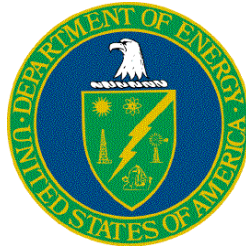# CFAST Computer Code

Application Guidance for

Documented Safety Analysis

Final Report

U.S. Department of Energy

Office of Environment, Safety and Health

1000 Independence Ave., S.W.
Washington, DC 20585-2040

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FOREWORD

This document provides guidance to Department of Energy (DOE) facility analysts in the use of the CFAST computer software for supporting Documented Safety Analysis applications. Information is provided herein that supplements information found in the CFAST documentation provided by the code developer. CFAST is one of six computer codes designated by DOE's Office of Environmental, Safety and Health as a toolbox code for safety analysis..

Suggestions for corrections or improvements to this document should be addressed to –

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2. Entire Document	2. Final Report May 28, 2004	2. Updated all sections per review comments.
3. 4-4/section 4.5 and misc. pages; Multiple pages	3. Final Report with NIST comment resolution, July 16, 2004	3. Added section 4.5 on file name extensions. Changed .txt to .lst; Miscellaneous editorial changes to improve document usefulness and readability.

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CFAST Computer Code Application Guidance for Documented Safety Analysis

EXECUTIVE SUMMARY

The Defense Nuclear Facilities Safety Board issued Recommendation 2002-1 on *Quality Assurance for Safety-Related Software* in September 2002. The Recommendation identified a number of quality assurance issues for software used in the Department of Energy (DOE) facilities for analyzing hazards, and designing and operating controls that prevent or mitigate potential accidents. The development and maintenance of a collection, or "toolbox," of high-use, Software Quality Assurance (SQA)-compliant safety analysis codes is one of the major commitments contained in *Implementation Plan for Recommendation 2002-1 on Quality Assurance for Safety Software at Department of Energy Nuclear Facilities*. In time, the DOE safety analysis toolbox will contain a set of appropriately quality-assured, configuration-controlled, safety analysis codes, managed and maintained for DOE-broad safety basis applications (DOE, 2002b). The Consolidated Fire and Smoke Transport (CFAST) code is one of the designated toolbox codes.

CFAST is a zone-based fire model, which was developed by the National Institute of Standards and Technology. The code has been widely used in the fire protection community to support alternate design approaches, post-fire investigations and as a research tool to better understand fire phenomena. This report sanctions the use of the two NIST supported versions, CFAST 3.1.7 and CFAST 5.1.1. The report explains the advantages of both versions.

The CFAST guidance report includes the following:

(i)   Applicability information for DSA-type analysis, specifically tailored for DOE safety analysis

(ii)   Code development information and SQA background

(iii)   Appropriate regimes and code limitations

(iv)   Valid ranges of input parameters consistent with code capability and DOE safety basis applications, and

(v)   Default input value recommendations for site-independent parameters.

Use of the information contained here, although not ensuring correct use of CFAST in each analytical context, will minimize potential user errors and the likelihood of CFAST use outside its regime of applicability.

This guidance report is supplemental in nature to documentation from the code developer such as the user's guide and model description.   The DOE safety analyst should obtain a complete and up to date set of documentation from the CFAST code maintainer.

1.0   INTRODUCTION

In January 2000, the Defense Nuclear Facilities Safety Board (DNFSB) issued Technical Report 25 (TECH-25), *Quality Assurance for Safety-Related Software at Department of Energy Defense Nuclear Facilities* (DNFSB, 2000). TECH-25 identified issues regarding the state of software quality assurance (SQA) in the Department of Energy (DOE) Complex for software used to make safety analysis decisions and to control safety-related systems. Instances were noted in which computer codes were either inappropriately applied or were executed with incorrect input data. Of particular concern were inconsistencies in the exercise of SQA from site to site, and from facility to facility, and in the variability of guidance and training in the appropriate use of accident analysis software.

During the subsequent 2000 to 2002 period, survey information on SQA programs, processes, and procedures was collected as well as the initial elements to a response plan. However, to expedite implementation of corrective actions in this area, the DNFSB issued Recommendation 2002-1, *Quality Assurance for Safety-Related Software at Department of Energy Defense Nuclear Facilities* (DNFSB, 2002). As part of its Recommendation to DOE, the DNFSB enumerated many of the points noted earlier in TECH-25, but noted specific concerns regarding the quality of the software used to analyze and guide safety-related decisions, the quality of the software used to design or develop safety-related controls, and the proficiency of personnel using the software.

DOE has developed a series of actions that address the DNFSB concerns, contained in the Implementation Plan for the DNFSB Recommendation, *Implementation Plan for Defense Nuclear Facilities Safety Board Recommendation 2002-1*. Two of the actions include

> (i)   Identification of a set of accident analysis software that is widely used in the DOE Complex, and

> (ii)   Issuance of code-specific guidance reports on the use of the "toolbox" codes for DOE facility accident analysis, identifying applicable regimes in accident analysis, default inputs, and special conditions for use.

Safety analysis software for the DOE "toolbox" status was designated by the DOE Office of Environment, Safety, and Health (DOE/EH, 2003). The supporting basis for this designation was provided by a DOE-chartered Safety Analysis Software Group in a technical report entitled, *Selection of Computer Codes for DOE Safety Analysis Applications* (see http://www.deprep.org/archive/rec/2002-1/NNSACCodes1.pdf). It includes the Consolidated Fire and Smoke Transport (CFAST) code.

It is believed that each code designated for the toolbox can be applied to accident analysis under the precautions and recommended input parameter ranges documented in its guidance report. The code-specific document will be maintained and updated until a minimum qualification software package is completed, or until such time that it is determined to no longer be necessary to update.

The contents of this report are applicable in the interim period until measures are completed to bring CFAST into compliance with defined SQA standards. The primary objective of this guidance report is to provide information on the use of CFAST for supporting DOE safety-basis accident analysis. Specifically, the report contains:

- Applicability guidance for Documented Safety Analysis (DSA)-type analysis, specifically tailored for DOE safety analysis

- Appropriate regimes, recommended configurations

- Overcoming known vulnerabilities and avoiding code errors

- Valid ranges of input parameters consistent with code capability and DOE safety basis applications

- Default input value recommendations for site-independent parameters, and

- Citations of currently available SQA documentation.

Thus, this report is intended to complement existing CFAST user's documentation. The latter tends to be much broader in coverage of the full range of capabilities of CFAST and the spectrum of inputs that might be needed depending upon the application, but lack cohesive and targeted guidance for particular applications such as DSA accident analyses. Furthermore, the goal of this document is to identify limitations and vulnerabilities not readily found in documentation from the code developer or published elsewhere.

The CFAST guidance document is written using the following outline. The first section contains an introduction and background providing an overview of toolbox software in the context of 10 CFR 830 (CFR, 2001c). It provides a brief description of the fire modeling software *Consolidated Model of Fire Growth and Smoke Transport* (CFAST) and its interface software Fire Growth And Smoke Transport (FAST) (Peacock 2000). More information follows on the scope and purpose of this document. The next major section is a summary description of CFAST. A third section discusses applicable regimes for using CFAST in performing accident analysis. A large section on default inputs and recommendations, emphasizing appropriate inputs for DOE applications, is next. Following this discussion are sections on special conditions for use of the software and software limitations. A sample case is then provided, followed by acronyms and definitions, references, and appendices. Appendix A discusses fire severity. Appendices B through I give sample problem detailed information. Appendix J discusses CFAST history. Appendix K provides an error message table for CFAST.

1.1   Background: Overview of Toolbox Software in Context of 10 CFR 830

In the context of 10 CFR 830, the Nuclear Safety Management rule, the six computer codes designated by DOE/EH as toolbox software will be of appropriate pedigree for support of safety basis documentation. After completion of the minimum required SQA upgrade measures for a toolbox code, the safety analyst would still need to justify the specific application with the code of interest, input parameters, and user assumptions, but many SQA burdens would be reduced from current requirements. The user would need to reference the toolbox code and version,

identify compliance with their organization's SQA requirements and demonstrate that the code is being applied in the proper accident analysis context using appropriate inputs. The SQA pedigree would be sufficiently established for technical review purposes since the code is recognized as toolbox-supported.

Only six codes out of more than one hundred software packages applied in the DOE Complex for accident analysis purpose have been designated as "toolbox" codes (DOE, 2002b). Other non-toolbox, dispersion and consequence software can still be applied in the context of support safety basis applications. However, each organization applying this category of software will need to demonstrate compliance with applicable SQA criteria, such as those applied to the toolbox software.

1.2 Scope

This CFAST guidance report includes the following:

- Applicability information for DSA-type analysis, specifically tailored for DOE safety analysis

- Code development information and SQA background

- Appropriate regimes and code limitations

- Valid ranges of input parameters consistent with code capability and DOE safety basis applications, and

- Default input value recommendations for site-independent parameters.

CFAST is a zone-based fire model that was developed by the National Institute of Standards and Technology (NIST). There are currently two versions of the software in general use, Version 3.1.7 (Jones, 2003; Peacock, 1993) and Version 5.1.1 (NIST, 2002, NIST, 2004). Both are available from the NIST web site http://cfast.nist.gov/.

1.3 Purpose

The CFAST code, while part of the toolbox collection of software, still may require Software Quality Assurance (SQA) upgrades prior to meeting current established standards for software. However, until these CFAST upgrades are completed, CFAST can be applied safely under the condition that the guidance contained in this and related reports is followed. Once upgrades are finalized with CFAST, it will be brought under configuration control and placed in the toolbox.

