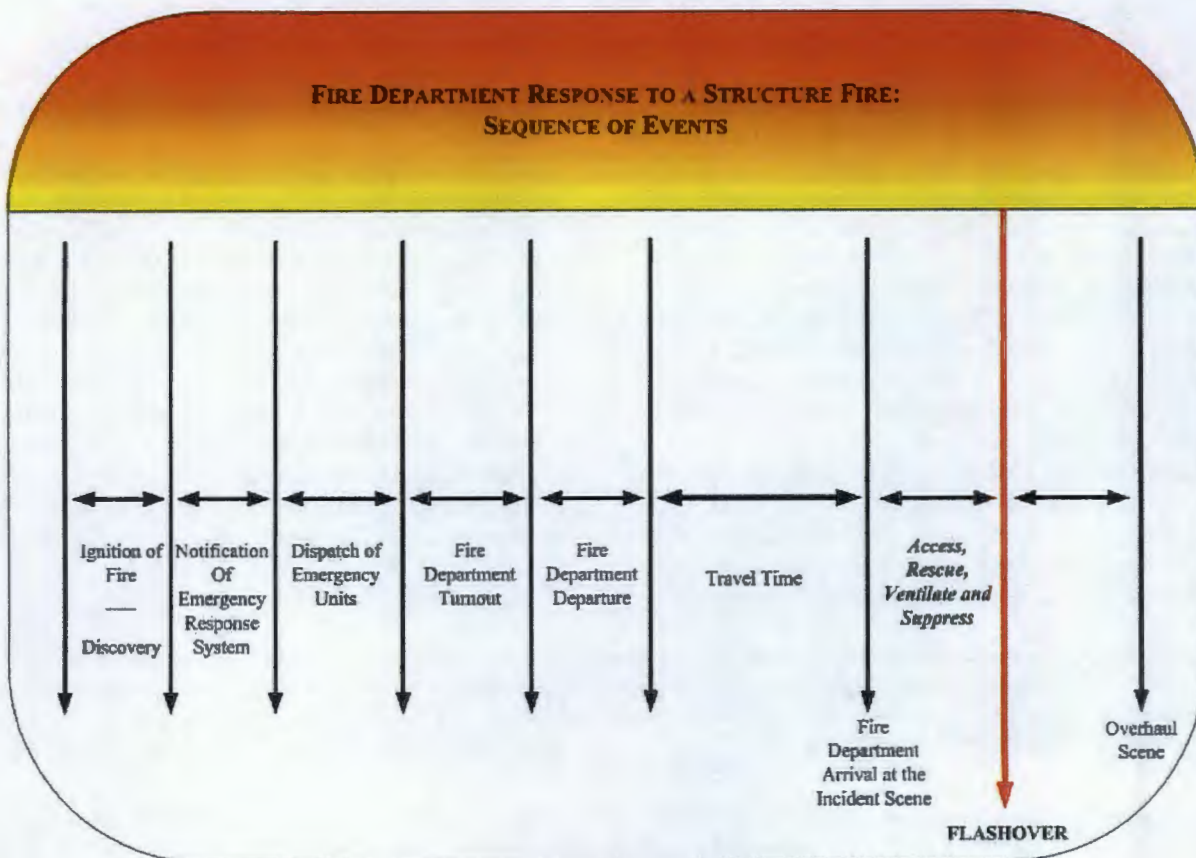


Figure 1: Hypothetical Timeline of Fire Department Response to Structure Fire

response time into a number of discrete segments, of which travel time — the time interval from the beginning of travel to the scene to the arrival at the scene — is particularly important for this study.

Arrival of a firefighting response force must be immediately followed by organization of the resources into a logical, properly phased sequence of tasks, some of which need to be performed simultaneously. Knowing the time it takes to accomplish each task with the allotted number of personnel and equipment is critical. Ideally crews should arrive and intervene in sufficient time to prevent flashover or spread beyond the room of origin.

Decision-making about staffing levels and geographic distribution of resources must consider those times when there will be simultaneous events requiring resource deployment. There should be sufficient redundancy or overlap in the system to

allow for simultaneous calls and high volume of near simultaneous responses without compromising the safety of the public or firefighters.

Policy makers have long lacked studies that quantify changes in fireground performance based on apparatus staffing levels and on-scene arrival time intervals. These experiments were designed to observe the impact of apparatus staffing levels and apparatus arrival times on the time it takes to execute essential fireground tasks and on the tenability inside the burn prop for a full initial alarm assignment response. It is expected that the results of this study will be used to evaluate the related performance objectives in *NFPA 1710*.

Part 1: Planning for the Field Experiments

Laboratory Experiments

The purpose of the first segment, the laboratory experiments, was to characterize the burning behavior of the wood pallets as a function of:

- number of pallets and the subsequent peak heat release rate (HRR)
- compartment effects on burning of wood pallets
- effect of window ventilation on the fire
- effect on fire growth rate of the loading configuration of excelsior (slender wood shavings typically used as packing material)

Characterization of the fuel package was critical in order to ensure that the field experiments would not result in a flashover condition, one of the primary safety considerations in complying with the protocols in *NFPA 1403: Standard on Live fire Training Evolutions*.⁷ Appendix A of this report contains the methods and full results for the laboratory experiments, which are summarized below. Figure 2 shows a test burn of pallets in the laboratory.

Results of Laboratory Experiments

The objective of the laboratory experiments was to quantify the spread of heat and smoke throughout the planned burn prop in order to ensure that the fuel package would result in a fire large enough to generate heat and smoke consistent with a residential structure fire, yet not so large as to transition to flashover. The full results of the laboratory experiments and modeling are shown in Appendix A and Appendix B. To summarize briefly, a four-pallet configuration, which produced a peak of approximately 2 MW, was determined to be the largest fuel load the room could support without the threat of transitioning to flashover. The compartment produced a negligible effect on the heat release rate of the fire compared to open burning conditions. The presence of an open window in the burn room reduced the



Figure 2: Test Burn of Pallets in Laboratory

production of carbon monoxide and carbon dioxide gases, primarily through enhanced oxygen availability and dilution, respectively. The location and quantity of excelsior had a significant impact on the growth rate of fire. More excelsior located nearer the bottom of the pallets resulted in a more rapid achievement of peak burning.

The results of the fuel load experiments to inform the building and experimental design indicated development of untenable conditions in the field experiments between 5 min and 15 min, depending upon several factors: fire growth rate, ventilation conditions, the total leakage of heat into the building and through leakage paths, and manual fire suppression. This time frame allowed for differentiation of the effectiveness of various fire

⁷ NFPA 1403 contains the minimum requirements for training all fire suppression personnel engaged in firefighting operations under live fire conditions.

Part 2: Field Experiment Methods

department response characteristics.

In part 2, fire experiments were conducted in a residential-scale burn prop at the Montgomery County Public Safety Training Academy in Rockville, MD.

Field Site

Montgomery County (MD) Fire and Rescue Department provided an open space to construct a temporary burn prop, with ready access to water and electrical utilities, at the Montgomery County Fire and Rescue Training Facility in Rockville, MD.

The burn prop was constructed as a two-story duplex with a common stairwell and movable walls between the sections to allow for multiple experiments daily. Symmetrically dividing the structure about the short axis allowed one side of the test structure to cool and dry out after a fire test with suppression. The burn prop contained two mirror-image, two-story units each totaling 2,000 ft² (186 m²), without basement or nearby exposures — each therefore a typical model of a low-hazard single-family residence identified in *NFPA 1710*. An exterior view of the burn prop is shown in Figure 3. For each experiment there was a confirmed fire in the living room in the first floor rear of one unit of the structure.



Figure 3: Exterior View of Burn Prop

Details and dimension are shown in the floor plan in Figure 4.

The black lines in Figure 4 indicate load-bearing reinforced concrete walls and red lines indicate the gypsum over steel stud partition walls. The ceiling height was 94 in (2.4 m) throughout the entire structure except in the burn compartments, where additional hardening was installed to protect against repeated exposure to fire during the experiments. This additional fire proofing slightly reduced the ceiling height. Complete details about the building construction are included in Appendix C.

Noncombustible furniture (angle iron and gypsum board construction) was fashioned to represent obstacles of realistic size and location for firefighters navigating the interior of the structure. The dimensions were typical of residential furnishings. Figure 5 shows an example of the noncombustible furniture used in the time-to-task experiments.

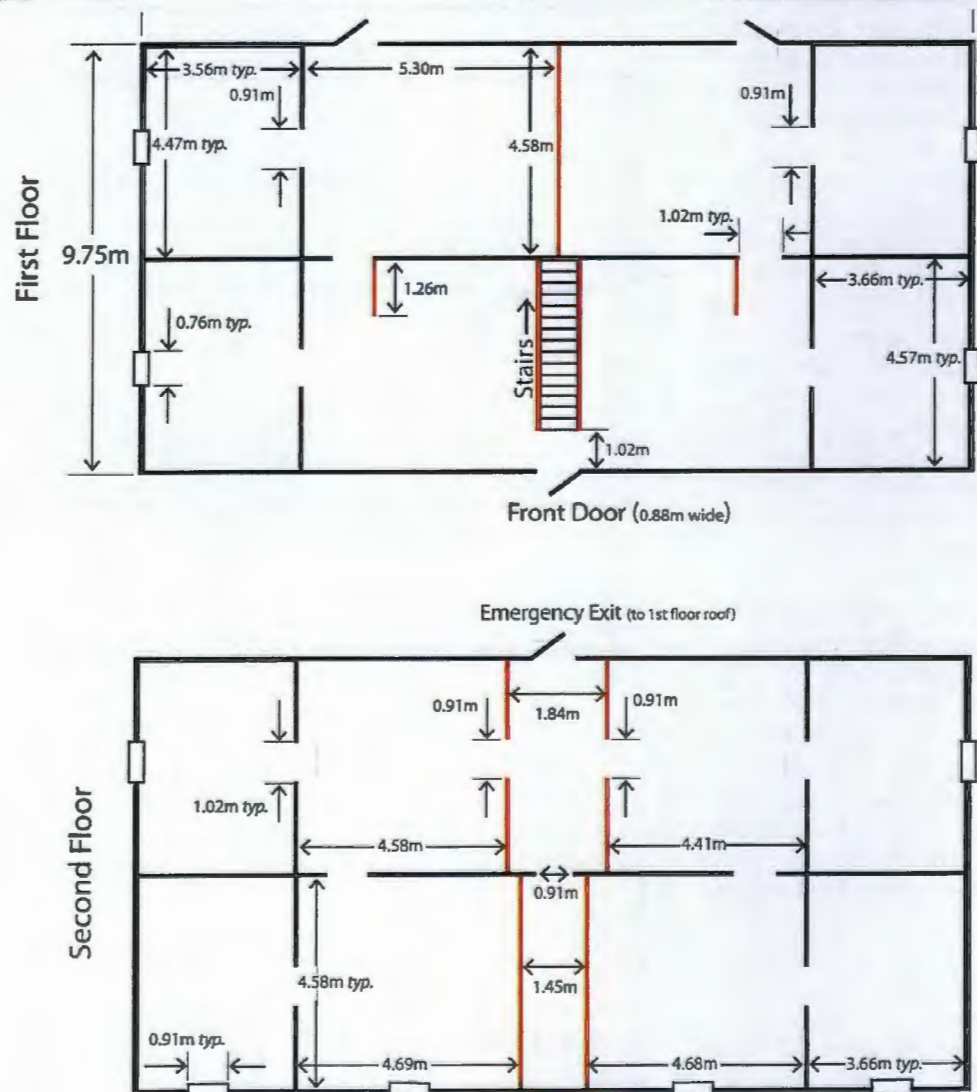


Figure 4: Dimensions of the Burn Prop Floor Plan

Overview of Field Experiments

In order to evaluate the performance representative of a *NFPA 1710*-compliant fire department, the field experiments consisted of two parts (the second and third parts of the four described in this report). In the first of the two parts of the field experiments, firefighter participants from Montgomery County (MD) and Fairfax County (VA) Fire Departments simulated an initial alarm assignment response to a structure described in *NFPA 1710* as a low-hazard residential structure to which firefighters respond on a regular basis. The staffing level of fire apparatus was varied incrementally from two to five personnel per piece. The interval between apparatus on-scene arrival times was varied at either 60 s or 120 s. Trained timing staff were used to record the start and completion times of 22 tasks deemed essential for mitigation of a residential fire incident by the study's technical experts. The pallet and excelsior configuration chosen from the laboratory experiments repeatedly produced a consistent and realistic quantity of heat and smoke, similar to what firefighters encounter at a residential structure fire.

Although the fire source used in part 2 of the field experiments created a realistic amount of heat and smoke, the requirements of *NFPA 1403* prevented use of a fire source which could potentially reach flashover within the structure. Therefore, part 3 of the fire experiments was conducted in order to change the fuel package to be representative of realistic fuel loading that could be found in a living room in a residential structure (sleeper-sofa, upholstered chairs, end tables, etc). The intent of this part of the study was to determine how the times of firefighter interactions, averaged with respect to the staffing and arrival intervals, impacted the interior tenability conditions. Fire fighting tactics were performed in a manner which complied with *NFPA 1403*; ventilation was performed with proper personal protective equipment (PPE) and hand tools from the exterior of the burn prop. Suppression was performed with an interior remote suppression device operated from the exterior of the burn prop.

Instrumentation

Instrumentation to measure gas temperature, gas concentrations, heat flux, visual obscuration, video, and time during the experiments was installed throughout the burn prop. The data were recorded at 1-second intervals on a computer-based data acquisition system. Figure 6 presents a schematic plan view of the instrumentation. All instruments were wired to a centralized data collection room attached as a separate space on the west side of the building, which is described later in this

report ensuring physical separation for the data collection personnel from the effects of the fire, while minimizing the wire and tube lengths to the data logging equipment. See Appendix C for additional details about the instrumentation.



Figure 5: Noncombustible Furniture Used in the Time-to-Task Experiments



Figure 6: Instrumentation and Furniture Prop Layout



Figure 7: Fireground Safety Officer

Safety Protocols

Firefighter safety was always a primary concern in conducting the research. Participants were drawn from two departments — Fairfax County, VA and Montgomery County, MD — that regularly conduct NFPA 1403 compliant live fire training for their staff and recruits.

A safety officer was assigned to the experiments by the Montgomery County Fire and Rescue Department to assure compliance with NFPA 1403. The safety officer (Figure 7) participated in all orientation activities, daily briefings, and firefighter gear checks and was always actively involved in overseeing all experiments. The safety officer had full authority to terminate any operation if any safety violation was observed. In addition to the safety officer, a rapid intervention team (RIT), assigned from dedicated crews not in the actual experiment, was in place for each experiment, and a staffed ambulance was on standby at the site. Radio communication was always available during the experiments should a “mayday” emergency arise.

Experiments were stopped for any action considered to be a protocol breach or safety concern. For example, all ladders — 24 ft (7.3 m) or 28 ft (8.5 m) — were to be raised by two firefighters. As crew sizes were reduced, some firefighters attempted to place ladders single-handedly in an effort to complete the task more quickly. This procedure, while vividly illustrating how firefighters try to do more with less in the field, is unsafe and could potentially result in strain or impact injuries.

Additional safety features were built in to the field structure. A deluge sprinkler system oriented to the known location of the fuel package could be remotely activated for rapid fire suppression. All first floor rooms had direct access to the exterior of the building through either doors or windows. The second story had an emergency exit to the roof of the attached instrumentation room.

A closely related concern to ensure firefighter safety and readiness to repeat experiments with equivalent performance was adequate rehabilitation (see Figure 8). At the beginning and end of each day, crews completed a health and safety check. The importance of staying well-hydrated before and during experiments was especially emphasized.



Figure 8: Crew Rehabilitation

Time-to-Task Experiments

On-Scene Fire Department Tasks

The on-scene fire department task part of the study focused on the tasks firefighters perform after they arrive on the scene of a low-hazard residential structure fire. A number of nationally recognized fire service experts were consulted during the development of the on-scene fire department tasks in order to ensure a broad applicability and appropriateness of the task distribution.⁸ The experiments compared crew performance and workload for a typical fire fighting scenario using two-, three-, four-, and five-person crews. 24 total experiments were conducted to assess the time it took various crew sizes to complete the same tasks on technically similar fires in the same structure. In addition to crew sizes, the experiments assessed the effects of stagger between the arriving companies. Close stagger was defined as a 1-minute time difference in the arrival of each responding company. Far stagger was defined as a 2-minute time difference in the arrival of each responding company. One-minute and two-minute arrival stagger times were determined from analysis of deployment data from more than 300 U.S. fire departments responding to a survey of fire department operations conducted by the International Association of Fire Chiefs (IAFC) and the International Association of Fire Fighters (IAFF). Considering both crew size and company stagger there were eight experiments conducted in triplicate totaling twenty-four tests, as shown in the full replicate block in Table 1. A full replicate was completed in a randomized order (determined by randomization software) before a test configuration was repeated.

Crew Size

For each experiment, three engines, a ladder-truck and a battalion chief and an aide were dispatched to the scene of the residential structure fire. The crew sizes studied included two-, three-, four-, and five-person crews assigned to each engine and truck dispatched. Resultant on-scene staffing totals for each experiment follow: (FF = firefighter)

- Two Person crews = 8 FFs + Chief and Aide = 10 total on-scene
- Three Person crews = 12 FFs + Chief and Aide = 14 total on-scene
- Four Person crews = 16 FFs + Chief and Aide = 18 total on-scene
- Five Person crews = 20 FFs + Chief and Aide = 22 total on-scene⁹

Department Participation

The experiments were conducted in Montgomery County, MD at the Montgomery County Fire Rescue Training Academy during the months of January and February 2009. All experiments took place in daylight between 0800 hours and 1500 hours. Experiments were postponed for heavy rain, ice, or snow and rescheduled for a later date following other scheduled experiments.

Montgomery County (MD) and Fairfax County (VA) firefighters participated in the field experiments. Each day both departments committed three engines, a ladder truck and

Crew Size	Apparatus Stagger
2 Person	Close Stagger (One minute)
3 Person	Close Stagger (One minute)
4 Person	Close Stagger (One minute)
5 Person	Close Stagger (One minute)
2 Person	Far Stagger (Two minutes)
3 Person	Far Stagger (Two minutes)
4 Person	Far Stagger (Two minutes)
5 Person	Far Stagger (Two minutes)

Table 1: Primary Variables for Time-to-Task Experiments

associated crews, as well as a battalion chief to the experiments. The two battalion chiefs, alternated between the roles of battalion chief and aide. Firefighters and officers were identified by participating departments and oriented to the experiments. Each experiment included engine crews, truck crews and command officers from each participating department. Participants varied with regard to age and experience. Crews that normally operated together as a company were kept intact for the experiments to assure typical operation for the crew during the scenarios. However, in all experiments crews were used from both departments, including engine crews, truck crews, and officers.

This allocation of resources made it possible to conduct back-to-back experiments by rotating firefighters between field work and rehabilitation areas.

Crew Orientation

All study participants were required to attend an orientation prior to the beginning of the experiments (see Figure 9, page 25). The orientations were used to explain experiment procedures, task flows, division of labor between crews, and milestone events in the scenario.

Daily orientations were conducted for all shifts to assure every participant attended. Orientations included a description of the overall study objectives as well as the actual experiments in which they would be involved. Per the requirements of *NFPA 1403*, full disclosure regarding the structure, the fire, and the tasks to be completed were provided. Crews were also oriented to the fireground props, instrumentation used for data collection, and the specific scenarios to be conducted. Every crew member was provided a walkthrough of the structure during the orientation and each day prior to the start of the experiments.

⁸ Technical experts included Dennis Compton, Russell Sanders, William "Shorty" Bryson, Vincent Dunn, David Rohr, Richard Bowers, Michael Clemens, James Walsh, Larry Jenkins and Doug Hinkle. More information about the experts is presented in the Acknowledgments later in this report.

⁹ Note that the on-scene totals account for only the personnel assigned to "work" the fire. Additional personnel were provided for an RIT team, a staffed ambulance on site, and a safety officer specific to the experiments. The additional personnel are not included in the staffing described above.

Tasks

Twenty-two fireground tasks were completed in each experiment. Meticulous procedures gathered data to measure key areas of focus, such as individual task start times, task completion times, and overall scenario performance times. Each task was assigned a standardized start and end marker, such as crossing the threshold to enter the building with a hose line or touching a ladder to raise it to a second story window. The 22 tasks, with the events for measuring start and stop times, are shown in Table 2 (page 26). Figures 10 — 19 illustrate firefighter activity in a number of the tasks to complete experiments or prepare for the next experiment.

For reasons of both safety and cost efficiency, two tasks — forcible entry of the front door and ventilation of the windows on the first and second stories — required special procedures.

The study could not accommodate replacing the doors and windows daily for the fire suppression experiments. Before the start of experiments with the full sequence of tasks, these two tasks were measured in a realistic manner using training props constructed at the site of the fireground experiments. As with the overall experiments, these two tasks were repeated in triplicate and the times averaged. The average time to complete the tasks was then used in the larger scale experiment. As firefighters came to the point of breaching the door or windows, the timers would hold them for the time designated by the earlier experiments and then give them the approval to open the door or windows. The start and end times were then recorded just as other tasks were.



Figure 9: Crew Orientation and Walkthrough



Figure 10: Ground Ladders



Figure 11: Ventilation



Figure 12: Ground Level Window Breakage Prop



Figure 13: Second Story Window Breakage Prop



Figure 14: Door Forcible Entry Prop



Figure 15: Crew Preparation and Cue Cards

Table 2: Tasks and Measurement Parameters

Tasks	Measurement Parameters	Tasks	Measurement Parameters
1. Stop at Hydrant, Wrap Hose	START - Engine stopped at hydrant STOP - Firefighter back on engine and wheels rolling	13. Conduct Primary Search	START - Firefighters enter front door STOP - Firefighters transmit "search complete"
2. Position Engine 1	START - Wheels rolling from hydrant STOP - Wheels stopped at structure	14. Ground Ladders in Place	START - Firefighter touches ladder to pull it from truck STOP - 4 Ladders thrown: 3 ladders on the 2 nd -story windows and 1 to the roof
3. Conduct Size-up (360-degree lap), transmit report, establish command	START - Officer off engine STOP - Completes radio transmission of report	15. Horizontal Ventilation (Ground)	START- Firefighter at 1 st window to begin ventilation (HOLD for 8 seconds) STOP - Hold time complete - window open
4. Engage Pump	START - Driver off engine STOP - Driver throttles up pump	16. Horizontal Ventilation (2 nd Story)	START - Firefighter grabs ladder for climb. (Firefighter must leg lock for ventilation. HOLD time at each window is 10 seconds) STOP - All 2 nd -story windows open - descend ladder - feet on ground.
5. Position Attack Line (Forward Lay)	START - Firefighter touches hose to pull it from engine STOP - Flake, charge and bleed complete (hose at front door prepared to advance)	17. Control Utilities (Interior)	START - Radio transmission to control utilities STOP - When firefighter completes the task at the prop
6. Establish 2 In/2 Out	Company officer announces - "2 In/2 Out established" (4 persons assembled on scene OR at the call of the Battalion Chief/Company Officer)	18. Control Utilities (Exterior)	START - Radio transmission to control utilities STOP - When firefighter completes the task at the prop
7. Supply Attack Engine	START - Firefighter touches hydrant to attach line STOP - Water supply to attack engine	19. Conduct Secondary Search	START - Firefighters enter front door STOP - Firefighters transmit "secondary search complete"
8. Establish RIT	Time that Company Officer announces RIT is established	20. Check for Fire Extension (walls)	START- Firefighters pick up check-for-extension prop STOP- Completion of 4 sets total (1 set = 4 in and 4 out) This task may be done by more than one person.
9. Gain/Force Entry	START - Action started (HOLD time= 10 seconds)	21. Check for Fire Extension (ceilings)	START - Firefighters pick up check-for-extension prop STOP - Completion of 4 sets total (1 set = 3 up and 5 down) This task may be done by more than one person.
10. Advance Attack Line	STOP - Door opened for entry START - Firefighter touches hose STOP - Water on fire	22. Mechanical Ventilation	START - Firefighters touch fans to remove from truck STOP - Fans in place at front door and started
11. Advance Backup Line (stop time at front door)	START - Firefighter touches hose to pull from engine bed STOP - Backup line charged to nozzle		
12. Advance Backup Line/Protect Stairwell	START - Firefighter crosses threshold STOP - Position line for attack at stairwell		

Data Collection: Standardized Control Measures

Several control measures were used to collect data, including crew cue cards, radio communications, task timers, and video recording.

Performance was timed for each task in each scenario including selected milestone tasks such as door breach, water-on-fire, and individual window ventilation. Data were collected for crew performance on each task, and individual firefighter performance was not considered.

Task Flow Charts and Crew Cue Cards

Task procedures were standardized for each experiment/scenario. Technical experts worked with study investigators to break down crew tasks into individual tasks based on crew size. Task flow charts were created and then customized for the various crew sizes. The carefully designed task flow ensured that the same overall workload was maintained in each experiment, but was redistributed based on the number of personnel available for the work. See Appendix D for additional details.

All tasks were included in each scenario and cue cards were developed for each individual participant in each scenario. For example, a four-person crew would have a cue card for each person on the crew including the officer, the driver, and the two firefighters. Cards were color coded by crew size to assure proper use in each scenario.

Radio communications

Interoperability of radio equipment used by both participating departments made it possible to use regular duty radios for communication during the experiments. Company officers were instructed to use radios as they would in an actual incident. Montgomery County Fire and Rescue Communications recorded all radio interaction as a means of data backup. Once all data quality control measure were complete, the records were then overwritten as a routine procedure.

Task Timers

Ten observers/timers, trained in the use of a standard stop watch with split-time feature, recorded time-to-task data for each field experiment. To assure understanding of the observed tasks,



Figure 16: Connecting to the Hydrant



Figure 17: Crews Responding



Figure 18: Ceiling Breach/Molitor Machine



Figure 19: Incident Command



Figure 20: Task Timers



Figure 21: Video Recording for Quality Control

firefighters were used as timers, each assigned specific tasks to observe and to record the start and end times.

To enhance accuracy and consistency in recording times, the data recording sheets used several different colors for the tasks (see Appendix D). Each timer was assigned tasks that were coded in the same color as on the recording sheet. All timers wore high-visibility safety gear on the fireground (see Figure 20).

Video records

In addition to the timers, video documentation provided a backup for timed tasks and for quality control (see Figure 21). No less than six cameras were used to record fireground activity from varied vantage points. Observer/timer data were compared to video records as part of the quality control process.

Crew Assignment

Crews from each department that regularly operated together were assigned to work as either engine or truck companies in each scenario. Both Fairfax County and Montgomery County crews participated in each experiment.

Crews assigned to each responding company position in one scenario were assigned to another responding company position in subsequent scenarios, with the objective of minimizing learning from one experiment to another. For example, crews in the role of engine 1 in a morning scenario might be assigned to the engine 3 position in the afternoon, thus eliminating learning from exact repetition of a task as a factor in time to completion. Additionally, participating crews from both Montgomery County and Fairfax County were from three different shifts, further reducing opportunities for participant repetition in any one position.

Response Time Assumptions

Response time assumptions were made based on time objectives set forth in the *NFPA 1710*. Time stagger allocations were set by the project technical advisors in order to assess the impact of arriving unit time separation on task start and completion times, as well as the overall scene time.

Below are the values assigned to the various time segments in the overall response time. The total of the response time segments may also be referred to as the total reflex time.

1. Fire ignition = time zero
2. 60 s for recognition (detection of fire) and call to 9-1-1
3. 60 s for call processing/dispatch
4. 60 s for turnout¹⁰
5. Close Stagger = 240 s travel time FIRST engine with 60 s ladder-truck lag and 90 s lag for each subsequent engine
 - a. Truck arrives at 300 s from notification
 - b. Second engine at 330 s from notification
 - c. Third engine at 420 seconds from notification
6. Far Stagger = 240 s travel time FIRST engine with 120 s ladder-truck lag and 150 s lag for each subsequent engine
 - a. Truck arrives at 360 s from notification
 - b. Second engine arrives at 390 s from notification
 - c. Third engine arrives at 540 s from notification.

The design of this part of the experiments allowed firefighter entry into the burn building. The next part of the experiments required a modified methodology.

¹⁰ After the experiments were complete, the NFPA 1710 technical committee released a new edition of the standard that prescribes 80 seconds for turnout time.

Part 3: Room and Contents Fires

As previously discussed, NFPA 1403 prohibits firefighters in a training exercise from entering a structure with sufficient fuel load to result in room flashover. But the value of the data from the time-to-task experiments lies not just in the duration and time-of-completion statistics for tasks, but also in measuring the tenability of the atmosphere for occupants urgently needing firefighter assistance. Therefore Part 3 of the experiments (room and contents fires) used a larger fuel load to focus on the seven of the 22 tasks that cause a change in the fire behavior through ventilation or active suppression:



The Tornado Remote Controlled Monitor is Produced by Task Force Tips, Valparaiso, Indiana, USA. Permission to publish courtesy of Task Force Tips

1. Forced entry of the front door
2. Water on fire
3. Second floor window #1 ventilated (burn room window)
4. Second floor window #2 ventilated (front window, near corner)
5. Second floor window #3 ventilated (front window, near front door)
6. First floor window #1 ventilated (window beside the fire room)
7. First floor window #2 ventilated (self-ventilated at flashover)

Because the fuel load was sufficient for flashover, all firefighter activity was conducted outside the building. Tasks that in Part 3 required entry into the building, such as search or interior utility control, were factored into this part by delaying the next task for the average duration of the task from Part 2. Firefighters in full gear opened the door with a gloved hand or opened windows from the ground with a tool such as a pike pole or angle iron, again at the time specified by the averages from Part 2. Averages were derived from the three iterations of each scenario. The different number of iterations in Part 3 will be explained later in this report.

Because firefighters could not enter the building, a nozzle controlled from the instrumentation room was installed. The nozzle was placed in the room directly outside the burn room and oriented toward the burn room near the doorway in order to best emulate the nozzle location of live firefighter suppression (see Figure 22). The nozzle was encased with mineral wool and heavy-duty aluminum foil (bottom picture in Figure 22) to protect the electronics and wiring from the intense radiation energy emitted by the fire. Blocks were used to anchor the nozzle against the lateral forces exerted by the momentum of the water supply. The activation time for suppression was determined by the data from the time-to-task test results.

A 15° spray pattern was directed toward the seat of the fire and swept horizontally from side to side. While the remotely controlled hose line knocked down the majority of the fire, it was



Figure 22: Remotely Controlled Fire Suppression Nozzle for Room and Contents Fires

not as effective as a live firefighter with a better view into the room of origin. Therefore, after the fire was diminished, a supplemental stream was applied through the burn room window in order to control the fire (see Figure 23). All personnel on the hose line were in full turnout gear and self-contained breathing apparatus during the exterior application of water.

Fuel Packages for the Room and Contents Fires

In order to maximize the repeatability of the fire development, nominally identical rooms of furniture of identical manufacturer, style, and age were used for each test. A plan-view schematic of the furniture is shown in Figure 24 and pictures of the burn room prior to testing are shown in Figure 25. Key dimensions, mass, and materials for combustible furnishings are detailed in Appendix C.



Figure 23: Supplemental Suppression Applied for Room and Contents Tests

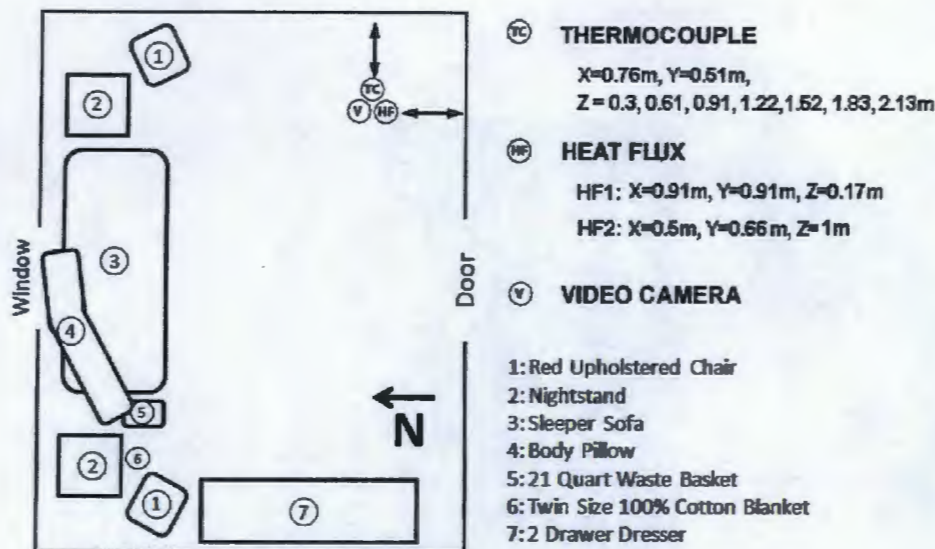


Figure 24: Configuration of Furnishings in Burn Room (Room and Contents Fires)



Figure 25: Pictures of the Room and Contents Furnishings

The ignition source consisted of a cardboard book of 20 matches that was ignited by an electrically heated wire, often referred to as an electric match. The electric match was placed near the bottom of a 21 qt (19.9 L) polypropylene waste container. The height of the waste container was 15.5 in (394 mm) with interior dimensions at the top opening of 14.5 in (368 mm) by 11.3 in (287 mm). Approximately 0.7 lbs (0.3 kg) of dry newspaper was added to the waste container. The majority of the newspaper was folded flat, and placed on edge along the sides of the waste container. Four sheets of newspaper, 22 in (559 mm) by 25 in (635 mm) were crumpled into "balls" approximately 3.9 in (100 mm) diameter and placed on top of the electric match in the center of the waste container.

Experimental Matrix for Room and Contents Fires

Sufficient amounts of furniture for 16 rooms were available for the room and contents fires, so eight experiment scenarios were conducted — each with a replicate. Because the time to untenable conditions was a primary variable of interest in the room and contents fires, the arrival time of the first due engine was a paramount consideration. Because the effects of the subsequent apparatus stagger were explored in the time-to-task tests, the stagger was fixed at the "close arrival" time. Additionally, a baseline measurement was required to compare the effectiveness of response to the absence of a fire department response. Therefore, a five-person, later arrival combination was eliminated in favor of a no-response scenario (with replicate). Table 3 summarizes the 16 tests conducted.

The first due engine arrival times were determined using the following assumptions: ignition of the fire occurs at

Crew Size	First Due Arrival Time
2-Person	Early Arrival of First Engine (6.5 min) – close stagger
3-Person	Early Arrival of First Engine (6.5 min) – close stagger
4-Person	Early Arrival of First Engine (6.5 min) – close stagger
5-Person	Early Arrival of First Engine (6.5 min) – close stagger
2-Person	Later Arrival of First Engine (8.5 min) – close stagger
3-Person	Later Arrival of First Engine (8.5 min) – close stagger
4-Person	Later Arrival of First Engine (8.5 min) – close stagger
No Response (Baseline)	N/A

Table 3: Experimental Matrix for Room and Contents Tests (Each Conducted in Replicate)

time zero. Smoke detector activation and a call to 9-1-1 occurs at 60 seconds after the fire starts. Call intake and processing requires an additional 90 seconds. The firefighters take 60 seconds to complete their turnout at the station and begin travel to the scene. Thus travel time begins 3.5 minutes into experiment. The two levels of arrival time are then determined by two different travel times: early arrival assumes a three-minute travel time, while later arrival assumes a five-minute travel time. For all scenarios in the room and contents experiments, the close stagger (60 seconds) between subsequent apparatus times was used.

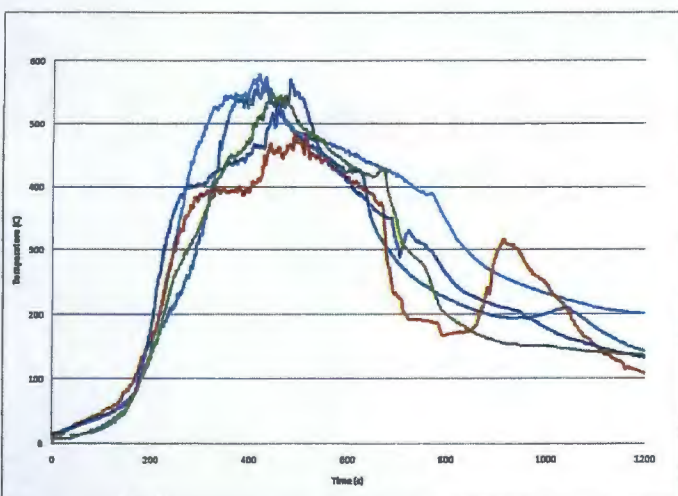
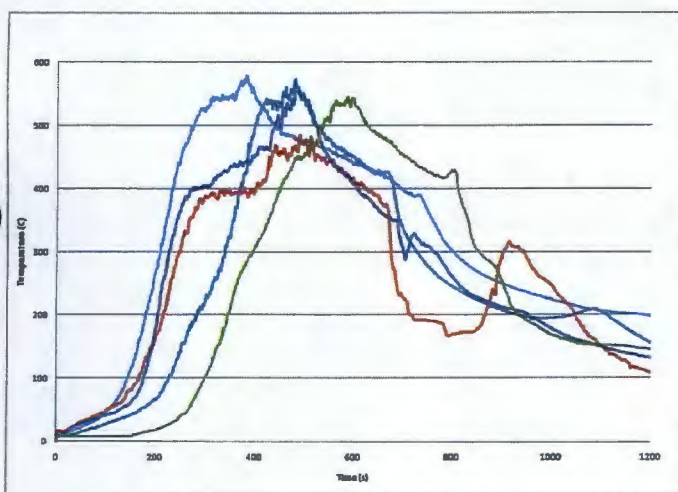


Figure 26: Direct Comparison of Temperatures, Before (Top) and After Adjustment (Bottom)

Procedure for Minimizing the Effect of Variance in Fire Growth Rate

Fires involving furnishings have inherent variance in burning behaviors. Factors such as humidity and minor variations in materials (particularly worn furnishings that may have different foam compression or fabric wear patterns), can result in uncertainty of 20 % or more, despite significant efforts to enhance repeatability. The early growth period of fire development is often associated with the greatest variance, since minor factors (as discussed above) can influence the thermal environment more easily when the fire is small. Therefore, the room and contents fires were normalized to the 212 °F (100 °C) temperature near the ceiling in the burn room in order to minimize the variance of the room and contents fires. The time at which the burn room reached this temperature (usually in approximately 180 seconds) rather than the actual ignition time, was designated as the “zero time.”

Figure 26 shows the time-temperature curves before and after normalizing at 100°C. This approach was implemented during the experiments by watching the time temperature data in real-time from the instrumentation room and announcing the “zero-time” over the fireground radio system. The normalization procedure did not negatively affect tenability measurements in the target room because when the fire is small, products of combustion do not reach the room because of lack of momentum. Therefore, adjusting all room and contents tests to the same upper layer temperature was an appropriate way to minimize variance.

Milestone Times for Critical Tasks

As stated earlier, firefighters could not enter the burn building during the room and contents experiments because of the danger for potential flashover in an experimental scenario. Therefore, prescribed tasks were performed at specified times based on data from part 2. In this section we report on significant data gathered from instrumentation and describe an additional part of the experiments designed to extend our understanding of the effect of crew size and stagger on the tenability of the atmosphere in a burning structure.

Table 4 (page 32) identifies significant tasks selected as key milestones because of the way they affect fire behavior and atmospheric tenability inside the structure.

2-Person Close Stagger	
Milestone Tasks	Time from ignition (min : s)
Breached Door	8:44
Water On Fire	9:56
Upper Fire Window	13:01
Ground Non-fire Window	14:51
Upper Corner Window	17:55
Upper Front Door Window	19:55
Ground Fire Window	4:30
3-Person Close Stagger	
Milestone Tasks	Time from ignition (min : s)
Breached Door	7:48
Water On Fire	8:54
Upper Fire Window	11:26
Ground Non-fire Window	13:31
Upper Corner Window	15:54
Upper Front Door Window	17:58
Ground Fire Window	4:30
4-Person Close Stagger	
Milestone Tasks	Time from ignition (min : s)
Breached Door	7:46
Water On Fire	8:41
Upper Fire Window	9:23
Ground Non-fire Window	10:32
Upper Corner Window	11:46
Upper Front Door Window	13:45
Ground Fire Window	4:30
5-Person Close Stagger	
Milestone Tasks	Time from ignition (min : s)
Breached Door	7:35
Water On Fire	8:03
Upper Fire Window	10:11
Ground Non-fire Window	10:54
Upper Corner Window	12:31
Upper Front Door Window	12:47
Ground Fire Window	04:30

Table 4: Tasks That Affect Fire Behavior and Atmospheric Tenability

Analysis of Experimental Results

This section describes the analytic approaches used to address the research objectives of the study. First the statistical methods used to analyze the fireground time-to-task observations are presented. Then the time-to-task data and the room and contents data were combined to assess crew performance in relation to tenability within the structure.

Time-to-Task Analysis

Time-to-task data were compiled into a database and assessed for outliers and missing entries. Because all time-to-task experiments were conducted in triplicate, missing data were apparent and were reviewed via video and radio tapes. Missing data attributable to timer error were replaced by a time observed in the video. Where video and/or radio documentation was not adequate, missing data were recoded to the mean of the task times from the other two experiments.

Data Queries

The statistical methods used to analyze the time-to-task data were driven by a principal goal of this research project — to assess the effect of crew size, first-due engine arrival time, and subsequent apparatus stagger on time-to-task for critical steps in response and fire fighting. This research goal motivated the development of four specific research questions (see Figure 27) that in turn pointed to specific statistical analyses for generating inference and insight.

Statistical Methods – Time-to-Task

The analysis of the time-to-task data involved a sequence of multiple linear regressions using Ordinary Least Squares to generate and test the effects of staffing and stagger on timings. The regressions were of the form:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_k x_{ik} + \varepsilon_i$$

where the x_{jk} reflect factors such as stagger and crew size, and the y represents our dependent/outcome variable.

Time-related outcomes (i.e., the dependent variables in the regression equations) could include task duration, elapsed time to start the task, and elapsed time until task completion, all measured in seconds. Table 5 (page 34) lists the time-related outcomes used to test the effect of crew size and stagger for the tasks in the field experiments.

The effects of crew size and stagger were explored using indicator variables in the regression analyses. The coefficient for a given indicator (for example, crew size of four relative to a crew size of two) indicated the number of seconds the larger crew size added or reduce the timing outcome of a task. Crew sizes were collapsed in some regressions to test whether the timings of “larger” crew sizes of four and five were significantly different than “smaller” crew sizes of two and three. Interaction terms were not assessed in these regression analyses because of the small number of experiments available for analysis.

Standard t-tests examined statistical significance (i.e., to see if the hypothesis of “no impact” could be rejected) to estimate the impact of several specific configurations:

- crew sizes of three versus two
- crew sizes of four versus three
- crew sizes of five versus four

Time-to-Task Research Questions

- 1) How do crew size and stagger (i.e., timing of between first engine and subsequent apparatuses) affect overall (i.e., start to completion) response timing?
 - a. To what extent do variations in crew size affect overall response timing?
 - b. To what extent do variations in both crew size and stagger affect overall response timing?
- 2) How do crew size and stagger affect the timings of task initiation, task duration, and task completion for each of the tasks comprising the suite of 22 tasks?
 - a. To what extent do variations in crew size affect timings across the suite of tasks?
 - b. To what extent do variations in both crew size and stagger affect response timings across the suite of tasks?
- 3) How does crew size affect elapsed times to achieve three critical events known to change fire behavior or atmospheric tenability for occupants?
 - a. Entry into structure
 - b. Water on fire
 - c. Ventilation of each window (three upstairs and one downstairs window and the burn room window)
- 4) How does the elapsed time to achieve the national standard of assembling 15 firefighters at the scene (measured using “at hydrant” as the start time) vary by crew sizes of 4 and 5?

Figure 27: Research Questions for Time-to-Task Experiments

- (occasionally) five versus two, and four versus two
- larger (four & five combined) versus smaller (two & three combined) and
- stagger

The specific tests for each task (regression analysis) are shown in the Appendix E. The actual coefficients of each regression and their corresponding standard errors are presented in Appendix F. To infer impact, significant tests were conducted at the 0.05 significance level. Only statistically significant contrasts of crew size and/or stagger are included in this section of the report. Graphic expositions of relevant time/task related findings are then presented as well. Where stagger was statistically significant, the effects are graphed separately. Where stagger was not statistically significant, the data for crew size were combined.

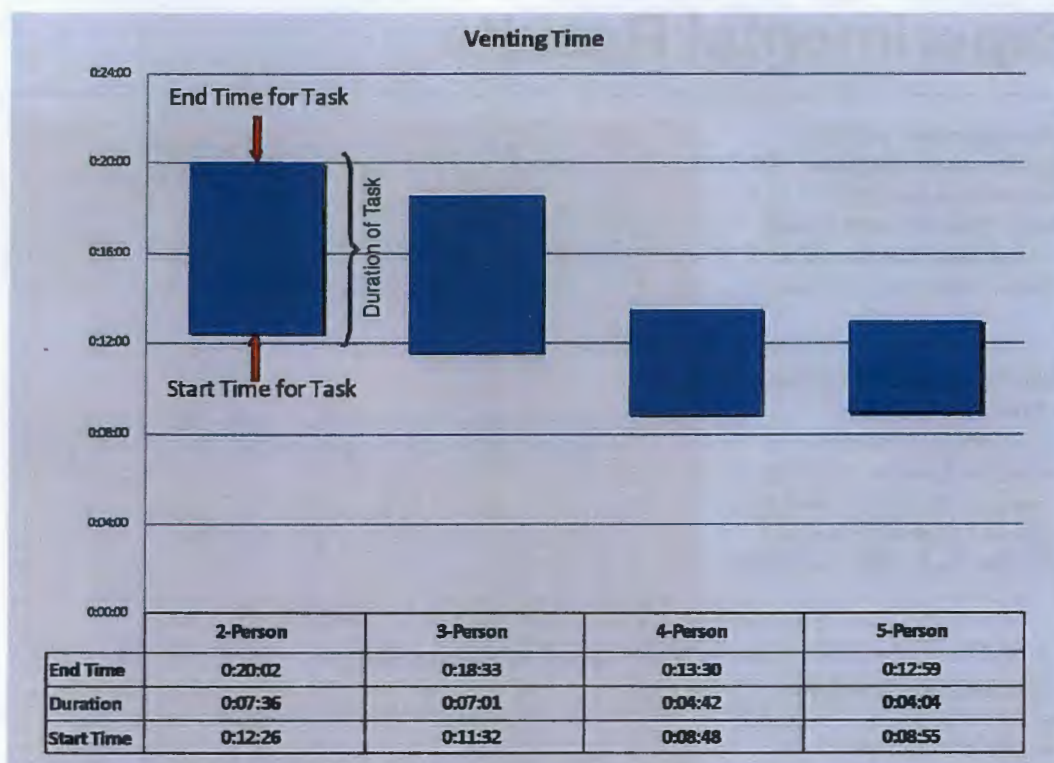


Figure 28: Example Time-to-Task Graph

Task:	Time-to-Task Outcome Measures		
	Elapsed Time Until Start*	Elapsed Time for Task Completion*	Duration*
Conduct size-up	X	X	X
Position attack line	X		X
Establish 2 in - 2 out		X	
Establish RIT		X	
Gain forced entry	X		
Advance line	X		
Advance line		X	
Advance backup line to door	X	X	
Advance backup line to stairwell	X		
Advance backup line 2		X	
Conduct primary search 1	X		
Ground ladders in place		X	X
Horizontal ventilation, second story, window 3	X	X	
Horizontal ventilation, second story, window 2	X	X	
Horizontal ventilation, second story, window 1	X	X	
Horizontal ventilation, first story, window 2	X	X	
Control utilities interior	X		
Control utilities exterior	X		
Conduct secondary search	X		
Check for fire extension walls	X		
Check for fire extension ceiling	X		

* The columns of this table show the dependent variables, and the rows indicate the Tasks; an 'X' in a cell indicates that a separate regression analysis was conducted for a given dependent variable.