Use of the information contained here, although not ensuring correct use of CFAST in all analytical contexts, will minimize potential user errors and the likelihood of use outside regimes of applicability.

1.4   Applicability

It is recognized that other computer codes besides CFAST exist that perform similar types of calculations. Moreover, manual or electronic spreadsheet calculations can be a viable alternative to using a computer code for some accident analysis applications that involve fire. The relative merits of using a different computer program or using a hand calculation for a given application is a judgment that must be made by the analyst on a case-by-case basis.

An uncontrolled fire in a nuclear facility can be a very energetic event. Severe smoke, excessive temperatures, and large thermal gradients are common. Such fires can readily breach containment barriers (glove box, ventilation ductwork and building envelope), and because of the significant thermal gradients, readily disperse radioactive material. While DOE has a good record on fire safety, an uncontrolled fire remains a dominant risk in many nuclear facilities (Shields, 2000).

To adequately evaluate the fire risk, calculations must be prepared that establish the fire severity and consequences expected for credible fire scenarios. There are a variety of analytical tools and techniques that can be implemented to accomplish this. Some of these are discussed in Appendix A. Because of the complexity of the fire phenomena, most of these tools and techniques are software based. The fire modeling software *Consolidated Fire Growth and Smoke Transport* (CFAST) is one of these tools.

In addition to the nuclear safety fire risk, worker, monetary and business interruption protection must also be addressed as part of the DOE Fire Protection Program. This program is established in two orders. DOE Order 420.1 (DOE, 2002a) requires each facility to have a program to minimize the likelihood of unacceptable fire losses or damage. DOE Order 440.1A (DOE, 1998) provides "the framework for an effective worker protection program" that includes the establishment of a "comprehensive fire protection program with the objective of providing an acceptable level of safety from fire and related hazards." For a discussion on how the DSA and Fire Hazard Analysis should be coordinated see DOE-HDBK-1163-2003 (DOE, 2003b).

The DNFSB in Tech-25 (Burns, 2000) identified the importance of trained and competent software users. The DOE Fire Protection Committee had recognized this many years prior to the inception of the DNFSB. This recognition is why the *Implementation Guide for use with DOE Orders 420.1 and 440.1 Fire Safety Program* (DOE, 1995, DOE G-420.1/B-0, DOE G-440.1/E-0) contains the following paragraph:

> A tool that may be used in the development of an FHA is a fire model, such as those developed by the National Institute of Standards and Technology, as applied by qualified fire protection engineers. However, the use of such models is predicated on their being conservative and validated. As of this date, DOE has not sanctioned the use of any one model for use in an FHA. DOE acceptance of individual models will be considered on a case-by-case basis.

During the review of this guidance report the DOE Fire Protection Committee was concerned that publication of this report would invalidate the guidance in DOE G-420.1/B-0, DOE G-440.1/E-0 (DOE, 1995). This CFAST guidance report does not replace the guidance in DOE G-

420.1/B-0, DOE G-440.1/E-0. Outside of its use to evaluate source terms, CFAST will still require the case-by-case authorization from the appropriate Authority having Jurisdiction (AHJ).

2.0   SUMMARY DESCRIPTION OF SOFTWARE

Computer-based solutions to fire models are often sought because of the complexity of fire phenomena. There are two basic fire model approaches in general use. They are the field model and the zone model. Both approaches solve the Navier-Stokes (N-S) equations for mass and energy transport. Field (or computational fluid dynamic) models solve the complete set of N-S equations using numerical methods subject only to the fire compartment boundary conditions. The solution is accomplished by descritizing the spatial regions of interest into a set of nodes or finite elements. The computer is then tasked with estimating the local conditions (e.g., temperature, pressure, and combustion products) by solving the time-averaged N-S equations for each node or element.

The zone (or control volume) fire model relies on the stratification behavior observed in most fires and represents the two layers as separate control volumes (i.e., upper layer and lower layer). Each layer is assumed to be uniform (i.e., temperature, smoke and gas concentrations are assumed to be homogeneous throughout the layer). The time-dependent fire response for each layer is predicted based on N-S equations integrated over the zones. Mass and energy exchange between the control volumes is estimated using both numerical techniques and correlations that approximate fire behavior. (For additional information on this behavior see Appendix A.)

CFAST is such a zone model. The model can accommodate 30 compartments with multiple openings between the compartments. A fire plume represents the movement of energy and mass between the lower layer and upper layer. Mass and energy can also be exchanged between the layers at the vents. Exchange between the layers resulting from wall flows is not modeled in CFAST.

CFAST was developed by NIST in the late 1980s. There are two current versions of CFAST supported by NIST. CFAST 5.1.1 (1 May 2004) is the most current version and is designed to operate on all versions of the Windows operating systems. CFAST 3.1.7 is DOS based and will run under Windows 3.1, 3.11, 95, 98, 2000 and Me. CFAST 3.1.7 is compatible with the graphical user interface (GUI) FAST.

The GUI simplifies the preparation process for initial input data files (Section 4.2) and modification of the data libraries (Section 4.1). As discussed Section 4.2 some users may find it easier to edit the input data files using WordPad after their initial assembly. Thus, FAST coupled with CFAST 3.1.7 can be used to establish the initial input data files and CFAST 5.1.1 can be used to perform the final calculations.

CFAST 5.1.1 includes modules to model corridor flow and horizontal heat transfer. It also includes tools to convert numerical results into SmokeView. SmokeView is a post-processing software tool that can be used to visualize numerical fire predictions (Forney, 2003). CFAST 5.1.1 replaces CFAST 5.1.0 as explained in Appendix J.

CFAST and FAST documentation consists of various reports that address multiple aspects of the code primarily in the form of NIST technical reports. Documentation includes:

- NIST Technical Note 1431, *A Technical Reference for CFAST: An Engineering Tool for Estimating Fire and Smoke Transport* (Jones, 2003)

- NIST Special Publication 921, 2000 Edition, *A User's Guide for FAST: Engineering Tools for Estimating Fire Growth and Smoke Transport* (Peacock, 2000)

- NIST Technical Note 1299, *CFAST, the Consolidated Model of Fire Growth and Smoke Transport* (Peacock, 1993)

- NISTIR 5486-1, *Technical Reference Guide for FPEtool Version 3.2* (Deal, 1995)

- NBSIR 85-3223, *Data Sources for Parameters Used in Predictive Modeling of Fire Growth and Smoke Spread* (Gross, 1985)

These documents are available from the NIST web site http://cfast.nist.gov/. This web site lists additional documents that may be useful to the analyst. There are also short explanations of various phenomena and guides to interpreting the results.

2.1   Program Availability and Installation

Both versions of CFAST and the Graphical User Interface (GUI) FAST may be downloaded from the NIST website at http://cfast.nist.gov/. CFAST 5.1.1 is downloaded as an executable file, which is named cfastv511.exe. When executed from the Windows desktop it will install the folders, files and programs listed in Table 2-1. CFAST 3.1.7 and FAST are also downloaded as an executable file. The file is titled fast317.exe and when executed will install the files and programs listed in Table 2-2.

Regardless of the CFAST version, the program and its associated files should be installed in a folder that is close to the top of the directory. (i.e., Keep the folder path short, C:NIST\CFAST). This will make the execution of CFAST easier.* After the appropriate executable files are installed in the "FAST" folder, the file "setupf.exe" should be run from the "start" button on the bottom left of the computer screen. If necessary, use the browse option under the run command. Follow the instructions on the screen as the program installs.

For CFAST 3.1.7 it is recommended that the analyst keep the CFAST and FAST executable files, the data files and the database files in the same folder. If not, it will be necessary to establish the path in the input data files.

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*   For CFAST 5.1.1 the setup file will automatically use the path C:\NIST\CFAST511.

Table 2-1. — Files Installed With CFAST Version 5.1.1

Installed in base folder (C:\NIST\CFAST511\)			Installed in data folder(C:\NIST\CFAST511\data\)		
Name	Size	Modified	Name	Size	Modified
data (see right)	folder	installation date	basecase.dat	2 KB	03/11/2004 2:55 PM
fonts (see right)	folder	installation date	hhtest.dat	1 KB	09/26/2003 1:45 PM
cfast.exe	1,244 KB	05/05/2004 3:34 PM	multi.dat	5 KB	03/11/2004 2:55 PM
cplot.exe	600 KB	05/02/1996 3:35 PM	nistdem2.dat	3 KB	03/11/2004 2:55 PM
curve.df	4 KB	05/02/1996 12:33 PM	nistdem2.map	1 KB	03/25/2002 5:32 PM
Hazard.tbl	1 KB	11/10/1998 6:36 PM	nistdem2.plt	14 KB	03/11/2004 2:56 PM
hv5.cf	1 KB	05/05/2004 3:47 PM	nistdem2.smv	1 KB	03/11/2004 2:56 PM
INSTALL.LOG	13 KB	installation date	nistdemo.dat	3 KB	03/11/2004 2:55 PM
limits.df	3 KB	08/01/2003 2:51 PM	nistdemo.map	1 KB	01/04/2002 12:13 PM
Objects.df	130 KB	10/24/2001 5:11 PM	o2test.dat	1 KB	03/08/2004 2:19 PM
Objects.ndx	1 KB	10/24/2001 4:55 PM	specieserror.dat	4 KB	03/10/2004 2:54 PM
readme.txt	10 KB	05/05/2004 3:47 PM	standard.csv	84 KB	05/05/2004 4:00 PM
report.exe	748 KB	05/05/2004 3:35 PM	standard.dat	2 KB	03/02/2004 6:10 PM
reportss.exe	728 KB	05/05/2004 3:35 PM	standard.xls	254 KB	05/05/2004 4:00 PM
Thermal.df	10 KB	02/15/2001 1:20 PM	test01.dat	2 KB	03/11/2004 2:55 PM
Thermal.ndx	1 KB	02/15/2001 1:20 PM	test02.dat	2 KB	03/11/2004 2:55 PM
ToPanel.exe	748 KB	05/05/2004 3:36 PM	test03.dat	2 KB	03/11/2004 2:55 PM
ToSmokeView.exe	388 KB	05/05/2004 3:36 PM	test03.hi	346 KB	03/11/2004 2:56 PM
UNWISE.EXE	161 KB	09/28/2001 6:00 PM	testob1.dat	2 KB	03/11/2004 2:55 PM
Varnames.dat	2 KB	11/10/1998 6:36 PM	testob2.dat	2 KB	03/11/2004 2:55 PM
			Ventlim.dat	1 KB	03/01/2004 3:34 PM

Installed in fonts folder (C:\NIST\CFAST511\fonts\)		
Name	Size	Modified
devfnt02.fnt	48 KB	11/03/1998 9:16 PM
devfnt03.fnt	48 KB	11/03/1998 9:16 PM
devfnt04.fnt	50 KB	11/03/1998 9:16 PM
devfnt05.fnt	50 KB	11/03/1998 9:16 PM
devfnt06.fnt	54 KB	11/03/1998 9:16 PM
devfnt07.fnt	52 KB	11/03/1998 9:16 PM
devfnt08.fnt	51 KB	11/03/1998 9:16 PM
devfnt09.fnt	51 KB	11/03/1998 9:16 PM
devfnt10.fnt	58 KB	11/03/1998 9:16 PM
devfnt11.fnt	56 KB	11/03/1998 9:16 PM
devfnt12.fnt	59 KB	11/03/1998 9:16 PM
devfnt13.fnt	68 KB	11/03/1998 9:16 PM
devfnt14.fnt	62 KB	11/03/1998 9:16 PM
devfnt15.fnt	77 KB	11/03/1998 9:16 PM
devfnt16.fnt	76 KB	11/03/1998 9:16 PM
devfnt17.fnt	93 KB	11/03/1998 9:16 PM
devfnt18.fnt	86 KB	11/03/1998 9:16 PM
devfnt19.fnt	77 KB	11/03/1998 9:16 PM
devfnt20.fnt	57 KB	11/03/1998 9:16 PM
devfnt21.fnt	50 KB	11/03/1998 9:16 PM
devfnt22.fnt	62 KB	11/03/1998 9:16 PM
devfnt23.fnt	52 KB	11/03/1998 9:16 PM
devfnt24.fnt	57 KB	11/03/1998 9:16 PM

Table 2-2. — Files Installed With CFAST Version 3.1.7

Name	Size	Modified	Name	Size	Modified
bintoasc.exe	345 KB	11/29/1999 11:51 AM	Draw2.exf	3 KB	04/01/1999 2:15 AM
Box.pic	4 KB	04/01/1999 2:15 AM	Draw2.pic	6 KB	04/01/1999 2:15 AM
build.exe	270 KB	04/01/1999 2:15 AM	Ecadtest.exf	1 KB	04/01/1999 2:15 AM
cedit.cfg	2 KB	04/01/1999 2:15 AM	Exf2bld.doc	3 KB	04/01/1999 2:15 AM
cfast.exe	1,707 KB	11/08/2001 4:32 PM	Exfast.dat	6 KB	10/01/1997 12:11 AM
Cfast.rsc	50 KB	11/14/2001 3:31 PM	Exftobld.exe	51 KB	04/01/1999 2:15 AM
colortes.exe	482 KB	04/01/1999 2:15 AM	Exmedium.dat	6 KB	10/01/1997 12:11 AM
compare.exe	262 KB	11/29/1999 11:51 AM	Exslow.dat	6 KB	10/01/1997 12:11 AM
compinfo.exe	258 KB	11/29/1999 11:51 AM	Exultra.dat	6 KB	10/01/1997 12:11 AM
cplot.exe	1,126 KB	11/08/2001 4:32 PM	Exwatts.dat	5 KB	10/01/1997 12:11 AM
curve.df	4 KB	04/01/1999 2:15 AM	Fast.exe	2,588 KB	11/14/2001 3:31 PM
devfnt02.fnt	12 KB	04/01/1999 2:15 AM	fast.ico	1 KB	05/14/1993 7:19 AM
devfnt03.fnt	12 KB	04/01/1999 2:15 AM	hazard.tbl	1 KB	04/01/1999 2:15 AM
devfnt04.fnt	13 KB	04/01/1999 2:15 AM	INSTALL.LOG	4 KB	08/22/2002 10:07 AM
devfnt05.fnt	13 KB	04/01/1999 2:15 AM	Objects.df	218 KB	04/01/1999 2:15 AM
devfnt06.fnt	14 KB	04/01/1999 2:15 AM	pallet.pal	1 KB	04/01/1999 2:15 AM
devfnt07.fnt	13 KB	04/01/1999 2:15 AM	Readme.txt	8 KB	11/14/2001 3:31 PM
devfnt08.fnt	13 KB	04/01/1999 2:15 AM	report.exe	1,116 KB	11/08/2001 4:32 PM
devfnt09.fnt	13 KB	04/01/1999 2:15 AM	reportg.exe	1,270 KB	11/08/2001 4:32 PM
devfnt10.fnt	15 KB	04/01/1999 2:15 AM	reportss.exe	1,096 KB	11/08/2001 4:32 PM
devfnt11.fnt	14 KB	04/01/1999 2:15 AM	romantri.fnt	9 KB	04/01/1999 2:15 AM
devfnt12.fnt	15 KB	04/01/1999 2:15 AM	system64.fnt	6 KB	04/01/1999 2:15 AM
devfnt13.fnt	17 KB	04/01/1999 2:15 AM	system72.fnt	0 KB	08/08/1997 3:28 PM
devfnt14.fnt	16 KB	04/01/1999 2:15 AM	test01.dat	2 KB	04/01/1999 2:15 AM
devfnt15.fnt	20 KB	04/01/1999 2:15 AM	test02.dat	2 KB	04/01/1999 2:15 AM
devfnt16.fnt	19 KB	04/01/1999 2:15 AM	test03.dat	2 KB	04/01/1999 2:15 AM
devfnt17.fnt	24 KB	04/01/1999 2:15 AM	test04.dat	2 KB	04/01/1999 2:15 AM
devfnt18.fnt	22 KB	04/01/1999 2:15 AM	testg1.dat	1 KB	04/01/1999 2:15 AM
devfnt19.fnt	20 KB	04/01/1999 2:15 AM	testg2.dat	4 KB	04/01/1999 2:15 AM
devfnt20.fnt	15 KB	04/01/1999 2:15 AM	testg3.dat	2 KB	04/01/1999 2:15 AM
devfnt21.fnt	13 KB	04/01/1999 2:15 AM	testg3b.pic	16 KB	04/01/1999 2:15 AM
devfnt22.fnt	16 KB	04/01/1999 2:15 AM	testg3t.pic	6 KB	04/01/1999 2:15 AM
devfnt23.fnt	13 KB	04/01/1999 2:15 AM	thermal.df	10 KB	04/01/1999 2:15 AM
devfnt24.fnt	15 KB	04/01/1999 2:15 AM	Thermal.ndx	1 KB	04/01/1999 2:15 AM
Draw1.exf	1 KB	04/01/1999 2:15 AM	UNWISE.EXE	146 KB	06/25/1999 10:55 AM
Draw1.pic	2 KB	04/01/1999 2:15 AM	Varnames.dat	2 KB	11/10/1998 5:36 PM

For CFAST 5.1.1 the default configuration is to keep the input data files (*.dat) in the data folder. CFAST will write the output files to this folder. This approach of keeping the data files in a separate folder from the executable files was introduced between the issuance of CFAST 5.0.1 and CFAST 5.1.0.

2.2   Program Execution

Either version of CFAST can be executed from the DOS command prompt. CFAST 3.1.7 may also be executed from the FAST GUI. This section will explain both methods.

2.2.1   DOS Command Prompt

Typically the command prompt can be accessed from the window desktop by clicking Start\ Programs\Accessories\Command Prompt. If the Command Prompt shortcut is not located in this

path, the user will need to establish the correct path. To simplify operation it is recommended that the analyst switch the active command prompt to the folder where CFAST is installed. This is done with the following statement:

```
CD \<path>\<folder containing CFAST.EXE>

CD \NIST\CFAST511
```

If the wrong drive device is noted in the command prompt (e.g., i:\> when c:\> is desired) change the drive by typing the desired drive letter followed by a colon (e.g., C:) followed by the return key.

The command line for CFAST is:

```
CFAST <input file> <output file> <options>
```

where:

> `<input file>`: is the name of the input data file

> `<output file>`: is the name of the file to which any specified text output will be written.

> `<options>`: specify any output reporting or other options to control the output of the program.

The available options are described in Appendix B of *A User's Guide for FAST: Engineering Tools for Estimating Fire Growth and Smoke Transport* (Peacock, 2000). The two most useful are:

> `/l` which directs that CFAST to generate an error log file named CFAST.LOG containing detailed debugging information.