Table 5: Dependent Variables Used in a Regression Analysis of the Effect of Crew Size and Stagger on Time-to-Task Outcomes

Regression analyses

Appendix F presents the regression results for each task and relevant outcome, along with their corresponding standard errors. The results of conducting significance tests at the 0.05 level of significance are shown in Appendix E. Rather than detailing each of the lengthy lists of coefficients found to be significant, only the answers to the primary research questions are presented for each task.

Measurement Uncertainty

The measurements of length, temperature, mass, moisture content, smoke obscuration, and stopwatch timing taken in these experiments have unique components of uncertainty that must be evaluated in order to determine the fidelity of the data. Appendix G summarizes the uncertainty of key measurements taken during the experiments. Importantly, the magnitudes of uncertainties associated with these measurements have no impact on the statistical inferences presented in this report.

How to Interpret Time-to-Task Graphs

Figure 28 presents a sample time-to-task analysis, in this case results for venting time. Each crew size has a column graphic showing the start time and completion time for the task. Visually, columns starting lower on the graph depict deployment configurations that resulted in earlier start times. The height of the column graphic is a visualization of the duration of the task, taller columns indicating longer times to task completion. Time data are also shown in a table below the graph. Where stagger was statistically significant, the effects are graphed separately. Where stagger was *not* statistically significant, as in the illustration, the data for crew size were combined.

Time-to-Task Graphs

Overall Scene Time (Time to Complete All 22 Tasks)

The four-person crews operating on a low-hazard structure fire completed the same number of tasks on the fireground (on average) 7 minutes faster than the two-person crews (see Figure 29). The four-person crews completed the same number of fireground tasks (on average) 5.1 minutes faster than the three-person crew. The four-person crews were able to complete necessary fireground tasks on a low-hazard residential structure fire nearly 30 % faster than the two-person crews and nearly 25 % faster than the three-person crews. Although on the low-hazard residential structure fire, adding a fifth person to the crews did not show any additional decrease in fireground task times, the benefits of a five-person vs. a four-person crew are significant in other measurements, particularly the "water-on-fire" time. Additionally, the greater need for five-person crews for medium- and high-hazard structures, particularly in urban settings, has been documented in other studies (Backoff et al., 1980; Cushman, 1982; McManis Associates et al., 1984) and five-person crews are required for areas that contain medium and high-hazard structures in fire protection consensus standards.¹¹

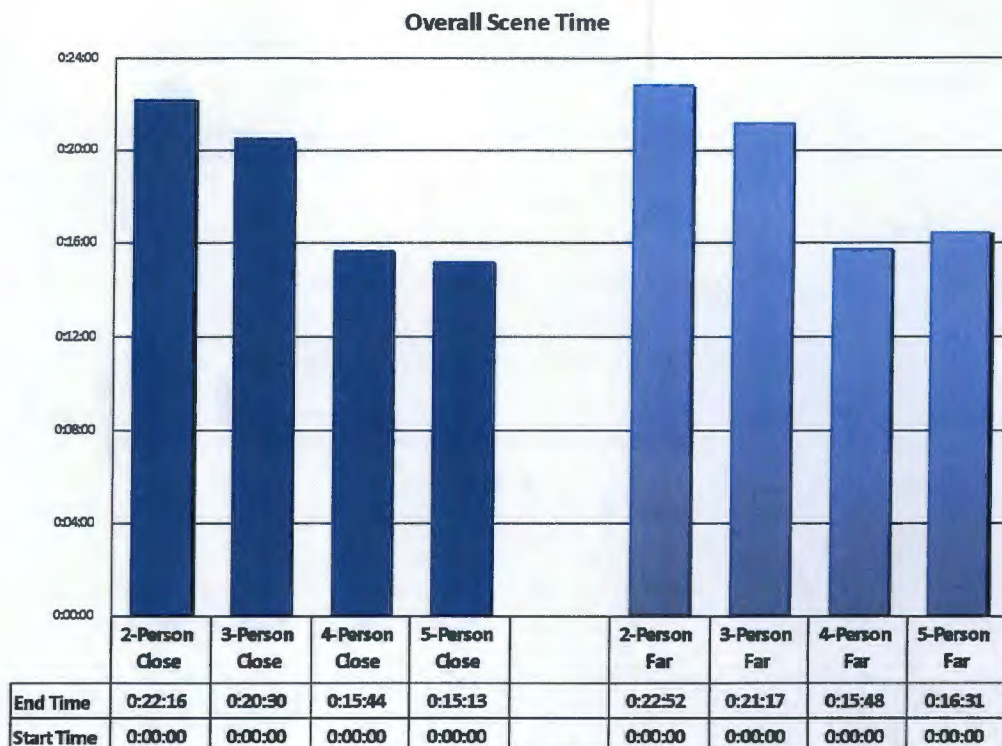


Figure 29: Overall Scene Time

¹¹ NFPA 1710, Section 5.2.3.1.2 and Section 5.2.3.2.2: In jurisdictions with tactical hazards, high-hazard occupancies, high incident frequencies, geographical restrictions, or other pertinent factors as identified by the AHJ, these companies shall be staffed with a minimum of five or six on duty members.

Overall Scene Time and Crew Sizes

The graphs in Figure 30 show average times for each task by crew size.

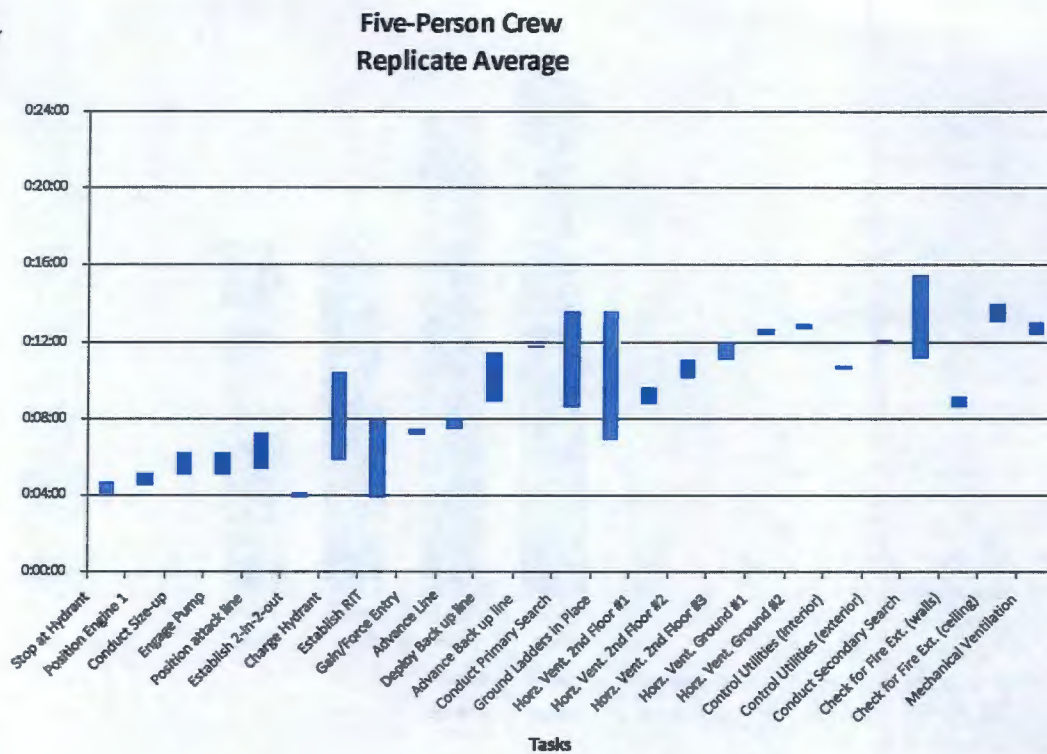


Figure 30 a: Overall Scene Time-Five Person Crew

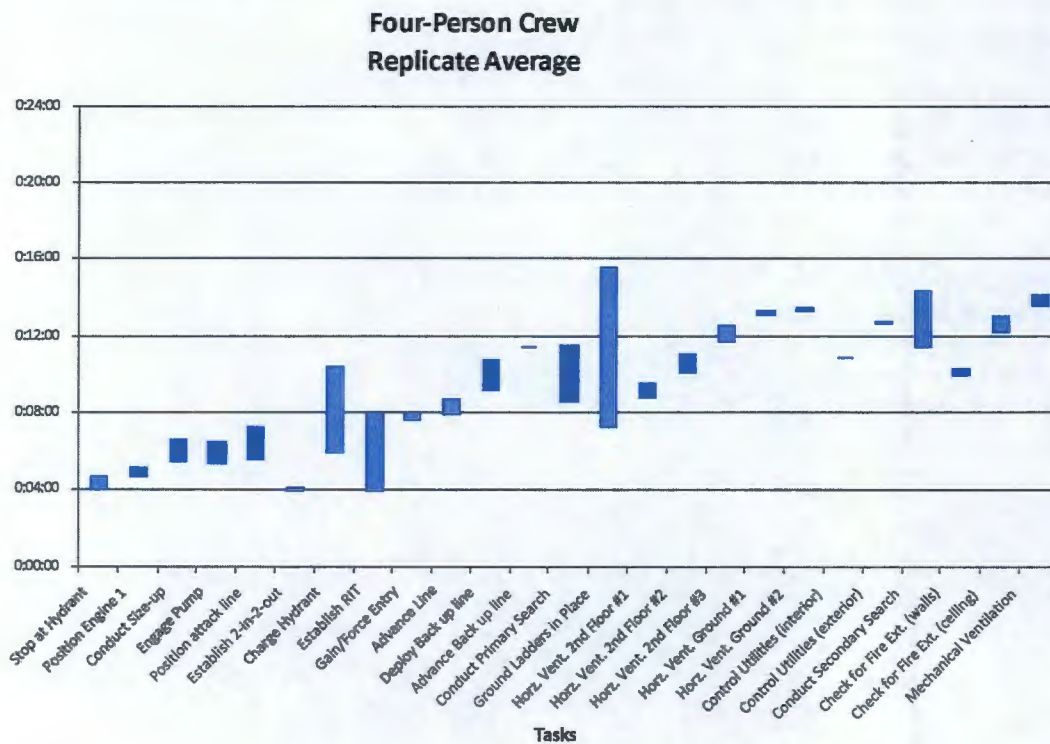


Figure 30 b: Overall Scene Time-Four Person Crew

Three-Person Crew Replicate Average

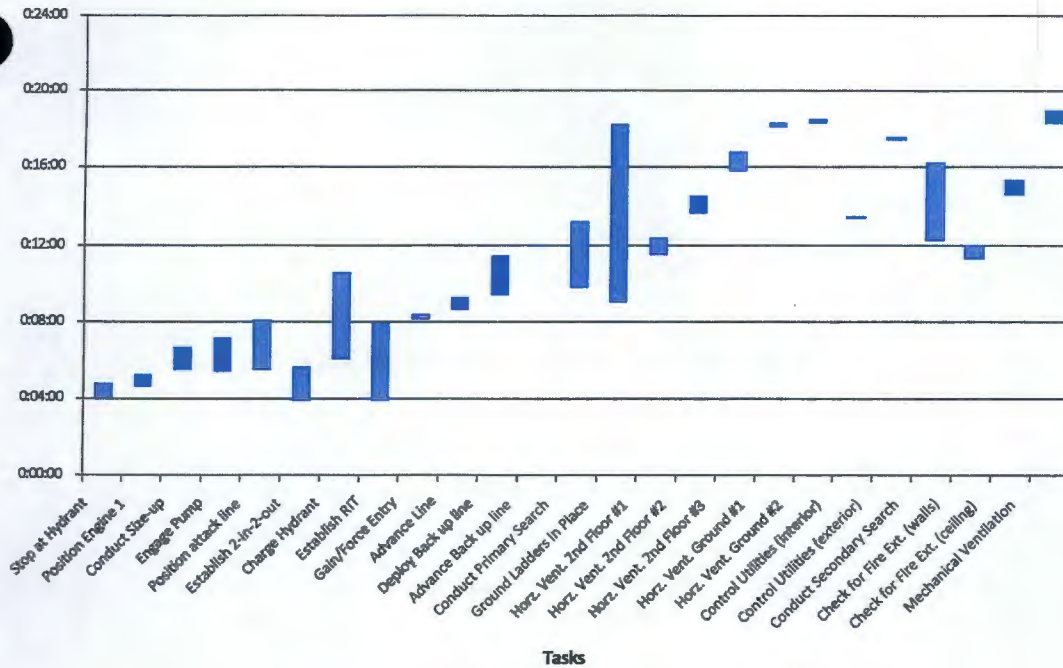


Figure 30 c: Overall Scene Time-Three Person Crew

Two-Person Crew Replicate Average

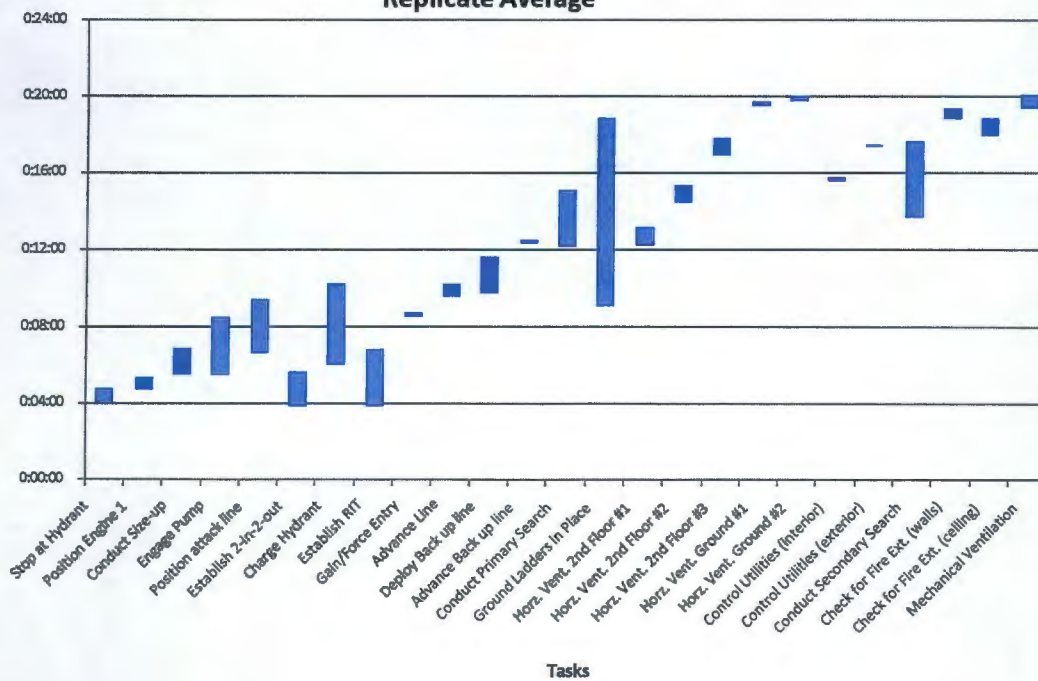


Figure 30 d: Overall Scene Time-Two Person Crew

Advance Attack Line Time (Hose Stretch Time)

Figure 31 measures the interval from the start of the task "Position Attack Line" to the end of the task "Advance Attack Line." In comparing four- and five-person crews to two and three-person crews collectively, the time difference for this measure was statistically significant at 76 seconds (1 minute 16 seconds). In conducting more specific analysis comparing all crew sizes to a two-person crew the differences are more distinct. A two-person crew took 57 seconds longer than a three-person crew to stretch a line. A two-person crew took 87 seconds longer than a four-person crew to complete the same task. Finally, the most notable comparison was between a two-person crew and a five-person crew, with a 122-second difference in task completion time.^{12, 13}

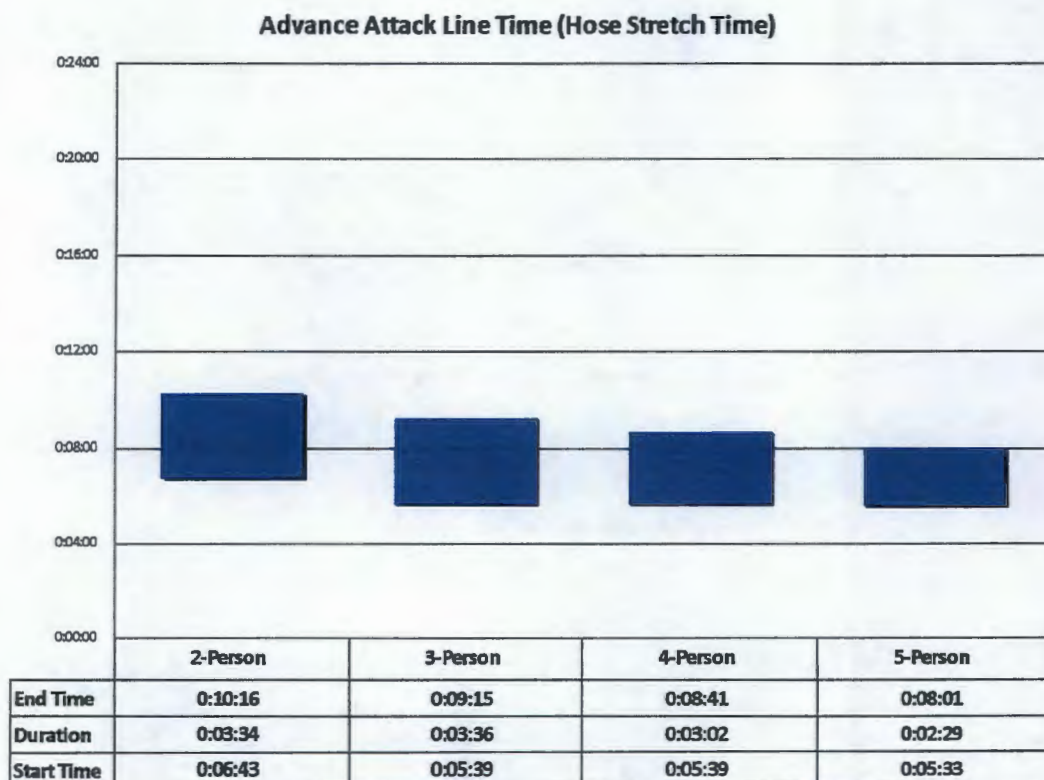


Figure 31: Advance Line Time (Hose Stretch Time) by Crew Size

¹² Apparatus stagger was not statistically significant, so the data for crew size were combined.

¹³ Where subtracting the start time from the end time yields a result that differs from the duration noted in the chart by one second, it is the result of rounding fractional seconds to the nearest whole second.

Water on Fire Time

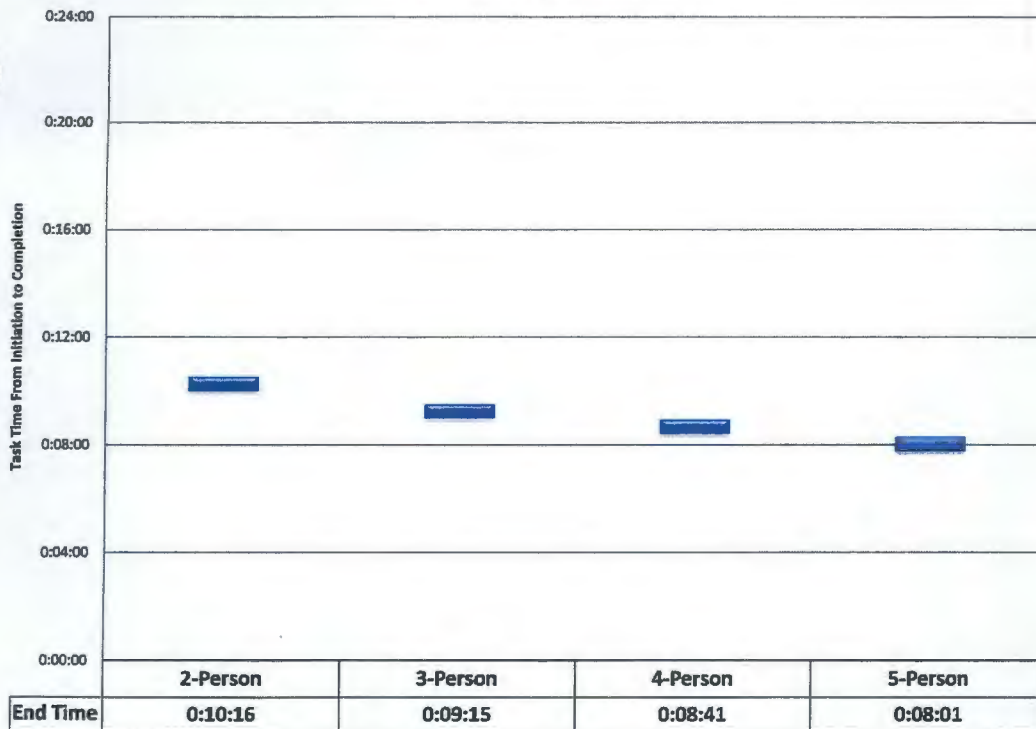


Figure 32: Water on Fire Time by Crew Size and Stagger

Time to Water on Fire

There was a 10% difference in the "water on fire" time between the two- and three-person crews. There was an additional 6% difference in the "water on fire" time between the three- and four-person crews. (i.e., four-person crews put water on the fire 16% faster than two person crews). There was an additional 6% difference in the "water on fire" time between the four- and five-person crews (i.e. five-person crews put water on the fire 22% faster than two-person crews).

Advance Back Up Line



Figure 33: Times to Advance Backup Line by Crew Size and Stagger

Advancing a Backup Line

Advancing a backup line to the door and stairwell was started 16 % faster and completed 9 % for replicates with shorter staggers between company arrivals. Advancing a backup line is typically a task completed by the third arriving engine on a full alarm assignment and is critical to the safety of firefighters already in the building on the initial attack line. For this task, stagger of arrival was statistically significant and is an important consideration for overall station location and full alarm response capability. The differences can be seen in Figure 33, which shows the time from the start for the task "Deploy Backup Line" to the end of the task "Advance Backup Line."

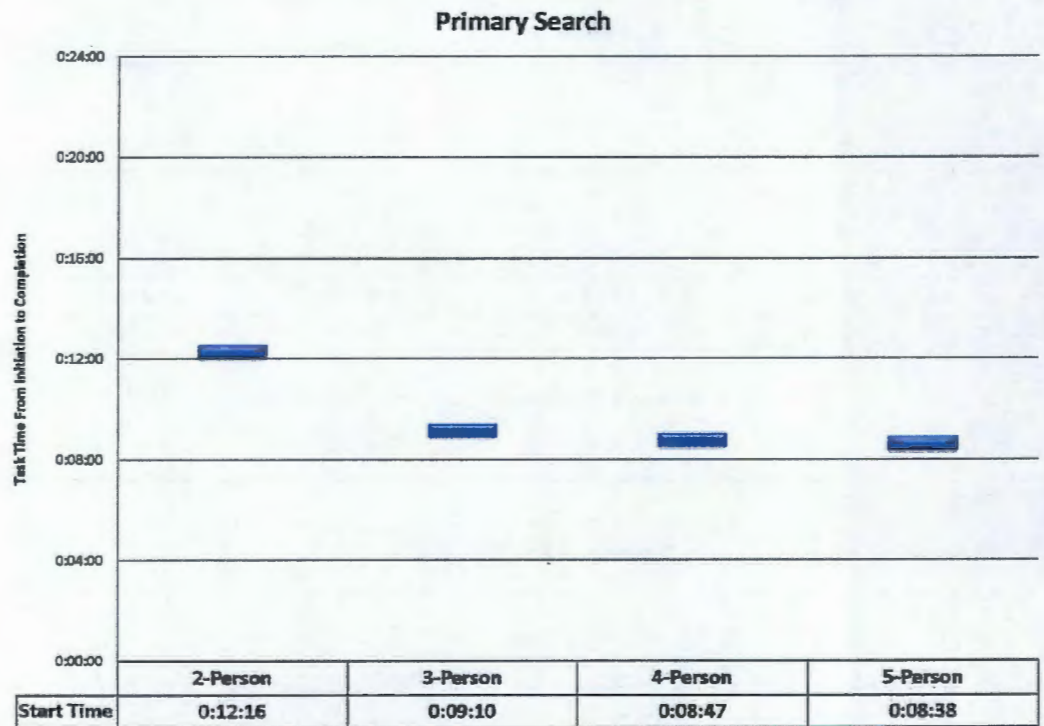


Figure 34: Times to Conduct Primary Search by Crew Size

14 Stagger was not significant, so data from close and far were combined to increase statistical power.

Laddering Time

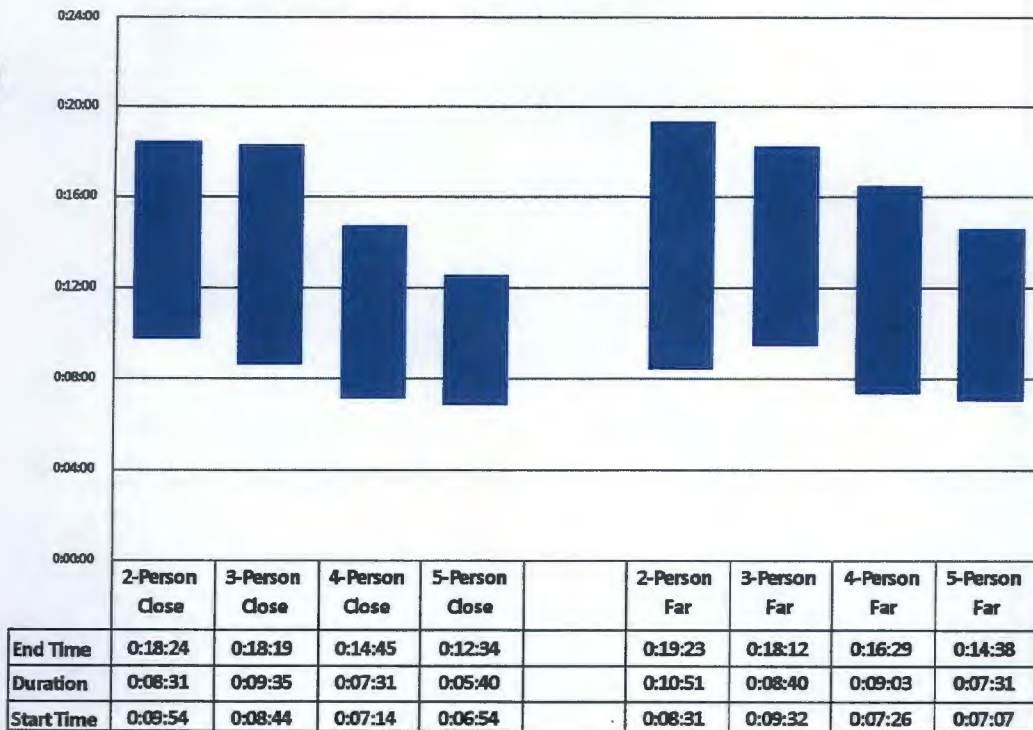


Figure 35: Laddering Time by Crew Size

Primary Search

Figure 34 summarizes the times that crews took to start the primary search. On the low-hazard, two-story single-family dwelling 2,000 sq ft (186 m²), the three-person crew started a primary search/rescue more than 25 % faster than the two-person crew. In the same structure, the four- and five-person crews started a primary search 6 % faster than the three-person crews and 30 % faster than the two-person crew. Note that there is no end time included in this figure. Primary search end times were reliant upon radio communication by firefighters inside the structure. On occasion this communication did not occur or was delayed. Therefore data reliability was insufficient for analysis of task duration and end time.¹⁴

Venting Time

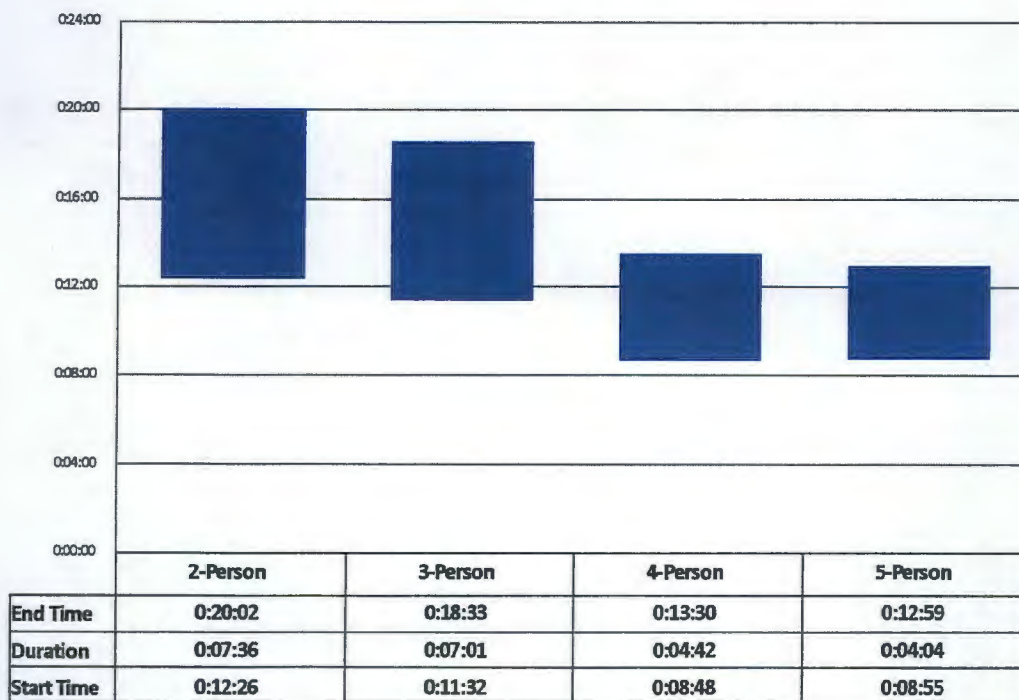


Figure 36: Ventilation Times by Crew Size¹⁶

Laddering and Venting Time

A four-person crew operating on a low-hazard structure fire completed laddering and ventilation (for life safety and rescue) 30 % faster than a two-person crew and 25 % faster than a three-person crew.

Ground laddering time started with the removal of the first ladder from the truck and stopped at end time of the last ladder put in place. A total of four ladders were raised on each experiment.

Truck operations ventilation time is the time from the start time of ventilation of the first window until the last window ventilation was complete.

The differences in start times and duration of the tasks can be seen in Figure 35 and Figure 36.

¹⁵ Stagger was not statistically significant, so the data for crew size were combined.

Industry Standard Effective Response Force Assembly Time

NFPA 1710 requires that a fire department have the capability to deploy an initial full-alarm assignment to a scene within eight-minutes (480 seconds). The number of people required falls between 15 and 17, depending on whether an aerial apparatus is used, and/or if two engines are being used to provide a continuous water supply. In these experiments, the measurement for an effective response force assembly time started from the first engine arrival at the hydrant and ended when 15 firefighters were assembled on scene. Figure 37 reveals the differences in assembly times between the four and five-person crews. An effective response force was assembled by the five-person crews a full three minutes faster than the four-person crews. It is important to note that (by definition), the two- and three-person crews were unable to meet this standard at any time during the experiments.¹⁶

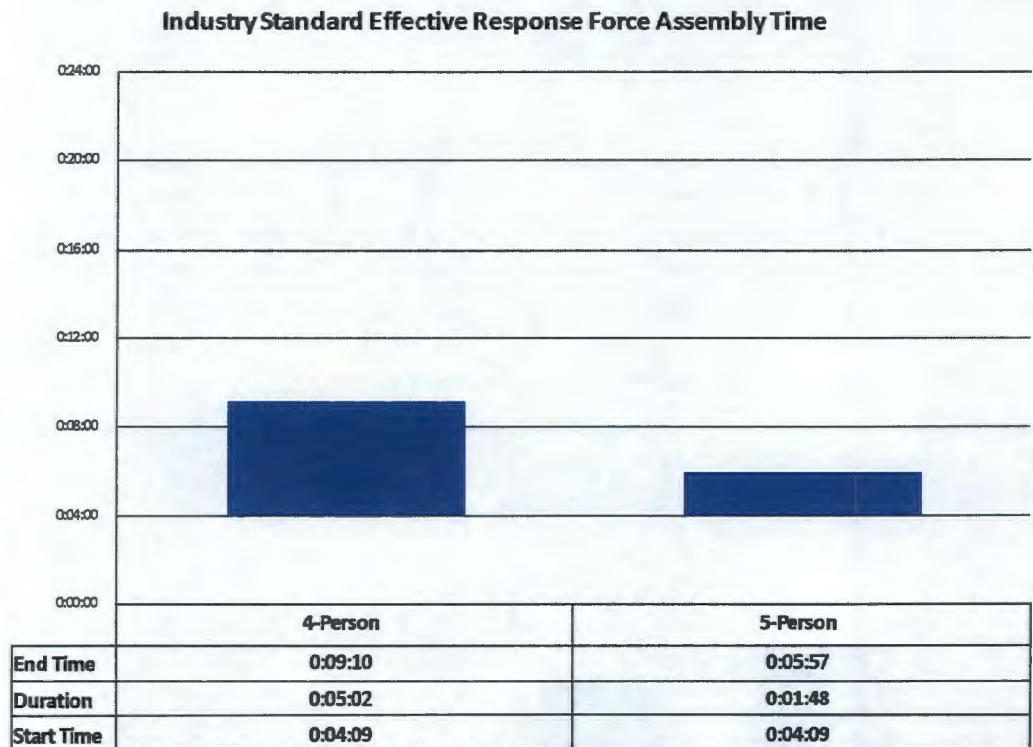


Figure 37: Industry Standard Effective Response Force Assembly Time

¹⁶ Stagger was not statistically significant, so the data for far and near stagger were combined.

Part 4: Fire Modeling

In the room and contents experiments conducted in Part 3 of the study, instrumentation measured oxygen, carbon dioxide, and carbon monoxide concentrations. Data were grouped by the type of experiment conducted with respect to crew size and first due engine arrival time. As previously shown in the experimental matrix, each group contained two replicate tests. In each group of data the results of the replicates were averaged to simplify the data for further comparison. Figure 38 and Figure 39 show the typical concentration curves for the experiments.

These two graphs show the ranges representative of those found in the experiments. Charts of gas curves for the remainder of the experiments — for both the burn room and the target room — can be found in Appendix H.

Fire Modeling Methods

A primary goal of fire department response is to prevent civilian injuries and deaths. Because the significant majority of fire deaths in the United States occur in residences, a rapid fire service response provides the last line-of-defense against civilian fire deaths. Further, because the fire service is less likely to rescue occupants intimate with the fire (i.e., inside the room of origin where conditions deteriorate rapidly), tenability measurements were taken in a remote bedroom on the second floor of the residential burn structure. The gas and temperature measurements were taken at the 5 ft (1.5 m) height above the floor, 3 ft (0.9 m) from the west wall in order to simulate a nonambulatory occupant (e.g., someone asleep, under the influence of alcohol or drugs, or otherwise mobility impaired).

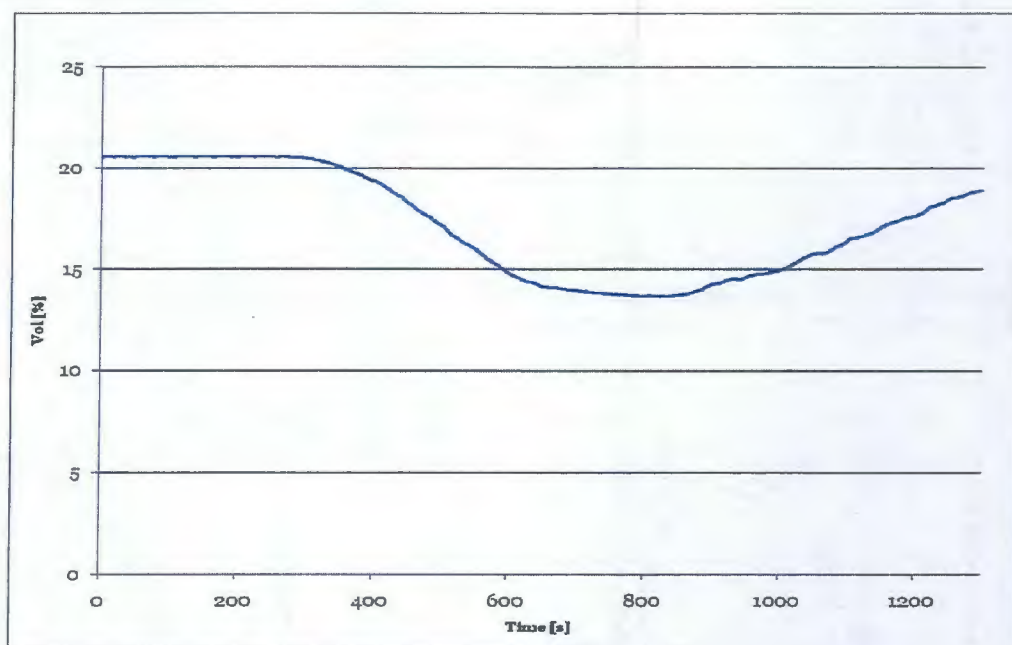


Figure 38: Representative Oxygen Concentration

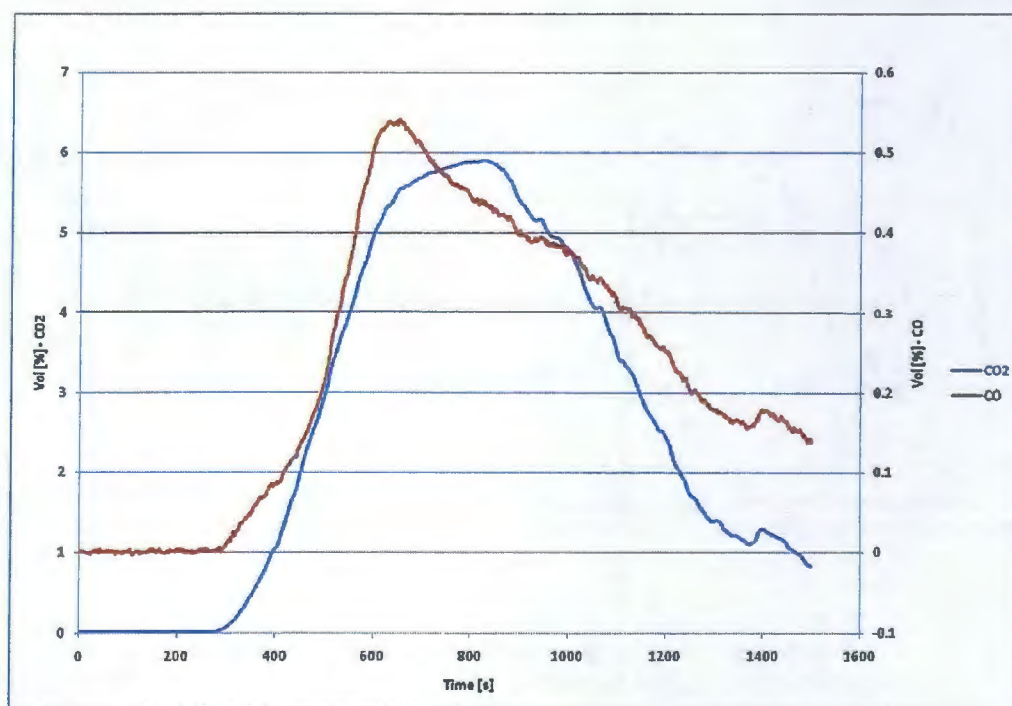


Figure 39: Representative Carbon Monoxide and Carbon Dioxide Concentrations

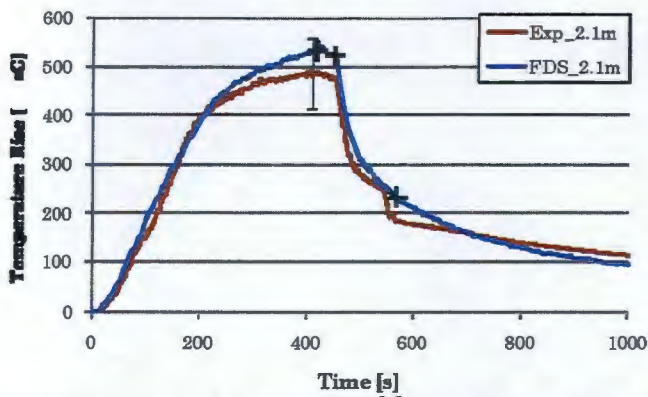


Figure 40: Measured vs. Predicted Temperature at the 2.1 m (6.9 ft) Thermocouple Location in the Burn Compartment

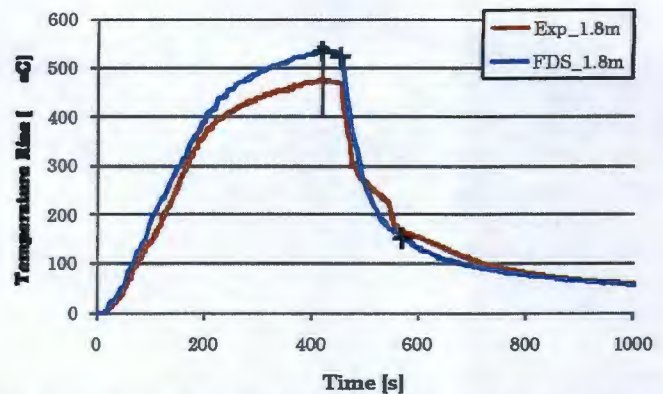


Figure 41: Measured vs. Predicted Temperature at the 1.8 m (5.9 ft) Thermocouple Location in the Burn Compartment

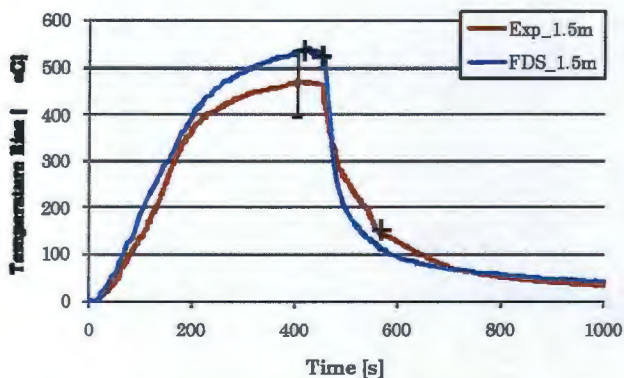


Figure 42: Measured vs. Predicted Temperature at the 1.5 m (4.9 ft) Thermocouple Location in the Burn Compartment

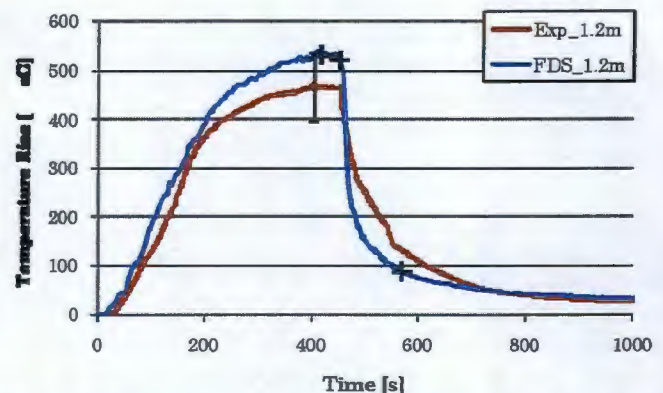


Figure 43: Measured vs. Predicted Temperature at the 1.2 m (3.9 ft) Thermocouple Location in the Burn Compartment

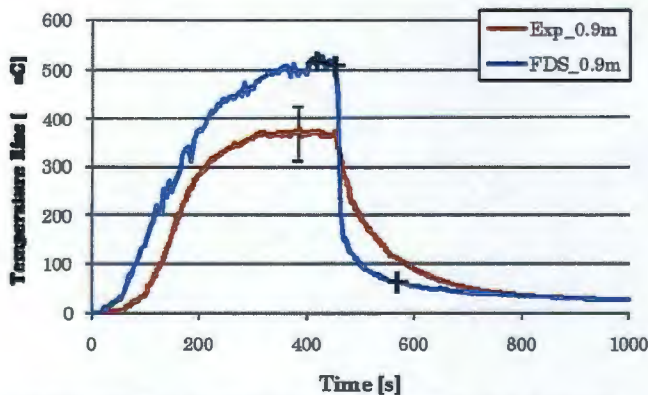


Figure 44: Measured vs. Predicted Temperature at the 0.9 m (2.9 ft) Thermocouple Location in the Burn Compartment

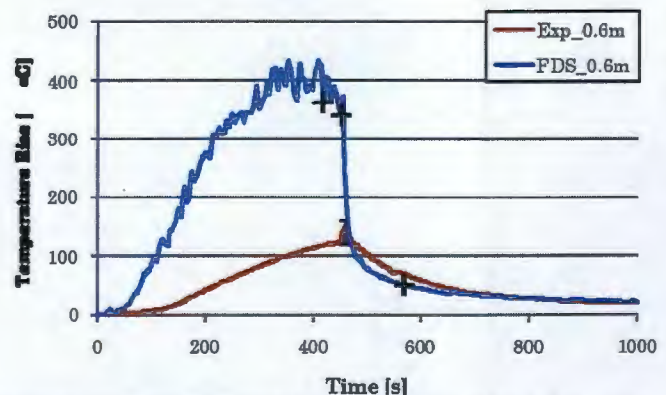


Figure 45: Measured vs. Predicted Temperature at the 0.6 m (1.9 ft) Thermocouple Location in the Burn Compartment

Computational fire models used the average suppression timings obtained from the time-to-task experiments under specific deployment configurations as inputs to the model. This quantitative approach eliminated the experimental variance of the fire. The resulting “computational” fire is repeatable, and therefore, any differences in occupant exposure to toxic gases will be due to the intervention times associated with a specific deployment configuration rather than the random variation that naturally occurs from fire to fire.