> `/r` which directs CFAST to includes additional variables in any text or spreadsheet output. The /r is followed by one or more of the following characters to produce the desired output:

> w – include wall surface and target fluxes in the output

> i – include model initial conditions and scenario description in the output

> n – include "normal" printout of layer temperatures, interface height, and fire size in the output

> f – include vent flows in the output

s – include layer and wall surface species concentrations in the output

t – include tenability estimates for each compartment in the output

p – include wall temperature profiles in the output

Thus, the option /rwinfstp would include the most complete spreadsheet output. A typical command line, as used for the later example problem would be:

    CFAST CAB042.DAT CAB042.LST /rin

2.2.2   FAST Graphical User Interface

The graphical user interface software FAST can be started from the DOS command prompt or by opening the file FAST.EXE in the appropriate Windows folder. To start from the DOS command prompt follow the instruction above to establish the appropriate active directory, then start FAST with the following command line

    FAST

FAST will automatically generate the input file* (*.DAT file). For the sample problem presented, the analyst will then need to provide the input data, which is discussed in the next section. The reader is referred to (Peacock, 2000), for a thorough description of the FAST interface.

In addition to the interface for CFAST, the GUI FAST provides a series of estimation tools, which were derived from FIREFORM. Most of these tools are numerical solutions of empirical correlations. While they are excellent tools for exploratory evaluation, in general they are not suitable for calculations that support a DSA. If it is necessary to present results of a FAST estimation tool in a calculation that supports a DSA, the analyst should provide a citation to the correlation source document, and provide adequate analytical discussion to allow a qualified analyst to replicate the calculations without the benefit of the FAST software.

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* Within the DOE community such files sometimes will be referred to as the input deck.

3.0   APPLICABLE REGIMES IN ACCIDENT ANALYSIS

Most DOE Nuclear Facilities have experienced at least one unwanted fire (i.e., initiating frequencies vary from 0.1 to 1 fire per year). Typically these fires remain small, and cause minimal damage. These successes occur because early detection systems coupled with operator intervention result in prompt suppression, or combustible control programs limit the fire propagation. These small fires, if not extinguished, can evolve to fully involve the room of origin. Most of the time the combustibles present in a nuclear facility will not promote a fire that can lead to full room involvement; however, to fully implement this preventive feature in all locations has usually proven impractical. Thus the optimistic probability of an incipient fire leading to full room involvement is about 0.05 if no automatic sprinkler is present.

If the automatic sprinkler system or the fire compartment walls do not contain the fire it will continue to grow in size. A typical failure probability for a sprinkler system is 0.04. For fire walls the failure probability typically ranges from 0.05 to 0.2. Since the fire department success probability in a nuclear facility, given failure of the sprinkler system is problematic (i.e., 50:50) the frequency of a propagating fire in a well-managed nuclear facility (as an example for discussion) is approximately $5\text{E-}06 \ yr^{-1}$ based on the most optimistic values presented above*. (Actual probability for a particular facility will vary and detailed discussion of frequency is beyond the scope of this guidance document.) This value is above the $1.0\text{E-}6 \ yr^{-1}$ threshold for incredibility recommended in DOE-STD-3009-94 (DOE, 2000b) for conservatively calculated natural phenomena events. While this threshold frequency does not explicitly apply to in-facility accidents and thus to fire events, it establishes a value that has repeatedly been used to evaluate accident credibility. Thus, this example serves to illustrate that the severity and consequences of a propagating fire must be evaluated as part of most facility DSAs.

3.1   Fire Scenario

The general sequence of a fire is predictable. With favorable geometry, adequate combustibles and no intervention most fires will proceed through the phases shown in Figure 3-1. Ignition will occur when a kindling material is brought in contact with an ignition source. When sufficient combustible materials are present, the fire will grow exponentially until fully developed. Full development occurs when rapid fire growth stops because of limited oxygen, fuel geometry limitations, or chemical kinetic restrictions. When the combustibles are exhausted, the room temperature will start to decrease (decay) as heat escapes the fire compartment.

---

*   (0.1 fires/yr)(0.05 propagates)(0.04 sprinkler fails)(0.05 wall fails)(0.5 fire department fails)
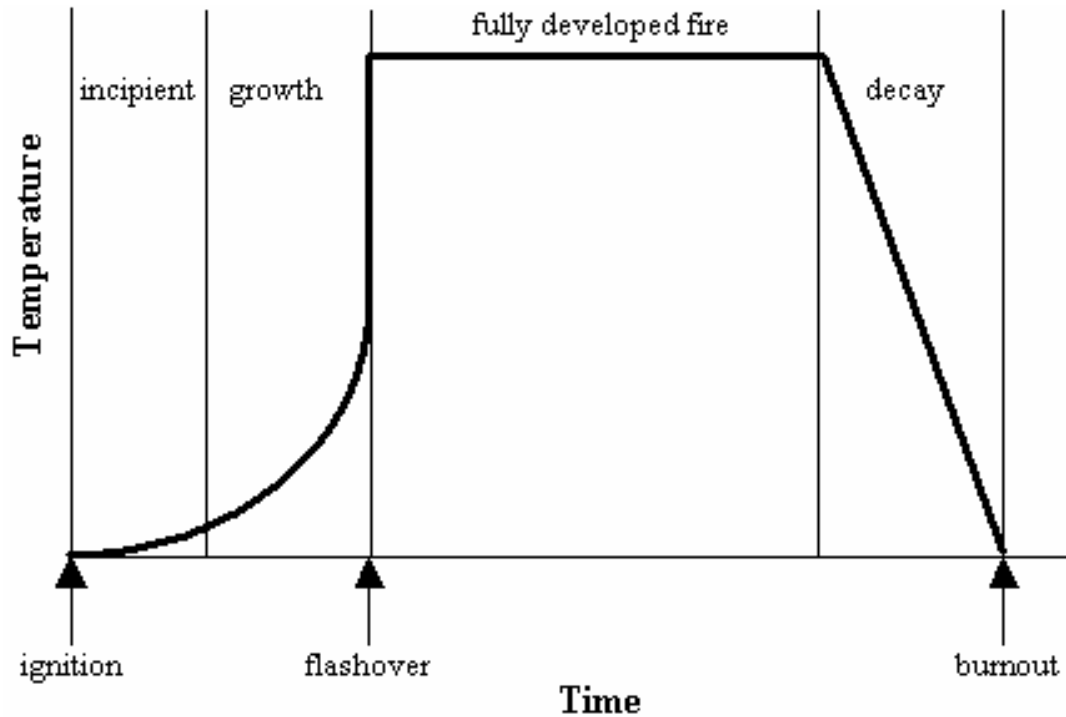
Figure 3-1. Typical Compartment Fire Curve

The consequences of a fire (e.g., bursting of a container, release of radioactive material) are strongly dependent on the container and building response to fire. The reasonably bounding responses of a building are fairly predictable. Some of the expectations are:

- Smoke migrates through a significant portion of the structure hampering emergency response and personnel evacuation.

- Ventilation systems shutdown if equipped with isolation dampers. HEPA filters become loaded and impede the exhaust flow.

- Intermediate walls (both rated and unrated) delay fire spread, but do not prevent it. Multiple room involvement occurs.

- Metal panel exterior walls open, venting smoke directly to the outside.

- Exposed structural steel fails, allowing additional venting.

- Reinforced concrete buildings maintain their configuration, thus limiting ventilation to the fire and extending the fire duration.

When evaluating the container response to fire, a model of the fire severity is necessary. This model must consider the fire conditions (e.g., heat flux, temperature as calculated by CFAST), container conditions (e.g., container strength, internal pressure as determined by structural and thermodynamic analyses) and secondary damage (e.g., impact from collapsing structures as determined by structural analyses).

3.2   Source Term

The radiological consequences are typically established using the methods discussed in the *Release Fraction Handbook* (DOE, 2000a). Since the dose from the inhalation pathway will usually dominate the overall dose, the handbook recommends that the source term be estimated from:

(1) $ST = MAR \cdot DR \cdot ARF \cdot RF \cdot LPF$

where:

- Source term (ST) is the total quantity of respirable material exiting the building (or area of interest) during the fire.

- Material-at-Risk (MAR) is the total quantity of radionuclides (in grams or curies of activity for each radionuclide) available that are subject to fire conditions.

- Damage Ratio (DR) is the fraction of the MAR actually impacted by the fire.

- Airborne Release Fraction (ARF) is the fraction of a radioactive material suspended in air as an aerosol and thus available for transport.

- Respirable Fraction (RF) "is the fraction of airborne radionuclides as particles that can be transported through air and inhaled into the human respiratory system and is commonly assumed to include particles 10-µm Aerodynamic Equivalent Diameter (AED) and less."

- Leakpath Factor (LPF) is the fraction of the radionuclides in the aerosol transported through some confinement deposition system (e.g., building rooms, ductwork) or filtration mechanism (e.g., fan filters or sand filter).

For most fire accident analyses the MAR is best defined as the maximum inventory that is permitted within the room, fire area or facility. While it is permissible to exclude material forms that are considered to be unaffected by a fire from the MAR, experience suggests that for these forms the DR is usually best set to zero for the fire release mechanism. The overall result using either approach is the same, but by assigning DR values to each combination of inventory form and release mechanism, there is the expectation that each credited form (e.g., a shipping package that is certified to withstand the postulated fire severity) is also reviewed against secondary fire events (e.g., building collapse initiated by the fire) and therefore, less likely to be overlooked.