Fire simulations were completed using the NIST Fire Dynamics Simulator (FDS). FDS is a computational fluid dynamics model of fire-driven fluid flow. The first version of the FDS was released in 2000. FDS has been extensively verified and validated (USNRC 2007). Since the initial release, numerous improvements have been made and new features added. This study used FDS version 5.4.2 (Sub-version #4957), which was released on October 19, 2009. In order to calibrate the model, simulations were performed to replicate the experimental results observed in the

room-and-contents fires. Once the ability of the model to replicate experimental results was established, the different fire growth rates and deployment configurations were simulated to characterize the effectiveness of different responses relative to different fire growth rates.

The occupant exposure to toxic gases was assumed to occur until the occupant is rescued by the truck crew (start time of primary search plus one minute). Table 6 shows the “rescue time” for the various crew sizes that correspond to the test matrix for the room and contents experiments.

Part 4 of the experiments used fire modeling to correlate response times to atmospheric tenability in a burning structure. In order to calibrate the computer fire model, simulations were performed to replicate the experimental results observed in the room-and-contents fires.

Model inputs include building geometry and material properties, ventilation paths (doors, windows, leakage paths), and heat release rate of the fuel package. While the building geometry is easily measured and material properties (such as the thermal properties of drywall and concrete) are readily estimated, the heat release rate was not directly measured during the experiments. The heat release rate of the fuel package is the primary determinant of the production rate of heat, smoke, and gas species (e.g., carbon dioxide, carbon monoxide).

Figures 40 through 45 compare the experimental and simulated burn room temperatures using the burn room thermocouple tree. The tree contained thermocouples located at 0.6 m (1.9 ft), 0.9 m (2.9 ft), 1.2 m (3.9 ft), 1.5 m (4.9 ft), 1.8 m (5.9 ft), and 2.1 m (6.9 ft) above the floor. For additional information about the instrumentation type location, see Appendix C. The results for thermocouples located in the hot gas layer show excellent agreement. The temperature at the lower two thermocouples show an overprediction of the hot gas layer depth in the computer simulation. A small difference in the location of the interface height (the steep temperature gradient between the relatively cool lower gas layer and the hot upper gas layer), can result in significant predicted temperature differences with relatively little effect on the bulk heat and mass transport accuracy. This explanation is supported by the agreement of the temperatures in the remote bedroom.

Figure 46 compares the experimental and predicted oxygen concentration levels in the upstairs bedroom (measured at 5 ft (1.5 m) above the floor, centered above the bed). Figures 47 through 52 compare the experimental and simulated temperatures in the upstairs (target room) bedroom. As expected, the temperatures are moderated by mixing (cool ambient air mixes with hot combustion gases during transport between the burn room and the target room) and by thermal losses to the (cooler) surfaces between the two rooms.

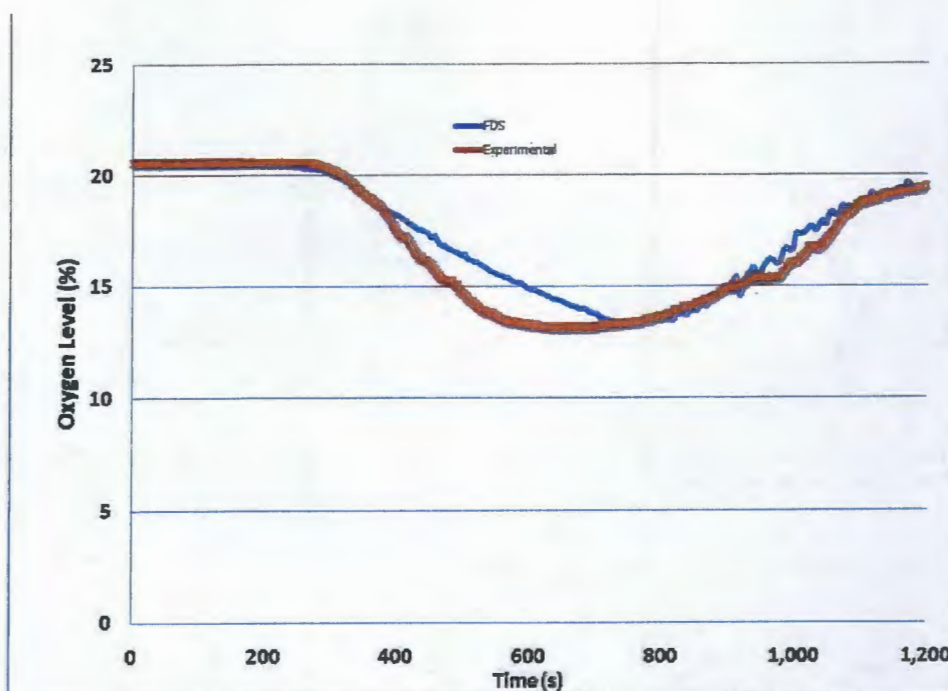


Figure 46: Measured Versus Predicted Oxygen Levels in the Upstairs Bedroom at 5 ft (1.5 m)

Once the model inputs were determined to agree with the experimental results, the input heat release rate was changed to represent three fire growth rates representative of a range of fire hazard development – slow, medium, and fast, which are described in greater detail in the following sections.

Time to Untenable Conditions: Research Questions

In the real world, fires grow at many different rates – from very slow, smoldering fires all the way to ultra-fast, liquid fuel or spray fires. In order to extend the applicability of the findings of this report beyond the one fire growth rate observed in part 3 of this report (residential room and contents fires), computer fire modeling was used to quantify the effectiveness of fire department operations in response to an idealized range of fire growth rates (characterized as slow, medium, and fast). Based on the research questions shown in Figure 53, fire modeling methods were then selected to maximize the applicability of the times to task results.

- 1) How do performance times relate to fire growth as projected by standard fire time/temperature curves?
- 2) How do these performance times vary by crew size, first due arrival time, and stagger?
- 3) How do crew size, stagger, and arrival time affect occupant tenability within the structure?

Figure 53: Research Questions for Time to Untenable Conditions

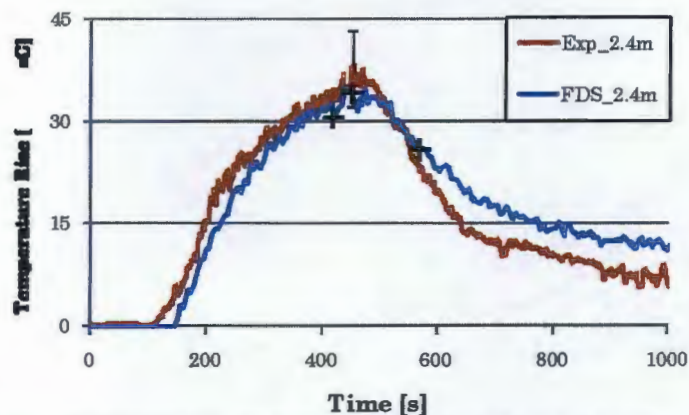


Figure 47: Measured vs. Predicted Temperature at the 2.4 m (7.8 ft) Thermocouple Location in the Bedroom

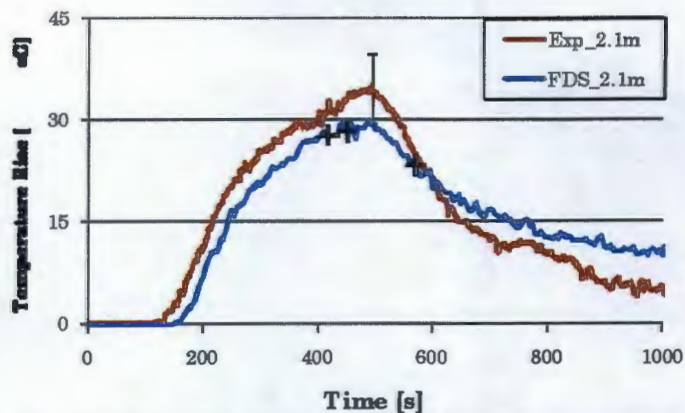


Figure 48: Measured vs. Predicted Temperature at the 2.1 m (6.8 ft) Thermocouple Location in the Bedroom

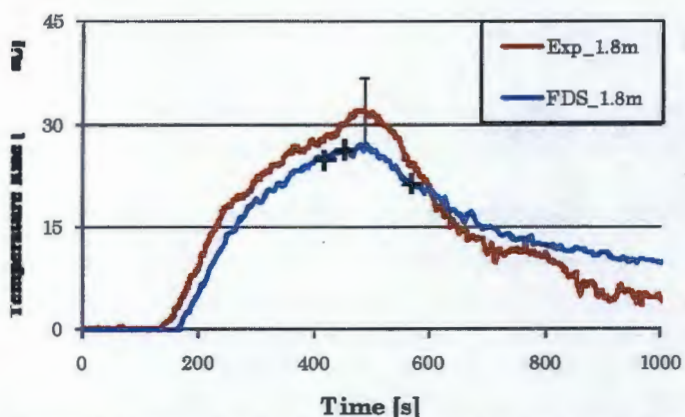


Figure 49: Measured vs. Predicted Temperature at the 1.8 m (5.9 ft) Thermocouple Location in the Bedroom

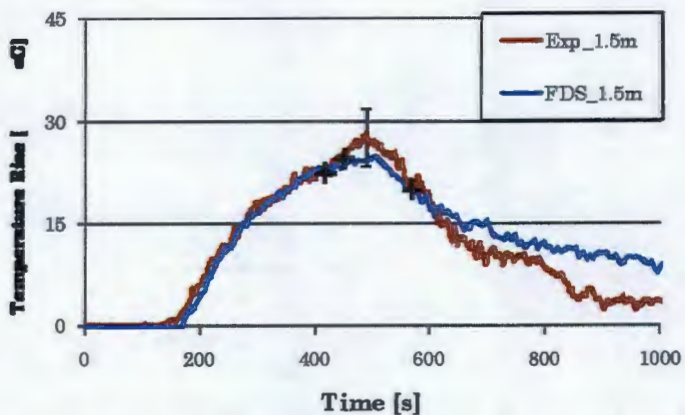


Figure 50: Measured vs. Predicted Temperature at the 1.5 m (4.9 ft) Thermocouple Location in the Bedroom

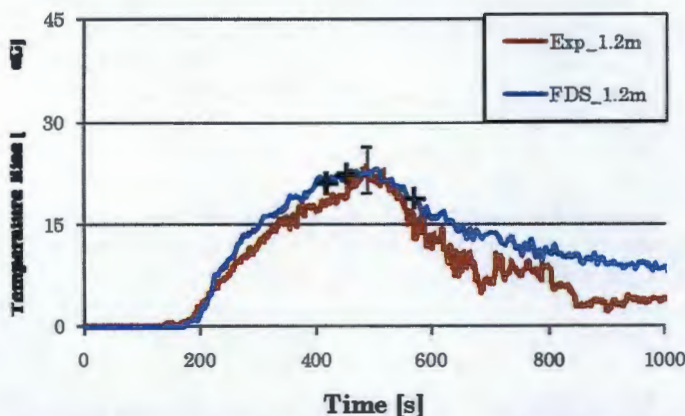


Figure 51: Measured vs. Predicted Temperature at the 1.2 m (3.9 ft) Thermocouple Location in the Bedroom

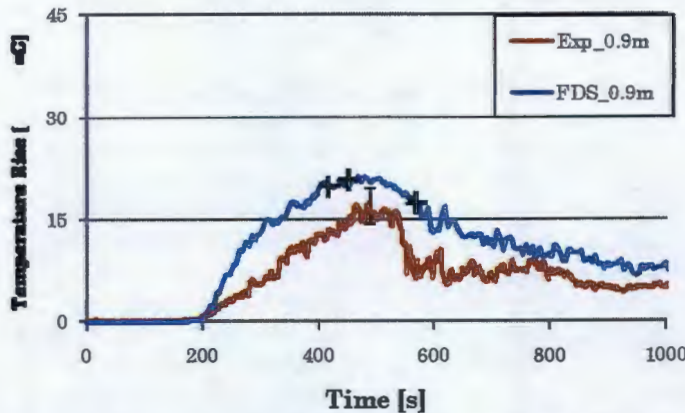


Figure 52: Measured vs. Predicted Temperature at the 0.9 m (2.9 ft) Thermocouple Location in the Bedroom

Fire Growth Rates

Three fire growth rates were used in the computer fire modeling to assess the effectiveness of different fire department deployment configurations in response to fires that were similar to, faster growing, and slower growing than the fires observed in the room-and-contents fires. The slow, medium, and fast fire growth rates are defined by the Society of Fire Protection Engineers according to the time at which they reach 1 megawatt (MW). A typical upholstered chair burning at its peak would produce a 1-MW fire, while a large sofa at its burning peak would produce roughly a 2-MW fire.

The growth rate of fires is often approximated by simple correlation of heat release rate to the square of time. If a fire is not suppressed before full-room involvement, the probability of spread beyond the room of origin increases dramatically if there is nearby fuel load to support fire spread. If a nearby fuel load is available, the 12 ft (3.7 m) by 16 ft (4.9 m) compartment used in the fire experiments would become fully involved at approximately 2 MW. Table 7 shows the time in seconds at which 1-MW and 2-MW (fully involved) fires in this compartment would be reached in the absence of suppression.

A fire department rescue operation is a race between the deteriorating interior conditions inside the structure and the rescue and suppression activities of the fire department. Each fire growth rate was used as a baseline heat release rate for the simulation. Intervention times (window and door opening times and suppression time) from the time-to-task tests were systematically input into the model to evaluate the effects on interior tenability conditions. The interior tenability conditions were calculated in a remote upstairs bedroom (above the room of fire origin on the first floor) in order to maximize the opportunity for differentiation among different crew configurations.

Fractional Effective Dose (FED)

In order to convert instantaneous measurements of local gas conditions, the fractional effective dose (FED) formulation published by the International Standards Organization (ISO) in document 13571 *Life-threatening Components of Fire – Guidelines for the Estimation of Time Available for Escape Using Fire Data* (ISO 2007) were used. FED is a probabilistic estimate of the effects of toxic gases on humans exposed to fire effluent. The formulation used in the

Fire Growth Rate	Time in Seconds Reach 1 MW	Time in Seconds to Reach to 2 MW
Slow	600	848
Medium	300	424
Fast	150	212

Table 7: Time to Reach 1 MW and 2 MW by Fire Growth Rate In the Absence of Suppression

simulations accounts for carbon monoxide (CO), carbon dioxide (CO₂), and oxygen (O₂) depletion. Other gases, including hydrogen cyanide (HCN) and hydrogen chloride (HCl), were not accounted for in this analysis and may alter FED for an actual occupant.

$$FED = \sum_{i=1}^n \frac{C_i}{(C_t)_i} \Delta t \quad \text{Eq.1}$$

Where C_i is the concentration of the i th gas and $(C_t)_i$ is the toxic concentration of i th gas and Δt is the time increment.

There are three FED thresholds generally representative of different exposure sensitivities of the general population. An FED value of 0.3 indicates the potential for certain sensitive populations to become incapacitated as a result of exposure to toxic combustion products. Sensitive populations may include elderly, young, or individuals with compromised immune systems. Incapacitation is the point at which occupants can no longer effect their own escape. An FED value of 1.0 represents the median incapacitating exposure. In other words, 50 % of the general population will be incapacitated at that exposure level. Finally, an FED value of 3.0 represents the value where occupants who are particularly tolerant of combustion gas exposure (extremely fit persons, for example) are likely to become incapacitated.

These thresholds are statistical probabilities, not exact measurements. There is variability in the way individuals respond to toxic atmospheric conditions. FED values above 2.0 are often fatal doses for so-called typical occupants. There is no threshold so low that it can be said to be safe for every exposed occupant.¹⁷

Deployment Configuration (All times with close stagger adjusted for early and late arrival of first due engine)	Rescue Time for Deployment Configuration (Min : Sec)
2-Person Early	12:47
3-Person Early	9:03
4-Person Early	9:10
5-Person Early	8:57
2-Person Late	14:47
3-Person Late	11:03
4-Person Late	11:10

Table 6: Rescue Time for Different Deployment Configurations

¹⁷ See the following sections of ISO Document 13571:

5.2 Given the scope of this Technical Specification, FED and/or FEC values of 1.0 are associated, by definition, with sublethal effects that would render occupants of average susceptibility incapable of effecting their own escape. The variability of human responses to toxicological insults is best represented by a distribution that takes into account varying susceptibility to the insult. Some people are more sensitive than the average, while others may be more resistant (see Annex A.1.5). The traditional approach in toxicology is to employ a safety factor to take into consideration the variability among humans, serving to protect the more susceptible subpopulations.

5.2.1 As an example, within the context of reasonable fire scenarios FED and/or FEC threshold criteria of 0.3 could be used for most general occupancies in order to provide for escape by the more sensitive subpopulations. However, the user of this Technical Specification has the flexibility to choose other FED and/or FEC threshold criteria as may be appropriate for chosen fire safety objectives. More conservative FED and/or FEC threshold criteria may be employed for those occupancies that are intended for use by especially susceptible subpopulations. By whatever rationale FED and FEC threshold criteria are chosen, a single value for both FED and FEC must be used in a given calculation of the time available for escape.

Results from Modeling Methods

Table 8 shows the FED for slow-, medium-, and fast-growth rate fires correlated to rescue times based on crew size and arrival time in the study. As with the room-and-contents fire in part 3, results in Table 8 included only the close-stagger rescue time data. The effect of far-stagger rescue times on occupant tenability should be

investigated in future studies. Values above 0.3 are shown in yellow, and those above the median incapacitating exposure of 1.0 are shown in red.

Figure 54 shows that with slow-growth fires in the experimental residential structure, all crew configurations could achieve rescue time before FED reached incapacitating levels. Figure 55

illustrates the greater danger of medium-growth fires, where the FED at rescue time for two-person crews is well above the 0.3 level, and almost to that level for the other crews.

Figure 56 (page 49) vividly illustrates the extreme danger of fast-growth fires. By the time a two-person crew is able to facilitate a rescue, the FED has far exceeded the median 1.0 level. For other crew sizes, the FED has exceeded 0.3, which is a threshold level for vulnerable populations.

Crew Configuration		Rescue Time	Fire Growth Rates		
			Slow	Medium	Fast
2 Early		12:47	.12	.72	1.49
2 Late		14:47	.35	1.37	2.56
3 Early		9:03	.01	.11	.40
3 Late		11:03	.04	.36	.84
4 Early		9:10	.01	.11	.42
4 Late		11:10	.05	.38	.91
5 Early		8:57	.01	.10	.38
KEY					
KEY	White	89% or more of population may be capable of effecting their own escape if they are able.			
	Yellow	Potential for certain sensitive populations (such as children and the elderly) to become incapacitated.			
	Red	More than 50% of the population would be incapable of effecting their own escape.			

Table 8: FED as a Function of Deployment Configuration and Fire Growth Rate

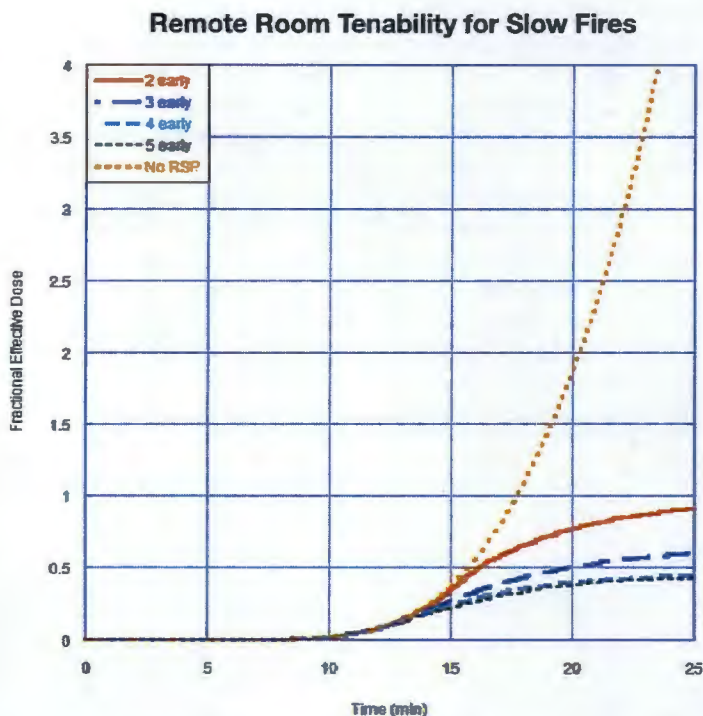


Figure 54: FED Curves for Early Arrival for All Crew Sizes at Slow-Growth Fires

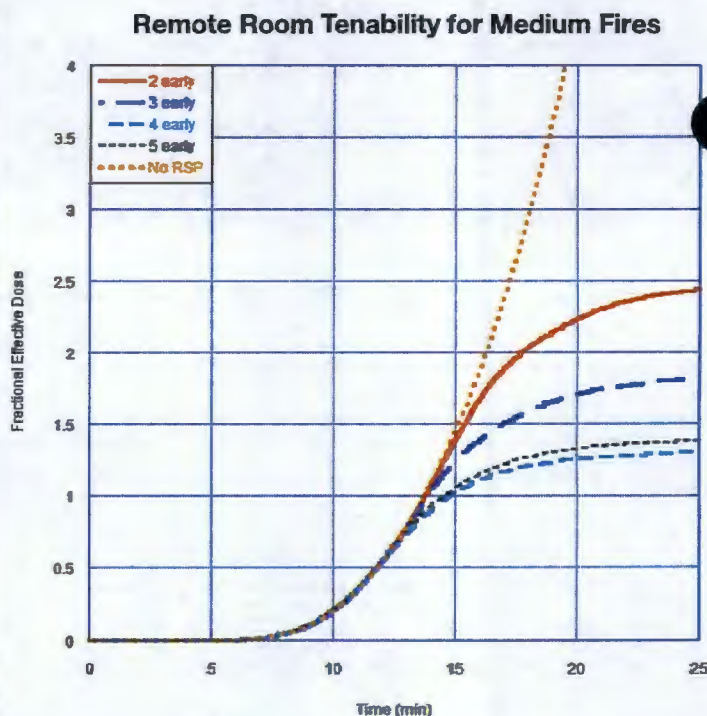


Figure 55: Average FED Curves for Early Arrival for All Crew Sizes at Medium-Growth Fires

Remote Room Tenability for Fast Fires

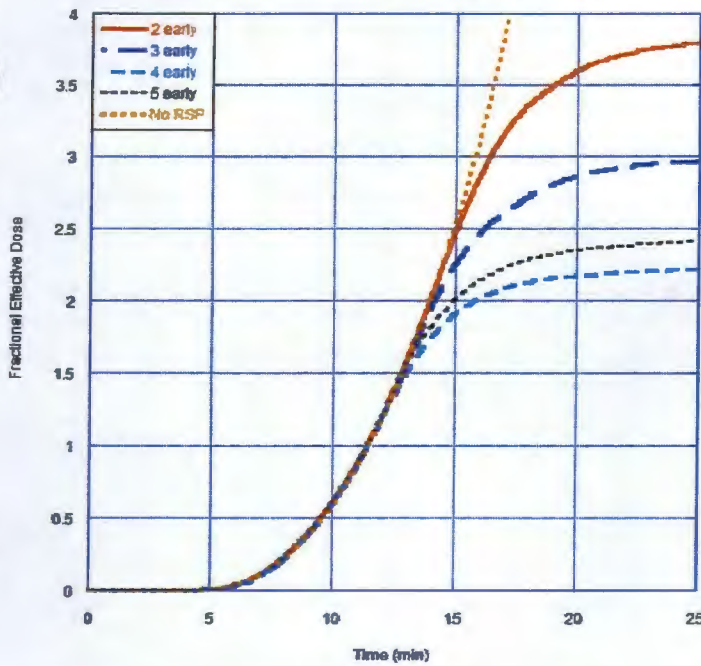


Figure 56: Average FED Curves for Early Arrival for All Crew Sizes at Fast-Growth Fires

Interior Firefighting Conditions and Deployment Configuration

The available time to control a fire can be quite small. Risks to firefighters are lower for smaller fires than larger fires because smaller fires are easier to suppress and produce less heat and fewer toxic gases. Therefore, firefighter deployment configurations that can attack fires earlier in the fire development process present lower risk to firefighters. The longer the duration of the fire development process without intervention, the greater the increase in risk for occupants and responding firefighters. Therefore, time is critical.

Stopping the escalation of the event involves firefighter intervention via critical tasks performed on the fireground. Critical tasks, as described previously, include those tasks that

directly affect the spread of fire as well as the associated structural tenability.

There are windows of opportunity to complete critical tasks. A fire in a structure with a typical residential fuel load at six minutes post-ignition is very different from the same fire at eight minutes or at ten minutes post-ignition. Some tasks that are deemed "important" (e.g., scene size-up) for a fire in early stages of growth become critical if intervention tasks are delayed. Time can take away opportunities. If too much time passes, then the window of opportunity to affect successful outcomes (e.g., rescue victim or stop fire spread) closes.

For a typical structure fire event involving a fire department response, there is an incident commander on the scene who determines both the strategy and tactics that will be employed to stop the spread of the fire, rescue occupants, ventilate the structure, and ultimately extinguish the fire. Incident commanders must deal with the fire in the present and make intelligent command decisions based on the circumstances at hand upon arrival. Additionally, arrival time and crew size are factors that contribute to the incident commander's decisions and affect the capability of the firefighters to accomplish necessary tasks on scene in a safe, efficient, and effective manner.

Table 9 illustrates vividly the more dangerous conditions small crews face because of the extra time it takes to begin and complete critical tasks (particularly fire suppression). In the two minutes more it took for the two-person crew (early arrival) than the five-person crew (early arrival) to get water on the fire, a slow growth rate fire would have increased from 1.1 MW to 1.5 MW. This growth would have been even more extreme for a medium- or fast-growth rate fire. The difference is even more substantial for the two-person crew with late arrival as the fire almost doubled in size in the time difference between this crew and the five-person crew.

Based on fire modeling for the low hazard structure studied with a typical residential fuel load, it is likely that medium- and fast-growth rate fires will move beyond the room of origin prior to the arrival of firefighters for all crew sizes. Note that results in Table 8 included only the close-stagger rescue time data. The effect of far-stagger rescue times on occupant tenability should be investigated in future studies. Therefore, the risk level of the event upon arrival will be higher for all crews which must be considered by the incident commander when assigning firefighters to on-scene tasks.

Deployment Configuration	Time to Water on Fire (Min : Sec)	Fire Size at Time of Suppression for Slow-Growth Fires
2-Person, Late Arrival	14:26	2.1 MW
2-Person, Early Arrival	12:26	1.5 MW
3-Person, Late Arrival	13:24	1.8 MW
3-Person, Early Arrival	11:24	1.3 MW
4-Person, Late Arrival	13:11	1.7 MW
4-Person, Early Arrival	11:11	1.3 MW
5-Person, Late Arrival	12:33	1.6 MW
5-Person, Early Arrival	10:33	1.1 MW

Table 9: Fire Size at Time of Fire Suppression

Physiological Effects of Crew Size on Firefighters

Reports on firefighter fatalities consistently document overexertion/overstrain as the leading cause of line-of-duty fatalities. There is strong epidemiological evidence that heavy physical exertion can trigger sudden cardiac events (Mittleman et al. 1993; Albert et al. 2000). Therefore, information about the effect of crew size on physiological strain is very valuable.

During the planning of the fireground experiments, investigators at Skidmore College recognized the opportunity to conduct an independent study on the relationship between firefighter deployment configurations and firefighter heart rates. With the approval of the Institutional Review Board of Skidmore College, they were able to leverage the resources of the field experiments to conduct a separate analysis of the cardiac strain on fire fighters on the fireground.

For details, consult the complete report (Smith 2009). Two important conclusions from the report reinforce the importance of crew size:

- Average heart rates were higher for members of small crews, particularly two-person crews.
- Danger is increased for small crews because the stress of fire fighting keeps heart rates elevated beyond the maximum heart rate for the duration of a fire response, and so the higher heart rates were maintained for sustained time intervals.

Study Limitations

The scope of this study is limited to understanding the relative influence of deployment variables to low-hazard, residential structure fires, similar in magnitude to the hazards described in *NFPA 1710*. The applicability of the conclusions from this report to commercial structure fires, high-rise fires, outside fires, terrorism/natural disaster response, HAZMAT or other technical responses has not been assessed and should not be extrapolated from this report.

Every attempt was made to ensure the highest possible degree of realism in the experiments while complying with the requirements of *NFPA 1403*, but the dynamic environment on the fireground cannot be fully reproduced in a controlled experiment. For example, *NFPA 1403* required a daily walkthrough of the burn prop (including identifying the location of the fire) before ignition of a fire that would produce an Immediately Dangerous to Life and Health (IDLH) atmosphere, a precaution not available to responders dispatched to a live fire.

The number of responding apparatus for each fireground response was held constant (three engines and one truck, plus the battalion chief and aide) for all crew size configurations. The effect of deploying either more or fewer apparatus to the scene was not evaluated.

The fire crews who participated in the experiments typically operate using three-person and four-person staffing. Therefore, the effectiveness of the two-person and five-person operations may have been influenced by a lack of experience in operating at

those staffing levels. Standardizing assigned tasks on the fireground was intended to minimize the impact of this factor, which has an unknown influence on the results.

The design of the experiments controlled for variance in performance of the incident commander. In other words, a more-or less-effective incident commander may have a significant influence on the outcome of a residential structure fire.

Although efforts were made to minimize the effect of learning across experiments, some participants took part in more than one experiment, and others did not.

The weather conditions for the experiments were moderate to cold. Frozen equipment such as hydrants and pumps was not a factor. However, the effect of very hot weather conditions on firefighter performance was not measured.

All experiments were conducted during the daylight hours. Nighttime operations could pose additional challenges.

Fire spread beyond the room of origin was not considered in the room and contents tests or in the fire modeling. Therefore, the size of the fire and the risk to the firefighter may be somewhat underestimated for fast-growing fires or slower-response configurations.

There is more than one effective way to perform many of the required tasks on the fireground. Attempts to generalize the results from these experiments to individual departments must take into account tactics and equipment that vary from those used in the experiments.

Conclusions

More than 60 laboratory and full-scale fire experiments were conducted to determine the impact of crew size, first-due engine arrival time, and subsequent apparatus arrival times on firefighter safety and effectiveness at a low-hazard residential structure fire. This report quantifies the effects of changes to staffing and arrival times for low-hazard residential firefighting operations. While resource deployment is addressed in the context of a single structure type and risk level, it is recognized that public policy decisions regarding the cost-benefit of specific deployment decisions are a function of many factors including geography, available resources, community expectations, as well as all local hazards and risks. Though this report contributes significant knowledge to community and fire service leaders in regard to effective resource deployment for fire suppression, other factors contributing to policy decisions are not addressed.

The objective of the experiments was to determine the relative effects of crew size, first-due engine arrival time, and stagger time for subsequent apparatus on the effectiveness of the firefighting crews relative to intervention times and the likelihood of occupant rescue using a parametric design. Therefore, the experimental results for each of these factors are discussed below.

Of the 22 fireground tasks measured during the experiments, the following were determined to have especially significant impact on the success of fire fighting operations. Their differential outcomes based on variation of crew size and/or apparatus arrival times are statistically significant at the 95 % confidence level or better.

Overall Scene Time:

The four-person crews operating on a low-hazard structure fire completed all the tasks on the fireground (on average) seven minutes faster — nearly 30 % — than the two-person crews. The four-person crews completed the same number of fireground tasks (on average) 5.1 minutes faster — nearly 25 % — than the three-person crew. For the low-hazard residential structure fire, adding a fifth person to the crews did not decrease overall fireground task times. However, it should be noted that the benefit of five-person crews has been documented in other evaluations to be significant for medium- and high-hazard structures, particularly in urban settings, and should be addressed according to industry standards.¹⁸

Time to Water on Fire:

There was a nearly 10 % difference in the “water on fire time” between the two and three-person crews and an additional 6 % difference in the “water on fire time” between the three- and four-person crews (i.e., 16 % difference between the four and two-person crews). There was an additional 6 % difference in the “water on fire” time between the four- and five-person crews (i.e., 22 % difference between the five and two-person crews).

Ground Ladders and Ventilation:

The four-person crew operating on a low-hazard structure fire can complete laddering and ventilation (for life safety and rescue) 30 % faster than the two-person crew and 25 % faster than the three-person crew.

Primary Search:

The three-person crew started and completed a primary search and rescue 25 % faster than the two-person crew. In the same

structure, the four- and five-person crews started and completed a primary search 6 % faster than the three-person crews and 30 % faster than the two-person crew. A 10 % difference was equivalent to just over one minute.

Hose Stretch Time:

In comparing four- and five-person crews to two- and three-person crews collectively, the time difference to stretch a line was 76 seconds. In conducting more specific analysis comparing all crew sizes to a two-person crew the differences are more distinct. A two-person crew took 57 seconds longer than a three-person crew to stretch a line. A two-person crew took 87 seconds longer than a four-person crew to complete the same tasks. Finally, the most notable comparison was between a two-person crew and a five-person crew — more than 2 minutes (122 seconds) difference in task completion time.

Industry Standard Achieved:

The “industry standard achieved” time started from the first engine arrival at the hydrant and ended when 15 firefighters were assembled on scene.¹⁹ An effective response force was assembled by the five-person crews three minutes faster than the four-person crews. According to study deployment protocol, the two- and three-person crews were unable to assemble enough personnel to meet this standard.

Occupant Rescue:

Three different “standard” fires (slow-, medium-, and fast-growth rate) were simulated using the Fire Dynamics Simulator (FDS) model. The fires grew exponentially with time. The fire modeling simulations demonstrated that two-person, late arriving crews can face a fire that is twice the intensity of the fire faced by five-person, early arriving crews. The rescue scenario was based on a nonambulatory occupant in an upstairs bedroom with the bedroom door open.

Independent of fire size, there was a significant difference between the toxicity, expressed as fractional effective dose (FED), for occupants at the time of rescue depending on arrival times for all crew sizes. Occupants rescued by crews starting tasks two minutes earlier had lesser exposure to combustion products.

The fire modeling showed clearly that two-person crews cannot complete essential fireground tasks in time to rescue occupants without subjecting either firefighters or occupants to an increasingly hazardous atmosphere. Even for a slow-growth rate fire, the FED was approaching the level at which sensitive populations, such as children and the elderly are threatened. For a medium-growth rate fire with two-person crews, the FED was far above that threshold and approached the level affecting the median sensitivity in general population. For a fast-growth rate fire, the FED was well above the median level at which 50 % of the general population would be incapacitated. Larger crews responding to slow-growth rate fires can rescue most occupants prior to incapacitation along with early-arriving larger crews responding to medium-growth rate fires. The result for late-arriving (two minutes later than early-arriving) larger crews may result in a threat to sensitive populations for medium-growth rate fires.” The new sentence is consistent with our previous description for two-person crews where we identify a threat to sensitive populations.. Statistical averages should not, however, mask the fact that there is no FED level so low that every occupant in every situation is safe.

18 NFPA Standard 1710 - A.5.2.4.2.1 ... Other occupancies and structures in the community that present greater hazards should be addressed by additional fire fighter functions and additional responding personnel on the initial full alarm assignment.

19 NFPA 1710 Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments. Section 5.2.1 – Fire Suppression Capability and Section 5.2.2 Staffing.

Summary:

The results of these field experiments contribute significant knowledge to the fire service industry. First, the results establish a technical basis for the effectiveness of company crew size and arrival time in *NFPA 1710*. The results also provide valid measures of total effective response force assembly on scene for fireground operations, as well as the expected performance of time-to-critical-task measures for a low-hazard structure fires. Additionally, the results provide tenability measures associated with the occupant exposure rates to the range of fires considered by the fire model.

Future Research

In order to realize a significant reduction in firefighter line-of-duty death (LODD) and injury, fire service leaders must focus directly on resource allocation and the deployment of resources, both contributing factors to LODD and injury. Future research should use similar methods to evaluate firefighter resource deployment to fires in medium- and high-hazard structures, including multiple-family residences and commercial properties. Additionally, resource deployment to multiple-casualty disasters or terrorism events should be studied to provide insight into levels of risks specific to individual communities and to recommend resource deployment proportionate to such risk. Future studies should continue to investigate the effects of resource deployment on the safety of both firefighters and the civilian population to better inform public policy.

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APPENDIX A: Laboratory Experiments

The fire suppression and resource deployment experiments consisted of four distinct parts: laboratory experiments, time-to-task experiments, room and contents experiments and fire modeling. The purpose of the laboratory experiments was to assure a fire in the field experiments that would consistently meet NFPA 1403 requirements for live fire training exercises. The laboratory experiments enabled investigators to characterize the burning behavior of the wood pallets as a function of:

- number of pallets and the subsequent peak heat release rate
- compartment effects on burning of wood pallets
- effect of window ventilation on the fire
- effect on fire growth rate of the loading configuration of excelsior (slender wood shavings typically used as packing material)

Design and Construction

Figure A-1 shows the experimental configuration for the compartment pallet burns. Two identically sized compartments (3.66 m x 4.88 m x 2.44 m) were connected by a hallway (4 m x 1 m x 2.4 m). At each end of the hallway, a single door connected the hallway to each of the compartments. In the burn compartment, a single window (3 m x 2 m) was covered with noncombustible board that was opened for some experiments and closed for others. At the end of test, it was opened to extinguish the remaining burning material and to remove any debris prior to the next test. In the second compartment, a single doorway connected the compartment to the rest of the test laboratory. It was kept open throughout the tests allowing the exhaust to flow into the main collection hood for measurement of heat release rate.

The structure was constructed of two layer of gypsum wallboard over steel studs. The floor of the structure was lined with two layers of gypsum wallboard directly over the concrete floor of the test facility. In the burn compartment, an additional lining of cement board was placed over the gypsum walls and ceiling surfaces near the fire source to minimize fire damage to the structure after multiple fire experiments. A doorway 0.91 m wide by 1.92 m tall connected the burn compartment to the hallway and an opening 1 m by 2 m connected the hallway to the target compartment. Ceiling height was 2.41 m throughout the structure, except for the slight variation in the burn room.

Fuel Source

The fuel source for all of the tests was recycled hardwood pallets constructed of several lengths of hardwood boards nominally 83

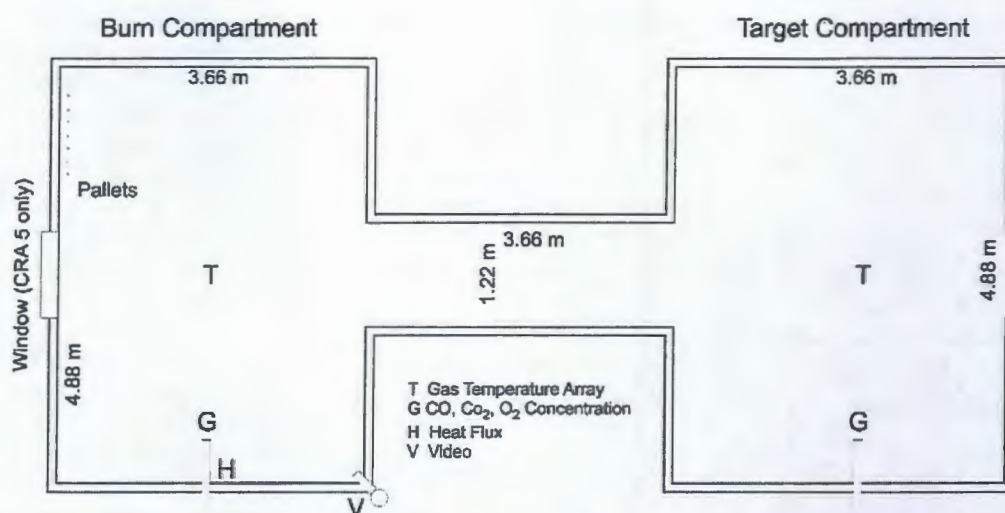


Figure A-1. Compartment Configuration and Instrumentation for Pallet Tests

mm wide by 12.7 mm thick. Lengths of the individual boards ranged from nominally 1 m to 1.3 m. The finished size of a single pallet was approximately 1 m by 1.3 m by 0.11 m. Figure A-2 shows the fuel source for one of the tests including six stacked pallets and excelsior ignition source. For an ignition source, excelsior was placed within the pallets, with the amount and location depending on the ignition scenario. Figure A-3 shows the pallets prior to a slow and a fast ignition scenario fire. Table A-1 details the total mass of pallets and excelsior for each of the free burn and compartment tests.

Experimental Conditions

The experiments were conducted in two series. In the first series, heat release measurements were made under free burn conditions beneath a 6 m by 6 m hood used to collect combustion gases and provide the heat release rate (HRR) measurement. A second series of tests was conducted with the fire in a compartmented structure to assess environmental conditions within the structure during the fires and determine the effect of the compartment enclosure on the fire growth. Table A-1 presents a summary of the tests conducted.



Figure A-2. Pallets and Excelsior Ignition Source Used as a Fuel Source

Table A-1. Tests Conducted and Ambient Conditions at Beginning of Each Test

Test	Test Type	Number of Pallets	Ignition Scenario	Total Pallet Mass (kg)	Excelsior Mass (kg)
PAL 1	Free burn	4	Fast	79.3	8.1
PAL 2	Free burn	6	Fast	118.8	15.1
PAL 3	Free burn	8	Fast	146.7	16.2
PAL 4	Free burn	4	Slow	51.0	1.65
PAL 5	Free burn	6	Slow	160.3	0.85
CRA 1	Compartment	6	Slow	114.0	0.83
CRA 2	Compartment	4	Slow	69.7	
CRA 3	Compartment	4	Fast	71.1	0.8
CRA 4	Compartment	4	Slow	73.9	0.83
CRA 5	Compartment	4	Slow	73.8	0.85

Notes: PAL stands for "pallet" and CRA ("Community Risk Assessment") is the designator for the configuration of pallets burned in the compartment. Efforts were made to use the same amount of excelsior mass for CRA 2 (~0.8 kg), but the value was not measured.

Measurements Conducted

Heat release rate (HRR) was measured in all tests. HRR measurements were conducted under the 3 m by 3 m calorimeter at the NIST Large Fire Research Laboratory. The HRR measurement was based on the oxygen consumption calorimetry principle first proposed by Thornton (Thornton 1917) and developed further by Huggett (Huggett 1980) and Parker (Parker 1984). This method assumes that a known amount of heat is released for each gram of oxygen consumed by a fire. The measurement of exhaust flow velocity and gas volume fractions (O_2 , CO_2 and CO) were used to determine the HRR based on the formulation derived by Parker (Parker 1984) and Janssens (Janssens 1981). The combined expanded relative uncertainty of the HRR measurements was estimated at $\pm 14\%$, based on a propagation of uncertainty analysis (Bryant 2004).

For the compartment fire tests, gas temperature measurements were made in the burn compartment and in the target compartment connected by a hallway to the burn compartment using 24 gauge bare-bead chromel-alumel (type K) thermocouples positioned in vertical array. Thermocouples were located at the center of each compartment at locations 0.03 m, 0.30 m, 0.61 m, 0.91 m, 1.22 m, 1.52 m, 1.83 m, and 2.13 m from the ceiling. The expanded uncertainty associated with a type K thermocouple is approximately $\pm 4.4^\circ C$. (Omega 2004)

Gas species were continuously monitored in the burn compartment at a level 0.91 m from the ceiling at a location centered on the side wall of the compartment, 0.91 m from the wall. Oxygen was measured using paramagnetic analyzers. Carbon monoxide and carbon dioxide were measured using non-dispersive infrared (NDIR) analyzers. All analyzers were calibrated with nitrogen and a known concentration of gas prior to each test for a zero and span concentration calibration. The expanded relative uncertainty of each of the span gas molar fractions is estimated to be $\pm 1\%$.

Total heat flux was measured on the side wall of the enclosure at a location centered on the side wall, 0.61 m from the ceiling level. The heat flux gauges were 6.4 mm diameter Schmidt-Boelter type, water cooled gauges with embedded type-K thermocouples (see Figure A-4). The manufacturer reports a $\pm 3\%$ expanded uncertainty in the response calibration (the slope in $kW/m^2/mV$). Calibrations at the NIST facility have varied within an additional $\pm 3\%$ of manufacturer's calibration. For this study, an uncertainty of $\pm 6\%$ is estimated.



Figure A-3. Fuel and Excelsior Source for Slow (top) and Fast (bottom) Ignition Scenarios



Figure A-4: Heat Flux Gauge with Radiation Shielding

Test	Test Type	Number of Pallets	Ignition Scenario	Peak HRR (kW)	Time to Peak HRR (s)
PAL 1	Free burn	4	Fast	2144	205
PAL 2	Free burn	6	Fast	2961	320
PAL 3	Free burn	8	Fast	3551	301
PAL 4	Free burn	4	Slow	1889	385
PAL 5	Free burn	6	Slow	2410	986
CRA 1	Compartment	6	Slow	1705	1102
CRA 2	Compartment	4	Slow	1583	649
CRA 3	Compartment	4	Fast	1959	159
CRA 4	Compartment	4	Slow	1620	775
CRA 5	Compartment	4	Slow	1390	927

Table A-2. Peak Heat Release Rate During Several Pallet Tests in Free-burn and in a Compartment

Results

Table A-2 shows the peak HRR and time to peak HRR for the free burn tests and for the compartment tests. Figure A-5 includes images from the free burn experiments near the time of peak HRR for each of the experiments. Figure A-6 illustrates the progression of the fire from the exit doorway looking down the hallway to the burn compartment for one of the tests. Figure A-7 to Figure A-10 present graphs of the heat release rate for all of the tests. Figure A-11 through Figure A-15 shows the gas temperature, major gas species concentrations, and heat flux in the burn compartment and target compartment in the five compartment tests.



PAL 1



PAL 2



PAL 3



PAL 4

Figure A-5. Free-Burn Experiments Near Time of Peak Burning



Figure A-6. Example Fire Progression from Test CRA 1

Slow Ignition Scenario

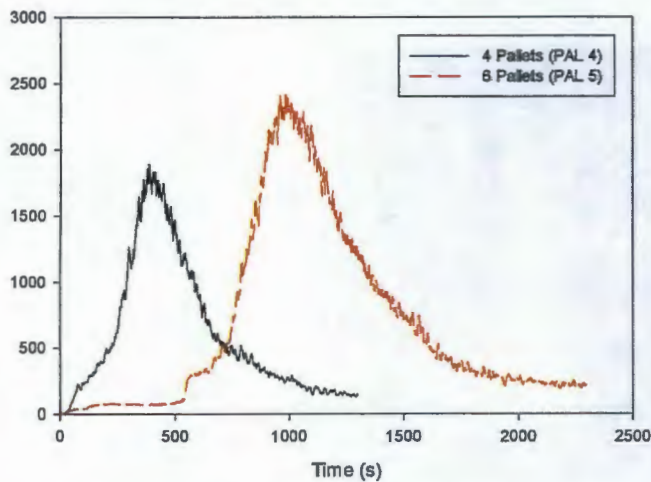


Figure A-7. HRR, Slow Ignition, Free Burn Scenario

Fast Ignition Scenario

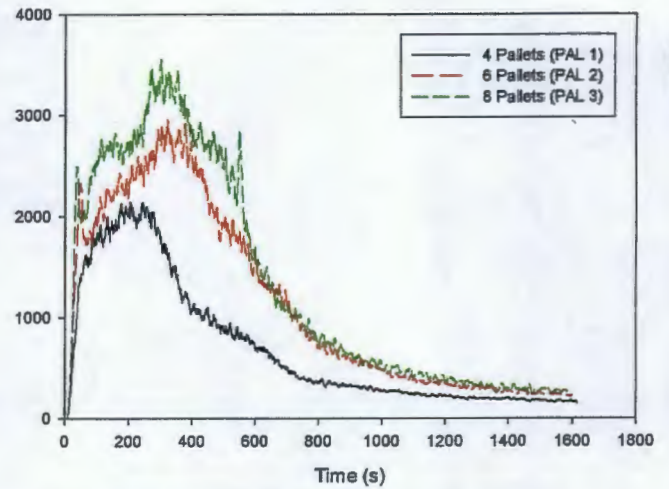


Figure A-8. HRR, Fast Ignition, Free Burn Scenario

Slow Ignition Scenario

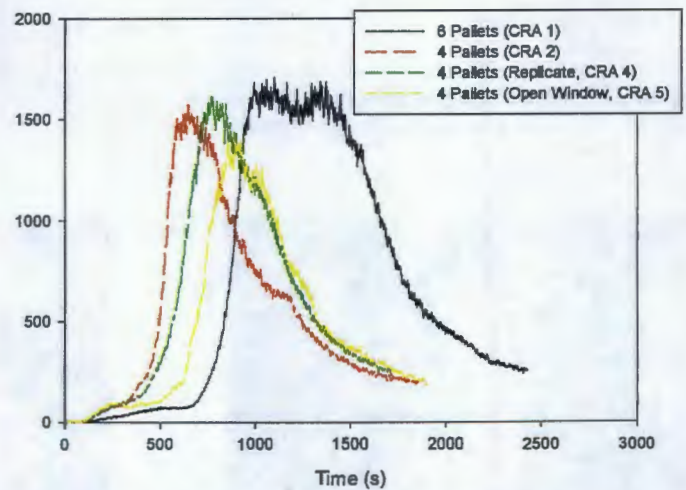


Figure A-9. HRR, Slow Ignition, Compartment Test

Fast Ignition Scenario

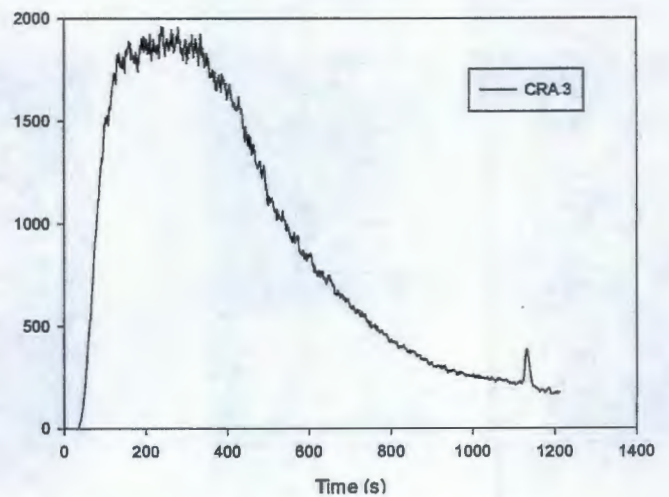
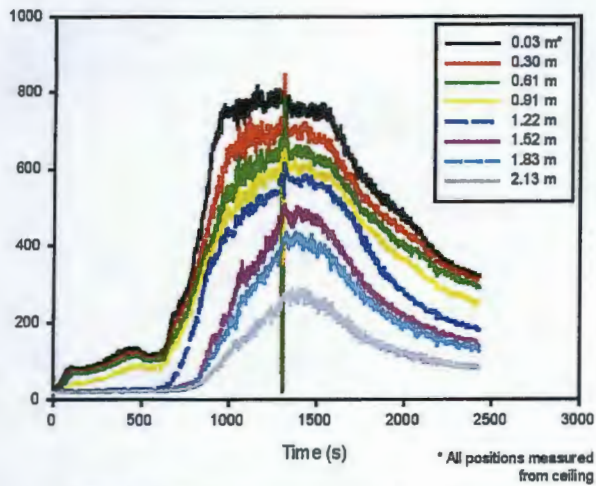
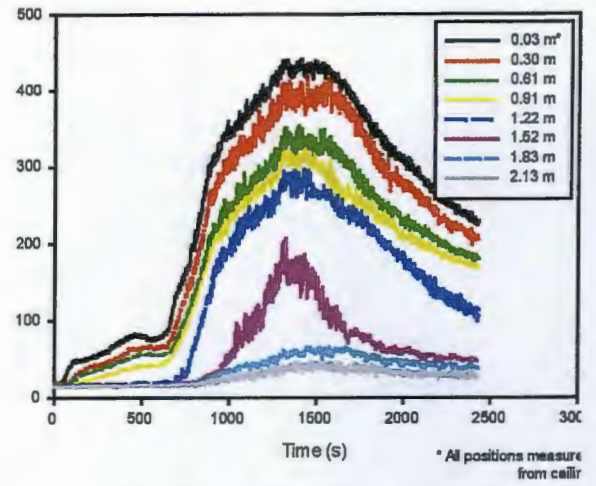


Figure A-10. HRR, Fast Ignition, Compartment Test

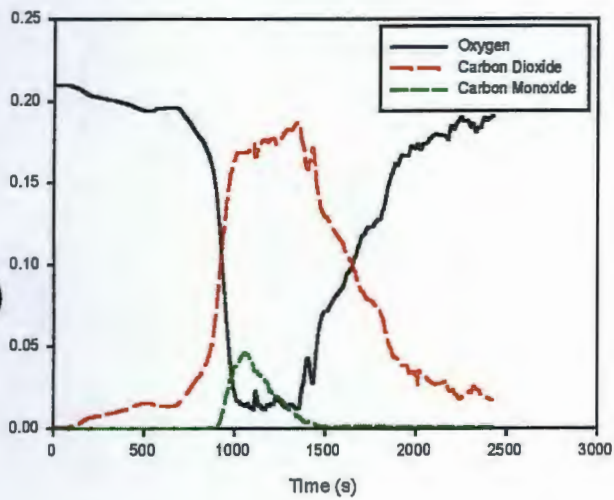
6 Pallets, Slow Ignition Scenario, Burn Room



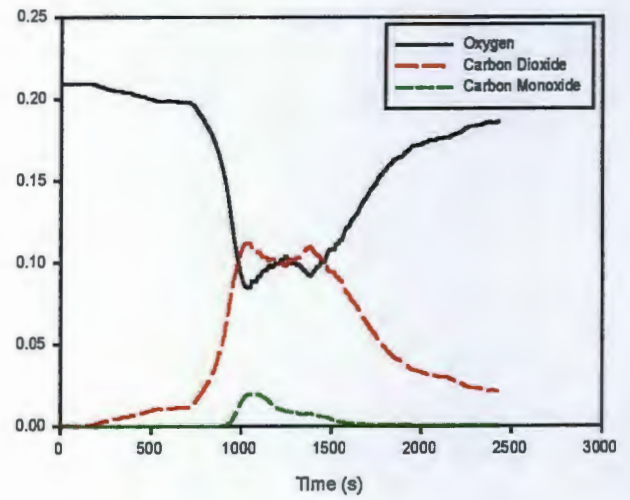
6 Pallets, Slow Ignition Scenario, Target Room



6 Pallets, Slow Ignition Scenario, Burn Room



6 Pallets, Slow Ignition Scenario, Target Room



6 Pallets, Slow Ignition Scenario, Burn Room

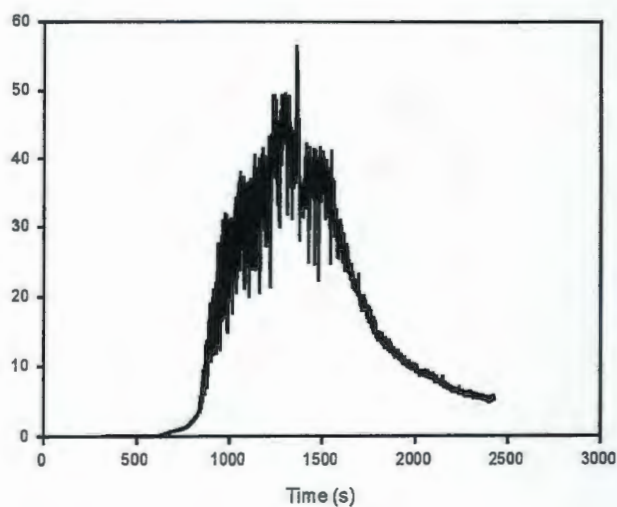
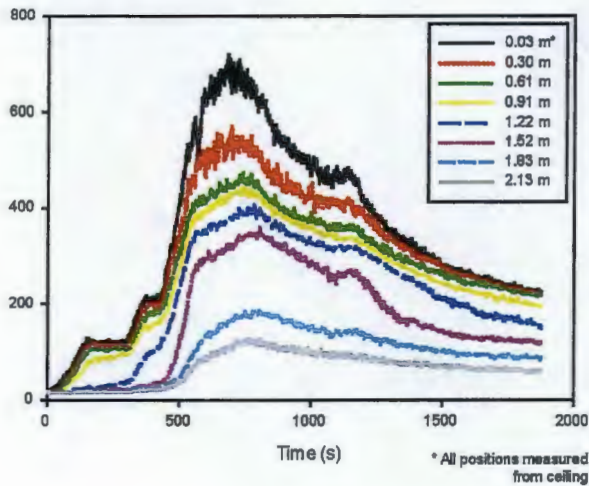
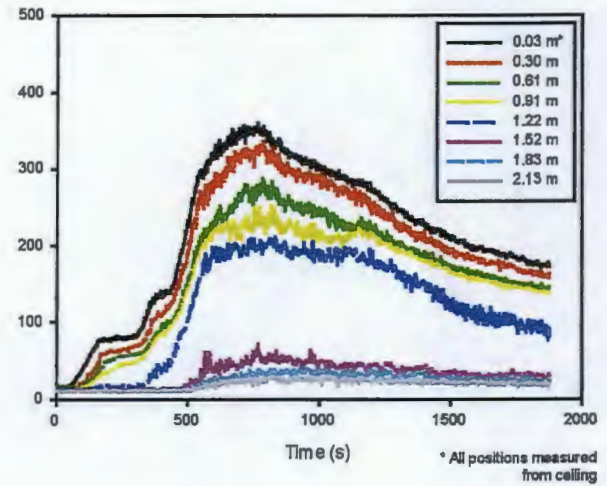


Figure A-11. Temperature, Gas Concentration, and Heat Flux During Test CRA 1, 6 Pallets, Slow Ignition Scenario

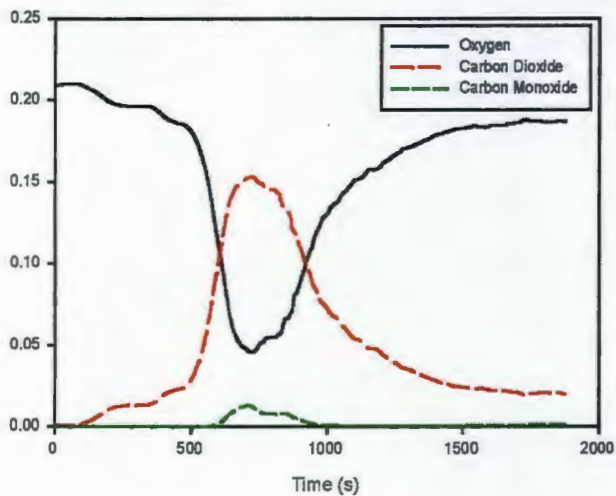
4 Pallets, Slow Ignition Scenario, Burn Room



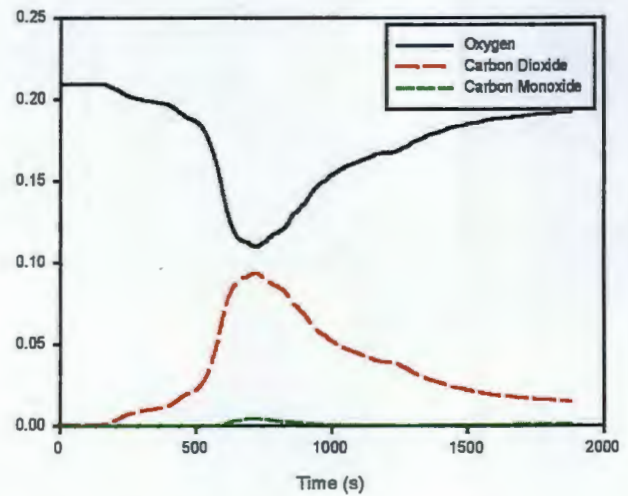
4 Pallets, Slow Ignition Scenario, Target Room



4 Pallets, Slow Ignition Scenario, Burn Room



4 Pallets, Slow Ignition Scenario, Target Room



4 Pallets, Slow Ignition Scenario, Burn Room

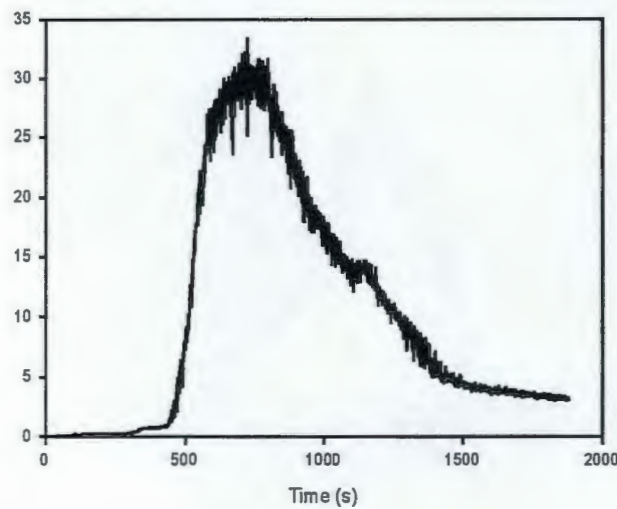
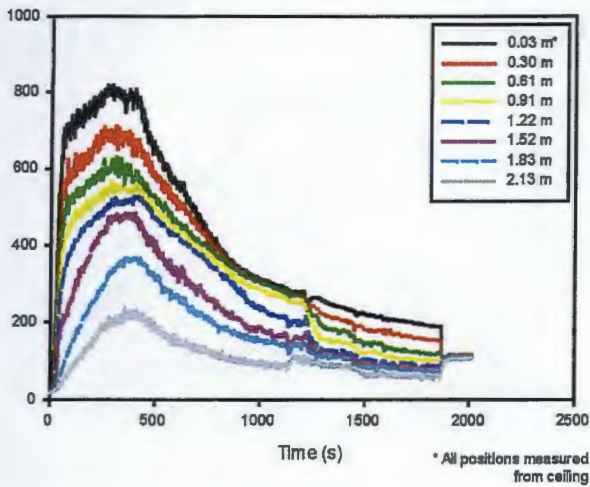
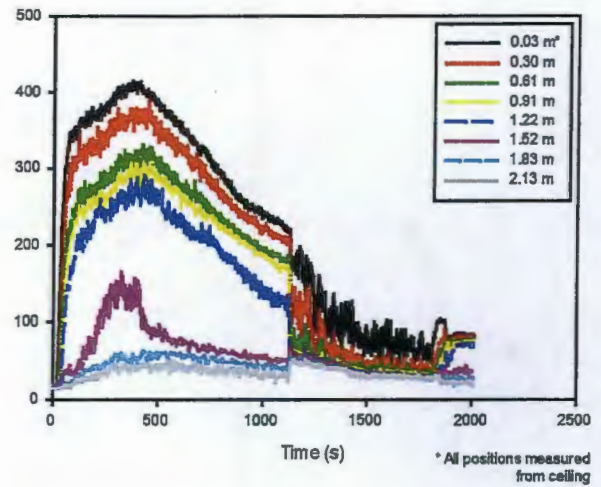


Figure A-12. Temperature, Gas Concentration, and Heat Flux During Test CRA 2, 4 Pallets, Slow Ignition Scenario

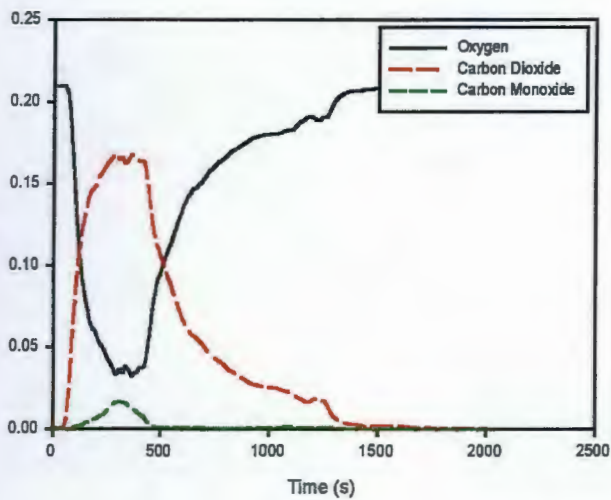
4 Pallets, Fast Ignition Scenario, Burn Room



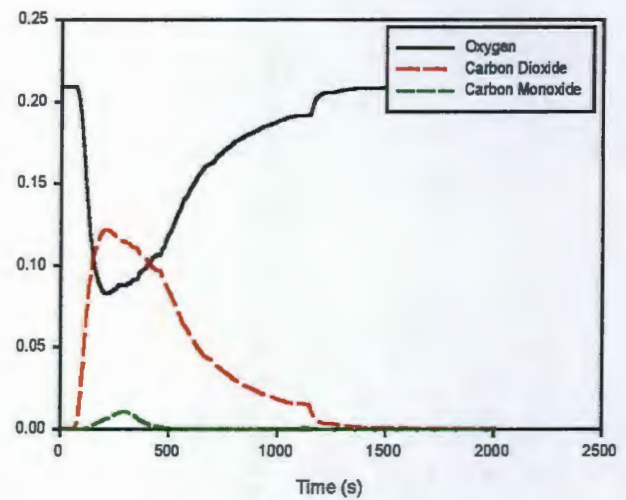
4 Pallets, Fast Ignition Scenario, Target Room



4 Pallets, Fast Ignition Scenario, Burn Room



4 Pallets, Fast Ignition Scenario, Target Room



4 Pallets, Fast Ignition Scenario, Burn Room

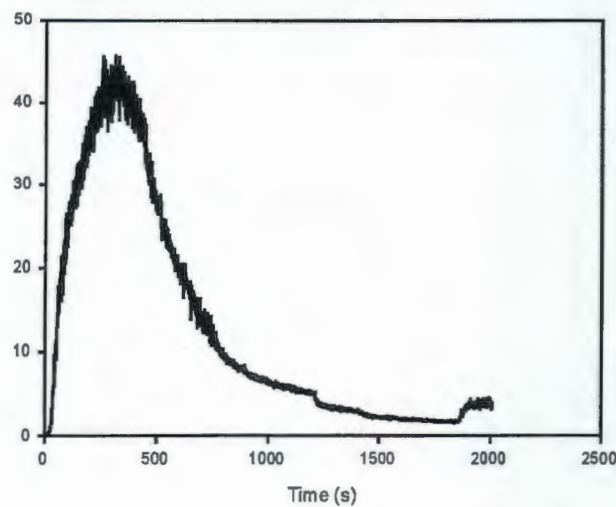
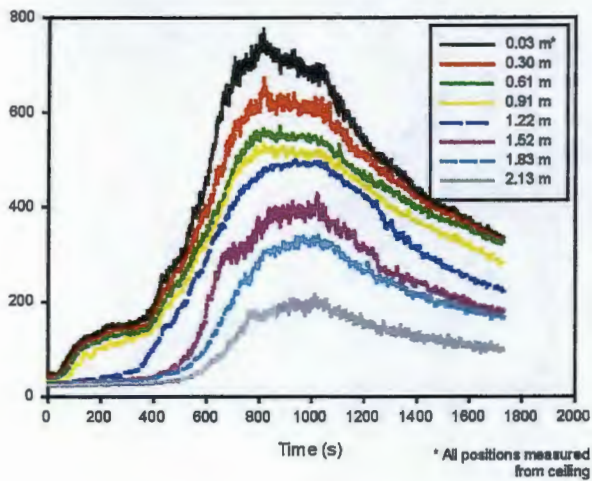
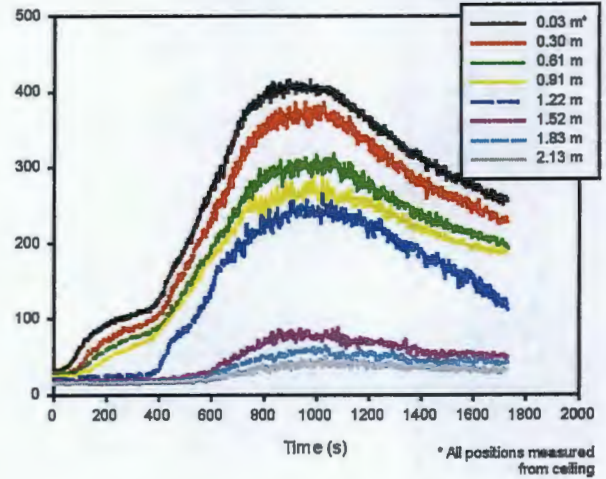


Figure A-13. Temperature, Gas Concentration, and Heat Flux During Test CRA 3, 4 Pallets, Fast Ignition Scenario

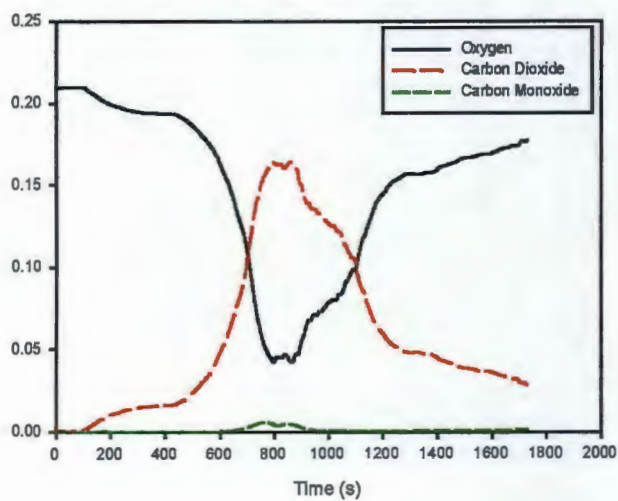
4 Pallets, Slow Ignition Scenario, Burn Room
(Replicate)



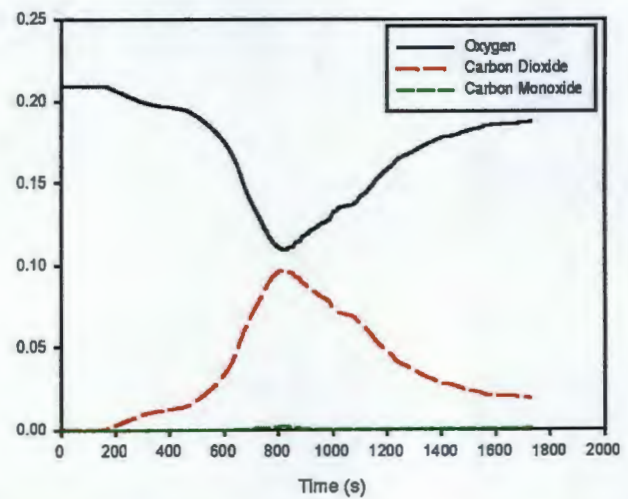
4 Pallets, Slow Ignition Scenario, Target Room
(Replicate)



4 Pallets, Slow Ignition Scenario, Burn Room
(Replicate)



4 Pallets, Slow Ignition Scenario, Target Room
(Replicate)



4 Pallets, Slow Ignition Scenario, Burn Room
(Replicate)

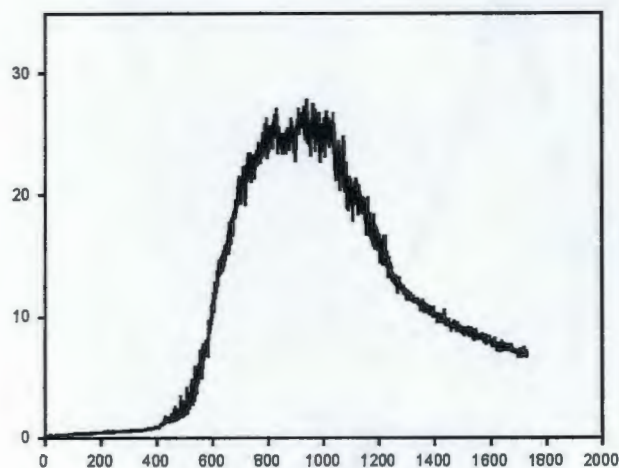
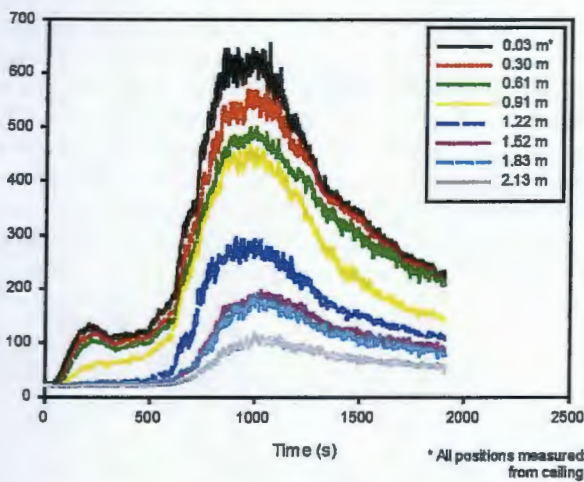
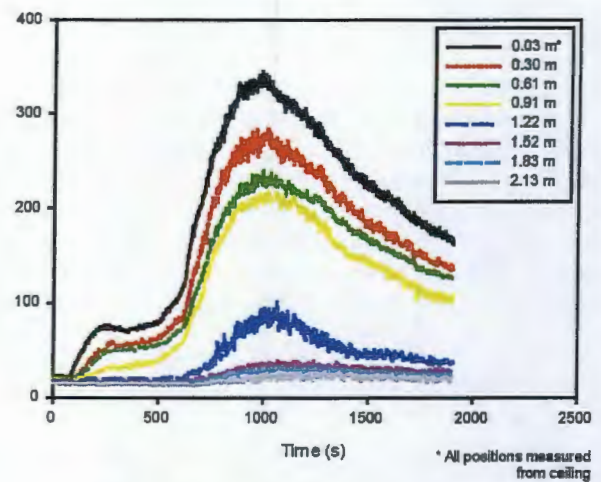


Figure A-14. Temperature, Gas Concentration, and Heat Flux During Test CRA 4, 4 Pallets, Slow Ignition Scenario (Replicate)

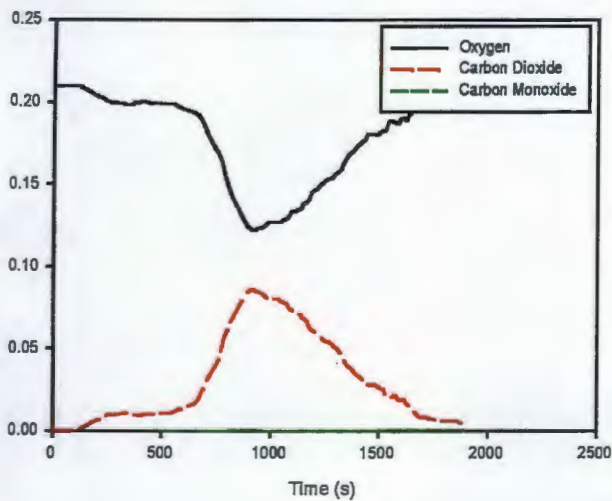
4 Pallets, Slow Ignition Scenario, Burn Room
(Open Window Venting)



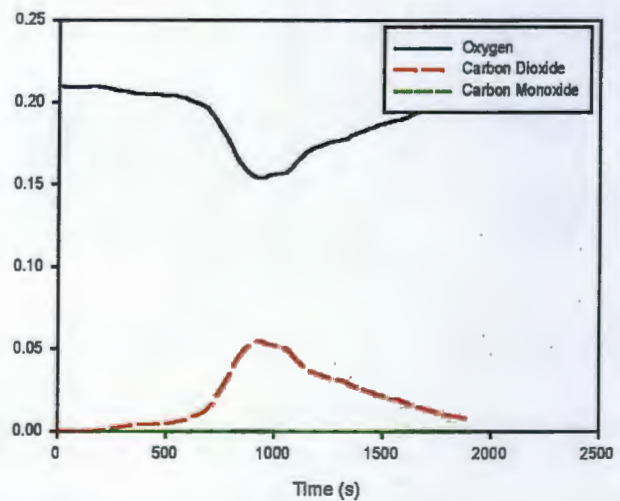
4 Pallets, Slow Ignition Scenario, Target Room
(Open Window Venting)



4 Pallets, Slow Ignition Scenario, Burn Room
(Open Window Venting)



4 Pallets, Slow Ignition Scenario, Target Room
(Open Window Venting)



4 Pallets, Slow Ignition Scenario, Burn Room
(Open Window Venting)

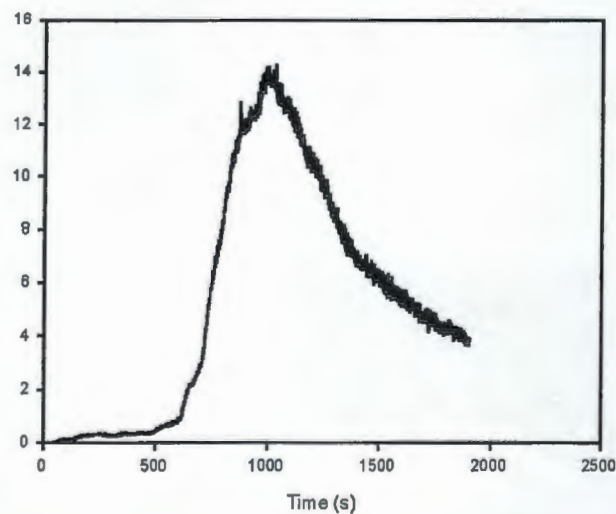


Figure A-15. Temperature, Gas Concentration, and Heat Flux During Test CRA 5, 4 Pallets, Slow Ignition Scenario
(Open Window Venting)

APPENDIX B: Designing Fuel Packages for Field Experiments

Based upon the results of the laboratory experiments, the project team determined that four pallets would provide both a realistic fire scenario, as well as a repeatable and well-characterized fuel source. Varying the placement and quantity of excelsior provided significant variance in the rate of fire growth. Prior to finalization of the fuel package and construction specifications, modeling was used to ensure that the combination of fuel and residential geometry would result in untenable conditions throughout the structure without subjecting the firefighters to unsafe testing conditions. Therefore, CFAST (the consolidated fire and smoke transport model (Jones 2000))

and FDS (fire dynamics simulator model (McGrattan 2006)) were used to predict the temperatures and toxic species within the structure as a function of the experimentally determined heat release rates. The results summarized below confirmed that the building geometry and fuel package produced adequate variation in tenability conditions in the residential structure and ensured that the room of origin would not reach flashover conditions (a key provision of *NFPA 1403*). Meeting these conditions provided the foundation for experiments to meet the two primary objectives of fire department response: preservation of life and property.

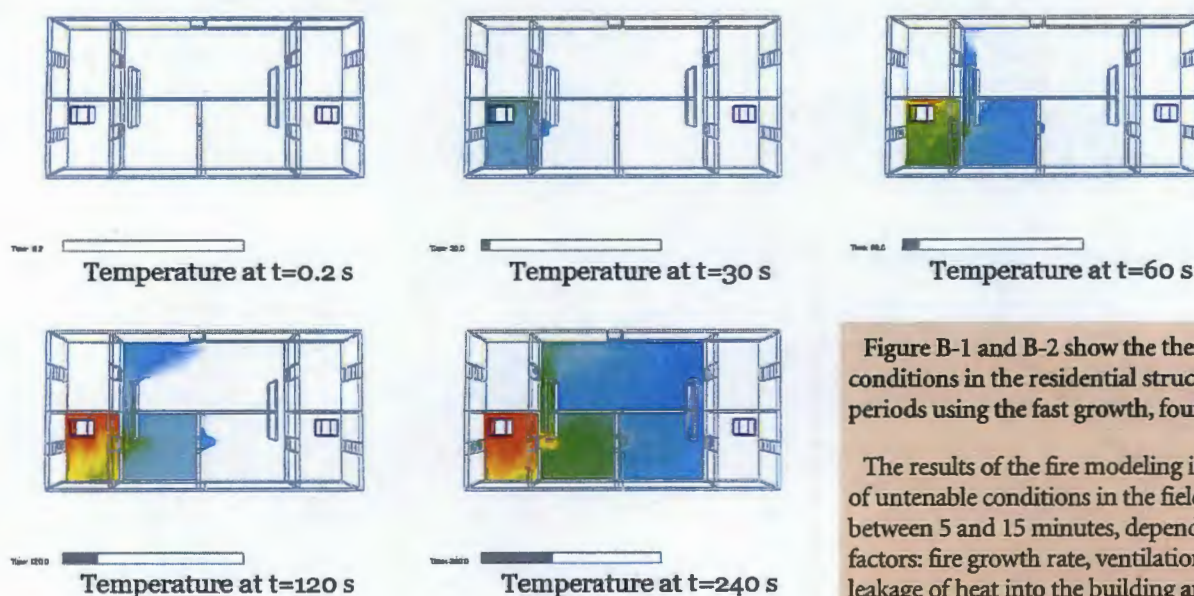


Figure B-1 and B-2 show the thermal and smoke conditions in the residential structure at different time periods using the fast growth, four pallet fuel package.

The results of the fire modeling indicated development of untenable conditions in the field experiments between 5 and 15 minutes, depending upon several factors: fire growth rate, ventilation conditions, the total leakage of heat into the building and through leakage paths, and firefighter intervention. This time frame allowed for differentiation of the effectiveness of various fire department deployment models.

Figure B-1: Time-dependent temperature contours in field structure with fast growth fire

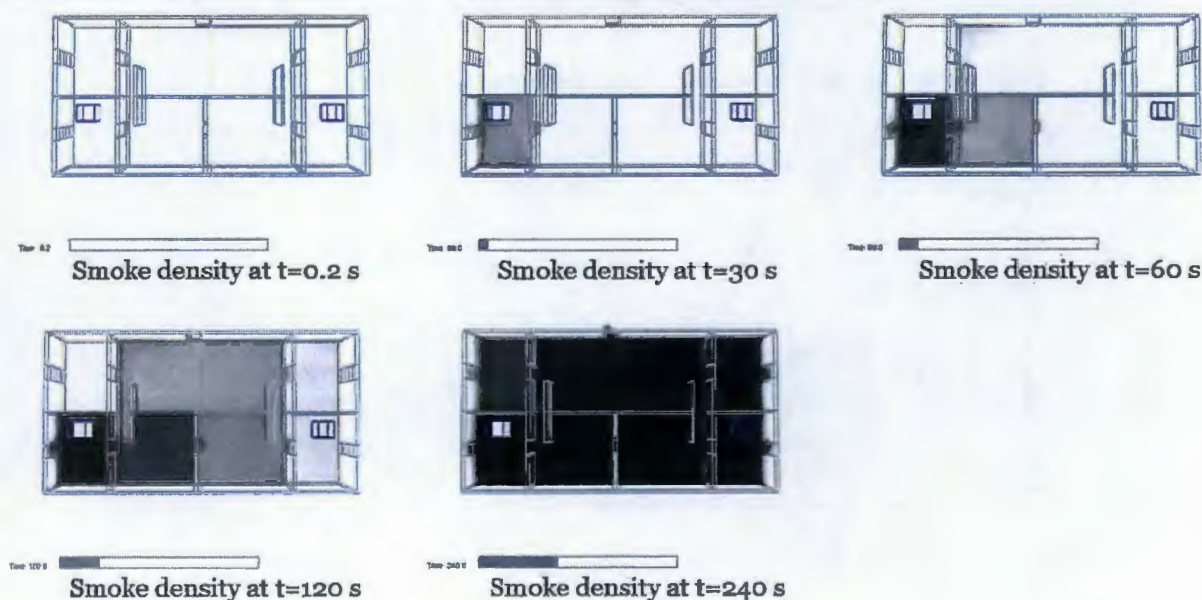


Figure B-2: Time-dependent smoke density contours in field structure with fast growth fire

APPENDIX C: Temporary Burn Prop Construction and Instrumentation

Through the generosity of the Montgomery County (MD), an open space was provided to construct a temporary burn prop at the Montgomery County Fire and Rescue Training Facility in Rockville, MD. The area had ready access to water and electrical utilities. A licensed general contractor was retained, including a structural engineer for the design of critical ceiling members, and the burn prop was constructed over a several month period in late 2008.

The burn prop consisted of two 2,000 ft.² (186 m²) floors totaling 4,000 ft.² (372 m²). An exterior view of two sides of the burn prop is shown in Figure C-1.

Additional partitions were installed by NIST staff to create a floor plan representative of a two-story, 186 m² (2,000 ft.²) single family residence. Note that the structure does not have a basement and includes no exposures. The overall dimensions are consistent with the general specifications of a typical low hazard residential structure that many fire departments respond to on a regular basis, as described in *NFPA 1710*.

Further details about typical single family home designs are not provided in the standard. Therefore, a floor plan representative of a typical single family home was created by the project team. Details and floor plan dimensions are shown in Figure C-2.



Figure C-1: View of two sides of the burn prop

The black lines indicate load-bearing reinforced concrete walls and red lines indicate the gypsum over steel stud partition walls. The ceiling height, not shown in Figure C-2, is 94 in. (2.4 m) throughout the entire structure except in the burn compartments, where the ceiling height is 93 in. (2.4 m). The purpose of the partition walls was to symmetrically divide the structure about the short axis in order to allow one side of the test structure to cool down and dry-out after a fire test with suppression while conducting experiments on the other side.

The concrete walls original to the burn prop were 8 in. (204 mm)

) thick steel reinforced poured concrete and the floors on the first level and second levels were 4 in. (102 mm) thick poured concrete. The support structure for the second floor and the roof consisted of corrugated metal pan welded to open web steel joists. The dimensions of the joists are shown in Figure C-3. The ceiling was constructed from ½ in. (13 mm) thick cement board fastened to the bottom chord of the steel joists. Partition walls were constructed from 5/8 in. (17 mm) thick gypsum panels attached to 20 gauge steel studs fastened to steel track, spaced 16 in. (407 mm) on center.

Additional construction was implemented in the burn compartments to address thermal loading and hose stream impingement concerns. Spray-on fireproofing was applied to the steel joists prior to fastening the ceiling, as shown in Figure C-4. The ceilings were constructed with three layers of ½ in. (13 mm) cement board, as opposed to one layer construction in the rest of the building. Each layer was fastened in a different direction so that seams of adjacent layers ran orthogonally. The difference in ceiling heights previously

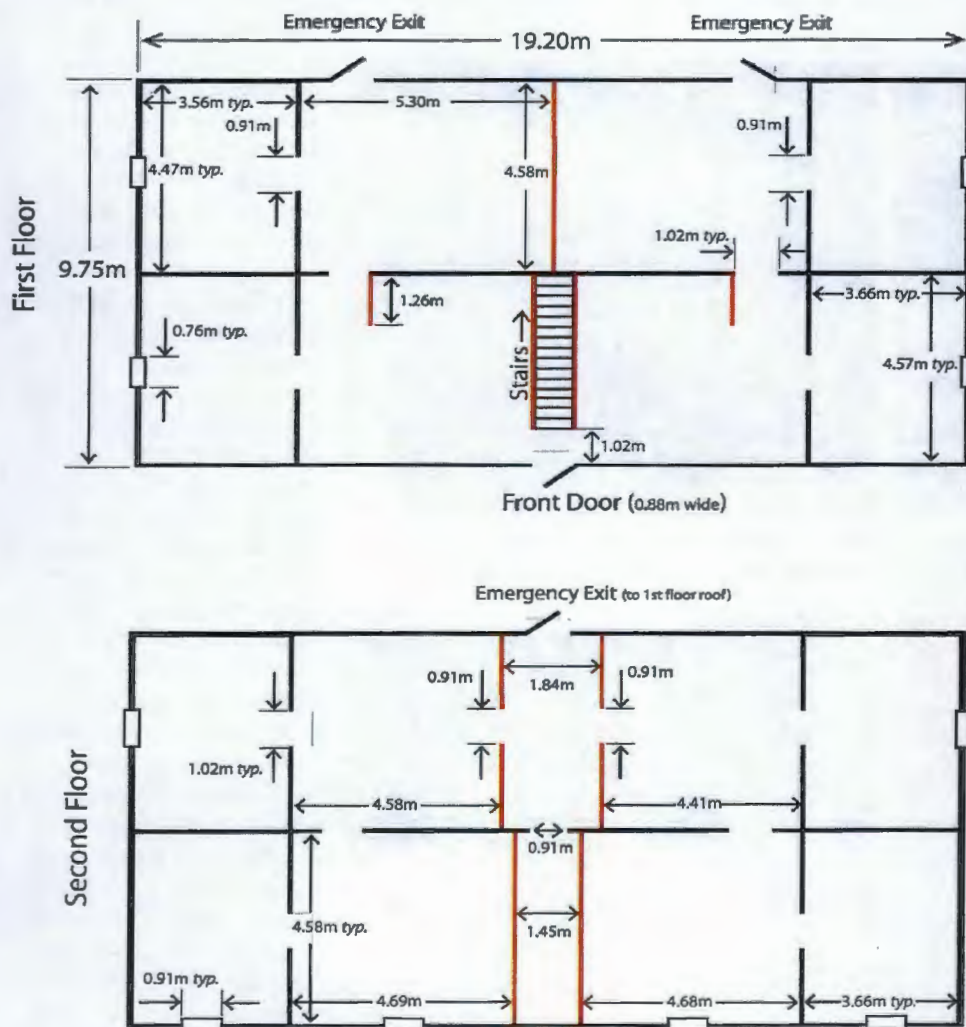


Figure C-2: Dimensions of the Burn Prop Floor Plan

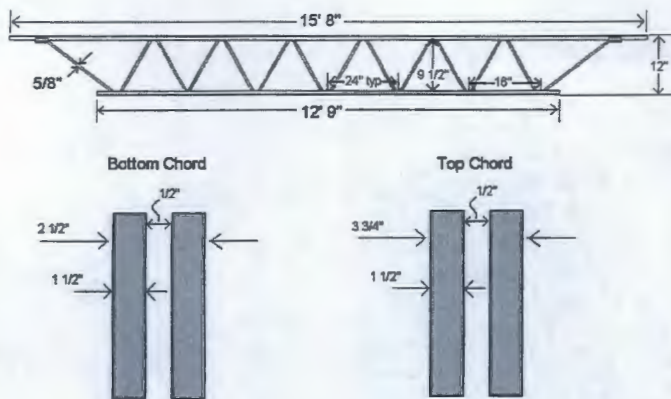


Figure C-3: Structural Steel Dimensions

mentioned is the result of the two additional sheets of cement board. The burn compartment walls were constructed from a single layer of $\frac{1}{2}$ in. (13 mm) cement board over a single layer of $\frac{5}{8}$ in. (16 mm) gypsum board, attached to $\frac{7}{8}$ in. (22 mm) offset metal furring strips. Particular care was taken so that all ceiling and partition wall seams were filled with chemically-setting type joint compound to prevent leakage into the interstitial space between the ceiling and the floor above. After construction of the ceiling was complete, a dry-standpipe deluge system was installed with one head in each burn room to provide emergency suppression. During an experiment, a 2.5 in. (104 mm) ball valve fitting was attached and charged from a nearby hydrant. Figure

C-5 was taken during the process of replacing “worn out” ceiling panels and shows the additional construction implemented in the burn room as well as the deluge sprinkler head.

Windows and exterior doors were constructed to be non-combustible. Windows were fabricated from 0.25 in. (10 mm) thick steel plate and the exterior doors were of prefabricated hollow-core steel design. The windows on the first floor were 30 in. (0.76 m) width x 36 in. (0.91 m) height and 36 in. (0.91 m) width x 40 in. (1.02 m) height on the second floor. Exterior doors were 35.8 in. (0.88 m) width x 80.5 in. (2.03 m) height. There were no doors attached to the doorways inside the structure. Figure C-6 shows the construction of the burn prop windows as well as the NFPA 1403-compliant latch mechanism. Figure C-7 is a picture of the interior of the burn prop taken just outside the burn compartment, showing the construction of the ceiling, interior doorway construction, gypsum wing wall and the joint compound used to seal seams in the ceiling and walls.

Instrumentation

After construction, the instrumentation to measure the propagation of products of combustion was installed throughout the burn prop. The instrumentation plan was designed to measure gas temperature, gas concentrations, heat flux, visual obscuration, video, and time during the experiments. The data were recorded at intervals of 1 s on a computer based data acquisition system. A schematic plan view of the instrumentation arrangement is shown in Figure C-8.

Table C-1 gives the locations of all of the instruments.



Figure C-4: Fireproofing added to structural steel



Figure C-5: Additional construction of burn room walls and ceiling and deluge sprinkler head.