The ARF and RF values presented in the *Release Fraction Handbook* (DOE, 2000a) are derived from discrete experiments that typically evaluated a single release mechanism. In a severe fire there may be many mechanisms occurring simultaneously. Powdered metals might be subject to entrainment by fire-induced air currents, falling because of equipment (glove box) collapse, and impact because of objects falling into the exposed fire. In addition, multiple occurrences could occur for specific mechanisms (e.g., impact of falling object on a stable powder). Aqueous solutions could be subject to boiling within the storage tank, spillage because of a tank collapse, and rapid evaporation plus splashing as the liquid sits in a diked area during the same postulated fire. Solid metals can be subject melting, dripping and burning during the same event. To

accommodate multiple mechanisms it is common to consider the ARF and RF values for each mechanism in the source term estimate.

Just as with the (ARF·RF) term, there can be multiple LPF terms applied to a single material form (e.g., room leakage, ventilation system deposition, filtration system effectiveness). Thus, their cumulative effect must be accounted for. There can be interdependence between the LPF and DR in some applications. If a shipping package is considered to leak during a fire, the leakpath effect as the material exits the packaging can be accounted for as an LPF or a DR. Based on experience, it is recommended that source term reductions related to localized conditions such as at shipping packages, and glove boxes be accounted for in the DR term. This approach allows the source term contribution from individual rooms to be readily compared. It also simplifies comparisons between the room source term and the building source term.

Based on the above discussion, Equation (1) can be generally reformatted as:

$$(2) \quad ST_{jk} = \sum_{i=1}^{n_i} \left\{ MAR_{ij} \cdot DR_{ijk} \cdot \left[(ARF \cdot RF)_{ijk} \cdot \left(\sum_{m=1}^{n_m} LPF_m \right)_{ijk} \right] \right\}$$

where: i   is the MAR component in a specific form

             j   is the MAR component by type (e.g., Pu_{238}, Pu_{239})

             k   is the release mechanism

            m   is the filtration or deposition stage

            n   is the number of parameters for the form, type, mechanism or stage based on the subscript.

Thus, the source term is usually expressed in terms of an isotopic activity distribution for each release mechanism. Source term components that are associated with the same release duration can be combined, but source term components that have different release mechanisms should be kept separate to account for time-dependent variance in atmospheric dispersion for consequence assessment.

Note that the DR, but not the MAR, is shown in Equation (2) as a function of the release mechanism (k subscript), based upon the recommendation above on how to best handle the interplay between the MAR and the DR. Frequently, the DR, ARF, RF, and LPF terms are specified independently of the type, and the j subscript can be dropped from these terms as applicable.

CFAST has the potential to assist the analyst in establishing the DR and LPF terms. Selection of the proper ARF/RF may also be assisted by CFAST (e.g., a pressurize release versus not pressurized). The heat flux and temperature predictions that can be obtained using CFAST can establish possible container and building responses that aid in the specification of the DR values. The mass transport terms in CFAST can be used to help derive room and building LPF values.

To date, CFAST use by the DOE safety analysis community has primarily focused on evaluating container and building responses.

CFAST was developed to support the general fire protection community. It is intended to predict the temperatures, gas concentrations and smoke layer heights in a multi-compartment structure during a postulated fire. The zone model approach that is implemented by the software tracks the energy and mass transfer in the building that is the result of a defined fire. The software can be used to estimate the timing of specific events in the building fire performance: detector activation, sprinkler activation, and flashover. The software is also used to estimate the environmental conditions (e.g., temperature, combustion product concentrations, layer height) in the fire compartment and neighboring compartments. These conditions can then be used to assess the effect of fire on building occupants. Using CFAST to assess the stress on packages, containers and buildings that house radiological material is a reasonable extension of this use.

3.3   Radiological Consequences

Once the source term is established, the consequences to the public and workers in neighboring facilities can be estimated. For fires scenarios at facilities with relatively short distances to the site boundary, the receptor at the site boundary may be exposed to lower concentrations as a result of plume buoyancy that can cause lofting of the plume core above the receptor. Under these circumstances, higher receptor exposures can be expected downwind of the site boundary as the effects of increasing downwind plume growth progressively makes plume rise effect less significant. The touchdown point refers to the location of maximum receptor concentration. Thus, the maximally exposed individual for a lofted plume is not at the site boundary, but rather at the touchdown point. Rather than evaluating for this point, it can be more cost effective to estimate the fire consequences as a ground level release with the maximally exposed individual at the site boundary. While the results will be higher than the plume-buoyancy credited analysis, the increase may not be significant when compared to the uncertainties in the analysis and the analysis complexity.

Typically the off-site radiological consequences are expressed as the total effective dose equivalent (TEDE) at the site boundary (or other receptor location of interest) assuming a ground-level release using software codes such as MACCS (Chanin, 1998). The TEDE includes the 50-year committed effective dose equivalent (CEDE) from inhalation both during plume passage and later from resuspension, the cloudshine effective dose equivalent (EDE), the groundshine EDE, and the skin absorption EDE. This TEDE calculation does not include the ingestion CEDE from consumption of contaminated water and foodstuffs. The inhalation CEDE is usually the dominant contributor and its relationship to the source term is highlighted below.

The basic equation for the radiological consequences to an individual receptor (i.e., stationary at a specific downwind location) from the inhalation pathway during plume passage is:

$$(3) \quad \text{Receptor Inhalation CEDE} = \text{BR} \cdot \sum_{k=1}^{n_k} \left\{ \left(\frac{c}{Q} \right)_j \sum_{j=1}^{n_j} \left[\text{ST}_{jk} \, C_j \, \text{IDCF}_j \right] \right\}$$

where: j, k, n   are as defined in Equation (2) above

BR is the breathing rate of the individual exposed to the plume of released radiological material, with typical units of m^3/s.

C_j is the specific activity of isotope j, with typical units of Ci/kg if ST is in mass units (kg) and unity if ST is in activity units (Ci).

$IDCF_j$ is the inhalation dose conversion factor for unit activity uptake of isotope j, with typical units of rem/Ci.

$(\chi/Q)_k$ is the downwind dilution factor from atmospheric transport and dispersion, which represents the time-integrated concentration at a specific downwind location that is normalized by the quantity released to the atmosphere, with typical units of s/m^3.

The inhalation CEDE as well as for TEDE is usually expressed in rem. The units for the ST and IDCF must be consistent. When developing the ST values, typical units for MAR and thus the ST are generally isotopic curies (but are also frequently isotopic grams). The corresponding IDCF values are rem per curie (or rem per isotopic gram).

When the ST value is input into the MACCS code, the MACCS output provides the TEDE values at the requested receptor locations that will include the contribution from the plume-passage inhalation CEDE as well as the contributions from resuspension inhalation CEDE, cloudshine EDE, groundshine EDE, and skin absorption EDE.

The sequence of steps that are outlined above represents the recommended approach for calculating receptor consequences. Sometimes for matters of convenience, other approaches besides direct input of the ST value into the MACCS code are used to calculate consequences. Two of these are described below. An advantage that both these approaches share is that they allow for MACCS consequence calculations to be performed independently of the source term calculations, which is a consideration when faced with a demanding schedule.

Recall that the DR, ARF, RF, and LPF terms are frequently specified independently of the type, and the j subscript can be dropped from these terms in Equation (2). Sometimes under these circumstances, an analyst uses a normalized MAR that equals the MAR divided by the total inventory mass or total inventory volume and inputs the normalized MAR into the MACCS calculation. Under these circumstances, the consequence calculations of MACCS yield normalized TEDE values that represent the receptor TEDE per unit quantity of mass or volume of respirable material that is released to the atmosphere for each release mechanism. The product of these TEDEs with the corresponding source term mass or volume (ST quantity as defined by Equation (4) below) will yield the receptor dose for each of the release mechanisms.

$$(4) \quad \left(\text{ST quantity}\right)_k = \sum_{i=1}^{n_i} \left\{ \left(\text{inventory mass or volume}\right)_i \cdot DR_{ik} \cdot \left[\left(ARF \cdot RF\right)_{ik} C \left(\sum_{m=1}^{n_m} LPF_m \right)_{ik} \right] \right\}$$

and

$$(5) \quad \text{Receptor TEDE} = \sum_{k=1}^{n_k} \left\{ (\text{ST quantity})_k \, C \, (\text{normalized TEDE})_k \right\}$$

Another approach that is sometimes employed is to individually input 1-Ci values of the inventory isotopes into the MACCS code for each release mechanism to yield unit-curie TEDEs. Recall, that the release duration that is associated with each release mechanism is a variable that factors into the χ/Q value that is calculated by MACCS. So, unit-curie TEDEs must be calculated individually for the various time durations that represent the various release mechanisms. With the unit-curie approach, the following equation is used to determine the receptor consequences.

$$(6) \quad \text{Receptor TEDE} = \sum_{j=1}^{n_j} \sum_{k=1}^{n_k} \left\{ \text{ST}_{jk} \, (\text{unit TEDE})_{jk} \right\}$$

4.0   DEFAULT INPUTS & RECOMMENDATIONS

This section provides a description of the data libraries, data files and output files associated with CFAST use.

4.1   Data Libraries

CFAST uses two data libraries. The first is the thermal data file THERMAL.DF and its index file THERMAL.NDX. This library provides the typical heat transfer data used to describe walls and other objects. The analyst may use the NIST provided thermal data file; however, to ensure proper configuration control, it may be appropriate for a given application to develop an application specific thermal data library. When a modification is made to the thermal data file (or to the object data file discussed below) the analyst should delete the applicable index file. CFAST will automatically rebuild the index files.