Figure C-6: Window & Latch Construction



Figure C-7: Interior View of Burn Prop

Measurements taken prior to the compartment fire experiments were length, wood moisture content, fuel mass and weather conditions (relative humidity, temperature, wind speed and direction). Gas temperatures were measured with two different constructs of type K (Chromel-Alumel) thermocouples. All thermocouples outside the burn compartments were fabricated from 30 gauge glass-wrapped thermocouple wire. Vertical arrays of three thermocouples were placed near the front door on the north side and south sides of the stairwell on the first floor. On the second floor, vertical arrays of eight thermocouples were placed near the center of each target room. Inside the burn compartments, seven 3.2 mm (0.125 in.) exposed junction thermocouples and 0.76 m (30 in.) SUPER OMEGACLAD XL® sheathed thermocouple probes were arranged in a floor-to-ceiling array. Figure C-9 shows the vertical array in the burn

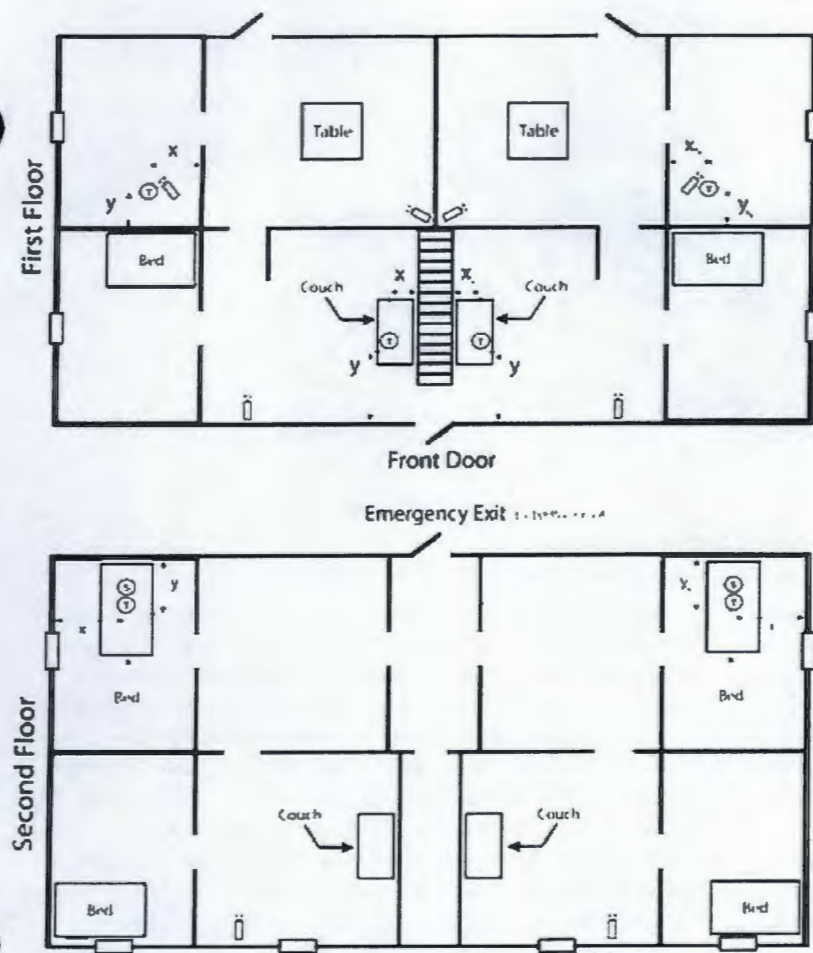


Figure C-8: Instrumentation & Furniture Prop Layout

compartment. Type K thermocouple probes were chosen because of their ability to withstand high temperature, moisture and physical abuse resulting from physical contact with hose streams and firefighters. To protect the extension wire and connectors from the effects of heat and water, through-holes were drilled in the burn compartment walls and the sheaths were passed through from the adjacent compartment. To prevent leakage through the holes, all void spaces were tightly packed with mineral wool. Inside the burn compartment the end of each probe was passed through an angle iron stand, and fastened to the floor and ceiling to provide additional protection from physical contact with firefighters and to ensure that the measurement location remained fixed throughout the experiments. In consideration of the risk associated with heating the open web steel joists, additional thermocouples were placed above each burn compartment to monitor the temperature of the interstitial space.

Table C-1: Detailed locations of instruments within respective rooms

Floor	Instrument	X_S [m]	Y_S [m]	Z_S [m]	X_N [m]	Y_N [m]	Z_N [m]	X_C [m]	Y_C [m]	Z_C [m]
1	Thermocouple	0.76	0.51	0.3, 0.61, 0.91, 1.22, 1.52, 1.83, 2.13	0.76	0.51	0.3, 0.61, 0.91, 1.22, 1.52, 1.83, 2.13	Find	Find	0.91, 1.52, 2.41
	HF Gauge 1		N/A		0.91	0.91	0.17			
	HF Gauge 2				0.5	0.66	1			
2	Thermocouple	1.83	0.91	0.3, 0.61, 0.91, 1.22, 1.52, 1.83, 2.13, 2.41	1.83	0.91	0.3, 0.61, 0.91, 1.22, 1.52, 1.83, 2.13, 2.41		N/A	
	Smoke Meter	1.7	0.49	1.52	1.64	0.43	1.5			
	Gas Probe	1.83	0.91	1.7	1.83	0.91	1.52			

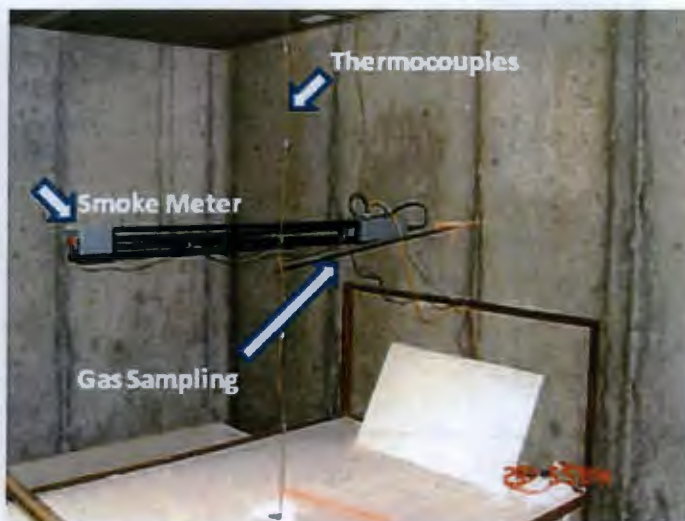


Figure C-9: Burn Room Thermocouple Array Figure C-10: Target Room Instrument Cluster

Gas concentrations were sampled at the same location in each target room. Both gas probes were plumbed to the same analyzer and isolated using a switch valve; gas was only sampled at one location during any given test. The gas sampling points were located in the center of the West wall (C Side) of both rooms, 1.5 m (5 ft.) above the floor. The sampling tubes were connected to a diaphragm pump which pulled the gas samples through stainless steel probes into a sample conditioning system designed to eliminate moisture in the gas sample. The dry gas sample was then piped to the gas analyzer setup. In all of the experiments, oxygen was measured using a paramagnetic analyzer and carbon monoxide and carbon dioxide were measured using a non-dispersive infrared (NDIR) analyzer. One floor-to-ceiling thermocouple array was also co-located with each sample port inlet.

Schmidt-Boelter heat flux gauges were placed in the North burn room. One gauge was located 1.0 m (3.3 ft.) above the floor and was oriented towards the fire origin (waste basket). This heat flux gauge was placed to characterize the radiative heat flux at the face piece level that would be experienced by a firefighter inside the room. A second flux gauge was placed on the floor in order to characterize the radiative heat flux from the upper layer and to make an estimate of how close the room was to flashing over with respect to time from ignition (using the common criteria of flashover occurring at $\sim 20 \text{ kW/m}^2$ at the floor level). The heat flux gauges were co-located with the thermocouple probe array.



Figure C-11: Non-combustible "Prop" Table

All length measurements were made using a steel measuring tape. Wood moisture content measurements were taken using a non-insulated-pin type wood moisture meter. Fuel mass was measured prior to each experiment using a platform-style heavy duty industrial scale. Mass was not measured after each experiment because of the absorption of fire suppression water. Publicly accessible Davis Vantage Pro2 weather instrumentation (available via <http://www.wunderground.com>) located approximately two miles from the experimentation site was used to collect weather data in five minute intervals for the each day that the experiments were conducted. Figure C-10 is a photograph of the West wall of the North target room, showing the thermocouple array, the smoke obscuration meter, and a gas sampling probe used during the phase two experiments. The layout is identical to that in the South target room.

Non-combustible "prop" furniture was fabricated from angle iron stock and gypsum wallboard. The purpose of the furniture was twofold. The furniture was placed inside the burn prop to simulate realistic obstacles which obscure the search paths and hose stream advancement. The second use for the furniture was so that measurement instrumentation could be strategically placed within the frame of the furniture. This served to protect instrumentation from physical damage as a result of contact with firefighters and their tools. Figure C-11 shows an example of a table placed outside the burn room.

All instruments were wired to a centralized data collection room, shown in Figure C-12, which was attached as a separate space on one side of the building. This ensured physical separation for the data collection personnel from the effects of the fire, while minimizing the wire and tube lengths to the data logging equipment. Note that the roof of the instrument room was designed to serve as an additional means of escape for personnel from the second floor of the burn prop through a metal door. A railing was installed in order to minimize the fall risk in the event that the emergency exit was required.



Outside



Inside

Figure C-12: Instrumentation Room

Table C-2: Dimensions and Mass of Furniture for Room and Contents Tests

Furniture	Width [m]	Depth [m]	Height [m]	Mass [kg]	Material
Couch	1.8	0.8	0.9	58.1	See D-3
Dresser	1.8	0.5	0.6	72.3	Laminated Particle Board
Nightstand	0.5	0.6	0.61	22.7	Laminated Particle Board
Chair	0.5	0.7	0.6	9.2	Wood, Fabric, and Polyurethane Foam
	Back cushion = 0.1m, Bottom cushion = 0.07m				
Blanket	1.8	-	2.4	1.3	100 % Cotton
Body Pillow	0.5	-	1.4	1.3	100 % cotton cover, polyester fill
Trash Can	0.4	0.3	0.4	1.3	Polypropylene
Towel	0.8	-	1.4	0.4	100 % Cotton
Wallboard	1.2	0.003	2.4	9.0	MDF

Table C-3: Materials in Couch

Body:	Resinated dyed fiber (unknown material) 3 %
	PU foam pad 46%
	Waste fiber batting (unknown material) 26 %
	Polyester fiber batting 25 %
Cushions:	PU foam pad 86 %
	Polyester fiber batting 14 %

APPENDIX D: Data Collection and Company Protocols for Time-to-Task Tests

Time-to-Task Data Collection Chart

Date _____ Start Time _____ End Time (all task complete) _____

Timer Name _____

Task	Start Time	Completion Time	Duration
Stop at Hydrant-- Wrap Hose			
Position Engine 1			
Conduct Size-up <ul style="list-style-type: none"> - 360° lap - Transmit report - establish command 			
Engage Pump			
Position attack line (stop time – at front door)			
Establish 2-in-2-out			
Charge Hydrant – supply attack Engine			
Establish RIT			
Gain/Force Entry			
Advance Line (stop time –water on fire)			
Deploy Back up line (stop time at front door)			
Advance Back up line/protect stairwell (start time at front door – Stop at stairwell)			
Conduct Primary Search			
Ground Ladders in Place			
Horizontal Ventilation (ground)			
Horizontal Ventilation (2 nd story)			
Control Utilities (interior)			
Control Utilities (exterior)			
Conduct Secondary Search			
Check for Fire Extension (walls)			
Check for Fire Extension (ceiling)			
Mechanical Ventilation			

Company Protocols: Crew Size of 2

(10 total personnel on scene)

PLUS 4 RIC – 1403 = total 14 needed

Tasks/Company	Engine 1/2	Truck 1/2	Engine 2/2	Battalion Chief/ Aide	Engine 3/2
Arrive on Scene - Arrive/ stop at hydrant - Position engine - Layout report - On-scene report - Conduct size-up – 360° lap – incident action plan – offensive – detail incident (situation report) - Transmit size-up to responding units - Transfer command to chief	Driver Officer -	-Arrive - 360° lap		- Arrives - Assumes Command - Evaluates Resources - Establishes Command post - Evaluates exposure problems - Directs hose positioning - Coordinates Units - Transmits Progress reports - Changes strategy - Orders, records, and transmits results of primary and secondary searches - Declares fire under control	
Establish Supply line - Hydrant-Drop line (wrap) - Position engine - Pump engaged - 4" straight lay - ----- - Supply attack engine	Driver/O Driver/O Driver/O	Position Truck	-Dry Lay – 2nd engine takes hydrant - Charged hydrant - Supply attack engine Driver		
Position attack line - Flake - Charge - Bleed - ----- - Advance	Officer – (Not interior—just front door) Officer	Officer			
Establish - 2 in – 2 out (Initial RIT)		O/D			
Establish RIT (Dedicated)		O/D (performs all RIT duties)			

Tasks/Company	Engine 1/2	Truck 1/2	Engine 2/2	Battalion Chief/ Aide	Engine 3/2
Gain/ Force Entry		O/D			
Advance Line - scan search fire room - suppression	Officer (if officer commits then he must pass command)		Officer		
Deploy Back-up Line and protect stairwell					O/D
Complete Primary Search (in combo with Fire Attack)					O/D
Search Fire Floor					
Search other Floors					
Ventilation (vent for fire or vent for life) - Horizontal - Ventilation		Driver/Officer			
Ground Laddering – 2nd story windows, front and side, for firefighter means of egress and for vertical ventilation – 24’/28’ and roof ladder in case of vertical vent.		Driver /Officer			
Control Utilities (Interior and exterior)					Driver/Officer
Conduct Secondary Search - Search Fire Floors - Search other Floors Check for Fire Extension	Officer		Officer		
Open ceiling walls near fire on fire floor Check floor above for fire extension - wall breach - ceiling breach	Officer		Officer		O/D
Mechanical Ventilation		Driver/Officer			

Company Protocols: Crew Size of 3

(14 total personnel on scene)

PLUS 4 RIC – 1403 = total 18 needed

Tasks/Company	Engine 1/3	Truck 1/3	Engine 2/3	Battalion Chief/ Aide	Engine 3/2
Arrive on Scene - Arrive/ stop at hydrant - Position engine ----- - Layout report - On-scene report - Conduct size-up – 360° lap – incident action plan – offensive – detail incident (situation report) - Transmit size-up to responding units - Transfer command to chief	Driver Officer -	-Arrive - 360 degree lap		- Arrives - Assumes Command - Evaluates Resources - Establishes Command post - Evaluates exposure problems - Directs hose positioning - Coordinates Units - Transmits Progress reports - Changes strategy - Orders, records, and transmits results of primary and secondary searches - Declares fire under control	
Establish Supply line - Hydrant-Drop line (wrap) - Position engine - Pump engaged - 4" straight lay ----- - Supply attack engine	Driver Driver Driver	Position Truck	Dry Lay – 2nd engine takes hydrant Charged hydrant – Supply attack engine Driver		
Position attack line - Flake - Charge - Bleed - Advance	D/RB				
Establish - 2 in – 2 out (Initial RIT)		O/RB			
Establish RIT (Dedicated)			O/RB— advance by foot to get to point of entry – performs all RIT duties		

Tasks/Company	Engine 1/3	Truck 1/3	Engine 2/3	Battalion Chief/ Aide	Engine 3/3
Gain/ Force Entry		O/RB			
Advance Line - scan search fire room - suppression	O/RB (if officer commits then he must pass command)				
Deploy Back-up Line and protect stairwell					O/RB
Complete Primary Search (in combo with Fire Attack)		O/ RB			
Search Fire Floor		-			
Search other Floors					
Ventilation (vent for fire or vent for life) - Horizontal - Ventilation		Driver			Driver
Ground Laddering – 2nd story windows, front and side, for firefighter means of egress and for vertical ventilation – 24'/28' and roof ladder in case of vertical vent.		Driver			Driver
Control Utilities (Interior and exterior)		Driver (exterior) O/RB (Interior)			Driver (exterior)
Conduct Secondary Search - Search Fire Floors - Search other Floors					O/RB
Check for Fire Extension Open ceiling walls near fire on fire floor Check floor above for fire extension - wall breach - ceiling breach	O/RB				
Mechanical Ventilation		Driver			Driver

Company Protocols: Crew Size of 4

Total on scene = 18

PLUS 4 RIC – 1403 = total 22 needed

Tasks/Company	Engine 1/4	Truck 1/4	Engine 2/4	Battalion Chief/ Aide	Engine 3/4
Arrive on Scene - Arrive/ stop at hydrant - Position engine - Layout report - On-scene report - Conduct size-up – 360° lap – incident action plan – offensive – detail incident (situation report) - Transmit size-up to responding units - Transfer command to chief	Driver Officer -	-Arrive - 360 degree lap		- Arrives - Assumes Command - Evaluates Resources - Establishes Command post - Evaluates exposure problems - Directs hose positioning - Coordinates Units - Transmits Progress reports - Changes strategy - Orders, records, and transmits results of primary and secondary searches - Declares fire under control	
Establish Supply line - Hydrant-Drop line (wrap) - Position engine - Pump engaged - 4" straight lay - Supply attack engine (1 3/4")	Driver Driver Driver	Position Truck	-Dry Lay – 2nd engine takes hydrant Charged hydrant – Supply attack engine Driver		
Position attack line - Flake - Charge - Bleed - Advance	RB/Nozzle LB/Flake Both advance line for fire attack				
Establish - 2 in – 2 out (Initial RIT)		D/LB			
Establish RIT (Dedicated)			O/LB/RB— advance by foot to get to point of entry – performs all RIT duties		

Tasks/Company	Engine 1/4	Truck 1/4		Battalion Chief/ Aide	Engine 3/4
Gain/ Force Entry		O/RB			
Advance Line - scan search fire room - suppression	RB/LB Officer – not on line (if officer commits then he must pass command)				
Deploy Back-up Line and protect stairwell					O/RB
Complete Primary Search (in combo with Fire Attack)		Officer and RB			
Search Fire Floor		-			
Search other Floors					
Ventilation - Horizontal - Ventilation		Driver and LB			
Ground Laddering – 2nd story windows, front and side, for firefighter means of egress and for vertical ventilation – 24'/28' and roof ladder in case of vertical vent.		Driver /LB			
Control Utilities (Interior and exterior)		Driver/LB (control exterior)			
Conduct Secondary Search - Search Fire Floors - Search other Floors		O/RB (control interior)			D/LB
Check for Fire Extension Open ceiling walls near fire on fire floor Check floor above for fire extension - wall breach - ceiling breach	O/RB	O/RB			
Mechanical Ventilation		D/LB			

Company Protocols: Crew Size of 5

D/O/LB/RB/CB Total on scene = 22

PLUS 4 RIC – 1403 = total 26 needed

Tasks/Company	Engine 1/5	Truck 1/5	Engine 2/5	Battalion Chief/ Aide	Engine 3/4
Arrive on Scene - Arrive/ stop at hydrant - Position engine ----- - Layout report - On-scene report - Locate Fire - Conduct size-up – 360° lap – incident action plan – offensive – detail incident (situation report) - Transmit size-up to responding units - Transfer command to chief	Driver Officer -	-Arrive - 360 degree Size up.		- Arrives - Assumes Command - Evaluates Resources - Establishes Command post - Evaluates exposure problems - Directs hose positioning - Coordinates Units - Transmits Progress reports - Changes strategy - Orders, records, and transmits results of primary and secondary searches - Declares fire under control	
Establish Supply line - Hydrant-Drop line (wrap) - Position engine - Pump engaged - 4" straight lay ----- - Supply attack engine (1 3/4")	Driver Driver Driver	Position Truck	-Dry Lay – 2nd engine takes hydrant Charged hydrant – Supply attack engine Driver		
Position attack line - Flake - Charge - Bleed - Advance	RB/Nozzle LB/Flake CB/ Control ----- Advance line for fire attack ----- The Officer responsibility is to supervise hose stretch /monitor safety and continually survey the scene				
Establish - 2 in – 2 out (Initial RIT)		D/LB			

Tasks/Company	Engine 1/5	Truck 1/5	Engine 2/5	Battalion Chief/ Aide	Engine 3/5
Establish RIT (Dedicated)			O/LB/RB— advance by foot to get to point of entry— performs all RIT duties		
Gain/ Force Entry		O/RB/CB			
Advance Line - scan search fire room - suppression	RB/LB/CB Officer – not on line (if officer commits then he must pass command)				
Insures first line flowing water— Deploy Back-up Line and protect stairwell (1 ¾")					O/RB/CB
Complete Primary Search (in combo with Fire Attack) Search Fire Floor – Search other floors-		Officer and RB/CB			
Ventilation (vent for fire or vent for life) - Horizontal - Vertical		Driver and LB			
Ground Laddering – 2nd story windows, front and side, for firefighter means of egress and for vertical ventilation – 24'/28' and roof ladder in case of vertical vent.		Driver /LB			
Control Utilities after search, force entry, venting and fire extinguished (Interior and exterior)		Driver/LB (control exterior) O/RB/CB (control interior)			
Conduct Secondary Search -Fire Floor -Primary and secondary search of entire floor above		D/LB			D/LB O/RB/CB
Check for Fire Extension Open ceiling walls near fire on fire floor Check floor above for fire extension wall breach ceiling breach-	O/RB				O/RB/CB
Mechanical Ventilation					

Appendix E: Statistical Analysis of Time to Task Test Data

Identifying Statistically Significant Differences in Crew Size and Stagger on a Number of Task Timings Using Regression Analyses of Times (Start, End and Duration) on Crew Size and Stagger

Task-Based Measure of Time	Crew Size			Stagger	Crew Size 5/4 vs. 3/2	Stagger
	3 vs. 2	4 vs. 3	5 vs. 4			
Total time	X *	X			X	
Conduct size up (start)			X		X	
Conduct size up (end)					X	
Conduct size up (duration)						
Position attack line (start)	X				X	
Position attack line (duration)		X			X	
Establish 2 in 2 out (end)		X		X	X	X
Establish RIT (end)	na	na	na	na	na	na
Gain forced entry (start)		X			X	
Advance line (start)	X	X			X	
Advance line (end)	X		X		X	
Deploy backup line (start)					X	X
Deploy backup line (end)				X		X
Advance backup line (start)				X		X
Advance backup line (end)				X		X
Conduct primary search (start)	X	X			X	
Ground ladders in place (end)		X	x	X	X	o
Ground ladders in place (duration)			X	X	X	X
Horizontal ventilation Story 2 window 3 (Start)		X			X	
Horizontal ventilation Story 2 window 3 (End)		X			X	
Horizontal ventilation Story 2 window 2 (Start)		X			X	
Horizontal ventilation Story 2 window 2 (End)		X			X	
Horizontal ventilation Story 2 window 1 (Start)		X			X	
Horizontal ventilation Story 2 window 1 (End)		X			X	
Horizontal ventilation Story 1 window 2 (Start)	o	X			X	
Horizontal ventilation Story 1 window 2 (End)		X			X	
Control utilities (Interior) (Start)	X	X			X	
Conduct Secondary Search (Start)	X				X	
Check for Fire Ext (walls) (Start)	X	X			X	
Check for Fire Ext (ceiling) (Start)		X				
Stretch time**	X		o		X	

* An 'X' denotes statistical significance at the 0.05 level; a 'o' denotes significance at the 0.10 level.

Appendix F: All Regression Coefficients

Regression Models of Time to Task (in Seconds) as a Function of Crew Size and Stagger
(Standard Errors are in Parentheses underneath coefficients)

	Coefficients					
Measure of Task Time	Time measured	Crew size of 3	Crew size of 4	Crew size of 5	Close Stagger	Constant
Total time		-100.5	-408.33	-402.17	-40.83	1374.42
		(50.29)	(50.29)	(50.29)	(35.56)	(39.77)
Conduct size up	Start	2.5	-5.167	-18.17	-1.25	335
		(5.97)	(5.97)	(5.97)	(4.22)	(4.72)
Conduct size up	Complete	-5.167	-13.17	-38.33	-12	416
		(13.60)	(13.60)	(13.60)	(9.62)	(10.75)
Conduct size up	Duration	-7.667	-8	-20.17	-10.75	81.04
		(12.10)	(12.10)	(12.10)	(8.56)	(9.57)
Position attack line	Start	-63.5	-63.5	-69.67	-11.17	408.1
		(14.09)	(14.09)	(14.09)	(9.96)	(11.14)
Position attack line	Duration	-16	-63.67	-61.67	5.167	160.6
		(13.79)	(13.79)	(13.79)	(9.75)	(10.90)
Establish 2in - 2 out	Complete	-6.7E-15	-90	-90	-30	355
		(9.73)	(9.73)	(9.73)	(6.88)	(7.69)
Establish RIT	Complete	70	70	70	-60	435
		0.00	0.00	0.00	0.00	0.00
Gain forced entry	Start	-23.5	-54	-80.83	-20.83	528.6
		(19.66)	(19.66)	(19.66)	(13.90)	(15.54)
Advance line	Start	-54	-97.83	-123.5	-17.5	586.3
		(18.83)	(18.83)	(18.83)	(13.31)	(14.88)
Advance line	Complete	-61	-95.5	-134.7	-19.08	625.5
		(20.35)	(20.35)	(20.35)	(14.39)	(16.08)
Deploy backup line	Start	-26	-42.67	-53.5	-96.75	641.5
		(17.11)	(17.11)	(17.11)	(12.10)	(13.53)
Deploy backup line	Complete	-15.83	-56.17	-17.5	-53.75	728.9
		(33.49)	(33.49)	(33.49)	(23.68)	(26.48)
Advance backup line	Start	-33	-66.83	-34.83	-63	779.7
		(29.65)	(29.65)	(29.65)	(20.97)	(23.44)
advancebackupline2	Complete	-34.5	-68.17	-36.17	-63.75	784.4
		(29.73)	(29.73)	(29.73)	(21.02)	(23.50)
conductprimarysearch1	Start	-147	-215.8	-211.5	0.1667	736.1
		(25.08)	(25.08)	(25.08)	(17.74)	(19.83)
Ground ladders in place	Complete	-38	-196.5	-317.8	-69.83	1168
		(48.38)	(48.38)	(48.38)	(34.21)	(38.24)
Ground ladders in place	Duration	-33.83	-83.67	-185.7	-72.08	617
		(48.12)	(48.12)	(48.12)	(34.03)	(38.04)
Horizontal ventilation, second story, window 3	Start	-53.67	-217.8	-211	-26.59	759.1
		(30.75)	(30.75)	(30.75)	(21.75)	(24.31)
Horizontal ventilation, second story, window 3	Complete	-64.83	-316	-353	-33.58	1088
		(49.74)	(49.74)	(49.74)	(35.17)	(39.32)
Horizontal ventilation, second story, window 2	Start	-51.67	-265.8	-261.2	-18.83	885.1
		(37.20)	(37.20)	(37.20)	(26.30)	(29.41)

All Regression Coefficients (CONTINUED)

Regression Models of Time to Task (in Seconds) as a Function of Crew Size and Stagger
(Standard Errors are in Parentheses underneath coefficients)

Horizontal ventilation, second story, window 2	Complete	-53.5	-259.8	-262.3	-13.33	931.3
		(39.97)	(39.97)	(39.97)	(28.26)	(31.60)
Horizontal ventilation, second story, window 1	Start	-70	-316.3	-348.8	-31.08	1038
		(48.37)	(48.37)	(48.37)	(34.20)	(38.24)
Horizontal ventilation, second story, window 1	Complete	-51.83	-219	-214.8	-24	805.7
		(33.71)	(33.71)	(33.71)	(23.83)	(26.65)
Horizontal ventilation, first story, window 2	Start	-87.17	-386.3	-428.5	-44.67	1200
		(45.13)	(45.13)	(45.13)	(31.91)	(35.68)
Horizontal ventilation, first story, window 2	Complete	-88.5	-391.5	-423.3	-44.17	1224
		(47.02)	(47.02)	(47.02)	(33.25)	(37.17)
Control utilities interior	Start	-136.5	-287.8	-300	-6.333	946.3
		(45.57)	(45.57)	(45.57)	(32.22)	(36.02)
Control utilities exterior	Start	6.667	-281.8	-312.8	-38.17	1063
		(70.21)	(70.21)	(70.21)	(49.65)	(55.51)
Conduct secondary search	Start	-92.5	-143	-152.7	-28.25	846
		(38.97)	(38.97)	(38.97)	(27.56)	(30.81)
Check for fire extension walls	Start	-453.8	-535.3	-608.7	-38.25	1155
		(38.28)	(38.28)	(38.28)	(27.07)	(30.26)
Check for fire extension ceiling	Start	-206.3	-349.7	-292.7	-2.833	1086
		(48.29)	(48.29)	(48.29)	(34.14)	(38.17)

Regression Models of Time to Task (in Seconds) as a Function of Combined Crew Size and Stagger (Standard Errors appear in Parentheses)

Measure of Task Time*	Time measured	Coefficients		
		Crew size of 4/5 vs. 3/2	Close Stagger	Constant
Total time		-355 (37.23)	-40.83 (37.23)	1324.00 (32.24)
Conduct size up	Start	-12.92 (4.50)	-1.25 (4.50)	336.2 (3.90)
Conduct size up	Complete	-23.17 (9.97)	-12 (9.97)	413.4 (8.64)
Conduct size up	Duration	-10.25 (8.44)	-10.75 (8.44)	77.21 (7.31)
Position attack line	Start	-34.83 (13.66)	-11.17 (13.66)	376.3 (11.83)
Position attack line	Duration	-54.67 (9.60)	5.167 (9.60)	152.6 (8.31)
Establish 2in - 2 out	Complete	-90 (6.55)	-30 (6.55)	355 (5.67)
Establish RIT	Complete	35 (10.80)	-60 (10.80)	470 (9.35)
Gain forced entry	Start	-55.67 (14.32)	-20.83 (14.32)	516.8 (12.40)
Advance line	Start	-83.67 (15.67)	-17.5 (15.67)	559.3 (13.57)
Advance line	Complete	-84.58 (17.67)	-19.08 (17.67)	595 (15.31)
Deploy backup line	Start	-35.08 (12.30)	-96.75 (12.30)	628.5 (10.65)
Deploy backup line	Complete	-28.92 (23.43)	-53.75 (23.43)	721 (20.29)
Advance backup line	Start	-34.33 (21.17)	-63 (21.17)	763.2 (18.33)
advancebackupline2	Complete	-34.92 (21.27)	-63.75 (21.27)	767.1 (18.42)
conductprimarysearch1	Start	-140.2 (28.28)	0.1667 (28.28)	662.6 (24.49)
Ground ladders in place	Complete	-238.2 (37.99)	-69.83 (37.99)	1149 (32.90)
Ground ladders in place	Duration	-117.7 (36.37)	-72.08 (36.37)	600.1 (31.49)
Horizontal ventilation, second story, window 3	Start	-187.6 (22.31)	-26.59 (22.31)	732.3 (19.32)
Horizontal ventilation, second story, window 3	Complete	-302.1 (35.38)	-33.58 (35.38)	1056 (30.64)

Regression Models of Time to Task (in Seconds) as a Function of Combined Crew Size and Stagger (CONTINUED) (Standard Errors appear in Parentheses)

Horizontal ventilation, second story, window 2	Start	-237.7 (26.27)	-18.83 (26.27)	859.3 (22.75)		
Horizontal ventilation, second story, window 2	Complete	-234.3 (28.12)	-13.33 (28.12)	904.6 (24.36)		
Horizontal ventilation, second story, window 1	Start	-297.6 (34.64)	-31.08 (34.64)	1003 (30.00)		
Horizontal ventilation, second story, window 1	Complete	-191 (24.05)	-24 (24.05)	779.8 (20.83)		
Horizontal ventilation, first story, window 2	Start	-363.8 (33.83)	-44.67 (33.83)	1156 (29.30)		
Horizontal ventilation, first story, window 2	Complete	-363.2 (34.80)	-44.17 (34.80)	1180 (30.14)		
Control utilities interior	Start	-225.7 (37.23)	-6.333 (37.23)	878.1 (32.25)		
Control utilities exterior	Start	-300.7 (47.48)	-38.17 (47.48)	1066 (41.12)		
Conduct secondary search	Start	-101.6 (29.88)	-28.25 (29.88)	799.7 (25.88)		
Check for fire extension walls	Start	-345.1 (75.46)	-38.25 (75.46)	927.9 (65.35)		
Check for fire extension ceiling	Start	-218 (46.32)	-2.833 (46.32)	983.1 (40.12)		
Stretch time = advance line minus position engine	Duration	-75.7 (16.68)	-17.2 (16.68)	273.3 (14.44)		
* Standard errors are in parentheses below coefficient value						
		Crew size of 3	Crew size of 4	Crew size of 5	Close Stagger	Constant
Stretch time = advance line minus position engine	Duration	-57.3 (19.39)	-86.7 (19.39)	-122.0 (19.39)	-17.2 (13.71)	301.9 (15.33)

APPENDIX G: Measurement Uncertainty

The measurements of length, temperature, mass, moisture content, smoke obscuration, and time taken in these experiments have unique components of uncertainty that must be evaluated in order to determine the fidelity of the data. These components of uncertainty can be grouped into two categories: Type A and Type B. Type A uncertainties are those evaluated by statistical methods, such as calculating the standard deviation of the mean of a set of measurements. Type B uncertainties are based on scientific judgment using all available and relevant information. Using relevant information, the upper and lower limits of the expected value are estimated so that the probability that the measurement falls within these limits is essentially 100 %. After all the component uncertainties of a measurement have been identified and evaluated it is necessary to use them to compute the combined standard uncertainty using the law of propagation of uncertainty (the “root sum of squares”). Although this expresses the uncertainty of a given measurement, it is more useful in a fire model validation exercise to define an interval for which the measurement will fall within a certain level of statistical confidence. This is known as the expanded uncertainty. The current international practice is to multiply the combined standard uncertainty by a factor of two ($k=2$), giving a confidence of 95 %.

Length measurements of room dimensions, openings and instrument locations were taken using a steel measuring tape with a resolution of 0.02 in (0.5 mm). However, measurement error due to uneven and unlevel surfaces results in an estimated uncertainty of ± 0.5 % for length measurements taken on the scale of room dimensions. The estimated total expanded uncertainty for length measurements is ± 1.0 %.

The standard uncertainty of the thermocouple wire itself is 1.1°C or 0.4 % of the measured value, whichever is greater (Omega 2004). The estimated total expanded uncertainty associated with type K thermocouples is approximately ± 15 %. Previous work done at NIST has shown that the uncertainty of the environment surrounding thermocouples in a full-scale fire experiment has a significantly greater uncertainty (Blevins 1999) than the uncertainty inherent with thermocouple design. Furthermore, while a vertical thermocouple array gives a good approximation of the temperature gradient with respect to height, temperatures cannot be expected to be uniform across a plane at any height because of the dynamic environment in a compartment fire. Inaccuracies of thermocouple measurements in a fire environment can be caused by:

- Radiative heating or cooling of the thermocouple bead
- Soot deposition on the thermocouple bead which change its mass, emissivity, and thermal conductivity
- Heat conduction along thermocouple wires
- Flow velocity over the thermocouple bead

To reduce these effects, particularly radiative heating and cooling, thermocouples with smaller diameter beads were chosen. This is particularly important for thermocouples below the interface because the radiative transfer between the surrounding room surfaces will be significantly less uniform than if the thermocouple were in the hot gas layer. It is suggested in [Pitts] that it may be possible to correct for radiative transfer given enough sufficient

knowledge about thermocouple properties and the environment. However, measurements of local velocity and the radiative environment were not taken. Additionally, the probes were located away from the burn compartment walls in order to avoid the effects of walls and corners.

The gas measurement instruments and sampling system used in this series of experiments have been demonstrated to have an expanded ($k = 2$) relative uncertainty of ± 1 % when compared with span gas volume fractions (Matheson). Given the limited set of sampling points in these experiments, an estimated uncertainty of ± 10 % is being applied to the results.

The potential for soot deposition on the face of the water-cooled total heat flux gauges contributes significant uncertainty to the heat flux measurements. Calibration of heat flux gauges was completed at lower fluxes and then extrapolated to higher values and this resulted in a higher uncertainty in the flux measurement. Combining all of component uncertainties for total heat flux resulted in a total expanded uncertainty of -24 % to +13 % for the flux measurements.

Prior to experimentation, ten of the wooden pallets used in the fuel packages were randomly selected for measurement. Two measurements were taken, moisture content and mass. Moisture content was measured using a pin-type moisture meter with a moisture measurement range of 6 % to 40% and an accuracy of <0.5 % of the measured value between 6 % and 12 % moisture content. Mass measurements were made with an industrial bench scale having a range of 0kg to 100 kg, a resolution of 0.1 kg and an uncertainty of ± 0.1 kg.

All timing staff were equipped with the same model of digital stopwatch with a resolution of 0.01 seconds and an uncertainty of ± 3 seconds per 24 hours; the uncertainty of the timing mechanism in the stopwatches is small enough over the duration of an experiment that it can be neglected. There are three components of uncertainty when using people to time fire fighting tasks. First, timers may have a bias depending on whether they record the time in anticipation of, or reaction to an event. A second component exists because multiple timers were used to record all tasks. The third component is the mode of the stimulus to which the staff is reacting: audible (firefighters announcing task updates over the radio) or visual (timing staff sees a task start or stop).

Milestone events in these experiments were recorded both audibly and visually. A test series described in the *NIST Recommended Practice Guide for Stopwatch and Timer Calibrations* found the reaction times for the two modes of stimulus to be approximately the same, so this component can be neglected. Because of the lack of knowledge regarding the mean bias of the timers, a rectangular distribution was assumed and the worst case reaction time bias of 120 ms was used, giving a standard deviation of 69 ms. The standard deviation of the reaction time was assumed to be the worst case of 230 ms. The estimated total expanded uncertainty of task times measured in these experiments is 240 ms.

An additional component of uncertainty exists for the time measurement of the application of water on the fire. In order to measure this time, timing staff were required to listen for radio confirmation that suppressing water had been applied by the interior attack crew. This process required a member of the interior crew to find and manipulate their microphone, wait for the radio to access a repeater, and transmit the message. Because of the lack of

knowledge about the distributions of time it takes for each part of this process, all parts are lumped into a single estimate of uncertainty and a rectangular distribution is assumed. This is most reasonably estimated to be 2.5 seconds with a standard deviation of ± 2.89 seconds and an expanded uncertainty of ± 5.78 seconds.

Weather measurement uncertainty was referenced to the published user's manual for the instrumentation used. The weather instrumentation has calibration certificates that are traceable to NIST standards. A summary of experimental measurement uncertainty is given in Table G-1.

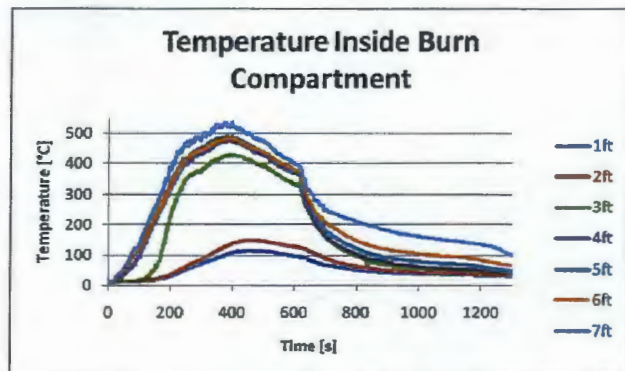
Table G-1: Summary of Measurement Uncertainty

Measurement	Component Standard Uncertainty	Combined Standard Uncertainty	Total Expanded Uncertainty
Length Measurements			
Instrumentation Locations	± 1 %	± 3 %	± 6 %
Building Dimensions	± 1 %		
Repeatability ¹	± 2 %		
Random ¹	± 2 %		
Gas Temperature – Lower Layer			
Calibration	± 1 %	± 8 %	± 15 %
Radiative Cooling	- 5 % to + 0 %		
Radiative Heating	0 % to + 5 %		
Repeatability ¹	± 5 %		
Random ¹	± 3 %		
Wood Moisture Content			
	± 0.5 %	± 0.5 %	± 1%
Wood Pallet Mass			
	± 0.2%	± 0.1%	± 0.1%
Weather			
Relative Humidity	± 3%		
Barometric Pressure	± 0.03" Hg		
Wind Speed	± 5%		
Wind Direction	± 5%		
Outside Temperature	±0.5°C		
Time			
Timer Bias	± 0.069s	± 2.90s	± 5.80 s
Reaction Time	± 0.230s		
Radio Operation	± 2.890s		
Notes: 1. Random and repeatability evaluated as Type A, other components as Type B.			

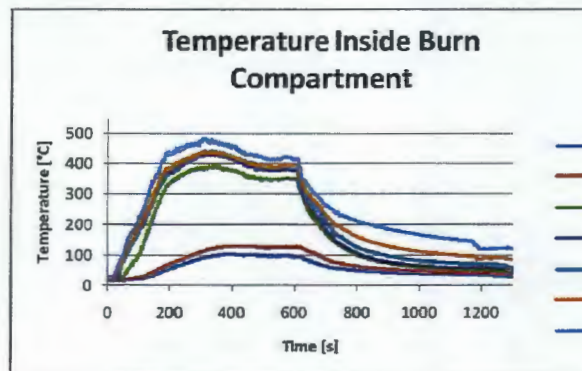
APPENDIX H: Charts of Gas and Temperature Data

Examples of Gas and Temperature Data for Time-to-Task Tests

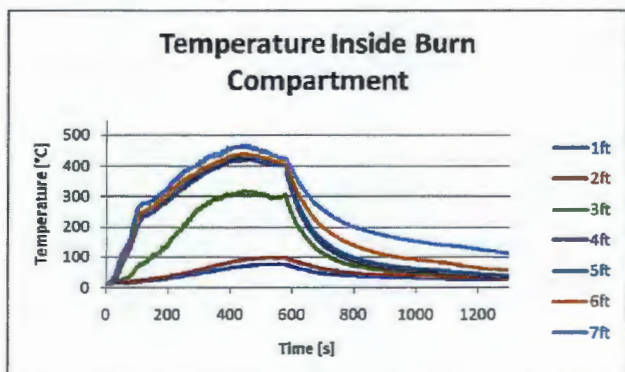
Burn Room Data



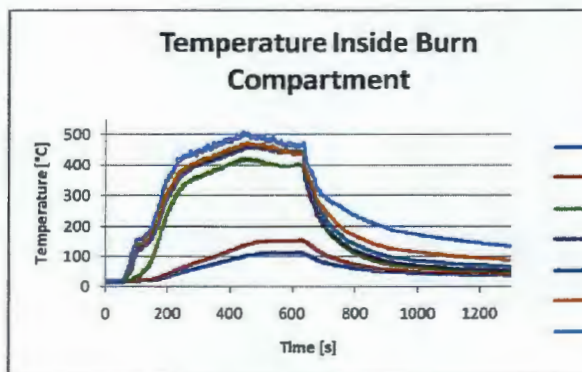
2 Person, Close Stagger



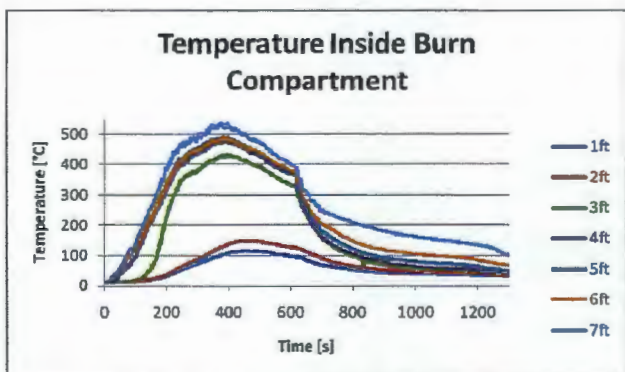
2 Person, Far Stagger



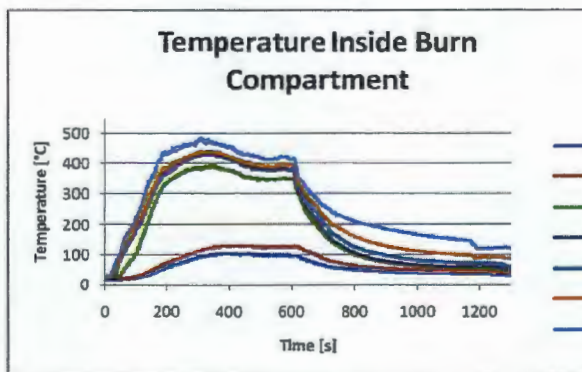
3 Person, Close Stagger



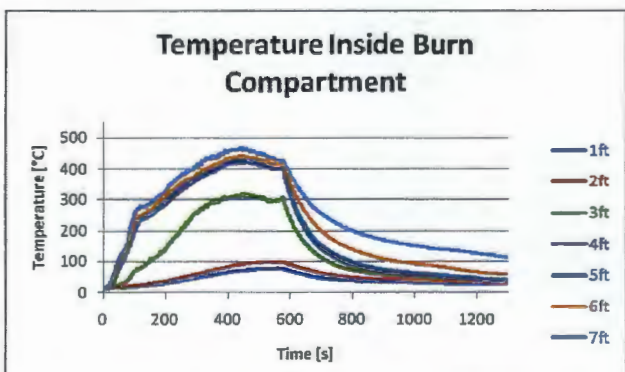
3 Person, Far Stagger



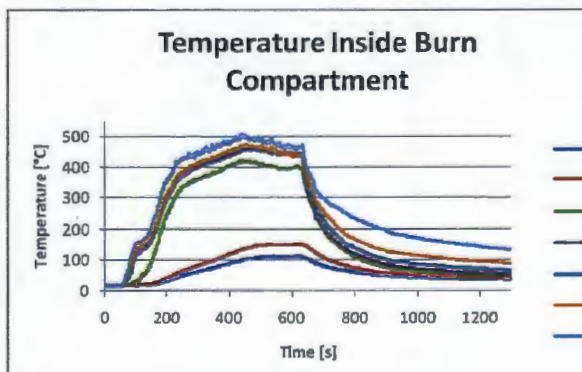
2 Person, Close Stagger



2 Person, Far Stagger

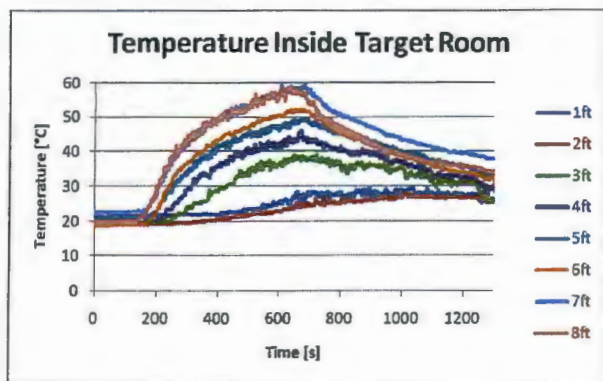


3 Person, Close Stagger

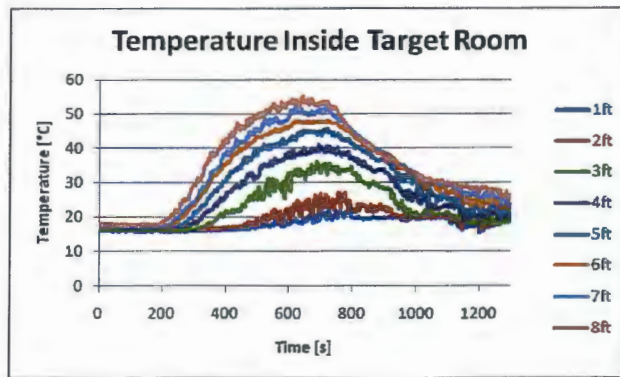


3 Person, Far Stagger

Target Room Data

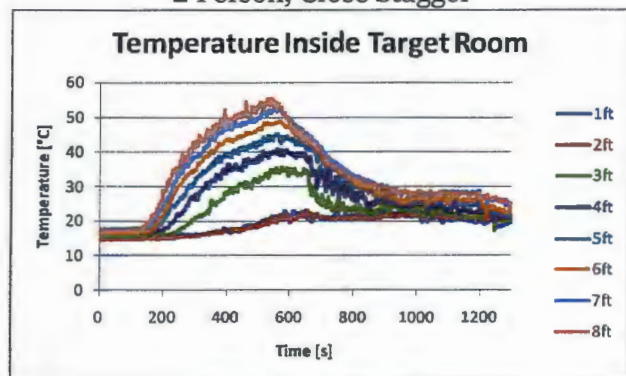


2 Person, Close Stagger

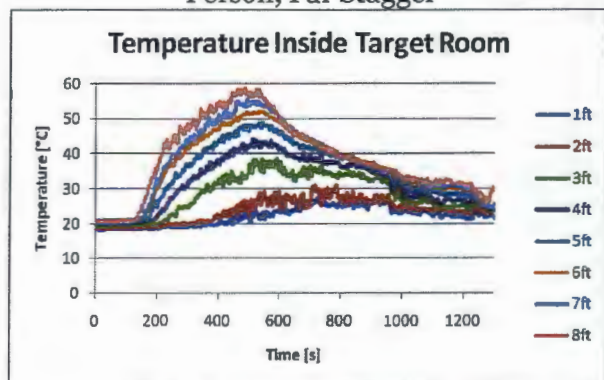


2

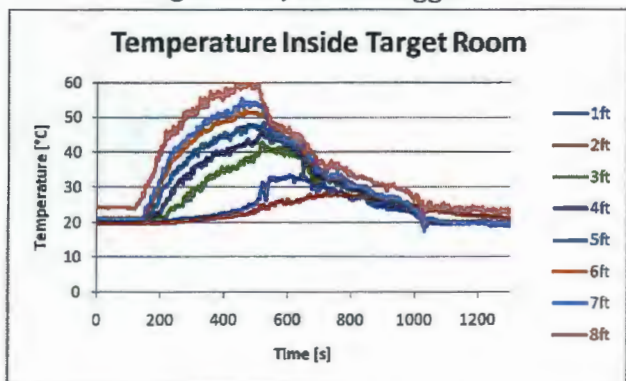
Person, Far Stagger



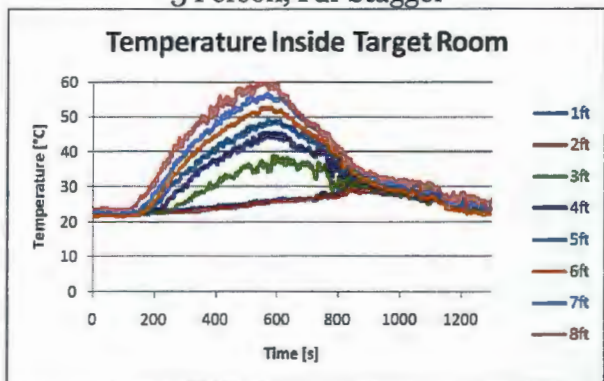
3 Person, Close Stagger



3 Person, Far Stagger

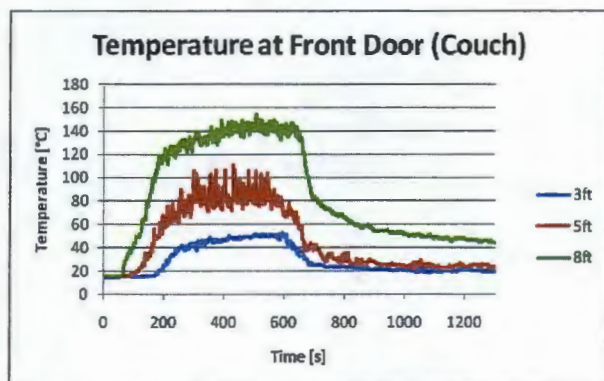


5 Person, Close Stagger

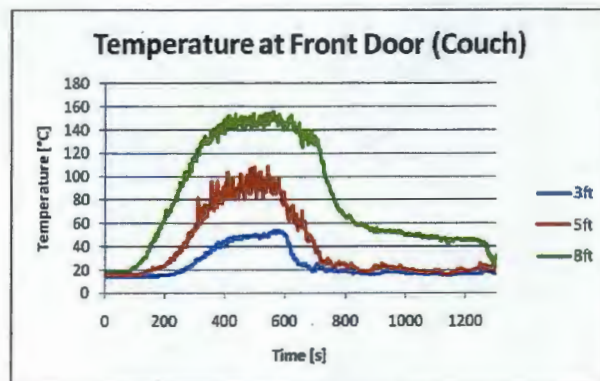


5 Person, Far Stagger

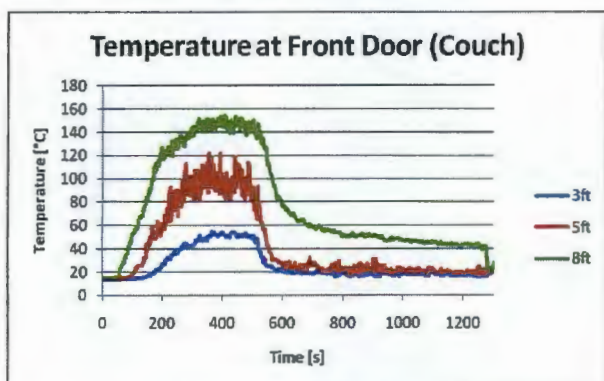
Temperature Near Front Door (Couch)