The second data library is the object data file OBJECT. DF and its index file OBJECT.NDX. This library provides object fire definitions that can be used to represent multiple fires in addition to the main fire. At this time the development of site-specific object files has been problematic. Thus, their use in most DSA work has been avoided. Since multiple fires are a real phenomenon, further evaluation of their use is warranted.

Font files are stored in the "font" sub-directory and data files in the "data" sub-directory. The data sub-directory is referenced in the configuration file hv3.cf and hv5.cf. This can be changed to accommodate various projects. Similarly, the databases are assumed to be in the same directory as the executables, but once again, this reference can be changed through the configuration file.

4.2   Input Data

The data file (*.DAT) provides all the simulation data necessary for CFAST to complete each simulation. The data is arranged by keywords, which are defined in Appendix A of Jones, 2003. Specific keywords are discussed in the sample problem .The files may be modified or created using any ASCII* text editor. Appendix B provides a sample data file.

The data file may also be generated using the graphical user interface software FAST. In general it is easier to construct the initial data file using the GUI and edit an existing data file in an ASCII text editor such as WordPad. This technique also allows the analysis to circumvent some of the numerical constraints that are established on some FAST inputs (e.g., ductwork is limited to a flow area of 1 m^2). When editing the data file using WordPad, save it as a text file with a *.DAT extension.

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*   American Standard Code for Information Interchange.

4.3 Output Files

CFAST will provide output files in several different formats. These include the history file (*.HI), a comma delimited file (*.csv) and a text file (*.lst). The name of the history file is established by the DUMPR keyword in the CFAST data file. If a name is not established in the data file, the history file will not be generated. The history file is accessed by the routine CPlot, which is executed from the DOS command prompt. This program is described in Appendix C of Peacock, 2000. CPlot 5.1.1 is provided with CFAST 5.1.1, while the version provided with CFAST 3.1.7 is identified as CPlot 3.1.7.

The comma delimited file name is established by the ADUMP keyword in the CFAST data file. As with the history file, if a name is not established in the data file, the comma-delimited file will not be generated. The comma-delimited file is readily opened with common spreadsheet programs such as Microsoft Excel. The data that will be written into the comma-delimited file is established by the output option characters. These characters are the same as those specified for the *.lst file in the command line.

The text file name is established by the analyst in the command line that executes CFAST. The options for the text file are discussed above. The text file will be ASCII compatible and can readily be read and written by a text editor or word processing program.

If FAST is being used to support the CFAST model, the history file and comma-delimited files can both be generated. When opening an existing data file with FAST, the output option characters in the data file will not be read. FAST will set the option to "n" which will limit the output to layer temperatures, interface height and fire size. If the analyst desires to have the comma-delimited file to contain other information, the options must be reset in FAST. Instead of the text file as discussed above, FAST will generate a file title "Lite.lst". This file contains the model initial conditions and the scenario description as well as selected data for each time step specified in the history interval. Each time a solution is initiated in FAST the Lite.lst file will be replaced. If the analyst is using FAST and wishes to retain the Lite.lst files, he or she should rename the files between each FAST solution.

4.4 Solution Method

When developing a DSA to the requirements of the 10 CFR 830 rule (CFR, 2001b), in the context of DOE-STD-94-3009 (DOE, 2000b), there is an expectation that the accident analysis modeling results will be reasonably bounding. A single fire modeling simulation or even a small set will not usually support this expectation. As discussed earlier, there are many variables associated with fire phenomena and sometimes the conservatism of the results is not necessarily intuitive. The analytical approach presented below will provide a technically appropriate approach for preparing a DSA.

Because some fire behaviors can be counter-intuitive it is strongly recommended that a fire model begin with nominal conditions, rather than forcing specific parameters to their most bounding state. When the nominal model is working successfully, the inputs can be systematically varied to demonstrate a reasonably bounding solution.

1. Establish the most likely ventilation conditions and geometry.

2. Establish a reasonably bounding HRR curve as the base condition. The total energy released should not exceed the total energy content of the combustibles that are permitted to be present.

3. Establish the room temperature profile for the above conditions.

4. Iterate the ventilation conditions (e.g., open or close doors, adjust fan operations) and geometry to maximize the upper level temperature. (See discussion on flashover below.)

5. Iterate the HRR curve to produce a Peak Heat Release Rate (PHRR) that is 50 percent higher than the base condition. The fire duration should be adjusted to avoid releasing more mass and energy than can credibly be present. (Usually, the constraint is total mass available for pyrolysis, so it is the area under the mass-loss curve that should be constant.) Repeat the ventilation iteration.

6. Iterate the HRR curve to produce a PHRR that is 80 percent of the base condition. The fire duration should be adjusted to avoid releasing more energy than can credibly be present. Repeat the ventilation iteration.

7. Report the most demanding time-temperature profiles developed above as sufficiently bounding temperature profiles.

The phenomenon of flashover can be accounted for using the following logic:

- Flashover is not expected if the maximum predicted upper layer temperatures resulting from the iterated ventilation conditions do not exceed 450°C. Thus, the maximum temperatures predicted in the above represent the most demanding expected.

- If the maximum predicted upper layer temperatures resulting from the iterated ventilation conditions exceed 600°C, flashover should be expected. The temperatures should be iterated to produce temperature curves that have extended high temperatures rather than very high short duration temperature peaks.*

- If the maximum predicted upper layer temperatures resulting from the iterated ventilation conditions is between 450 and 600°C, the occurrence of flashover is indeterminate. To account for the flashover threshold uncertainty the HRR curve should be increased slightly, the duration extended, or both. If the total energy released from the HRR curve (integrated value) exceeds the total energy content of the combustibles that are permitted to be present by a factor of two and the maximized predicted temperature does not exceed

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*This approach is recommended since the fire demand is usually defined in terms of absorbed energy, which is the heat flux integrated over time. Typically, varying the boundary conditions to increase the fire exposure 5 or 10 minutes results in a nominal reduction in room temperature (~ 50°C) and heat flux, but a significant increase in the fire demand.

600°C, the maximum temperatures predicted using the nominal HRR curve are considered representative. If the maximized predicted temperature exceeds 600°C, then that value should be used in the DSA.

Analysis Margin – In establishing the HRR and combustible loading values the confidence level of these two values should be considered. The *SFPE Engineering Guide to Performance-Based Fire Protection* (SFPE, 2000) recommends that the term sufficiently bounding may be used "when all but one parameter used for an analysis are set to best-estimate values, and the one extreme parameter is set as follows:

- "Values associated with operating expectations (e.g., combustible loading) should be taken at a minimum of 90 percent of the anticipated situation…

- "Scientific input values (e.g., [failure thresholds] and flashover temperature) should be taken at 95 percent coverage."

Example: If the best estimate HRR is considered to be 20 MW with a standard deviation of 1 MW, then the 90 percent coverage value would be:

(7) $20\,\text{MW} + (1.28 \times 1\,\text{MW}) = 21.3\,\text{MW}$

4.5   File Name Extensions

In addition to the file name extensions used above, NIST recommends the following normal naming convention for the CFAST suite of programs:

Data (input)	dat
Listing from CFAST (output)	lst
List data from CPLOT (output)	out
Spreadsheet from REPORTSS (output)	csv
Normal report, REPORT (output)	rs
Smoke View plot header (output)	smv
Smoke View plot file (output)	plt
History files (input and output)	hi

5.0 SPECIAL CONDITIONS FOR USE OF SOFTWARE

This section provides guidance on how to address the key uncertainties associated with most fire modeling predictions. The section contains explicit instructions on how to use CFAST to establish defensible and reproducible results.

5.1 Heat Release Rate

The single best metric to evaluate the severity of a fire is the Heat Release Rate (HRR). This is the quantity of energy released by the fire resulting from the combustion process. The HRR in a well-ventilated fire is proportional to its pyrolysis rate (i.e., solid combustible mass converted to vapor). These two terms are related by the heat of combustion.

$$(8) \quad \dot{Q} = ? H_c \dot{m}$$

Thus, if the HRR, $\dot{Q}$, and heat of combustion, ΔH_c, are known, the pyrolysis rate, $\dot{m}$, can be calculated and as long as there is adequate oxygen, the HRR can be estimated from the pyrolysis rate and the heat of combustion. When the availability of oxygen limits the combustion rate (i.e., ventilation limited) the HRR will decrease while the pyrolysis rate, depending on fire conditions, could remain constant or accelerate.

It is common practice to establish the HRR empirically. A typical HRR test result is presented in Figure 5-1. These tests are typically conducted in a free-burn (i.e., non-oxygen limited) arrangement using a calorimeter (ASTM, 1999b). For this type of test, the item in question is burned in a controlled situation where the plume flow rate and oxygen concentration can be accurately measured. This data is then used to calculate the HRR.

While empirical heat release rates for many types of residential furnishings are available, the data for materials that are common to nuclear processing facilities is very limited. To compensate for this, it is common to extrapolate HRR curves from known test data.