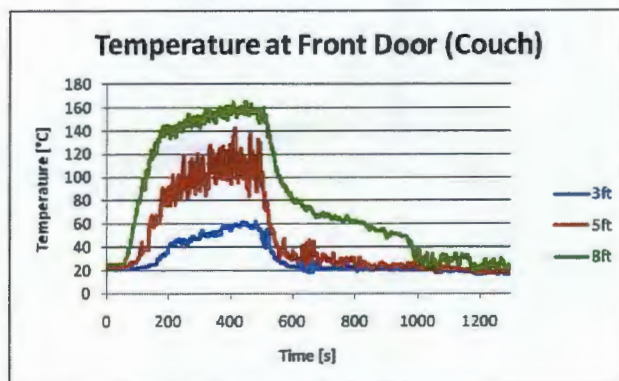
2 Person, Close Stagger



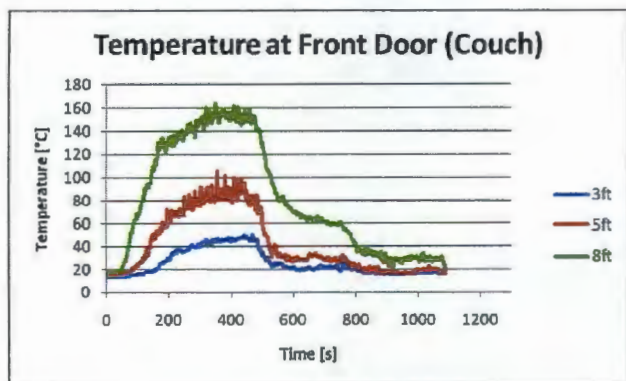
2 Person, Far Stagger



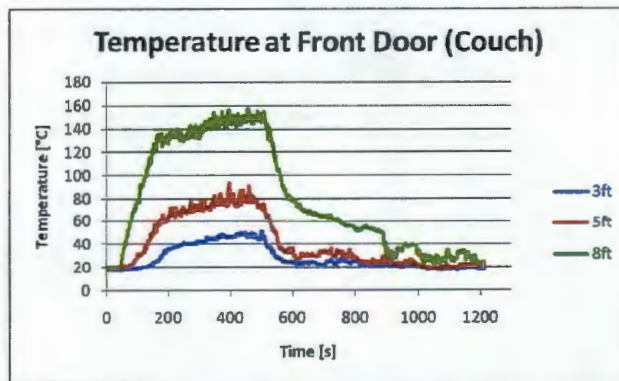
3 Person, Close Stagger



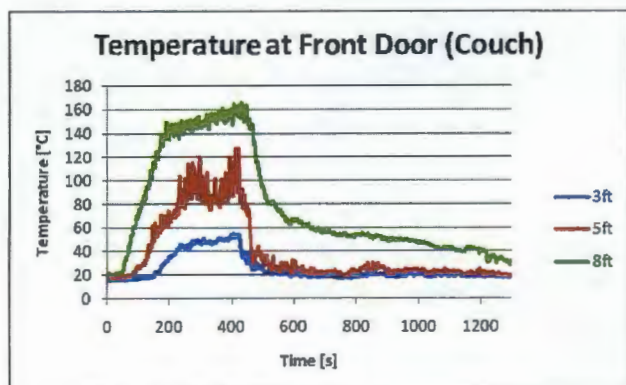
3 Person, Far Stagger



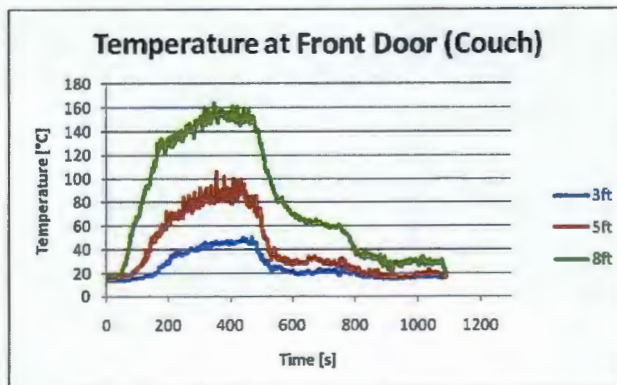
4 Person, Close Stagger



4 Person, Far Stagger



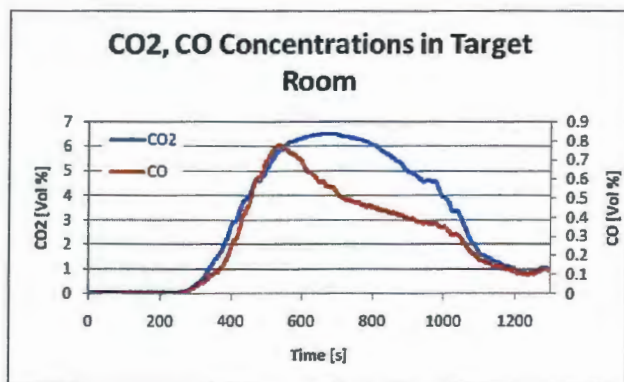
5 Person, Close Stagger



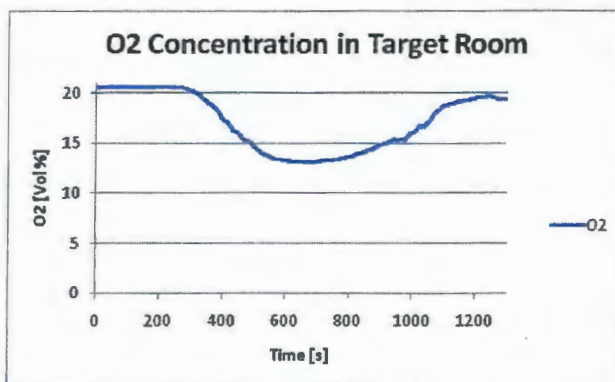
5 Person, Far Stagger

Gas and Temperature Data for Room and Contents Tests

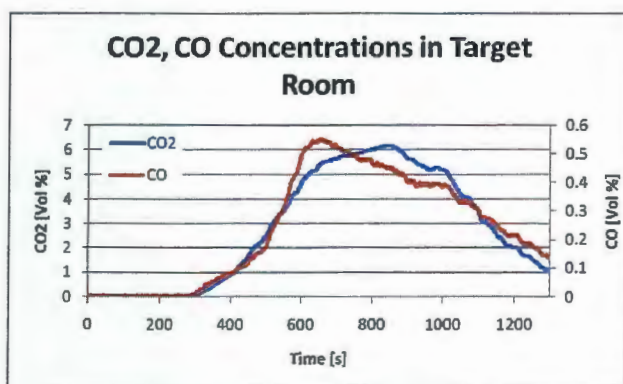
Examples of Gas Data in Target Room



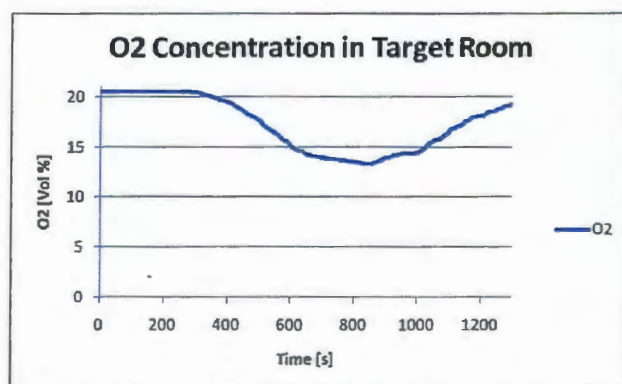
2-Person, Early Arrival



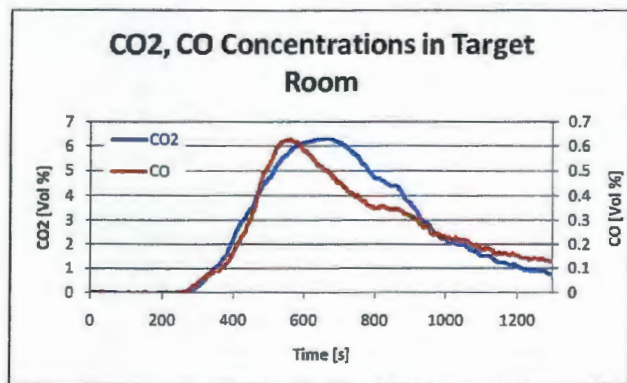
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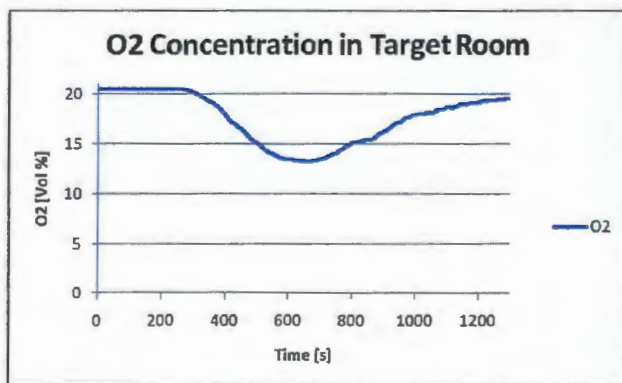
2-Person, Late Arrival



2-Person, Late Arrival



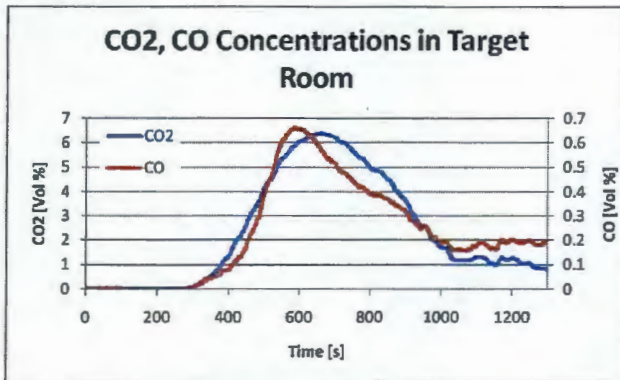
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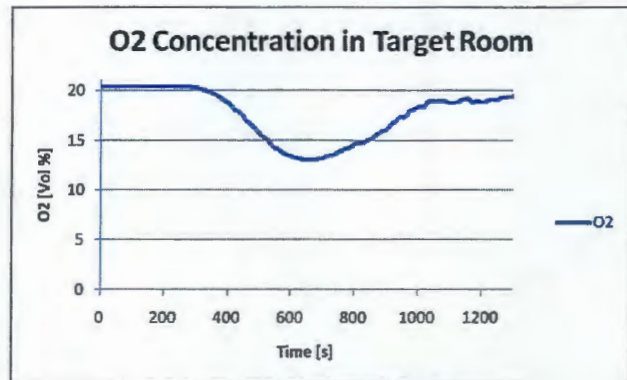
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Gas and Temperature Data for Room and Contents Tests

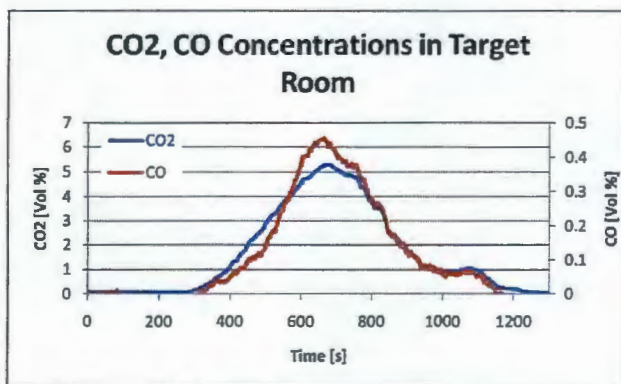
Examples of Gas Data in Target Room



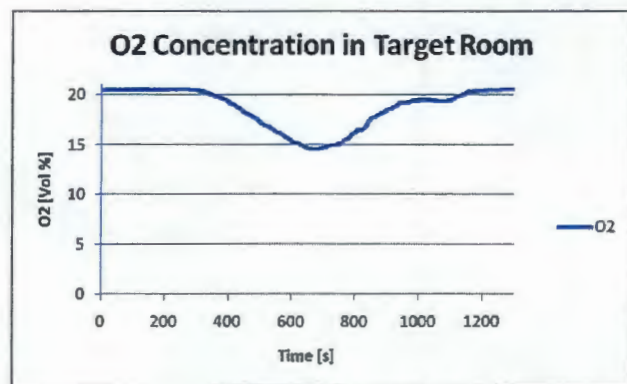
3-Person, Late Arrival



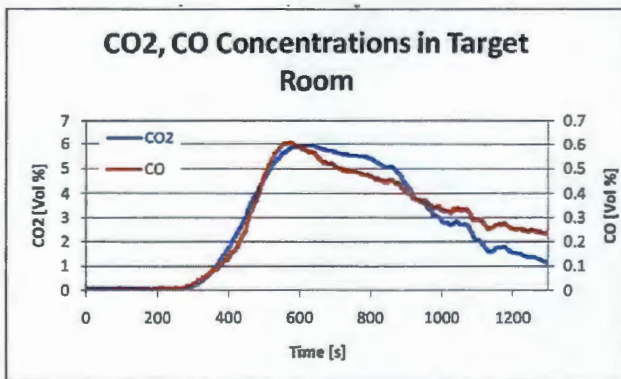
3-Person, Late Arrival



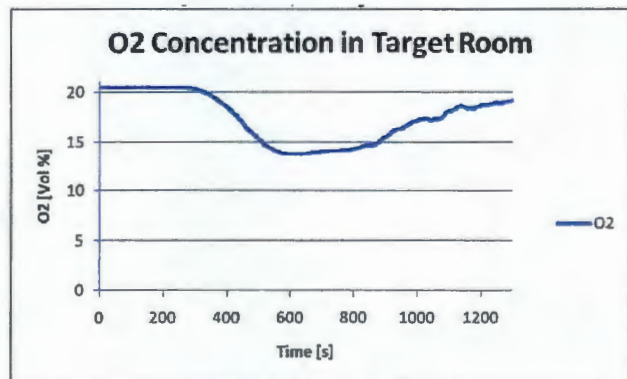
4-Person, Early Arrival



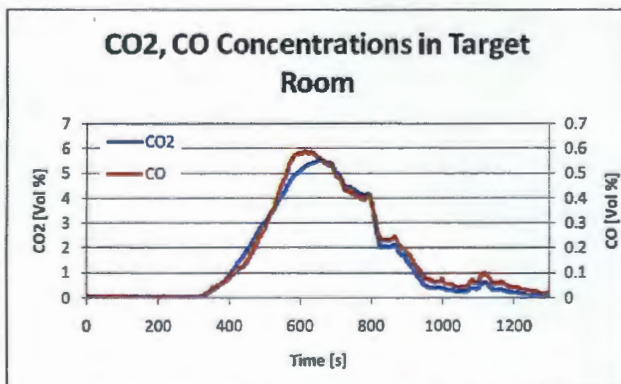
4-Person, Early Arrival



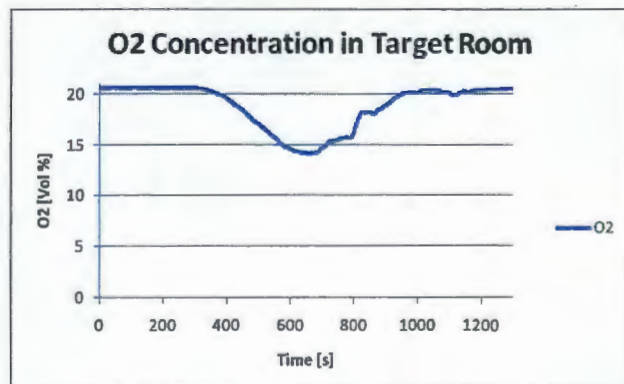
4-Person, Late Arrival



4-Person, Late Arrival

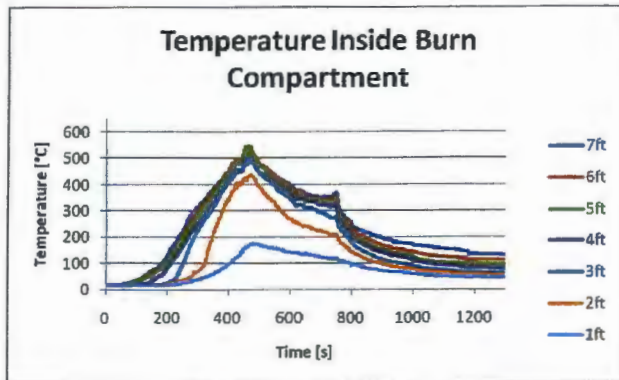


5-Person, Early Arrival

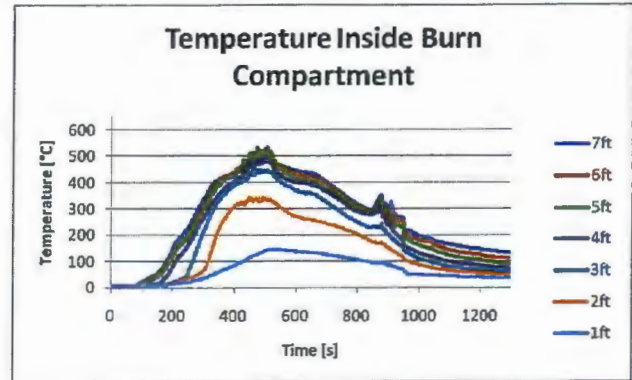


5-Person, Early Arrival

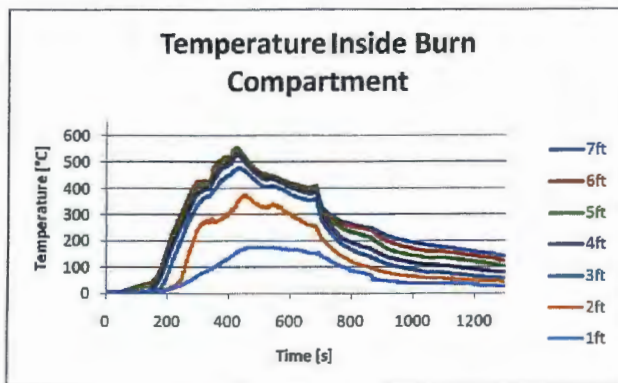
Temperatures in Burn Room



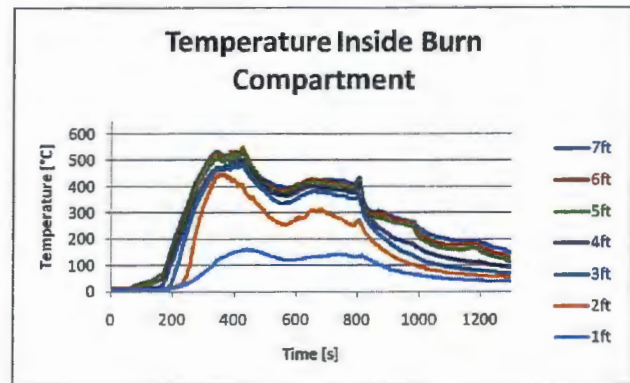
2-Person, Early Arrival



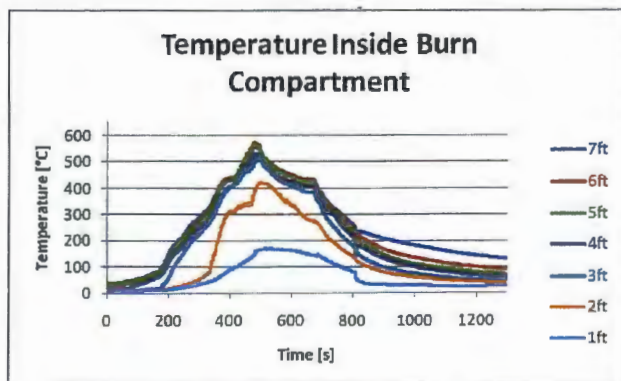
2-Person, Late Arrival



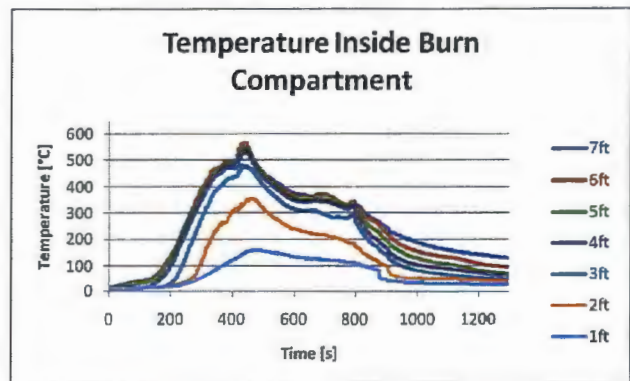
3-Person, Early Arrival



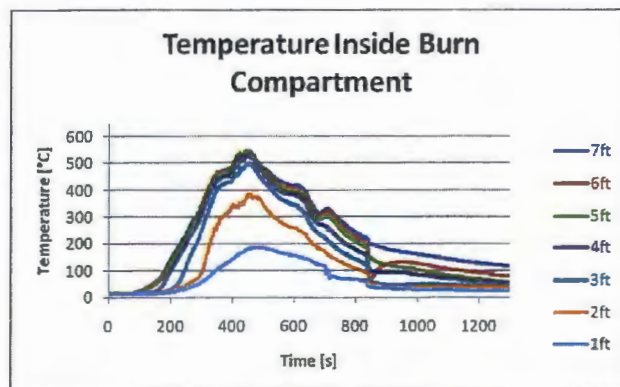
3-Person, Late Arrival



4-Person, Early Arrival

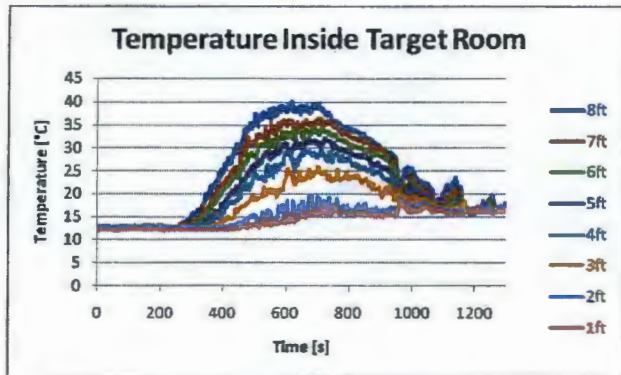


4-Person, Late Arrival

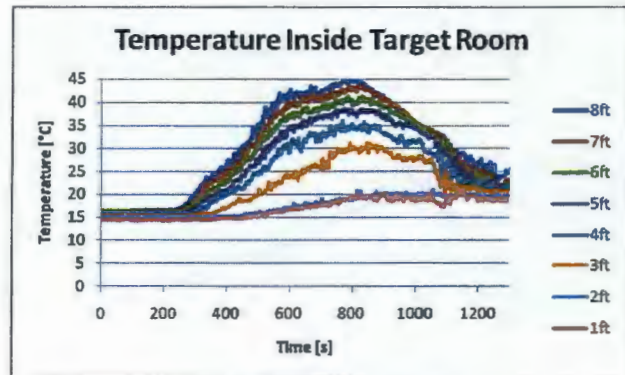


5-Person, Early Arrival

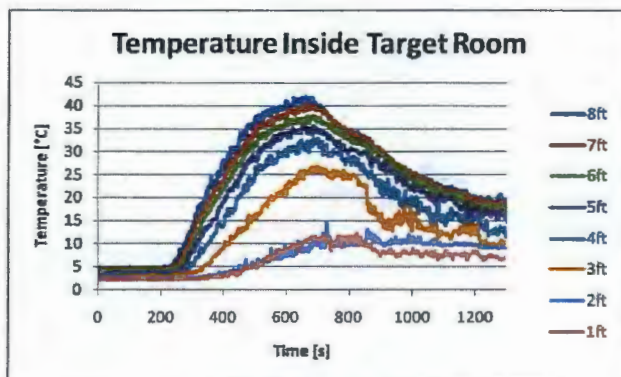
Temperatures in Target Room



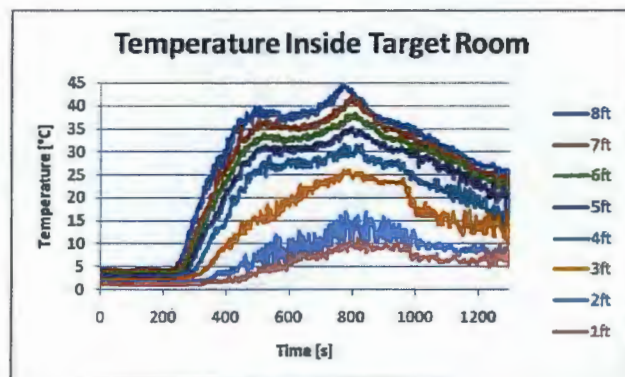
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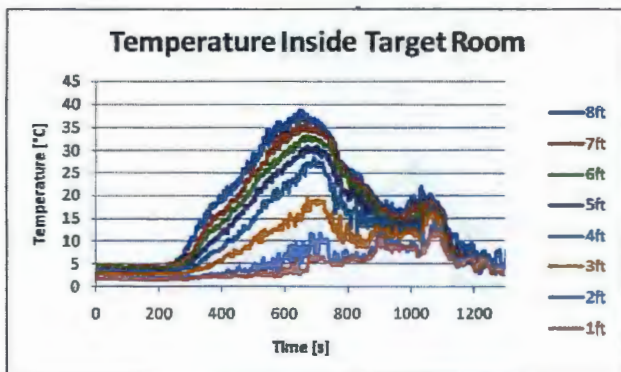
2-Person, Late Arrival



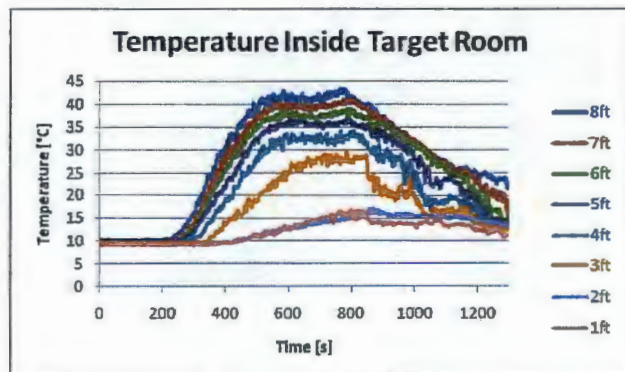
3-Person, Early Arrival



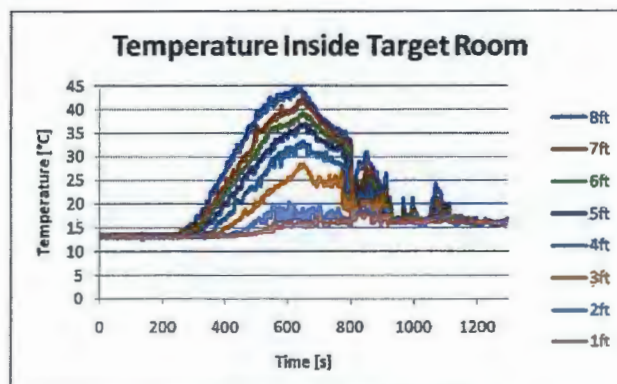
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4-Person, Early Arrival

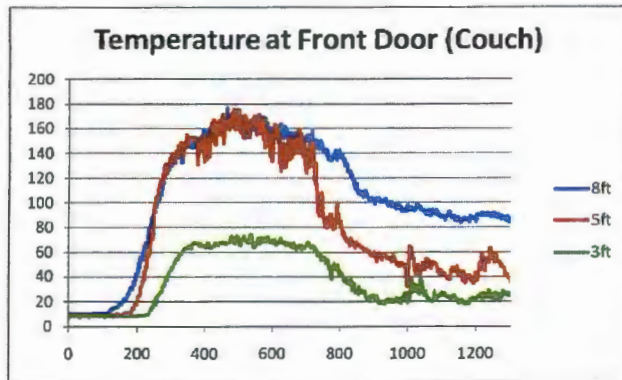


4-Person, Late Arrival

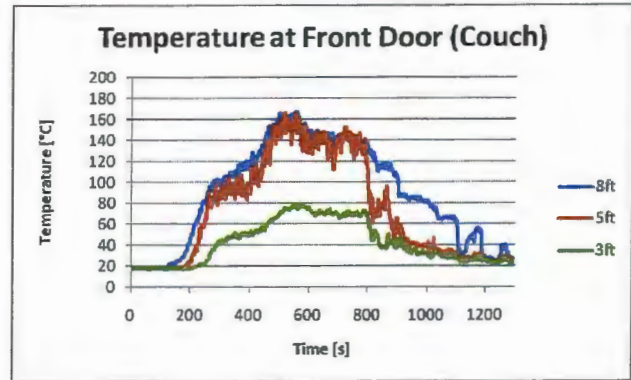


5-Person, Early Arrival

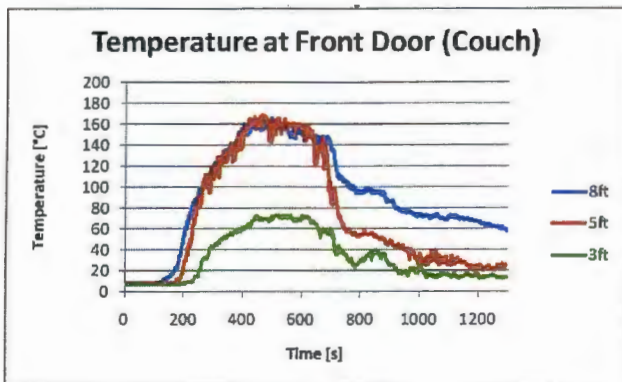
Temperatures Near Front Door (Couch)



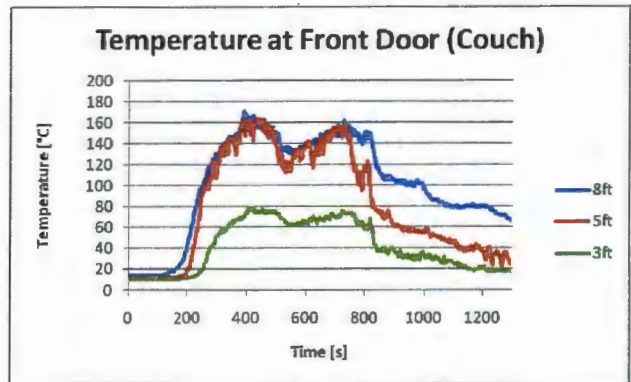
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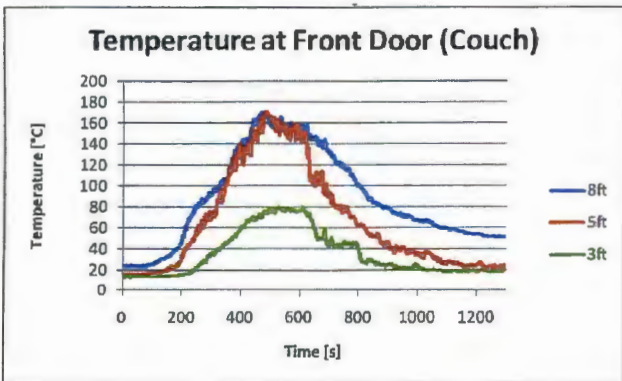
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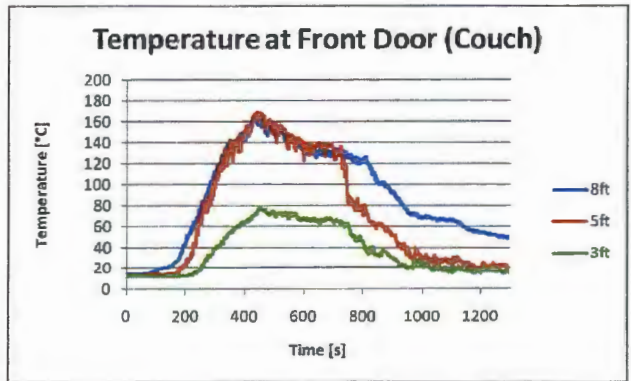
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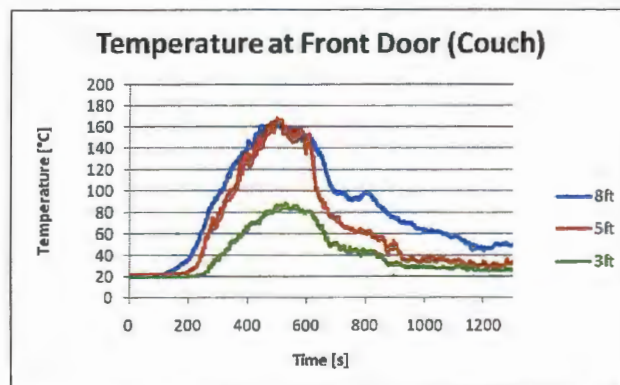
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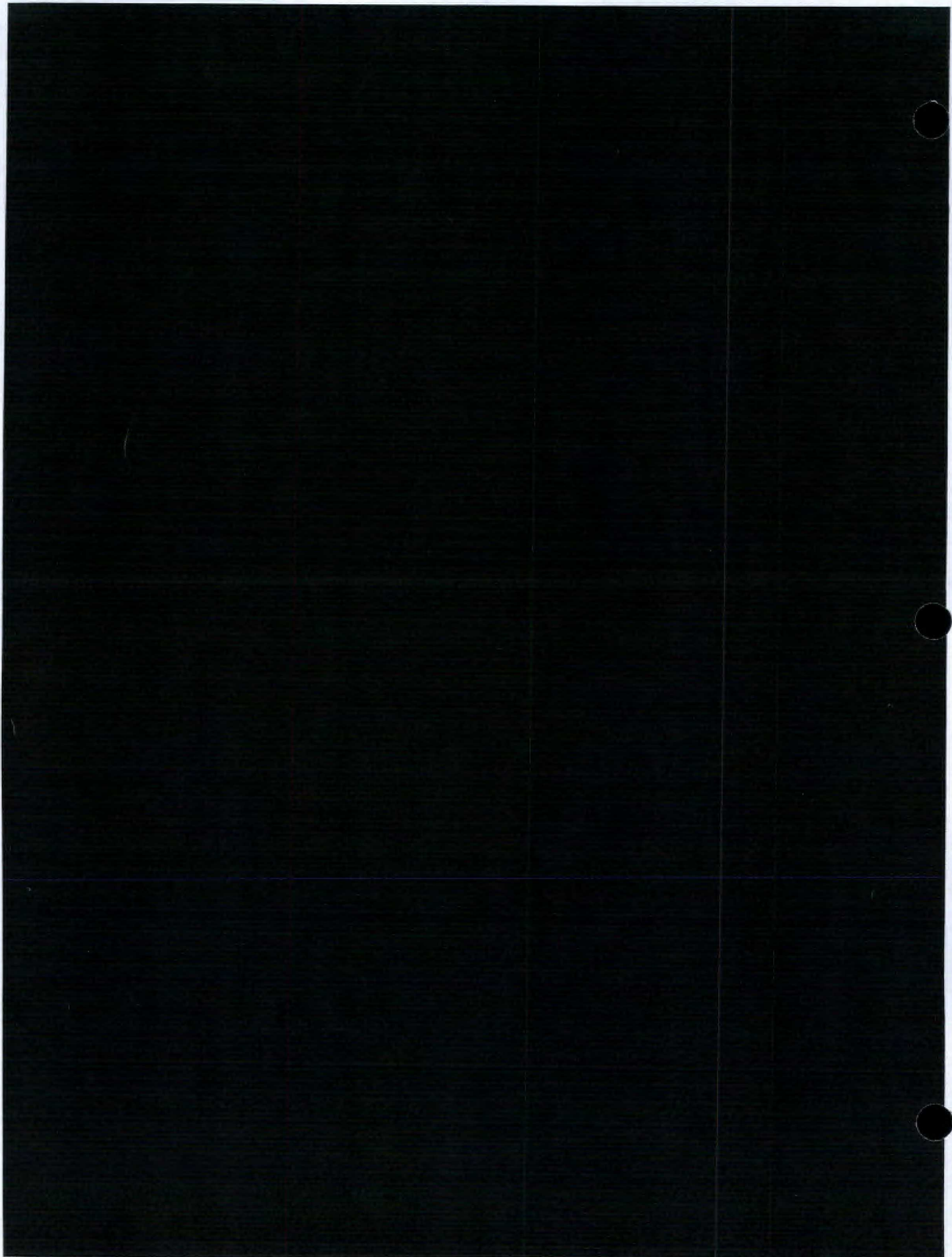
4-Person, Early Arrival



4-Person, Late Arrival



5-Person, Early Arrival



NFPA® 1710

Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments

2016 Edition



NFPA, 1 Batterymarch Park, Quincy, MA 02169-7471
An International Codes and Standards Organization

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NFPA® 1710

Standard for the

Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments

2016 Edition

This edition of NFPA 1710, *Standard for the Organization and Deployment of Fire Suppression Operations, Emergency Medical Operations, and Special Operations to the Public by Career Fire Departments*, was prepared by the Technical Committee on Fire and Emergency Service Organization and Deployment—Career and acted on by NFPA at its June Association Technical Meeting held June 22–25, 2015, in Chicago, IL. It was issued by the Standards Council on August 18, 2015, with an effective date of September 7, 2015, and supersedes all previous editions.

This edition of NFPA 1710 was approved as an American National Standard on September 7, 2015.

Origin and Development of NFPA 1710

In 2001, the first edition of NFPA 1710 was issued. The development of that benchmark standard was the result of a considerable amount of hard work and tenacity by the Technical Committee members and the organizations they represented. That standard was the first organized approach to defining levels of service, deployment capabilities, and staffing levels for substantially career fire departments. Research work and empirical studies in North America were used by the Committee as a basis for developing response times and resource capabilities for those services, as identified by the fire department.

Following the issuance of the first edition, the NFPA Standards Council asked the Technical Committee to begin the revision process for a 2004 edition of the standard. The Committee formed several Task Groups to look at various aspects of the document. However, recognizing that the standard had not been fully field tested, the extent of the changes proposed were minimal with a cleanup of definitions, the addition of wording regarding equivalency in the annex, and clarification that the discussion on rate of fire propagation in the annex involved unsprinklered rooms.

The 2010 edition of NFPA 1710 standardized and refined terminology and definitions used in the document. Particular attention was paid to terminology for time frames for the various events that occur from event initiation to the end of the fire department's involvement with the incident. This included recognition that there is a time interval to initiate action or intervene at the end of travel time and before control and mitigation actually begin. The requirements for time frames for alarm handling were revised to correspond to changes being made to NFPA 1221. The time allowance for turnout for fires and special operations was lengthened to 80 seconds, but the time measurement was defined to start at the beginning of the transmission of response data to the emergency response units or emergency response facilities. All times shown as both minutes and seconds were changed to seconds only because that is the level of precision in which the committee intends time to be measured. An application section was added in Chapter 1. The travel times for units responding on the first alarm were clarified to indicate the first unit must arrive within 4 minutes travel time and all units must arrive within 8 minutes travel time. The quadrennial report required to be provided to the AHJ in the previous edition was changed to an annual report.

The annex material related to the requirement stated for an initial full alarm assignment capability has been moved to the body of the standard to clarify that the requirement applies to a structure fire in a typical 2000 ft² (186m²), two-story single-family dwelling without basement and with no exposures. In addition, wording was added to require additional resources be deployed on fires in occupancies that present hazards greater than the two-story single-family dwelling. The community-wide risk management model that has been in an annex to NFPA 1720 has been added as an annex to NFPA 1710.

1710-2 ORGANIZATION AND DEPLOYMENT OF FIRE SUPPRESSION OPERATIONS BY CAREER FIRE DEPARTMENTS

The work done by the Committee provided the user with a template for developing an implementation plan on the standard. Most important, it provided the body politic and citizens a true picture of the risks in their communities and the fire departments' capabilities to respond to and manage those risks.

In the 2016 edition, the Committee has added three new occupancies and the appropriate response staffing levels for garden-style apartment, open-air strip mall, and high-rise occupancies. In addition, redundant text has been removed, and some language has been clarified.



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Committee Scope: This Committee shall have primary responsibility for documents on the organization, operation, deployment, and evaluation of substantially all career public fire protection and emergency medical services.

1710-4 ORGANIZATION AND DEPLOYMENT OF FIRE SUPPRESSION OPERATIONS BY CAREER FIRE DEPARTMENTS

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NFPA 1710

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2016 Edition

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NOTICE: An asterisk (*) following the number or letter designating a paragraph indicates that explanatory material on the paragraph can be found in Annex A.

A reference in brackets [] following a section or paragraph indicates material that has been extracted from another NFPA document. As an aid to the user, the complete title and edition of the source documents for extracts in mandatory sections of the document are given in Chapter 2 and those for extracts in informational sections are given in Annex C. Extracted text may be edited for consistency and style and may include the revision of internal paragraph references and other references as appropriate. Requests for interpretations or revisions of extracted text shall be sent to the technical committee responsible for the source document.

Information on referenced publications can be found in Chapter 2 and Annex C.

Chapter 1 Administration

1.1* Scope. This standard contains minimum requirements relating to the organization and deployment of fire suppression operations, emergency medical operations, and special operations to the public by substantially all career fire departments.

1.1.1 The requirements address functions and objectives of fire department emergency service delivery, response capabilities, and resources.

1.1.2 This standard also contains general requirements for managing resources and systems, such as health and safety,

incident management, training, communications, and pre-incident planning.

1.1.3 This standard addresses the strategic and system issues involving the organization, operation, and deployment of a fire department and does not address tactical operations at a specific emergency incident.

1.2 Purpose.

1.2.1* The purpose of this standard is to specify the minimum criteria addressing the effectiveness and efficiency of the career public fire suppression operations, emergency medical service, and special operations delivery in protecting the citizens of the jurisdiction and the occupational safety and health of fire department employees.

1.2.2 Nothing herein is intended to restrict any jurisdiction from exceeding these minimum requirements.

1.3 Application.

1.3.1 This standard applies to the deployment of resources by a fire department to emergency situations when operations can be implemented to save lives and property.

1.3.2 The standard is a benchmark for most common responses and a platform for developing the appropriate plan for deployment of resources for fires in higher hazard occupancies or more complex incidents.

1.4* Equivalency. Nothing in this standard is intended to prohibit the use of systems, methods, or approaches of equivalent or superior performance to those prescribed by this standard, provided technical documentation is submitted to the authority having jurisdiction to demonstrate equivalency.

Chapter 2 Referenced Publications

2.1 General. The documents or portions thereof listed in this chapter are referenced within this standard and shall be considered part of the requirements of this document.

2.2 NFPA Publications. National Fire Protection Association, 1 Batterymarch Park, Quincy, MA 02169-7471.

NFPA 403, *Standard for Aircraft Rescue and Fire-Fighting Services at Airports*, 2014 edition.

NFPA 472, *Standard for Competence of Responders to Hazardous Materials/Weapons of Mass Destruction Incidents*, 2013 edition.

NFPA 1143, *Standard for Wildland Fire Management*, 2014 edition.

NFPA 1221, *Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems*, 2016 edition.

NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*, 2013 edition.

NFPA 1561, *Standard on Emergency Services Incident Management System and Command Safety*, 2014 edition.

NFPA 1670, *Standard on Operations and Training for Technical Search and Rescue Incidents*, 2014 edition.

2.3 Other Publications.

2.3.1 U.S. Government Publications. U.S. Government Publishing Office, Washington, DC 20402.

Title 29, Code of Federal Regulations, Part 1910.120, "Hazardous Waste Operations and Emergency Response."

Title 29, Code of Federal Regulations, Part 1910.146, "Permit-Required Confined Space."

2.3.2 Other Publications.

Merriam-Webster's Collegiate Dictionary, 11th edition, Merriam-Webster, Inc., Springfield, MA, 2003.

2.4 References for Extracts in Mandatory Sections.

NFPA 472, *Standard for Competence of Responders to Hazardous Materials/Weapons of Mass Destruction Incidents*, 2013 edition.

NFPA 1002, *Standard for Fire Apparatus Driver/Operator Professional Qualifications*, 2014 edition.

NFPA 1081, *Standard for Industrial Fire Brigade Member Professional Qualifications*, 2012 edition.

NFPA 1142, *Standard on Water Supplies for Suburban and Rural Fire Fighting*, 2012 edition.

NFPA 1221, *Standard for the Installation, Maintenance, and Use of Emergency Services Communications Systems*, 2016 edition.

NFPA 1500, *Standard on Fire Department Occupational Safety and Health Program*, 2013 edition.

NFPA 1521, *Standard for Fire Department Safety Officer Professional Qualifications*, 2015 edition.

NFPA 1561, *Standard on Emergency Services Incident Management System and Command Safety*, 2014 edition.

NFPA 1901, *Standard for Automotive Fire Apparatus*, 2016 edition.

Chapter 3 Definitions

3.1 General. The definitions contained in this chapter shall apply to the terms used in this standard. Where terms are not defined in this chapter or within another chapter, they shall be defined using their ordinarily accepted meanings within the context in which they are used. *Merriam-Webster's Collegiate Dictionary*, 11th edition, shall be the source for the ordinarily accepted meaning.

3.2 NFPA Official Definitions.

3.2.1* Approved. Acceptable to the authority having jurisdiction.

3.2.2* Authority Having Jurisdiction (AHJ). An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.

3.2.3 Shall. Indicates a mandatory requirement.

3.2.4 Should. Indicates a recommendation or that which is advised but not required.

3.2.5 Standard. An NFPA Standard, the main text of which contains only mandatory provisions using the word "shall" to indicate requirements and that is in a form generally suitable for mandatory reference by another standard or code or for adoption into law. Nonmandatory provisions are not to be considered a part of the requirements of a standard and shall be located in an appendix, annex, footnote, informational note, or other means as permitted in the NFPA Manuals of Style. When used in a generic sense, such as in the phrase "standards development process" or "standards development activities," the term "standards" includes all NFPA Standards, including Codes, Standards, Recommended Practices, and Guides.

3.3 General Definitions.

3.3.1 Advanced Life Support (ALS). See 3.3.36.1.

3.3.2 Aid.

3.3.2.1* Automatic Aid. A plan developed between two or more fire departments for immediate joint response on first alarms. [1142, 2012]

3.3.2.2 Mutual Aid. A written intergovernmental agreement between agencies and/or jurisdictions that they will assist one another on request by furnishing personnel, equipment, and/or expertise in a specified manner.

3.3.3 Aircraft Rescue and Fire Fighting. See 3.3.21.1.

3.3.4* Aircraft Rescue and Fire-Fighting (ARFF) Vehicle. A vehicle intended to carry rescue and fire-fighting equipment for rescuing occupants and combating fires in aircraft at, or in the vicinity of, an airport. [1002, 2014]

3.3.5* Alarm. A signal or message from a person or device indicating the existence of an emergency or other situation that requires action by an emergency response agency. [1221, 2016]

3.3.6 Alarm Answering Time. See 3.3.53.1.

3.3.7 Alarm Handling Time. See 3.3.53.2.

3.3.8 Alarm Processing Time. See 3.3.53.3.

3.3.9 Alarm Transfer Time. See 3.3.53.4.

3.3.10 Apparatus.

3.3.10.1 Fire Apparatus. A vehicle designed to be used under emergency conditions to transport personnel and equipment, and to support the suppression of fires and mitigation of other hazardous situations. [1901, 2016]

3.3.10.2 Quint Apparatus. A fire apparatus with a permanently mounted fire pump, a water tank, a hose storage area, an aerial device with a permanently mounted waterway, and a complement of ground ladders.

3.3.10.3 Specialized Apparatus. A fire apparatus or vehicle that is used for support or specialized equipment and services at emergency scenes for functions such as, but not limited to, command, technical rescue, hazardous materials mitigation, urban search and rescue, air supply, electrical generation and lighting, or transport of equipment and personnel.

3.3.11 Automatic Aid. See 3.3.2.1.

3.3.12 Basic Life Support (BLS). See 3.3.36.2.

3.3.13* Company. A group of members: (1) under the direct supervision of an officer; (2) trained and equipped to perform assigned tasks; (3) usually organized and identified as engine companies, ladder companies, rescue companies, squad companies, or multi-functional companies; (4) operating with one piece of fire apparatus (pumper, aerial fire apparatus, elevating platform, quint, rescue, squad, ambulance) except where multiple apparatus are assigned that are dispatched and arrive together, continuously operate together, and are managed by a single company officer; (5) arriving at the incident scene on fire apparatus. [1500, 2013]

3.3.14 Company Officer. See 3.3.40.1.

3.3.15 Crew. See 3.3.52, Team.

3.3.16 Emergency Incident. Any situation to which an emergency services organization responds to deliver emergency services, including rescue, fire suppression, emergency medical



care, special operations, law enforcement, and other forms of hazard control and mitigation. [1561, 2014]

3.3.17 Emergency Medical Care. The treatment of patients using first aid, cardiopulmonary resuscitation, basic life support, advanced life support, and other medical procedures prior to arrival at a hospital or other health care facility.

3.3.18 Emergency Operations. See 3.3.41.1.

3.3.19 Fire Apparatus. See 3.3.10.1.

3.3.20 Fire Department Member. See 3.3.38, Member.

3.3.21 Fire Fighting.

3.3.21.1* Aircraft Rescue and Fire Fighting. The fire-fighting actions taken to rescue persons and to control or extinguish fire involving or adjacent to aircraft on the ground. [1500, 2013]

3.3.21.2* Marine Rescue and Fire Fighting. The fire-fighting action taken to prevent, control, or extinguish fire involved in or adjacent to a marine vessel and the rescue actions for occupants using normal and emergency routes for egress.

3.3.21.3 Structural Fire Fighting. The activities of rescue, fire suppression, and property conservation in buildings or other structures, vehicles, rail cars, marine vessels, aircraft, or like properties.

3.3.22 Fire Protection. Methods of providing fire detection, control, and extinguishment.

3.3.23* Fire Suppression. The activities involved in controlling and extinguishing fires. [1500, 2013]

3.3.24* First Responder (EMS). Functional provision of initial assessment (i.e., airway, breathing, and circulatory systems) and basic first-aid intervention, including CPR and automatic external defibrillator (AED) capability.

3.3.25 Forcible Entry. Techniques used by fire personnel to gain entry into buildings, vehicles, aircraft, or other areas of confinement when normal means of entry are locked or blocked.

3.3.26* Hazard. A condition that presents the potential for harm or damage to people, property, or the environment.

3.3.27 Hazardous Material. A substance that is capable of creating harm to people, the environment, or property due to its toxicity, chemical reactivity, decomposition, or corrosivity; is capable of explosion or detonation; or presents etiological hazards, whether used for its intended purpose or as a weapon of mass destruction (WMD) or for illicit labs purposes, environmental crimes, or industrial sabotage.

3.3.28* High-Hazard Occupancy. An occupancy that presents a high life hazard or large fire potential due to its construction, configuration, or the presence of specific materials, processes, or contents.

3.3.29 Incident Commander. The member responsible for all incident activities, including the development of strategies and tactics and the ordering and the release of resources. [472, 2013]

3.3.30* Incident Management System (IMS). An organized system that defines the roles and responsibilities to be assumed by responders and the standard operating procedures to be used in the management and direction of emergency incidents and other functions.

3.3.31 Incident Safety Officer. See 3.3.40.2.

3.3.32 Initial Full Alarm Assignment. Those personnel, equipment, and resources ordinarily dispatched upon notification of a structure fire.

3.3.33 Initial Rapid Intervention Crew (IRIC). See 3.3.44.1.

3.3.34 Initiating Action/Intervention Time. See 3.3.53.5.

3.3.35 Intergovernmental Agreement. A written formal authorization for services between two or more jurisdictions.

3.3.36 Life Support.

3.3.36.1 Advanced Life Support (ALS). Emergency medical treatment beyond basic life support that provides for advanced airway management including intubation, advanced cardiac monitoring, defibrillation, establishment and maintenance of intravenous access, and drug therapy.

3.3.36.2* Basic Life Support (BLS). A specific level of pre-hospital medical care provided by trained responders, focused on rapidly evaluating a patient's condition; maintaining a patient's airway, breathing, and circulation; controlling external bleeding; preventing shock; and preventing further injury or disability by immobilizing potential spinal or other bone fractures.

3.3.37 Marine Rescue and Fire Fighting. See 3.3.21.2.

3.3.38* Member. A person involved in performing the duties and responsibilities of a fire department, under the auspices of the organization. [1500, 2013]

3.3.39 Mutual Aid. See 3.3.2.2.

3.3.40 Officer.

3.3.40.1* Company Officer. A supervisor of a crew/company of personnel.

3.3.40.2 Incident Safety Officer. A member of the command staff responsible for monitoring and assessing safety hazards or unsafe situations and for developing measures for ensuring personnel safety.

3.3.40.3* Supervisory Chief Officer. A member whose responsibility is to assume command through a formalized transfer of command process and to allow company officers to directly supervise personnel assigned to them.

3.3.41 Operations.

3.3.41.1 Emergency Operations. Activities of the fire department relating to rescue, fire suppression, emergency medical care, and special operations, including response to the scene of the incident and all functions performed at the scene. [1500, 2013]

3.3.41.2* Special Operations. Those emergency incidents to which the fire department responds that require specific and advanced training and specialized tools and equipment. [1500, 2013]

3.3.42 Public Safety Answering Point (PSAP). A facility in which 9-1-1 calls are answered. [1221, 2016]

3.3.43 Quint Apparatus. See 3.3.10.2.

3.3.44* Rapid Intervention Crew (RIC). A dedicated crew of fire fighters who are assigned for rapid deployment to rescue lost or trapped members.

3.3.44.1 Initial Rapid Intervention Crew (IRIC). Two members of the initial attack crew who are assigned for rapid deployment to rescue lost or trapped members.

3.3.45 Rescue. Those activities directed at locating endangered persons at an emergency incident, removing those persons from danger, treating the injured, and providing for transport to an appropriate health care facility. [1500, 2013]

3.3.46 Special Operations. See 3.3.41.2.

3.3.47 Specialized Apparatus. See 3.3.10.3.

3.3.48* Staff Aide. A fire fighter or fire officer assigned to a supervisory chief officer to assist with the logistical, tactical, and accountability functions of incident, division, or sector command.

3.3.49 Standard Operating Procedure. A written organizational directive that establishes or prescribes specific operational or administrative methods to be followed routinely for the performance of designated operations or actions. [1521, 2015]

3.3.50 Structural Fire Fighting. See 3.3.21.3.

3.3.51 Supervisory Chief Officer. See 3.3.40.3.

3.3.52 Team. Two or more members who have been assigned a common task and are in communication with each other, coordinate their activities as a work group, and support the safety of one another. [1081, 2012]

3.3.53 Time.

3.3.53.1 Alarm Answering Time. The time interval that begins when the alarm is received at the communication center and ends when the alarm is acknowledged at the communication center.

3.3.53.2 Alarm Handling Time. The time interval from the receipt of the alarm at the primary PSAP until the beginning of the transmittal of the response information via voice or electronic means to emergency response facilities (ERFs) or the emergency response units (ERUs) in the field.

3.3.53.3 Alarm Processing Time. The time interval from when the alarm is acknowledged at the communication center until response information begins to be transmitted via voice or electronic means to emergency response facilities (ERFs) and emergency response units (ERUs).

3.3.53.4 Alarm Transfer Time. The time interval from the receipt of the emergency alarm at the PSAP until the alarm is first received at the communication center.

3.3.53.5* Initiating Action/Intervention Time. The time interval from when a unit arrives on the scene to the initiation of emergency mitigation.

3.3.53.6* Total Response Time. The time interval from the receipt of the alarm at the primary PSAP to when the first emergency response unit is initiating action or intervening to control the incident.

3.3.53.7 Travel Time. The time interval that begins when a unit is en route to the emergency incident and ends when the unit arrives at the scene.

3.3.53.8 Turnout Time. The time interval that begins when the emergency response facilities (ERFs) and emergency response units (ERUs) notification process begins by

either an audible alarm or visual annunciation or both and ends at the beginning point of travel time.

3.3.54 Total Response Time. See 3.3.53.6.

3.3.55 Travel Time. See 3.3.53.7.

3.3.56 Turnout Time. See 3.3.53.8.

Chapter 4 Organization

4.1 Fire Department Organizational Statement.

4.1.1* The authority having jurisdiction (AHJ) shall maintain a written statement or policy that establishes the following:

- (1) Existence of the fire department
- (2) Services that the fire department is required to provide
- (3) Basic organizational structure
- (4) Expected number of fire department members
- (5) Functions that fire department members are expected to perform

4.1.2* The fire department organizational statement shall provide service delivery objectives, including specific time objectives for each major service component [i.e., fire suppression, emergency medical services (EMS), special operations, aircraft rescue and fire fighting, marine rescue and fire fighting, and/or wildland fire fighting] and objectives for the percentage of responses that meet the time objectives.

4.1.2.1 The fire department shall establish the following objectives:

- (1) Alarm handling time to be completed in accordance with 4.1.2.3.
- (2) 80 seconds turnout time for fire and special operations response and 60 seconds turnout time for EMS response
- (3)*240 seconds or less travel time for the arrival of the first arriving engine company at a fire suppression incident
- (4) For other than high-rise, 480 seconds or less travel time for the deployment of an initial full alarm assignment at a fire suppression incident
- (5) For high-rise, 610 seconds or less travel time for the deployment of an initial full alarm assignment at a fire suppression incident
- (6) 240 seconds or less travel time for the arrival of a unit with first responder with automatic external defibrillator (AED) or higher level capability at an emergency medical incident
- (7) 480 seconds or less travel time for the arrival of an advanced life support (ALS) unit at an emergency medical incident, where this service is provided by the fire department provided a first responder with AED or basic life support (BLS) unit arrived in 240 seconds or less travel time

4.1.2.2 The fire department shall document the initiating action/intervention time.

4.1.2.3 Alarm Handling.

4.1.2.3.1 The fire department shall establish a performance objective of having an alarm answering time of not more than 15 seconds for at least 95 percent of the alarms received and not more than 40 seconds for at least 99 percent of the alarms received, as specified by NFPA 1221.



4.1.2.3.1.1 Any call not answered within 20 seconds shall be routed to a secondary answering (alternate) center if the primary center is full. An alarm should sound if a call is not answered (not processed, just answered) within 60 seconds.

4.1.2.3.2 When the alarm is received at a public safety answering point (PSAP) and transferred to a secondary answering point or communication center, the agency responsible for the PSAP shall establish a performance objective of having an alarm transfer time of not more than 30 seconds for at least 95 percent of all alarms processed, as specified by NFPA 1221.

4.1.2.3.3 The fire department shall establish a performance objective of having an alarm processing time of not more than 64 seconds for at least 90 percent of the alarms and not more than 106 seconds for at least 95 percent of the alarms, as specified by NFPA 1221.

4.1.2.3.3.1 Emergency alarm processing for the following call types shall be completed within 90 seconds 90 percent of the time and within 120 seconds 99 percent of the time:

- (1) Calls requiring emergency medical dispatch questioning and pre-arrival medical instructions
- (2) Calls requiring language translation
- (3) Calls requiring the use of a TTY/TDD device or audio/video relay services
- (4) Calls of criminal activity that require information vital to emergency responder safety prior to dispatching units
- (5) Hazardous material incidents
- (6) Technical rescue
- (7) Calls that require determining the location of the alarm due to insufficient information
- (8) Calls received by text message

4.1.2.4 The fire department shall establish a performance objective of not less than 90 percent for the achievement of each turnout time and travel time objective specified in 4.1.2.1.

4.1.2.5 Evaluations.

4.1.2.5.1* The fire department shall evaluate its level of service and deployment delivery and alarm handling time, turnout time, and travel time objectives on an annual basis.

4.1.2.5.2* The evaluations shall be based on emergency incident data relating to level of service, deployment, and the achievement of each time objective in each geographic area within the jurisdiction of the fire department.

4.1.2.6 The fire department shall provide the AHJ with a written report annually.

4.1.2.6.1 The annual report shall define the geographic areas and/or circumstances in which the requirements of this standard are not being met.

4.1.2.6.2 The annual report shall explain the predictable consequences of these deficiencies and address the steps that are necessary to achieve compliance.

4.2 Fire Suppression Services. The fire department organizational statement shall set forth the criteria for the various types of fire suppression incidents to which the fire department is required to respond.

4.3 Emergency Medical Services.

4.3.1 The fire department organizational statement shall set forth the criteria for the various types of emergency medical

incidents to which the fire department is required and/or expected to respond.

4.3.2 The fire department organizational statement shall ensure that the fire department's emergency medical response capability includes personnel, equipment, and resources to deploy at the first responder level with AED or higher treatment level.

4.3.3 Where emergency medical services beyond the first responder with AED level are provided by another agency or private organization, the AHJ, based on recommendations from the fire department, shall include the minimum staffing, deployment, and response criteria as required in Section 5.3 in the following:

- (1) The fire department organizational statement
- (2) Any contract, service agreement, governmental agreement, or memorandum of understanding between the AHJ and the other agency or private organization

4.4 Special Operations.

4.4.1 The fire department organizational statement shall set forth the criteria for the various types of special operations response and mitigation activities to which the fire department is required or expected to respond.

4.4.2* The fire department organizational statement shall ensure that the fire department's hazardous materials response capability includes personnel, equipment, and resources to deploy at the first responder operational level as required by 29 CFR 1910.120.

4.4.3 The fire department organizational statement shall ensure that the fire department's confined space response capability includes personnel, equipment, and resources to deploy at the confined space operational level as required by 29 CFR 1910.146.

4.4.4 The fire department organizational statement shall set forth the criteria for the various types of fire department response during natural disasters or terrorism incidents, weapons of mass destruction incidents, or large-scale or mass casualty events.

4.5 Airport Rescue and Fire-Fighting Services. The fire department organizational statement shall set forth the criteria for the various types of airport rescue and fire-fighting incidents to which the fire department is required or expected to respond.

4.6 Marine Rescue and Fire-Fighting Services. The fire department organizational statement shall set forth the criteria for the various types of marine rescue and fire-fighting incidents to which the fire department is required or expected to respond.

4.7 Wildland Fire Suppression Services. The fire department organizational statement shall set forth the criteria for the various types of wildland fire suppression incidents to which the fire department is required and/or expected to respond.

4.8 Intercommunity Organization.

4.8.1* Mutual aid, automatic aid, and fire protection agreements shall be through a written intergovernmental agreement and shall address issues such as liability for injuries and deaths, disability retirements, cost of service, authorization to respond, staffing, and equipment, including the resources to

be made available, availability of interoperable communications, and the designation of the incident commander.

4.8.2 Procedures and training of personnel for all fire departments in mutual aid, automatic aid, and fire protection agreement plans shall be comprehensive to produce an effective fire force and to ensure uniform operations.

Chapter 5 Fire Department Services

5.1 Purpose.

5.1.1 The services provided by the fire department shall include those activities identified by the organizational statement developed as required by Chapter 4.

5.1.2 The procedures involved in providing these services, including operations and deployment, shall be established through written administrative regulations, standard operating procedures (SOPs), and departmental orders.

5.2* Fire Suppression Services.

5.2.1 Fire Suppression Capability.

5.2.1.1 Fire suppression operations shall be organized to ensure that the fire department's fire suppression capability encompasses deployment of personnel, equipment, and resources for an initial arriving company, the initial full alarm assignment, and additional alarm assignments.

5.2.1.2 The fire department shall be permitted to use established automatic aid and mutual aid agreements to comply with the requirements of Section 5.2.

5.2.2* Staffing. The number of on-duty fire suppression members shall be sufficient to perform the necessary fire-fighting operations given the expected fire-fighting conditions.

5.2.2.1 These numbers shall be determined through task analyses that take the following factors into consideration:

- (1) Life hazard to the populace protected
- (2) Provisions of safe and effective fire-fighting performance conditions for the fire fighters
- (3) Potential property loss
- (4) Nature, configuration, hazards, and internal protection of the properties involved
- (5) Types of fireground tactics and evolutions employed as standard procedure, type of apparatus used, and results expected to be obtained at the fire scene

5.2.2.2* On-duty members assigned to fire suppression shall be organized into company units and shall have appropriate apparatus and equipment assigned to such companies.

5.2.2.2.1* The fire department shall identify minimum company staffing levels as necessary to meet the deployment criteria required in 5.2.4 to ensure that a sufficient number of members are assigned, on duty, and available to safely and effectively respond with each company.

5.2.2.2.2 Each company shall be led by an officer who shall be considered a part of the company.

5.2.2.2.3* Supervisory chief officers shall be dispatched or notified to respond to all full alarm assignments.

5.2.2.2.4 The supervisory chief officer shall ensure that the incident management system is established as required in Section 6.2.

5.2.2.2.5* Supervisory chief officers shall have staff aides deployed to them for purposes of incident management and accountability at emergency incidents.

5.2.3 Operating Units. Fire company staffing requirements shall be based on minimum levels necessary for safe, effective, and efficient emergency operations.

5.2.3.1 Fire companies whose primary functions are to pump and deliver water and perform basic fire fighting at fires, including search and rescue, shall be known as engine companies.

5.2.3.1.1 These companies shall be staffed with a minimum of four on-duty members.

5.2.3.1.2 In jurisdictions with a high number of incidents or geographical restrictions, as identified by the AHJ, these companies shall be staffed with a minimum of five on-duty members.

5.2.3.1.2.1 In jurisdictions with tactical hazards, high-hazard occupancies, or dense urban areas, as identified by the AHJ, these fire companies shall be staffed with a minimum of six on-duty members.

5.2.3.2 Fire companies whose primary functions are to perform the variety of services associated with truck work, such as forcible entry, ventilation, search and rescue, aerial operations for water delivery and rescue, utility control, illumination, overhaul, and salvage work, shall be known as ladder or truck companies.

5.2.3.2.1 These fire companies shall be staffed with a minimum of four on-duty members.

5.2.3.2.2 In jurisdictions with a high number of incidents or geographical restrictions, as identified by the AHJ, these fire companies shall be staffed with a minimum of five on-duty members.

5.2.3.2.2.1 In jurisdictions with tactical hazards, high-hazard occupancies, or dense urban areas, as identified by the AHJ, these fire companies shall be staffed with a minimum of six on-duty members.

5.2.3.3 Other Types of Companies.

5.2.3.3.1 Other types of companies equipped with specialized apparatus and equipment shall be provided to assist engine and ladder companies where necessary to support the fire departments' SOPs.

5.2.3.3.2 These companies shall be staffed with the minimum number of on-duty members required to deal with the tactical hazards, high-hazard occupancies, high incident frequencies, geographical restrictions, or other pertinent factors as identified by the AHJ.

5.2.3.4 Fire Companies with Quint Apparatus.

5.2.3.4.1 A fire company that deploys with quint apparatus, designed to operate as either an engine company or a ladder company, shall be staffed as specified in 5.2.3.

5.2.3.4.2 If the company is expected to perform multiple roles simultaneously, additional staffing, above the levels specified in 5.2.3, shall be provided to ensure that those operations can be performed as required.

5.2.4 Deployment.

5.2.4.1 Single-Family Dwelling Initial Full Alarm Assignment Capability.

5.2.4.1.1* The initial full alarm assignment to a structure fire in a typical 2000 ft² (186 m²), two-story single-family dwelling



without basement and with no exposures shall provide for the following:

- (1) Establishment of incident command outside of the hazard area for the overall coordination and direction of the initial full alarm assignment with a minimum of one member dedicated to this task
- (2) Establishment of an uninterrupted water supply of a minimum of 400 gpm (1520 L/min) for 30 minutes with supply line(s) maintained by an operator
- (3) Establishment of an effective water flow application rate of 300 gpm (1140 L/min) from two handlines, each of which has a minimum flow rate of 100 gpm (380 L/min) with each handline operated by a minimum of two members to effectively and safely maintain the line
- (4) Provision of one support member for each attack and backup line deployed to provide hydrant hookup and to assist in laying of hose lines, utility control, and forcible entry
- (5) Provision of at least one victim search and rescue team with each such team consisting of a minimum of two members
- (6) Provision of at least one team, consisting of a minimum of two members, to raise ground ladders and perform ventilation
- (7) If an aerial device is used in operations, one member to function as an aerial operator to maintain primary control of the aerial device at all times
- (8) Establishment of an IRIC consisting of a minimum of two properly equipped and trained members

5.2.4.1.2 When an incident escalates beyond an initial full alarm assignment, or when significant risk is present to the member due to the magnitude of the incident, the incident commander shall request an EMS crew consisting of a minimum of two members to provide treatment and transport for injured members and civilians.

5.2.4.1.3 When an incident escalates beyond an initial full alarm assignment or when significant risk is present to the members due to the magnitude of the incident, the incident commander shall upgrade the IRIC to a full rapid intervention crew (s) (RIC) that consists of an officer and at least three members who are fully equipped and trained in RIC operations.

5.2.4.2 Open-Air Strip Shopping Center Initial Full Alarm Assignment Capability.

5.2.4.2.1* The initial full alarm assignment to a structure fire in a typical open-air strip shopping center ranging from 13,000 ft² to 196,000 ft² (1203 m² to 18,209 m²) in size shall provide for the following:

- (1) Establishment of incident command outside the hazard area for the overall coordination, direction, and safety of the initial full alarm assignment with a minimum of two members dedicated to managing this task.
- (2) Establishment of two uninterrupted water supplies at a minimum of 500 gpm (1892 L/min), with each supply line maintained by an operator.
- (3) Establishment of an effective water flow application rate of 500 gpm (1892 L/min) from three handlines, each of which has a minimum flow rate of 150 gpm (568 L/min), with each handline operated by a minimum of two members to effectively and safely maintain each handline.
- (4) Provision of one support member for each attack, backup, and exposure line deployed to provide hydrant hookup and to assist in laying of hose lines, utility control, and forcible entry.

- (5) Provision of at least two victim search-and-rescue teams, each team consisting of a minimum of two members.
- (6) Provision of at least two teams, each team consisting of a minimum of two members, to raise ground ladders and perform ventilation.
- (7) If an aerial device(s) is used in operations, one member to function as an aerial operator and maintain primary control of the aerial device at all times.
- (8) The establishment of an RIC consisting of an officer and at least three members who are fully equipped and trained in RIC operations.
- (9) The establishment of an initial medical care component consisting of at least two members capable of providing immediate on-scene emergency medical support and transport that provides rapid access to civilians or members potentially needing medical treatment. Where this level of emergency medical care is provided by outside agencies or organizations, these agencies and organizations shall be included in the deployment plan and meet these requirements.

5.2.4.3 Apartment Initial Full Alarm Assignment Capability.

5.2.4.3.1 The initial full alarm assignment to a structure fire in a typical 1200 ft² (111 m²) apartment within a three-story, garden-style apartment building shall provide for the following:

- (1) Establishment of incident command outside the hazard area for the overall coordination, direction, and safety of the initial full alarm assignment with a minimum of two members dedicated to managing this task.
- (2) Establishment of two uninterrupted water supplies at a minimum of 400 gpm (1520 L/min), with each supply line maintained by an operator.
- (3) Establishment of an effective water flow application rate of 300 gpm (1140 L/min) from three handlines, each of which has a minimum flow rate of 100 gpm (380 L/min), with each handline operated by a minimum of two members to effectively and safely maintain each handline.
- (4) Provision of one support member for each attack, backup, and exposure line deployed to provide hydrant hookup and to assist in laying of hose lines, utility control, and forcible entry.
- (5) Provision of at least two victim search-and-rescue teams, each team consisting of a minimum of two members.
- (6) Provision of at least two teams, each team consisting of a minimum of two members, to raise ground ladders and perform ventilation.
- (7) If an aerial device is used in operations, one member to function as an aerial operator and maintain primary control of the aerial device at all times.
- (8) The establishment of an RIC consisting of an officer and at least three members who are fully equipped and trained in RIC operations.
- (9) The establishment of an initial medical care component consisting of at least two members capable of providing immediate on-scene emergency medical support, and transport that provides rapid access to civilian or members potentially needing medical treatment. Where this level of emergency medical care is provided by outside agencies or organizations, those agencies and organizations must be included in the deployment plan and meet these requirements.

5.2.4.4* High-Rise Initial Full Alarm Assignment Capability.

5.2.4.4.1 Initial full alarm assignment to a fire in a building with the highest floor greater than 75 ft (23 m) above the

lowest level of fire department vehicle access shall provide for the following:

- (1) Establishment of a stationary incident command post outside the hazard area for overall coordination and direction of the initial full alarm assignment with a minimum of one officer with an aide dedicated to these tasks. All operations shall be conducted in compliance with the incident command system.
- (2) Establishment of an uninterrupted water supply to the building standpipe/sprinkler connection sufficient to support fire attack operations maintained by an operator. If the building is equipped with a fire pump, one additional member with a radio shall also be sent to the fire pump location to monitor and maintain operation.
- (3) Establishment of an effective water flow application rate on the fire floor at a minimum of 500 gpm (1892 L/m) from two handlines, each operated by a minimum of two members to safely and effectively handle the line.
- (4) Establishment of an effective water flow application rate on the floor above the fire floor at a minimum of 250 gpm (946 L/m) from at least one handline, with each handline deployed operated by a minimum of two members to safely and effectively handle the line.
- (5) The establishment of an RIC consisting of four properly equipped and trained members to replace the IRIC two floors below the fire floor (non-IDLH atmosphere) or on the ground floor if the fire is on the second floor or below.
- (6) Provision of two or more search-and-rescue teams consisting of a minimum of two members each.
- (7) Provision of one officer, with an aide dedicated to these tasks, to establish oversight at or near the entry point on the fire floor(s) and on the floor above the fire.
- (8) Provision of two or more evacuation management teams to assist and direct building occupants with evacuation or sheltering actions, with each team consisting of a minimum of two members.
- (9) Provision of one or more members to account for and manage elevator operations.
- (10) Provision of a minimum of one trained incident safety officer.
- (11) Provision of a minimum of one officer two floors below the fire floor to manage the interior staging area.
- (12) Provision of a minimum of two members to manage member rehabilitation. At least one of the members shall be trained to the ALS level.
- (13) Provision of an officer and a minimum of three members to conduct vertical ventilation operations.
- (14) Provision of a minimum of one officer to manage the building lobby operations.
- (15) Provision of a minimum of two members to transport equipment to a location below the fire floor.
- (16) Provision of one officer to manage external base operations.
- (17) Provision of a minimum of two crews trained in emergency medical services with on-scene transport capability, each crew with a minimum of two members. At least one of the members shall be trained to the ALS level.

5.2.4.5 Additional Alarm Assignments.

5.2.4.5.1* Fire departments that respond to fires in occupancies that present hazards greater than those found in the occupancy described in 5.2.4.1 shall deploy additional resources on the initial alarm.

5.2.4.5.2* The fire department shall have the capability to deploy additional alarm assignments that can provide for additional command staff, members, and additional services, including the application of water to the fire; engagement in search and rescue, forcible entry, ventilation, and preservation of property; safety and accountability for personnel; and provision of support activities for those situations that are beyond the capability of the initial full alarm assignment.

5.2.4.5.3 An incident safety officer shall be deployed to all incidents that escalate beyond an initial full alarm assignment or when significant risk is present to members.

5.2.4.5.4 The incident safety officer shall ensure that the safety and health system is established as required in Section 6.1.

5.3* **Emergency Medical Services (EMS).** The purpose of this section shall be to provide standards for the delivery of EMS by fire departments.

5.3.1 The fire department shall clearly document its role, responsibilities, functions, and objectives for the delivery of EMS.

5.3.1.1 EMS operations shall be organized to ensure that the fire department's emergency medical capability includes members, equipment, and resources to deploy the initial arriving company and additional alarm assignments.

5.3.1.2 The fire department shall be permitted to use established automatic aid or mutual aid agreements to comply with the requirements of Section 5.3.

5.3.2* System Components.

5.3.2.1 Treatment Levels.

5.3.2.1.1 The basic treatment levels within an EMS system, for the purposes of this standard, shall be categorized as first responder, basic life support (BLS), and advanced life support (ALS).

5.3.2.1.2 The specific patient treatment capabilities associated with each level shall be determined by the AHJ based on the requirements for approval and licensing of EMS providers within each state or province.

5.3.2.2 Training Levels.

5.3.2.2.1 The minimal level of training for all members that respond to emergency incidents shall be to the first responder/AED level.

5.3.2.2.2 The AHJ shall determine if further training is required.

5.3.3 EMS System Functions.

5.3.3.1 The AHJ shall determine which of the following components of an EMS system the fire department shall be responsible for providing:

- (1) Initial response to provide medical treatment at the location of the emergency (first responder with AED capability or higher)
- (2) BLS response
- (3) ALS response
- (4) Patient transport in an ambulance or alternative vehicle designed to provide for uninterrupted patient care at the ALS or BLS level while en route to a medical facility
- (5) Assurance of response and medical care through a quality management program



5.3.3.2 Staffing.

5.3.3.2.1 On-duty EMS units shall be staffed with the minimum members necessary for emergency medical care relative to the level of EMS provided by the fire department.

5.3.3.2.2 EMS staffing requirements shall be based on the minimum levels needed to provide patient care and member safety.

5.3.3.2.2.1 Units that provide emergency medical care shall be staffed at a minimum with members trained to the first responder/AED level.

5.3.3.2.2.2 Units that provide BLS transport shall be staffed and trained at the level prescribed by the state or provincial agency responsible for providing EMS licensing.

5.3.3.2.2.3 Units that provide ALS transport shall be staffed and trained at the level prescribed by the state or provincial agency responsible for providing EMS licensing.

5.3.3.3 Service Delivery Deployment.

5.3.3.3.1 The fire department shall adopt service delivery objectives based on time standards for the deployment of each service component for which it is responsible.

5.3.3.3.2 Personnel deployed to ALS emergency responses shall include a minimum of two members trained at the emergency medical technician-paramedic level and two members trained at the emergency medical technician-basic level arriving on scene within the established travel time.

5.3.4 Quality Management.

5.3.4.1 The fire department shall institute a quality management program to ensure that the service has met time objectives as required in 4.1.2 for all medical responses.

5.3.4.2 Fire Department Medical Personnel Review.

5.3.4.2.1 All first responder and BLS medical care provided by the fire department shall be reviewed by the fire department medical personnel.

5.3.4.2.2 This review process shall be documented.

5.3.4.3 Medical Director Review.

5.3.4.3.1 All fire departments with ALS services shall have a named medical director with the responsibility to oversee and ensure quality medical care in accordance with state or provincial laws or regulations.

5.3.4.3.2 This review process shall be documented.

5.3.4.4 Fire departments providing ALS services shall provide a mechanism for immediate communications with EMS supervision and medical oversight.

5.4 Special Operations Response. Special operations shall be organized to ensure that the fire department's special operations capability includes members, equipment, and resources to deploy the initial arriving company and additional alarm assignments providing such services.

5.4.1 The fire department shall be permitted to use established automatic aid or mutual aid agreements to comply with the requirements of Section 5.4.

5.4.2 The fire department shall adopt a special operations response plan and SOPs that specify the roles and responsibilities of the fire department and the authorized functions of

members responding to hazardous materials emergency incidents.

5.4.3 All fire department members expected to respond to emergency incidents beyond the first responder operations level for hazardous materials response shall be trained to the applicable requirements of NFPA 472.

5.4.4 All fire department members expected to respond to emergency incidents beyond the confined space operations level for confined space operations shall be trained to the applicable requirements of NFPA 1670.

5.4.5 The fire department shall have the capacity to implement an RIC during all special operations incidents that would subject members to immediate danger or injury in the event of equipment failure or other sudden events, as required by NFPA 1500.

5.4.6 If a higher level of emergency response is needed beyond the capability of the fire department for special operations, the fire department shall determine the availability of outside resources that deploy these capabilities and the procedures for initiating their response.

5.4.7 The fire department shall limit its activities to only those specific special operations functions for which its members have been trained and are correctly equipped.

5.5 Airport Rescue and Fire-Fighting (ARFF) Services.

5.5.1 Airport fire departments shall adopt operations response plans and SOPs that specify the roles and responsibilities for nonaircraft incidents as required by 5.1.2.

5.5.2 ARFF operations shall be organized to ensure that the fire department's capability includes members, equipment, and resources to deploy the initial arriving company, the initial full alarm assignment, and additional alarm assignments as required in 5.2.4.

5.5.3 Airport fire departments shall have access to special tools, equipment, supplies, personal protective equipment (PPE), and other airport resources that are required to perform operations in their assigned roles and responsibilities.

5.5.4 Deployment.

5.5.4.1 The airport fire department shall deploy the required number of ARFF vehicles required for the airport's assigned category as established by NFPA 403.

5.5.4.2 Airport fire department companies equipped with specialized apparatus and equipment shall be provided to assist ARFF companies where deemed necessary as identified in 5.5.1.

5.5.4.3 Airport fire department companies that deploy to structure fire incidents on airport property shall meet the time objective requirements of 4.1.2.

5.5.4.4 Airport fire department companies that deploy to emergency medical incidents on airport property shall meet the time objective requirements of 4.1.2.

5.5.4.5 The airport fire department shall be permitted to use established automatic aid or mutual aid agreements to comply with the requirements of Section 5.5.

5.5.5 Staffing.

5.5.5.1 Airport fire department ARFF companies shall be staffed as required by NFPA 403.

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5.5.5.2 Airport fire department companies that deploy to structure fire incidents on airport property shall meet the staffing requirements of 5.2.2.

5.5.5.3 Airport fire department companies that deploy to emergency medical incidents on airport property shall meet the staffing requirements of 5.3.3.2.

5.5.6 Emergency Operations.

5.5.6.1 At all emergency scene operations, an incident management system shall be used that meets the requirements of Section 6.2.

5.5.6.2* Incident command shall be established outside of the hazard area for the overall coordination and direction of the initial full alarm assignment.

5.5.6.3 A member shall be dedicated to the task of incident commander.

5.5.6.4 Incident Safety Officer.

5.5.6.4.1 An incident safety officer shall be deployed to all incidents that escalate beyond a full alarm assignment or when members face significant risk.

5.5.6.4.2 The incident safety officer shall ensure that the safety and health system is established as required in Section 6.1.

5.6* Marine Rescue and Fire-Fighting (MRFF) Services.

5.6.1 MRFF operations shall be organized to ensure that the fire department's marine capability includes members, equipment, and resources to deploy to the alarm assignments associated with a marine emergency incident.

5.6.2 Response Plan.

5.6.2.1 The fire department shall adopt a marine operations response plan and SOPs that specify the roles and responsibilities of the fire department and the authorized functions of members responding to marine emergencies.

5.6.2.2 Fire department marine operations response plans and SOPs shall be coordinated with the applicable agencies, such as the port or harbor authority and supporting agencies.

5.6.3 Marine fire departments shall have access to special tools, equipment, supplies, PPE, and other marine resources that are required to perform operations in their assigned roles and responsibilities.

5.6.4 Staffing.

5.6.4.1 Numbers of On-Duty Marine Personnel.

5.6.4.1.1 On-duty marine personnel shall consist of the number necessary for fire-fighting performance relative to the expected MRFF conditions.

5.6.4.1.2 On-duty marine members numbers shall be determined through task analyses as required for types of marine vessels and through additional task analyses that take the following factors into consideration:

- (1) Life hazard to the populace protected
- (2) Provisions of safe and effective fire-fighting performance conditions for the members
- (3) Potential property loss
- (4) Nature, configuration, hazards, and internal protection of the properties involved

(5) Types of tactics and evolutions employed as standard procedure, type of marine vessel used, and results expected to be obtained at the fire scene

(6) Requirements of the regulatory AHJs over navigable waters, ports, and harbors

5.6.4.2 Organization of On-Duty Members.

5.6.4.2.1 On-duty members assigned to marine fire fighting shall be organized into company units and shall have required vessels and equipment assigned to such companies.

5.6.4.2.2 Each marine company shall be led by an officer who shall be considered a part of the company.

5.6.5 Operating Units.

5.6.5.1* Fire companies whose primary function is to deliver and pump water and extinguishing agents at the scene of a marine incident shall be known as marine companies.

5.6.5.2 These companies shall be staffed with a minimum number of on-duty members as required by the tactical and occupancy hazards to which the marine vessel responds and by the regulatory AHJs over navigable waters, ports, and harbors.

5.7 Wildland Fire Suppression Services.

5.7.1 Wildland fire suppression operations shall be organized to ensure that the fire department's wildland fire suppression capability includes members, equipment, and resources to deploy wildland direct operations that can address marginal situations before they get out of control and wildland indirect fire-fighting operations that can be assembled and placed into operation against major wildland fires.

5.7.2 Organization.

5.7.2.1 Fire departments performing wildland operations shall adopt a wildland fire-fighting operations response plan and SOPs that specify the roles and responsibilities of the fire department and the authorized functions of members responding to wildland fire emergencies.

5.7.2.2 All wildland fire suppression operations shall be organized to ensure compliance with NFPA 1143.

5.7.3 Fire departments performing wildland operations shall have access to special tools, equipment, supplies, PPE, and other wildland resources that are required to perform operations in their assigned roles and responsibilities.

5.7.4 Staffing. The number of on-duty wildland fire-fighting personnel shall be sufficient to perform the necessary fire-fighting operations given the expected wildland fire-fighting conditions.

5.7.4.1 On-duty wildland fire-fighting members numbers shall be determined through task analyses that take the following factors into consideration:

- (1) Life hazard to the populace protected
- (2) Provisions of safe and effective fire-fighting performance conditions for the members
- (3) The number of trained response members available to the department, including mutual aid resources
- (4) Potential property loss
- (5) Nature, configuration, hazards, and internal protection of the properties involved



- (6) Types of wildland tactics and evolutions employed as standard procedure, type of apparatus used, and results expected to be obtained at the fire scene
- (7) Topography, vegetation, and terrain in the response area(s)

5.7.4.2 On-duty personnel assigned to wildland operations shall be organized into company units and shall have required apparatus and equipment assigned to such companies.

5.7.4.2.1 The fire department shall identify minimum company staffing levels necessary to meet the deployment criteria to ensure that a sufficient number of members are assigned, on duty, and available to respond with each company.

5.7.4.2.2 Each company shall be led by an officer who shall be considered a part of the company.

5.7.4.2.3 Supervisory chief officers shall be dispatched or notified to respond to all full alarm assignments.

5.7.4.2.4 The supervisory chief officer shall ensure that the incident management system is established as required in Section 6.2.

5.7.5 Operating Units. Fire companies whose primary function is to deliver and pump water and extinguishing agents at the scene of a wildland fire shall be known as wildland companies.

5.7.5.1 These companies shall be staffed with a minimum of four on-duty members.

5.7.5.2 Engine and ladder (truck) companies that respond to wildland fire fighting and/or urban interface wildland fire fighting incidents shall be staffed as required by 5.2.3.

5.7.5.3 Other Types of Companies.

5.7.5.3.1 Other types of companies equipped with specialized apparatus and equipment for wildland fire fighting, including aircraft, heavy equipment, mini pumpers, and fast attack vehicles, shall be provided to assist wildland engine and ladder companies where deemed necessary as part of established practice.

5.7.5.3.2 These companies shall be staffed with a minimum number of on-duty personnel as required by the tactical, topographical, environmental, fuel (vegetation), and occupancy hazards.

5.7.6 Deployment.

5.7.6.1 Required Number of Vehicles.

5.7.6.1.1 The fire department shall deploy from its wildland resources the number of vehicles required for a direct and/or indirect attack.

5.7.6.1.2* Prior to the initiation of any wildland fire attack, the fire department shall have the capacity to establish a lookout(s), communications with all crew members, escape route(s), and safety zone(s) for vehicles and members.

5.7.6.2 Direct Attack.

5.7.6.2.1 The fire department shall have the capability to initiate a direct wildland attack within 10 minutes after arrival of the initial company or crew at the fire scene.

5.7.6.2.2 One member in the first arriving company or crew shall be assigned as the incident commander for the overall coordination and direction of the direct attack activities.

5.7.6.2.3 The direct wildland attack shall include the establishment of an effective water flow application rate of 30 gpm (114 L/min) from at least two 500 ft (150 m) 1½ in. (38 mm) diameter attack handlines from two engines.

5.7.6.2.4 Each attack handline shall be operated by a minimum of two members to deploy and maintain the line.

5.7.6.2.5 One operator shall remain with each fire apparatus supplying water flow to ensure uninterrupted water flow application.

5.7.6.2.6 A wildland crew leader or company officer shall be provided with each crew to be responsible for overall supervision of each of the crew and for maintaining personnel accountability and crew safety.