It is very important that the analyst using CFAST understand that CFAST does not evaluate the HRR. Rather CFAST accepts the HRR curve as an input that is reflected by three interrelated quantities mass loss rate (keyword: FMASS), Heat Release Rate (keyword: FQDOT) and heat of combustion (keyword; CHEMI). In most cases the keyword order in the data file is CHEMI, FMASS and FQDOT. The actual order is important since <u>CFAST calculates the third parameter based on the last two parameters specified</u>. Thus, for the most common sequence, CFAST will estimate the heat of combustion as the HRR divided by the mass loss rate as a function of time. (See Appendix B-10 of (Jones, 2003) for further discussion of this treatment.)
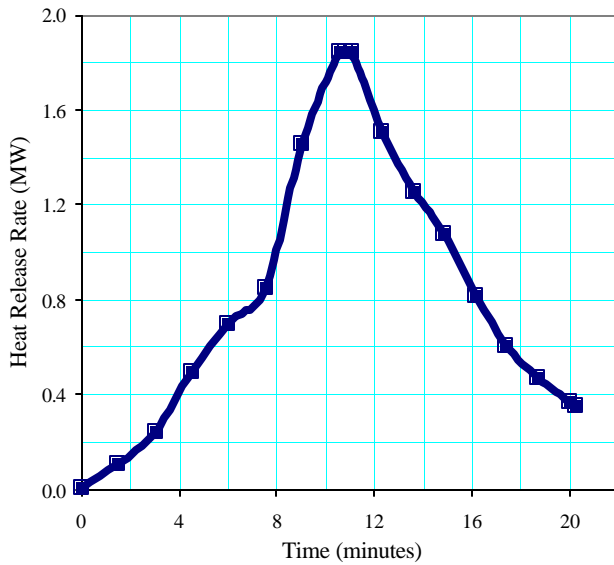
Figure 5-1 Typical HRR Curve.

CFAST uses the pyrolysis curve to represent the fire and the HRR curve to estimate the energy released. The model will limit the energy release to account for limited oxygen conditions. (See Section 3.1.2 of (Jones, 2003) for further discussion of this subject.) Because the pyrolysis curve is an input value, CFAST results do not account for increased pyrolysis due to radiative feedback from the flame or the compartment. This shortcoming can be accounted for by implementing the solution methods proposed in Section 4.4.

5.2   Performance Thresholds

There are several thresholds that are commonly used in executing fire analysis. This section will present three of the most common.

5.2.1   Secondary Ignition

The ignition process is very complex. It is influenced by the target surface finish, imposed radiation heat flux, the convective heat flux, the thermal mass, ambient environment, chemical kinetics and exposure duration. Many of these influences are not independent. In addition, most liquid and solid materials do not burn directly; rather, heat causes the materials to emit combustible vapors (e.g., pyrolysis). These vapors are the material that combust. Thus, most ignition tests focus on demonstrating the conditions that must exist to generate sufficient vapors to support ignition.

Ignition test approaches usually focus on a single ignition mode (piloted or spontaneous) and a single heat transfer mechanism (radiation or convection). Two basic ignition criteria are used in current tests, ignition temperature and critical heat flux. The ignition temperature is usually

measured at the target surface. The crucial heat flux (i.e., minimum flux to cause ignition) is measured as the total incident flux. Depending on the specific test approach the test material might only be exposed to fire conditions for a short duration (seconds to minutes).

In general, piloted ignition occurs at lower temperatures than spontaneous ignition. In addition, spontaneous ignition occurs at higher temperatures for radiant exposure when compared to convective exposure. Typical data are (Drysdale, 1998):

Mode of heat transfer	Spontaneous ignition	Piloted ignition
Radiation	600°C	300 – 410°C
Convection	490°C	450°C

As might be expected if a target is in a severe fire environment, the heat transfer will be a mix of radiation and convection. Thus, spontaneous ignition would be expected at the convective value or below, perhaps as low as 400°C, which is in the range for piloted ignition. While specific studies have not been conducted, it is expected that this behavior exists for most other materials. Thus, for most fire modeling work, when temperature will be used as the ignition criterion, the piloted ignition temperature should be used unless specific data supporting a higher value is provided.

As mentioned earlier, most heat flux tests measure the incident heat flux. Typically these tests have little or no convective heat transfer component. The target heat flux values calculated by CFAST are the net values (i.e., incident radiation from all sources, convective flux, less reflected radiation flux). Since surface temperatures are often close to, or higher than air temperatures it is common for the convective flux to be small or negative. The test values neglect reflected radiation and re-radiation resulting from low ambient air conditions. Thus, comparing most empirical heat flux test data to the net flux data calculated by CFAST is usually not appropriate. Unless specific test data is available that is consistent with the modeled problem, the heat flux criterion for ignition should not be used.

5.2.2 Flashover

As stated above, flashover is the transition from a growing fire to a fully developed fire where all combustible items in the compartment ignite simultaneously. An upper layer room temperature of 600°C is a commonly used threshold to predict the onset of flashover; however, there is no explicit temperature at which flashover will always occur. A reasonable range for the flashover threshold is 450°C to 700°C (NFPA, 2000), however flashover has been observed to occur at gas temperatures as low as 300°C (Walton, 2002).

In preparing a fire temperature profile, if the upper-layer room temperature remains below 450°C then room temperature predictions may be assumed to be reasonably accurate. If the prediction is that the 600°C flashover threshold will be exceeded, then temperatures are again usually considered reasonable predictions. When predicted peak temperatures are in the range of 450 to 600°C, then the analysts must account for the flashover criterion uncertainty.

5.2.3   Steel failure

The critical temperature for the failure of steel is sometimes defined as the temperature at which steel has 50 percent of its strength at ambient temperature. For structural steel this is 538°C (Kodur, 2002). This does not imply that the failure temperature is 538°C. When plutonium oxide is packaged in welded containers it is common to have moisture in the container. When the container is heated this moisture will turn to steam, pressurizing the container, which can result in container burst. Depending on the moisture content this failure can occur at temperatures well below the critical temperature. It is important to investigate and understand the accident conditions and context under which a structural failure might occur when assessing the structural integrity of components during a fire.

6.0   SOFTWARE LIMITATIONS

This section describes two known weaknesses in the CFAST documentation, error messages and validation documentation. It also provides an overview of the technical limits associated with CFAST.

First, as discussed earlier, there are multiple documents that describe CFAST. At present there is no formally published comprehensive listing of error messages that CFAST or FAST might generate, however Appendix K does contain such a listing that was provided through a private communication with NIST.

Second, there is unfortunately no comprehensive publicly available listing of CFAST validation efforts. CFAST has evolved over the past 20 years and has become a well-accepted tool within the fire engineering community. This evolution process has included multiple benchmarking efforts that have compared CFAST results to controlled fire tests and real-world fires. Much of this work is published in NIST reports or peer reviewed journals. While this lack of a comprehensive listing is a known shortcoming, it is not considered to be prohibitive in using CFAST to support a DSA. As with most modeling efforts, it is the responsibility of the analyst to demonstrate that the model results are a reasonable representation of reality and that the selected controls ensure safe nuclear operations.

To address some of the fire modeling software quality assurance questions, the Nuclear Regulatory Commission (NRC) and NIST are coordinating a fire modeling benchmarking effort, *International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications* (NRC, 2002). This multi-national project is intended to share the knowledge and resources of various participating organizations to evaluate and improve the state of the art of fire models for use in nuclear power plant fire safety and fire hazard analyses. The group has completed one benchmark exercise and is in the process of developing a second. The first exercise modeled a medium sized room with a fire, which exposed a cable. The second exercise will model a large two-story structure and will evaluate both cable and steel targets.

While CFAST has some published physical operating limits such as the maximum number of rooms that can be modeled (30 per Appendix B of (Peacock, 2000)), there are few absolute limits on the input parameters (e.g., room size, HRR, physical properties). The GUI, FAST, does have some numerical limits for specific room dimensions and other parameters. These limits are not documented and in many cases are artificial; they were intended to prevent unintentional errors rather than to limit how the model itself is used. They can be bypassed by using the GUI to establish most of the input file (*.dat) and then editing the input file in WordPad. Thus, there are few if any absolute parameter limits, rather the uncertainties associated with the more extreme room geometries are greater. The user must judge the significance of these uncertainties.

One technique to minimize the uncertainties is to benchmark CFAST to a known fire experiment that is similar to the fire scenario being evaluated in CFAST. Thus, CFAST is being used to judge the effect of changing the scenario from a known test result, rather then doing an absolute prediction. The more similar the fire experiment is to the DSA fire scenario, the lower the uncertainties associated with the fire severity and consequences.

7.0   SAMPLE CALCULATIONS APPLYING SOFTWARE

This section discusses a typical fire analysis problem that is evaluated in a DSA. The analysis starts by evaluating the nominal fire, which would typically be considered the most likely scenario. It then evaluates possible variations in the scenario that could lead to increased consequences. For this and similar problems it must be recognized that the solution is iterative. Preparing a single CFAST run does not adequately model the problem. Rather, it is expected that several variations should be presented in the DSA, and that multiple iterations will need to be prepared to support the final documentation.