5.7.6.3 Indirect Attack.

5.7.6.3.1 The fire department providing wildland fire suppression operations shall have the capability to deploy an indirect attack, including application of water to the fire, engagement in search and rescue and preservation of property, accountability for personnel, and provision of support activities for those situations that are beyond the capability of the direct attack.

5.7.6.3.2 An incident safety officer shall be deployed to all incidents that escalate beyond a direct attack alarm assignment or when members face significant risk.

5.7.7 Non-Wildland Emergencies.

5.7.7.1 Wildland companies that deploy to structure fire incidents shall meet the time objective requirements of 4.1.2.

5.7.7.2 Wildland companies that deploy to emergency medical incidents shall meet the time objective requirements of 4.1.2.

Chapter 6 Systems

6.1 Safety and Health System. A fire-fighter occupational safety and health program shall be provided in accordance with NFPA 1500.

6.2* Incident Management System.

6.2.1 An incident management system shall be provided in accordance with NFPA 1561 to form the basic structure of all emergency operations of the fire department, regardless of the scale of the department or the emergency.

6.2.2* An incident management system shall be designed to manage incidents of different types, including structure fires, wildland fires, hazardous materials incidents, emergency medical operations, and other types of emergencies that could be encountered by the department.

6.3 Training Systems.

6.3.1 The fire department shall have a training program and policy that ensure that members are trained and competency is maintained to execute all responsibilities consistent with the department's organization and deployment as addressed in Chapters 4 and 5.

6.3.2 The agency must demonstrate in its annual report that it has ensured competency for necessary knowledge, skills, and abilities based on the community's specific hazards and risks, to include at least the hazards specifically addressed in

this standard, for each member that is considered part of the effective response force.

6.3.3 The agency must adopt training standards based on the sited hazards and risk, set appropriate objectives to achieve the standards, and demonstrate that it is meeting the objectives as part of demonstrating training and competency.

6.4 Communications Systems.

6.4.1 The fire department shall have a reliable communications system to facilitate prompt delivery of public fire suppression, EMS, and special operations.

6.4.2 All communications facilities, equipment, staffing, operating procedures, performance objectives, and reporting shall comply with NFPA 1221.

6.4.3 Operating procedures for radio communications shall provide for the use of standard protocols and terminology at all types of incidents.

6.4.4 Standard terminology, in compliance with NFPA 1561, shall be established to transmit information, including strategic modes of operation, situation reports, and emergency notifications of imminent hazards.

6.5* Pre-Incident Planning.

6.5.1 The fire department shall set forth operational requirements to conduct pre-incident planning.

6.5.2 Particular attention shall be provided to all target hazards.

Annex A Explanatory Material

Annex A is not a part of the requirements of this NFPA document but is included for informational purposes only. This annex contains explanatory material, numbered to correspond with the applicable text paragraphs.

A.1.1 The standard includes minimum requirements that are intended to provide effective, efficient, and safe protective services that operate on a sound basis to prevent fires, reduce risk to lives and property, deal with incidents that occur, and prepare for anticipated incidents. It sets minimum standards considered necessary for the provision of public fire protection by career fire departments. It addresses the structure and operation of organizations providing such services, including fire suppression and other assigned emergency response responsibilities, which include EMS and special operations.

A.1.2.1 A fundamental concept of fire risk is associated with modern society. Public fire service organizations are expected to reduce the risk within their areas of jurisdiction by taking measures to prevent the outbreak of fires, limit the extent and severity of fires, provide for the removal or rescue of endangered persons, control and extinguish fires that occur within the jurisdiction, and perform other emergency response operations and delivery of EMS.

The cumulative effects of preventive efforts, risk reduction and control, and fire suppression capabilities result in variable levels of risk to the jurisdictions and their residents.

The risk remaining after deducting the cumulative effect of the public fire service organization's efforts is the responsibility of each individual, including owners, operators, occupants, and casual visitors to properties. It should be noted that fire risk cannot be completely avoided or eliminated.

A.1.4 Nothing in this standard is intended to prohibit the use of systems, methods, or approaches of equivalent or superior performance to those prescribed by this standard. The equivalency statement contained in this standard allows jurisdictions to use other "systems, methods, or approaches" to meet requirements of the standard if they can validate and document in writing that such are equal or superior to the requirements contained in the standard. This equivalency statement is not intended to allow any jurisdiction or fire department to reduce the requirements in the standard and still claim compliance. Moreover, it specifically requires any jurisdiction relying on "equivalent" systems, methods, or approaches to validate, demonstrate, and document in writing that the standard is equal or superior to the requirements contained in this standard.

The authority having jurisdiction (AHJ) determines what systems, methods, or approaches are equivalent or superior in performance. The AHJ should approach the assessment by reviewing the overall public fire protection and EMS system performance.

A.3.2.1 Approved. The National Fire Protection Association does not approve, inspect, or certify any installations, procedures, equipment, or materials; nor does it approve or evaluate testing laboratories. In determining the acceptability of installations, procedures, equipment, or materials, the authority having jurisdiction may base acceptance on compliance with NFPA or other appropriate standards. In the absence of such standards, said authority may require evidence of proper installation, procedure, or use. The authority having jurisdiction may also refer to the listings or labeling practices of an organization that is concerned with product evaluations and is thus in a position to determine compliance with appropriate standards for the current production of listed items.

A.3.2.2 Authority Having Jurisdiction (AHJ). The phrase "authority having jurisdiction," or its acronym AHJ, is used in NFPA documents in a broad manner, since jurisdictions and approval agencies vary, as do their responsibilities. Where public safety is primary, the authority having jurisdiction may be a federal, state, local, or other regional department or individual such as a fire chief; fire marshal; chief of a fire prevention bureau, labor department, or health department; building official; electrical inspector; or others having statutory authority. For insurance purposes, an insurance inspection department, rating bureau, or other insurance company representative may be the authority having jurisdiction. In many circumstances, the property owner or his or her designated agent assumes the role of the authority having jurisdiction; at government installations, the commanding officer or departmental official may be the authority having jurisdiction.

A.3.3.2.1 Automatic Aid. Automatic aid is established through a written intergovernmental agreement that provides for the simultaneous dispatch of a predetermined response of personnel and equipment to a neighboring jurisdiction upon receipt of an alarm and is included as part of a communication center's dispatch protocols.

A.3.3.4 Aircraft Rescue and Fire-Fighting (ARFF) Vehicle. The apparatus is typically equipped with a large water tank [commencing at 1000 gal (3800 L) and extending to over 6000 gal (22,800 L)]; a supply of fire-fighting extinguishing agents; remote-controlled large roof turret(s), extendable turret nozzle(s), and bumper turret(s) (ground sweep nozzles) that are used for the discharge of extinguishing agent; and pre-connected handlines.



A.3.3.5 Alarm. In some jurisdictions, an alarm is referred to as an incident or call for service.

A.3.3.13 Company. For fire suppression and other emergency operations, in some jurisdictions, the response capability of the initial arriving company is configured with two apparatus operating together. This can be a result of apparatus not being configured with seated and belted positions for four members, therefore requiring a second vehicle to carry additional personnel. It can also be the result of the fire department's SOPs, which require two apparatus operating together to complete the operational procedures. The objective is to ensure that a minimum of four personnel are assigned to and deployed as a company. The two (or more) pieces of apparatus would always be dispatched and respond together as a single company. Some examples of this include the following:

- (1) A pumper and tanker/tender that would be responding together outside a municipal water district
- (2) A multiple-piece company, specified as such in a fire department's SOPs, such as an engine or ladder company that responds with a rescue unit, water tender, or other type of apparatus
- (3) A company that consists of a pumper with an additional vehicle as a personnel carrier
- (4) A pumper and an ambulance or rescue unit that always respond together

A.3.3.21.1 Aircraft Rescue and Fire Fighting. Such rescue and fire-fighting actions are performed both inside and outside of the aircraft.

A.3.3.21.2 Marine Rescue and Fire Fighting. Marine companies can be utilized for special operations, including a platform for dive and scuba operations and for providing a secure water supply for land-based operations.

A.3.3.23 Fire Suppression. Fire suppression includes all activities performed at the scene of a fire incident or training exercise that expose fire department members to the dangers of heat, flame, smoke, and other products of combustion, explosion, or structural collapse. [1500, 2013]

A.3.3.24 First Responder (EMS). A first responder also assists higher level EMS providers.

A.3.3.26 Hazard. Hazards include the characteristics of facilities, equipment systems, property, hardware, or other objects; and the actions and inactions of people that create such hazards.

A.3.3.28 High-Hazard Occupancy. These occupancies include schools, hospitals, and other special medical facilities, nursing homes, high-risk residential occupancies, neighborhoods with structures in close proximity to one another, high-rise buildings, explosives plants, refineries, and hazardous materials occupancies.

A.3.3.30 Incident Management System (IMS). The system should be consistent with NIMS and the National Response Framework. The system is also referred to as an incident command system (ICS).

A.3.3.36.2 Basic Life Support (BLS). Basic life support could also include expediting the safe and timely transport of the patient to a hospital emergency department for definitive medical care.

A.3.3.38 Member. A fire department member can be a full-time or part-time employee or a paid or unpaid volunteer, can

occupy any position or rank within the fire department, and can engage in emergency operations. [1500, 2013]

A.3.3.40.1 Company Officer. This person can be someone appointed in an acting capacity. The rank structure could be either sergeant, lieutenant, or captain.

A.3.3.40.3 Supervisory Chief Officer. The position of supervisory chief officer is above that of a company officer, who responds automatically and/or is dispatched to an alarm beyond the initial alarm capabilities, or other special calls. In some jurisdictions, this is the rank of battalion chief, district chief, deputy chief, assistant chief, or senior divisional officer (U.K. fire service).

A.3.3.41.2 Special Operations. Special operations include water rescue, extrication, hazardous materials, confined space entry, high-angle rescue, aircraft rescue and fire fighting, and other operations requiring specialized training. [1500, 2013]

A.3.3.44 Rapid Intervention Crew (RIC). The RIC reports directly to the incident commander or operations chief. This dedicated crew is not to be confused with the IRIC.

A.3.3.48 Staff Aide. This member is assigned to a supervisory chief officer who assists at incident scene operations, which can include personnel accountability, communications, and other logistical and administrative support. In addition, this member can assist in coordinating training activities, respond to citizen inquiries, coordinate staffing issues and sick leave follow-up, and assign resource allocations for facilities and apparatus under the supervisory chief officer's jurisdiction. Staff aides can be known as field incident technician, staff assistant, battalion fire fighter, or battalion adjutant.

A.3.3.53.5 Initiating Action/Intervention Time. A benchmark time frame isn't set to initiate a mitigating action or take other steps to intervene in resolving the issue that created the incident. Fire departments should track these times based on their SOPs and evaluate the data based on the nature of the incident.

A.3.3.53.6 Total Response Time. A "cascade of events" chart, shown as Figure A.3.3.53.6, is provided to assist understanding the relationship between NFPA 1221, NFPA 1710, and Initiating Time/Intervention Time (currently not addressed by a single NFPA standard). Three phases are included in total response time. They are as follows:

- (1) Phase One — Alarm Handling Time, which includes alarm transfer time, alarm answering time, and alarm processing time (addressed by NFPA 1221)
- (2) Phase Two — Turnout Time and Travel Time (addressed by NFPA 1710)
- (3) Phase Three — Initiating Action/Intervention Time

A.4.1.1 The AHJ generally has the responsibility to determine the following:

- (1) Scope and level of service provided by the fire department
- (2) Necessary level of funding
- (3) Necessary level of personnel and resources, including facilities

To provide service, the AHJ should have the power to levy taxes or solicit funding, to own property and equipment, and to cover personnel costs. The authority necessary is conveyed by law to a local jurisdiction.

In addition, the governing body also should monitor the achievement of the management goals of the department,

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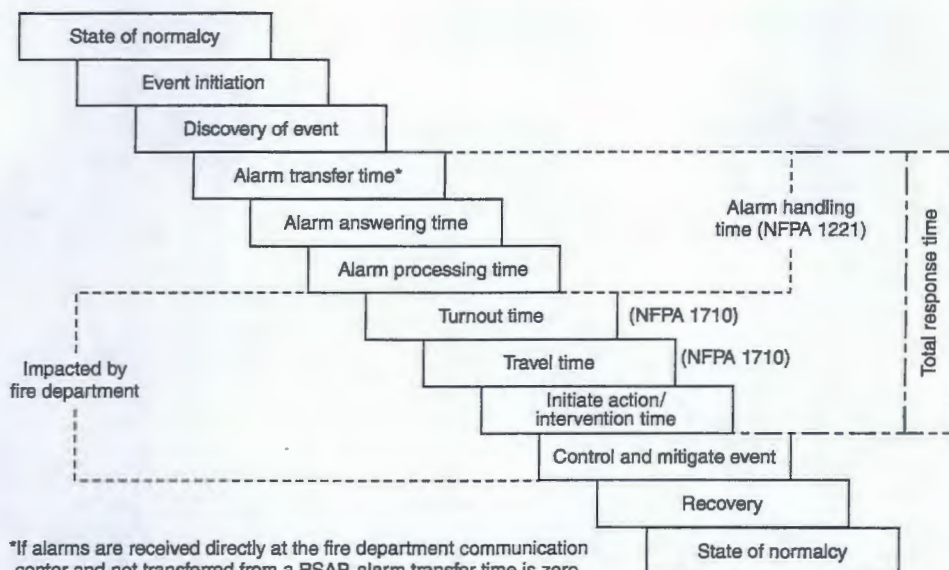


FIGURE A.3.3.53.6 Cascade of Events Chart.

such as fire prevention, community life safety education, fire suppression, employee training, communications, maintenance, and department administration.

The organizational statement is a very important basis for many of the provisions of this standard. The statement sets forth the legal basis for operating a fire department, the organizational structure of the fire department, number of members, training requirements, expected functions, and authorities and responsibilities of various members or defined positions.

A key point is to clearly set out the specific services the fire department is authorized and expected to perform. Most fire departments are responsible to a governing body. The governing body has the right and should assert its authority to set the specific services and the limits of the services the fire department will provide. It also has the responsibility to furnish the necessary resources for delivery of the designated services. The fire department should provide its governing body with a specific description of each service, with options or alternatives and an accurate analysis of the costs and resources needed for each service.

Such services could include structural fire fighting, wildland fire fighting, airport/aircraft fire fighting, emergency medical services, hazardous materials response, high-angle rescue, heavy rescue, and others.

Spelling out the specific parameters of services to be provided allows the fire department to plan, staff, equip, train, and deploy members to perform these duties. It also gives the governing body an accounting of the costs of services and allows it to select those services it can afford to provide. Likewise, the governing body should identify services it cannot afford to provide and cannot authorize the fire department to deliver, or it should assign those services to another agency.

The factors that should be included in the AHJ's risk assessment process include adopted building codes, required fire/life safety related engineering controls, accepted service delivery performance objectives, complexity of facilities, and

occupancy hazards (low, medium, and high) within the jurisdiction.

The fire department should be no different than any other government agency that has the parameters of its authority and services clearly defined by the governing body.

Legal counsel should be used to ensure that any statutory services and responsibilities are being met.

The majority of public fire departments are established under the charter provisions of their governing body or through the adoption of statutes. These acts define the legal basis for operating a fire department, the mission of the organization, the duties that are authorized and expected to be performed, and the authority and responsibilities that are assigned to certain members to direct the operations of the fire department.

The documents that officially establish the fire department as an identifiable organization are necessary to determine specific responsibilities and to determine the parties responsible for compliance with the provisions of this standard.

In many cases, these documents can be part of state laws, a municipal charter, or an annual budget. In such cases, it would be appropriate to make these existing documents part of the organizational statement, if applicable.

A.4.1.2 There can be incidents or areas where the response criteria are affected by circumstances such as response personnel who are not on duty, unstaffed fire station facilities, natural barriers, traffic congestion, insufficient water supply, and density of population or property. The reduced level of service should be documented in the written organizational statement by the percentage of incidents and geographical areas for which the total response time criteria are achieved.

Additional service delivery performance objectives should be established by the AHJ for occupancies other than those identified within the standard for benchmark single-family dwellings. Factors to be considered include specific response areas (i.e., suburban, rural, and wilderness) and occupancy hazards.

A.4.1.2.1(3) This service delivery requirement is intended to have a fire department plan and situate its resources to consistently meet a 240-second travel time for the initial company fire suppression response; for other than high-rise, a 480-second travel time for the full alarm fire response assignment; and for high-rise, a 610-second travel time for the full alarm fire response assignment.

A.4.1.2.5.1 The evaluation of the fire department's provided level of service needs to be performed against the AHJ's established service delivery performance objectives. These objectives should be based on a jurisdictional risk assessment. The objectives established within this standard are based on a 2000 ft² (186 m²), two-story, single-family home without a basement and having no exposures. The AHJ's response objectives should be established based on numerous factors such as the circumstances affecting response personnel, adopted building codes, required fire/life safety-related engineering controls, accepted turnout/travel times, complexity of facilities, and occupancy hazards within the jurisdiction.

A.4.1.2.5.2 The collection of data is required to determine the organization's ability to meet its locally determined objectives and the performance objectives contained in the standard with regard to emergency incidences (warning lights and sirens). Organizations respond to numerous types of emergency and nonemergency incidents. While the collection and analysis of all of the response data is important, attainment of the 90 percent objective is only to be evaluated against emergency incident responses.

A.4.4.2 Occupational Safety and Health Administration (OSHA) regulations require that all fire departments be trained to respond to hazardous materials incidents at the first responder operations level.

Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA), known as the Emergency Planning and Community Right-to-Know Act, established requirements for federal, state, and local governments and industrial facilities regarding emergency planning for spills or other releases, community right-to-know, and reporting of hazardous and toxic chemicals.

The Emergency Planning and Community Right-to-Know Act covers the following four major areas that provide the fire service and communities with a broad perspective on the chemical hazards within the local area and those at individual facilities:

- (1) Sections 301 through 303 — emergency planning
- (2) Section 304 — emergency release notification
- (3) Sections 311 and 312 — community right-to-know reporting requirements
- (4) Section 313 — toxic chemical release inventory

A.4.8.1 Where appropriate, the mutual aid agreement should include automatic responses on first alarms (automatic aid). This concept contemplates joint response of designated apparatus and personnel on a predetermined running assignment basis.

Mutual aid concepts should be considered on a regional basis. In an effective mutual aid arrangement, each fire department should retain reserves of personnel and apparatus. Traditionally and legally, overall command of the incident is vested with the senior officer of the jurisdiction experiencing the emergency.

Some areas use consolidated dispatching to coordinate the response of fire companies to assist an outside fire depart-

ment. The management of responses can be made easier by utilizing computerization, "running cards," and other advance planning.

A.5.2 Suppression capability is an expression of how much fire-fighting power can be put into action when there is a fire. It includes the amount of apparatus, equipment, and personnel available; the time needed to respond and place equipment in action; the water supply; the application of strategy and tactics; the level of training; and all of the components that add up to effective fireground operations.

A.5.2.2 For more information, see NFPA 1250; FEMA, National Fire Academy, "Fire Risk Analysis: A Systems Approach"; and Phoenix, AZ, Fire Department, "Fire Department Evaluation System (FIREDAPE)."

A.5.2.2.2 For further information on companies, see 3.3.13 and A.3.3.13.

A.5.2.2.2.1 An early, aggressive, and offensive primary interior attack on a working fire, where feasible, is usually the most effective strategy to reduce loss of lives and property damage. In Figure A.5.2.2.2.1, the line, which combines temperature rise and time, represents a rate of fire propagation in an unsprinklered room and roughly corresponds to the percentage of property destruction. At approximately 10 minutes into the fire sequence, the hypothetical room of origin flashes over. Extension outside the room begins at that point.

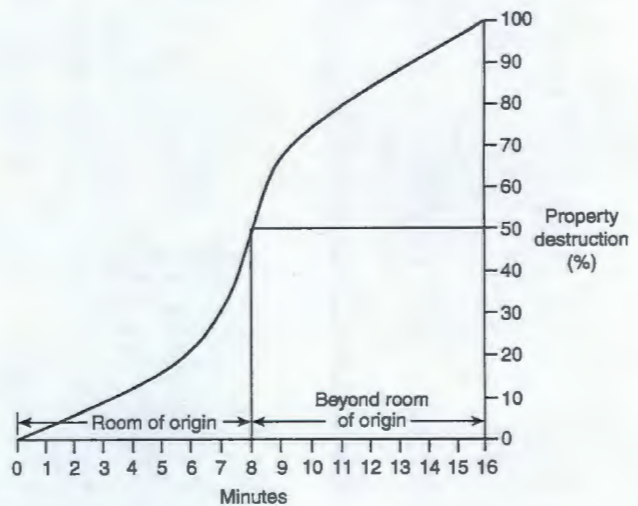


FIGURE A.5.2.2.2.1 Fire Propagation Curve.

Consequently, given that the progression of a structure fire to the point of flashover (i.e., the very rapid spreading of the fire due to superheating of room contents and other combustibles) generally occurs in less than 10 minutes, two of the most important elements in limiting fire spread are the quick arrival of sufficient personnel and equipment to attack and extinguish the fire as close to the point of its origin as possible. For more information, refer to *Fire Service Today*, "Reduced Staffing: At What Cost," and NIST, "Hazard I Fire Hazard Assessment Method." Also, refer to National Fire Academy, "Fire Risk Analysis: A Systems Approach," and Office of the Ontario Fire Marshal, *Shaping the Future of Fire Ground Staffing and Delivery Systems Within a Comprehensive Fire Safety Effectiveness Model*.

The ability of adequate fire suppression forces to significantly influence the outcome of a structure fire is undeniable and predictable. Data generated by NFPA and used by the committee in developing this standard provide empirical data that rapid and aggressive interior attack can substantially reduce the human and property losses associated with structure fires [see Table A.5.2.2.2.1(a) and Table A.5.2.2.2.1(b)].

The NFPA Fire Analysis and Research Division provided the data in Table A.5.2.2.2.1(b) as an update of Table A.5.2.2.2.1(a).

Table A.5.2.2.2.1(a) Fire Extension in Residential Structures, 1994–1998

Extension	Rate per 1000 Fires		
	Civilian Deaths	Civilian Injuries	Average Dollar Loss per Fire
Confined to room of origin	2.32	35.19	\$3,185
Beyond the room but confined to floor of origin	19.68	96.86	\$22,720
Beyond floor of origin	26.54	63.48	\$31,912

Note: Residential structures include dwellings, duplexes, manufactured homes (also called mobile homes), apartments, row houses, townhouses, hotels and motels, dormitories, and barracks.

Source: NFPA Annual Fire Experience Survey and National Fire Incident Reporting System (NFIRS).

A.5.2.2.2.3 The assignment of specific response districts to command officers should be based on the number of companies, workload, and response distances. Department administrative procedures should indicate clearly the jurisdiction of command officers.

A.5.2.2.2.5 For further information on staff aides, see 3.3.48 and A.3.3.48.

A.5.2.4.1.1 The hazards presented by this scenario are not unusual, as all communities respond to fire incidents in this type of structure on a regular basis.

A.5.2.4.2.1 The open-air strip shopping center represents more than 67 percent of types of shopping centers, as described by the International Council of Shopping Centers (ICSC). The ICSC describes these centers as “usually configured in a straight line as a strip, or may be laid out in an L or U shape, depending on the site and design. They consist of an attached row of stores or service outlets managed as a coherent retail entity, with on-site parking usually located in front of the stores. Open canopies may connect the store fronts, but a strip center does not have enclosed walkways linking the stores. The open air strip shopping center may contain between five and 40 stores of varying occupancy types and hazards with three or more being larger, anchor stores such as a discount store, supermarket, drug, or large specialty discount store.”

A.5.2.4.4 See “Report on High-Rise Fireground Field Experiments,” NIST, April 2013, for more information.

A.5.2.4.5.1 Other occupancies and structures in the community that present greater hazards should be addressed by addi-

Table A.5.2.2.2.1(b) Fire Extension Home Structure Fires, 2006–2010 Rate per 1000 Fires

Flame Spread	Rate per 1000 Fires		
	Civilian Deaths	Civilian Injuries	Average Dollar Loss per Fire
Confined fires or contained fire identified by incident type*	0.000	10.29	\$212
Confined fire or flame damage confined to object of origin	0.65	13.53	\$1,565
Confined to room of origin, including confined fires and fires confined to object	1.91	25.32	\$2,993
Beyond the room but confined to floor of origin	22.73	64.13	\$7,445
Beyond floor of origin	24.63	60.41	\$58,431

* NFIRS 5.0 has six categories of confined structure fires: cooking fires confined to the cooking vessel, confined chimney or flue fires, confined incinerator fires, confined fuel burner or boiler fires or delayed ignitions, confined commercial compactor fires, and trash or rubbish fires in a structure with no flame damage to the structure or its contents.

Note: Homes include one- and two-family homes (including manufactured housing) and apartments or other multifamily housing. These statistics are national estimates based on fires reported to U.S. municipal fire departments and so exclude fires reported only to federal or state agencies. National estimates are projections. Casualty and loss projections can be heavily influenced by the inclusion or exclusion of one unusually serious fire. Property damage has not been adjusted for inflation.

Source: NFPA Annual Fire Experience Survey and National Fire Incident Reporting System (NFIRS).

tional fire fighter functions and additional responding personnel on the initial full alarm assignment. The NFPA *Fire Protection Handbook* categorizes occupancies in three broad groups:

- (1) High-hazard occupancies: schools, hospitals, nursing homes, explosives plants, refineries, high-rise buildings, and other high life hazard or large fire potential occupancies
- (2) Medium-hazard occupancies: apartments, offices, mercantile, and industrial occupancies not normally requiring extensive rescue or fire-fighting forces
- (3) Low-hazard occupancies: one-, two- or three-family dwellings and scattered small businesses and industrial occupancies. The NFPA 1710 benchmark occupancy fits into this low-hazard category.

In determining the initial responding force to these occupancies, AHJs must consider the additional potential of fire

spread, types of combustibles, increased life hazard, and various tasks that must be accomplished to achieve their mission.

A.5.2.4.5.2 Once units arrive, or a determination is made that other resources are required, additional alarms should be called for and dispatched. Departments should have predetermined procedures for additional alarms. Many departments send the same number and type of units on the second alarm as on the first alarm. Incident commanders can always request unique resources when required. Many departments will only be able to handle additional alarms through automatic or mutual aid agreements that have been previously established.

A.5.3 An EMS system is defined as a comprehensive, coordinated arrangement of resources and functions that are organized to respond in a timely, staged manner to medical emergencies, regardless of their cause. The term *system* can be applied locally or at the state, provincial, or national level. The fundamental functions of an EMS system are the following:

- (1) System organization and management
- (2) Medical direction
- (3) Human resources and training
- (4) Communications
- (5) Emergency response
- (6) Transportation
- (7) Care facilities
- (8) Quality assurance
- (9) Public information and education
- (10) Disaster medical services
- (11) Research
- (12) Special populations

A.5.3.2 The following four functions do not necessarily exist as separate elements in a particular system:

- (1) The first responding unit can be an advanced life support (ALS) ambulance that can provide ALS treatment and ambulance transportation.
- (2) The first responding unit can be a fire suppression unit that can provide both initial and advanced-level medical care.
- (3) ALS can be provided by the ambulance or by an additional fire suppression unit or a unit that is dedicated to ALS response only.
- (4) The system might not have ALS treatment capability — only a fire apparatus with fire fighters trained as first responder AED can respond.

A.5.5.6.2 The U.S. Air Force has defined the areas involved in the emergency within 75 ft (23 m) of the aircraft as immediately dangerous to life and health (IDLH).

A.5.6 For additional information on marine fire fighting, see NFPA 1405.

A.5.6.5.1 For additional information on marine rescue and fire-fighting vessels, see NFPA 1925.

A.5.7.6.1.2 A system developed by Chief Paul Gleason of the United States Forest Service addresses specific mandatory fire orders in a system termed *LCES*, which stands for lookout(s), communication(s), escape route(s), and safety zone(s). These four items are to be implemented as an integrated system by a single resource unit, a strike team, or a full assignment. The implementation of LCES is a minimum safety requirement prior to the initiation of any wildland fire-fighting operations.

A.6.2 Emergency incidents can involve operations that vary considerably in their complexity and scale. The control of

these incidents depends on the planned, systematic implementation of an effective fireground organization to accomplish identified objectives. Every fire department, regardless of size, needs a proper system to regulate and direct emergency forces and equipment at both routine and major incidents. The incident management system forms the basic structure of operations, regardless of scale. An effective system is designed to manage incidents of different types, including structure fires, wildland fires, hazardous materials incidents, and medical and other emergencies.

A.6.2.2 Unlike fire incidents where command is normally predicated by rank structure, EMS patient care is based on statutory recognition of the member with the highest level of medical certification. The recommendation is that departments adopt protocols that define the degree of both member and nonmember involvement in direct patient care based on local standards, medical control, and statutory requirements.

A.6.5 For additional information, see NFPA 1620.

Annex B Community-Wide Risk Management Model

This annex is not a part of the requirements of this NFPA document but is included for information purposes only.

B.1 This model is an example of how a community-wide risk management plan can be used to protect both citizens and property. While NFPA 1710 is scoped to focus strictly on deployment, staffing, and service levels, it is one component of a total community fire protection planning process. An AHJ can determine other components that could reduce the risks of fire and adopt stronger building and fire prevention codes, enforce those more vigorously, and enhance public life safety education components. This model is included for that purpose. Figure B.1 illustrates a fire department process map.

NFPA 1730, Chapter 5 establishes a process to identify and analyze community risks to assist in the development and implementation of a community risk reduction (CRR) plan. Detailed guidance on conducting a CRR plan is provided in Annex B of NFPA 1730.

For other documents on community risk assessment and community risk reduction, see: *Fire Service Deployment: Assessing Community Vulnerability*, Urban Fire Forum; *ISO Fire Suppression Rating Schedule*, CPSE Standard of Cover; *IFE V2020 CRR 2009 Project Report*; *IFE V2020 CRR Symposium Report*; and *Washington Association of State Fire Marshals CRR Project Report*.

B.1.1 This annex addresses the need for fire departments to develop an overall “defense-in-depth” strategy for the delivery of fire services. The development of such a strategy should include an assessment of the tools available to the fire service for accomplishing the goals of fire safety.

B.1.2 Fire safety objectives can be defined as those ideas that a department aspires to deliver. For example, fire department objectives could include such statements as “Maintain injuries and life/property losses as low as reasonably achievable (community and department).” The accomplishment of this objective should not be left to fire-fighting operations alone. See Figure B.1.2 for fire safety concepts.

B.1.3 Fire prevention is not simply preventing fire. It is the systematic application of codes, standard, engineering principles, and an understanding of human behavior to achieve the objective of limiting the loss of life and property.

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FIGURE B.1 Fire Department Process Map.

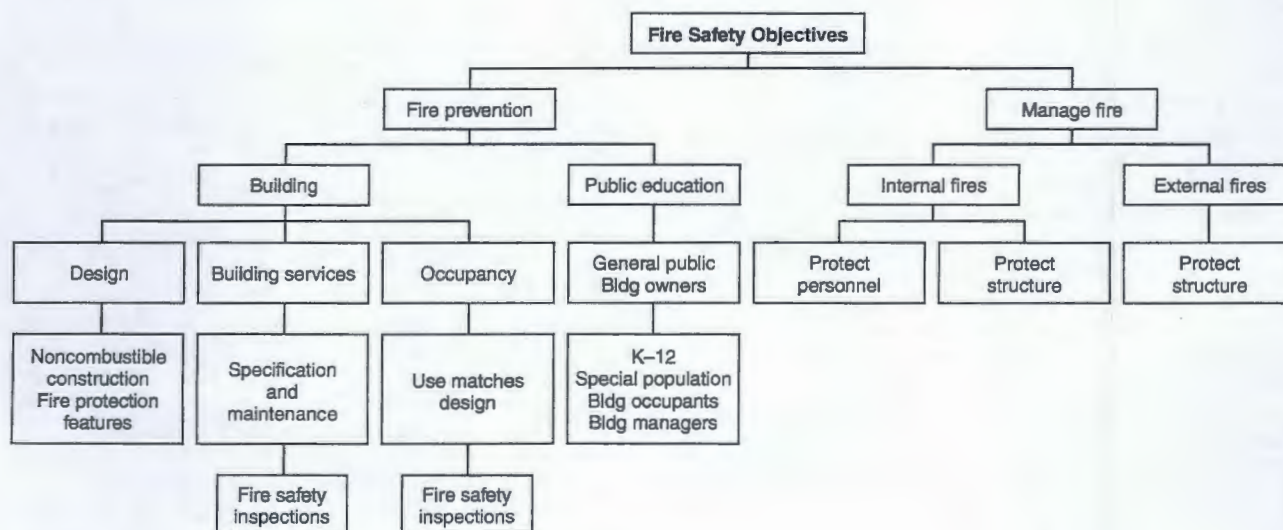


FIGURE B.1.2 Fire Safety Concepts for Fire Department Operations.

B.1.3.1 As outlined in NFPA 1, fire prevention includes egress, construction design, building services, fire protection, and occupancy. All of these elements work together to provide the occupants and fire department personnel with a level of fire safety not otherwise available.

B.1.3.2 By ensuring that each of these elements is balanced, the fire department can maintain a reasonable level of risk for the community and the department.

B.1.3.3 To provide risk management, the fire department must utilize all of the tools available. In order of preference, those tools are as follows:

- (1) Fire-safe design and construction
- (2) Suppression systems
- (3) Detection systems
- (4) Occupant fire prevention practices
- (5) Fire department-conducted fire-safety inspections
- (6) Fire rescue response

B.1.3.4 A structure designed and constructed to withstand the effects of fire is the most important asset in achieving fire risk management. A structure relying solely on fire rescue response offers the greatest challenge to the occupants and fire department personnel.

B.1.4 Fire impact management is the ability to manage the impact of a fire on occupants and structures. The participation of the fire department in the design, construction, maintenance, and use of a structure provides defense-in-depth against fire losses.

B.1.4.1 Structures that are designed with noncombustible construction, are protected with fire protection systems, and are routinely inspected to ensure appropriate occupant use are most likely to provide the lowest risk levels and therefore are the least difficult to manage.

B.1.4.2 Fire-fighting operations on fully compliant structures for which the fire fighters know the occupancy conditions can be conducted with a plan that commits resources only as necessary to accomplish the pre-established goals.

B.1.4.3 Pre-established goals for each structure define the commitment of resources in order to limit risk to occupants, the structure, and fire department personnel.

Annex C Informational References

C.1 Referenced Publications. The documents or portions thereof listed in this annex are referenced within the informational sections of this standard and are not part of the requirements of this document unless also listed in Chapter 2 for other reasons.

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C.2 Informational References. The following documents or portions thereof are listed here as informational resources only. They are not a part of the requirements of this document.

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C.2.2 Government Accounting Standards Board. Government Accounting Standards Board, 401 Merritt 7, P.O. Box 5116, Norwalk, CT 06856-5116.

C.2.3 IAFC/IAFF Publications. International Association of Fire Chiefs/International Association of Fire Fighters. International Association of Fire Chiefs, 4025 Fair Ridge Drive, Suite 300, Fairfax, VA 22033-2868. International Association of Fire Fighters, 1750 New York Avenue, NW, Washington, DC 20006.

"NFPA 1710 Implementation Guide," August 2002.

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Total Response Time

Definition	3.3.54
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Travel Time

Definition	3.3.55
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Turnout Time

Definition	3.3.56
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Sequence of Events for the Standards Development Process

As soon as the current edition is published, a Standard is open for Public Input

Step 1: Input Stage

- Input accepted from the public or other committees for consideration to develop the First Draft
- Committee holds First Draft Meeting to revise Standard (23 weeks)
Committee(s) with Correlating Committee (10 weeks)
- Committee ballots on First Draft (12 weeks)
Committee(s) with Correlating Committee (11 weeks)
- Correlating Committee First Draft Meeting (9 weeks)
- Correlating Committee ballots on First Draft (5 weeks)
- First Draft Report posted

Step 2: Comment Stage

- Public Comments accepted on First Draft (10 weeks)
- If Standard does not receive Public Comments and the Committee does not wish to further revise the Standard, the Standard becomes a Consent Standard and is sent directly to the Standards Council for issuance
- Committee holds Second Draft Meeting (21 weeks)
Committee(s) with Correlating Committee (7 weeks)
- Committee ballots on Second Draft (11 weeks)
Committee(s) with Correlating Committee (10 weeks)
- Correlating Committee First Draft Meeting (9 weeks)
- Correlating Committee ballots on First Draft (8 weeks)
- Second Draft Report posted

Step 3: Association Technical Meeting

- Notice of Intent to Make a Motion (NITMAM) accepted (5 weeks)
- NITMAMs are reviewed and valid motions are certified for presentation at the Association Technical Meeting
- Consent Standard bypasses Association Technical Meeting and proceeds directly to the Standards Council for issuance
- NFPA membership meets each June at the Association Technical Meeting and acts on Standards with "Certified Amending Motions" (certified NITMAMs)
- Committee(s) and Panel(s) vote on any successful amendments to the Technical Committee Reports made by the NFPA membership at the Association Technical Meeting

Step 4: Council Appeals and Issuance of Standard

- Notification of intent to file an appeal to the Standards Council on Association action must be filed within 20 days of the Association Technical Meeting
- Standards Council decides, based on all evidence, whether or not to issue the Standards or to take other action

Committee Membership Classifications^{1,2,3,4}

The following classifications apply to Committee members and represent their principal interest in the activity of the Committee.

1. M *Manufacturer*: A representative of a maker or marketer of a product, assembly, or system, or portion thereof, that is affected by the standard.
2. U *User*: A representative of an entity that is subject to the provisions of the standard or that voluntarily uses the standard.
3. IM *Installer/Maintainer*: A representative of an entity that is in the business of installing or maintaining a product, assembly, or system affected by the standard.
4. L *Labor*: A labor representative or employee concerned with safety in the workplace.
5. RT *Applied Research/Testing Laboratory*: A representative of an independent testing laboratory or independent applied research organization that promulgates and/or enforces standards.
6. E *Enforcing Authority*: A representative of an agency or an organization that promulgates and/or enforces standards.
7. I *Insurance*: A representative of an insurance company, broker, agent, bureau, or inspection agency.
8. C *Consumer*: A person who is or represents the ultimate purchaser of a product, system, or service affected by the standard, but who is not included in (2).
9. SE *Special Expert*: A person not representing (1) through (8) and who has special expertise in the scope of the standard or portion thereof.

NOTE 1: "Standard" connotes code, standard, recommended practice, or guide.

NOTE 2: A representative includes an employee.

NOTE 3: While these classifications will be used by the Standards Council to achieve a balance for Technical Committees, the Standards Council may determine that new classifications of member or unique interests need representation in order to foster the best possible Committee deliberations on any project. In this connection, the Standards Council may make such appointments as it deems appropriate in the public interest, such as the classification of "Utilities" in the National Electrical Code Committee.

NOTE 4: Representatives of subsidiaries of any group are generally considered to have the same classification as the parent organization.

Submitting Public Input / Public Comment through the Electronic Submission System (e-Submission):

As soon as the current edition is published, a Standard is open for Public Input.

Before accessing the e-Submission System, you must first sign-in at www.NFPA.org. *Note: You will be asked to sign-in or create a free online account with NFPA before using this system:*

- a. Click in the gray Sign In box on the upper left side of the page. Once signed-in, you will see a red "Welcome" message in the top right corner.
- b. Under the Codes and Standards heading, Click on the Document Information pages (List of Codes & Standards), and then select your document from the list or use one of the search features in the upper right gray box.

OR

- a. Go directly to your specific document page by typing the convenient short link of www.nfpa.org/document#, (Example: NFPA 921 would be www.nfpa.org/921) Click in the gray Sign In box on the upper left side of the page. Once signed in, you will see a red "Welcome" message in the top right corner.

To begin your Public Input, select the link The next edition of this standard is now open for Public Input (formally "proposals") located on the Document Information tab, the Next Edition tab, or the right-hand Navigation bar. Alternatively, the Next Edition tab includes a link to Submit Public Input online

At this point, the NFPA Standards Development Site will open showing details for the document you have selected. This "Document Home" page site includes an explanatory introduction, information on the current document phase and closing date, a left-hand navigation panel that includes useful links, a document Table of Contents, and icons at the top you can click for Help when using the site. The Help icons and navigation panel will be visible except when you are actually in the process of creating a Public Input.

Once the First Draft Report becomes available there is a Public comment period during which anyone may submit a Public Comment on the First Draft. Any objections or further related changes to the content of the First Draft must be submitted at the Comment stage.

To submit a Public Comment you may access the e-Submission System utilizing the same steps as previous explained for the submission of Public Input.

For further information on submitting public input and public comments, go to: <http://www.nfpa.org/publicinput>

Other Resources available on the Doc Info Pages

Document information tab: Research current and previous edition information on a Standard

Next edition tab: Follow the committee's progress in the processing of a Standard in its next revision cycle.

Technical committee tab: View current committee member rosters or apply to a committee

Technical questions tab: For members and Public Sector Officials/AHJs to submit questions about codes and standards to NFPA staff. Our Technical Questions Service provides a convenient way to receive timely and consistent technical assistance when you need to know more about NFPA codes and standards relevant to your work. Responses are provided by NFPA staff on an informal basis.

Products/training tab: List of NFPA's publications and training available for purchase.

Community tab: Information and discussions about a Standard

Information on the NFPA Standards Development Process

I. Applicable Regulations. The primary rules governing the processing of NFPA standards (codes, standards, recommended practices, and guides) are the *NFPA Regulations Governing the Development of NFPA Standards (Regs)*. Other applicable rules include *NFPA Bylaws*, *NFPA Technical Meeting Convention Rules*, *NFPA Guide for the Conduct of Participants in the NFPA Standards Development Process*, and the *NFPA Regulations Governing Petitions to the Board of Directors from Decisions of the Standards Council*. Most of these rules and regulations are contained in the *NFPA Standards Directory*. For copies of the *Directory*, contact Codes and Standards Administration at NFPA Headquarters; all these documents are also available on the NFPA website at "www.nfpa.org."

The following is general information on the NFPA process. All participants, however, should refer to the actual rules and regulations for a full understanding of this process and for the criteria that govern participation.

II. Technical Committee Report. The Technical Committee Report is defined as "the Report of the responsible Committee(s), in accordance with the Regulations, in preparation of a new or revised NFPA Standard." The Technical Committee Report is in two parts and consists of the First Draft Report and the Second Draft Report. (See *Regs* at 1.4)

III. Step 1: First Draft Report. The First Draft Report is defined as "Part one of the Technical Committee Report, which documents the Input Stage." The First Draft Report consists of the First Draft, Public Input, Committee Input, Committee and Correlating Committee Statements, Correlating Input, Correlating Notes, and Ballot Statements. (See *Regs* at 4.2.5.2 and Section 4.3) Any objection to an action in the First Draft Report must be raised through the filing of an appropriate Comment for consideration in the Second Draft Report or the objection will be considered resolved. [See *Regs* at 4.3.1(b)]

IV. Step 2: Second Draft Report. The Second Draft Report is defined as "Part two of the Technical Committee Report, which documents the Comment Stage." The Second Draft Report consists of the Second Draft, Public Comments with corresponding Committee Actions and Committee Statements, Correlating Notes and their respective Committee Statements, Committee Comments, Correlating Revisions, and Ballot Statements. (See *Regs* at Section 4.2.5.2 and 4.4) The First Draft Report and the Second Draft Report together constitute the Technical Committee Report. Any outstanding objection following the Second Draft Report must be raised through an appropriate Amending Motion at the Association Technical Meeting or the objection will be considered resolved. [See *Regs* at 4.4.1(b)]

V. Step 3a: Action at Association Technical Meeting. Following the publication of the Second Draft Report, there is a period during which those wishing to make proper Amending Motions on the Technical Committee Reports must signal their intention by submitting a Notice of Intent to Make a Motion. (See *Regs* at 4.5.2) Standards that receive notice of proper Amending Motions (Certified Amending Motions) will be presented for action at the annual June Association Technical Meeting. At the meeting, the NFPA membership can consider and act on these Certified Amending Motions as well as Follow-up Amending Motions, that is, motions that become necessary as a result of a previous successful Amending Motion. (See 4.5.3.2 through 4.5.3.6 and Table 1, Columns 1-3 of *Regs* for a summary of the available Amending Motions and who may make them.) Any outstanding objection following action at an Association Technical Meeting (and any further Technical Committee consideration following successful Amending Motions, see *Regs* at 4.5.3.7 through 4.6.5.3) must be raised through an appeal to the Standards Council or it will be considered to be resolved.

VI. Step 3b: Documents Forwarded Directly to the Council. Where no Notice of Intent to Make a Motion (NITMAM) is received and certified in accordance with the Technical Meeting Convention Rules, the standard is forwarded directly to the Standards Council for action on issuance. Objections are deemed to be resolved for these documents. (See *Regs* at 4.5.2.5)

VII. Step 4a: Council Appeals. Anyone can appeal to the Standards Council concerning procedural or substantive matters related to the development, content, or issuance of any document of the Association or on matters within the purview of the authority of the Council, as established by the *Bylaws* and as determined by the Board of Directors. Such appeals must be in written form and filed with the Secretary of the Standards Council (See *Regs* at 1.6). Time constraints for filing an appeal must be in accordance with 1.6.2 of the *Regs*. Objections are deemed to be resolved if not pursued at this level.

VIII. Step 4b: Document Issuance. The Standards Council is the issuer of all documents (see Article 8 of *Bylaws*). The Council acts on the issuance of a document presented for action at an Association Technical Meeting within 75 days from the date of the recommendation from the Association Technical Meeting, unless this period is extended by the Council (See *Regs* at 4.7.2). For documents forwarded directly to the Standards Council, the Council acts on the issuance of the document at its next scheduled meeting, or at such other meeting as the Council may determine (See *Regs* at 4.5.2.5 and 4.7.4).

IX. Petitions to the Board of Directors. The Standards Council has been delegated the responsibility for the administration of the codes and standards development process and the issuance of documents. However, where extraordinary circumstances requiring the intervention of the Board of Directors exist, the Board of Directors may take any action necessary to fulfill its obligations to preserve the integrity of the codes and standards development process and to protect the interests of the Association. The rules for petitioning the Board of Directors can be found in the *Regulations Governing Petitions to the Board of Directors from Decisions of the Standards Council* and in 1.7 of the *Regs*.

X. For More Information. The program for the Association Technical Meeting (as well as the NFPA website as information becomes available) should be consulted for the date on which each report scheduled for consideration at the meeting will be presented. For copies of the First Draft Report and Second Draft Report as well as more information on NFPA rules and for up-to-date information on schedules and deadlines for processing NFPA documents, check the NFPA website (www.nfpa.org/aboutthecodes) or contact NFPA Codes & Standards Administration at (617) 984-7246.