7.1   Description

A common room arrangement in the DOE community is a process or laboratory room that can be entered through an airlock from a long hallway. Often there is a window between the process room and the corridor, but no direct access to the corridor. The sample problem arrangement is shown in Figure 7-1 and Figure 7-2. For this sample problem the fire is limited to several trash bags containing 12 kg of contaminated polyethylene waste.
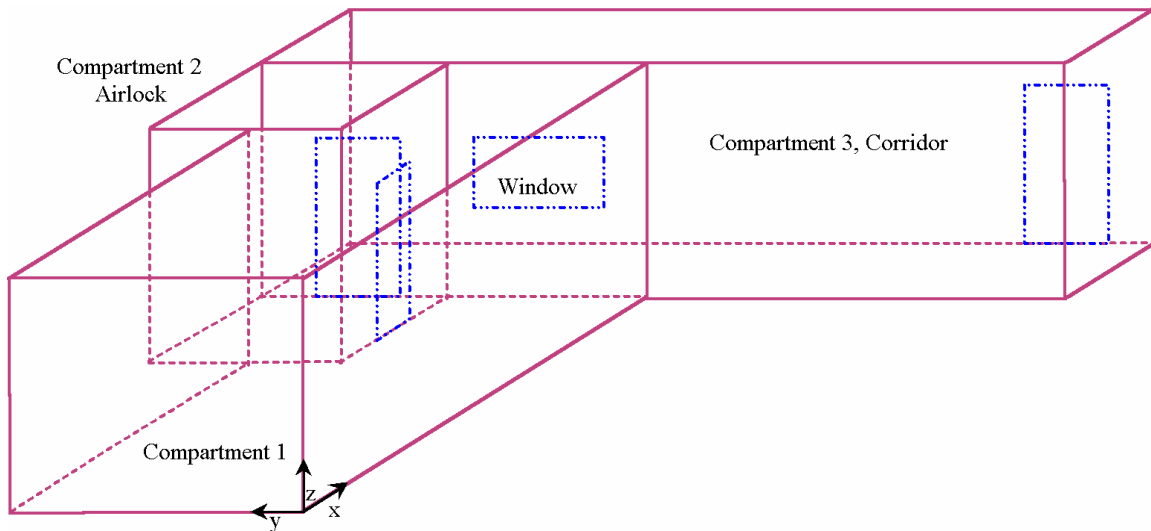
Figure 7-1. Sample Problem Arrangement – Isometric View
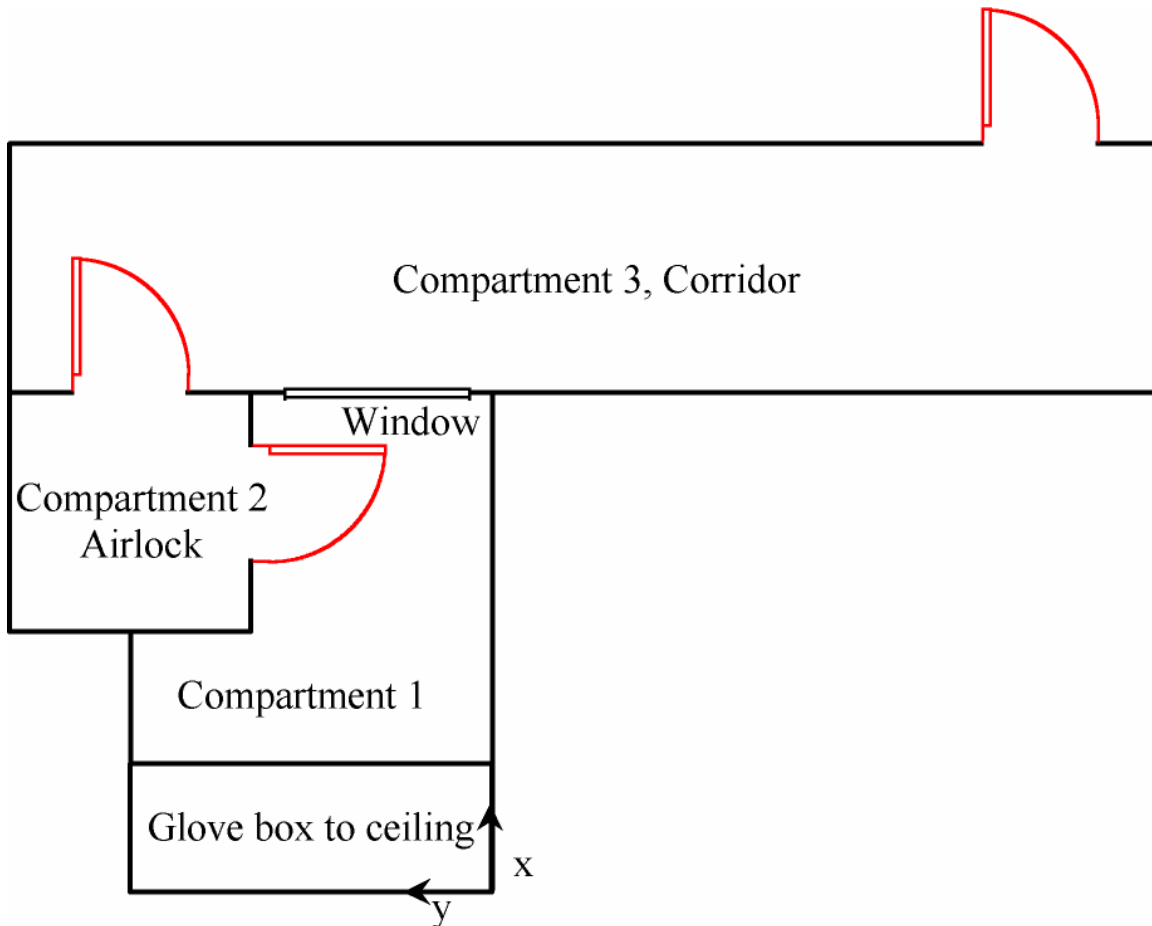
Figure 7-2. Sample Problem - Plan View

Usually the design fire starts with a description of the combustibles involved in the fire. The analyst must then postulate a reasonable HRR curve based on the material description. While there are published results for trash fires, these tests are more applicable to residential and office situations. Most of the tests involve less than 5 kg of material, burn for less than 10 minutes and have a peak heat release rate (PHRR) of 50 to 300 kW. These fires are smaller than those that could occur in a process room with several bags of waste. The polyethylene waste has a heat of combustion of 43 MJ/kg (SFPE, 2002). Thus the total available energy is about 516 MJ, or approximately 60 pounds of wood equivalent[*]. For this sample problem the fire is taken as a slow to medium growth fire[†], with a PHRR of 500 kW. If the fire decay is linear and occurs between 900 and 1200 seconds, then the total energy released is 430 MJ. This equates to an efficiency of slightly more than 80 percent, thus the HRR is judged to be reasonably bounding.

---

[*] pounds of wood equivalent is an energy unit. It is equal to 8,000 Btu/pound or 19 MJ/kg.

[†] The growth period is taken as $Q = 0.00556 \ t^2$, where the heat release rate, Q, is in kW, and the time, t, is in seconds.

7.2 Input File

This section provides a line-by-line explanation of the data file, CAB042.DAT, which is provided in Appendix B. The order of the discussion is based on the windows that are established in FAST. The headers in this section are based on the window title bars in FAST. Additional information for each keyword can be found in Appendix A of (Peacock, 2000), and Appendix B of (Jones, 2003). The file was initially constructed using the FAST GUI. Once the steady-state, no-fire data file (Appendix C) was successfully executed the data file was modified using WordPad to that shown in Appendix B. Keywords that begin with the symbol "#" are comments and do not affect the results. Where there are multiple entries for the same keyword (e.g., HVENT, CVENT) only a single data file line is presented.

7.2.1 Desktop Information

VERSN specifies the version of the CFAST model for which the input data file was prepared and an optional user defined title for the file. When using the FAST interface, the version number is automatically assigned for the corresponding CFAST version.

```
VERSN    3BASE CASE FOR EXAMPLE - FIRE
#VERSN 3 BASE CASE FOR EXAMPLE - FIRE
```

7.2.2 Model Input/Output

TIMES, in units of seconds, are the simulation time, print interval, history interval and display interval followed by the copy count.

```
TIMES   2710    10    10    20    0
```

The simulation time is a required input that has a maximum value of 86400 seconds (i.e., one day). The print interval is the time interval between each printing of the output values. If omitted or less than or equal to zero, no printing of the output values will occur. The history interval is the time interval between each writing of the output to the history file. Documentation ((Peacock, 2000), Section A.3) states that this value must be zero if no history file is to be used; however, non-specification of this parameter leads to no spreadsheet file output (i.e., even if no history output file is to be generated, the history file is still "used" to generate the spreadsheet output file). The display interval and copy count pertain to the graphical display.

DUMPR gives the location and name of the history file output.

```
DUMPR CAB042.HI
```

History file is an optional input. If omitted, the file will not be generated. Note that, in order to obtain a history file, this parameter must be specified and the history interval must be set to a non-zero number. NOTE: As FAST is a DOS based program, the DOS naming conventions apply.

ADUMP (Note: ADUMPF is incorrectly identified in the documentation, (Peacock, 2000), Section A.3.) gives the location and name of the spreadsheet (output) file and a specification of

the type of output written to the spreadsheet file (n = normal, f = flow field, w = targets and walls, s = species, p = wall temperatures profiles).

        ADUMP CAB042.CSV NFS

The spreadsheet file is an optional input. If omitted, the file will not be generated. Note that in order to obtain a spreadsheet file, this parameter must be specified and the history interval must be set to a non-zero number. Normal output is the default setting for type of output. It appears that the settings are usually not loaded from this line, thus whenever a new file is loaded the output is set to Normal. If it is desired to produce additional outputs they must be manually specified for each execution of the file. This is accomplished within FAST by selecting the filename icon in the environment section of the overview window. Next, select the *Spreadsheet* text button and then check the radio button(s) for the desired output. Click "OK", then specify the path and filename for the spreadsheet output file. Specifying a *.CSV file creates a comma delimited file that can then be opened with a spreadsheet program (e.g, Excel). NOTE: As FAST is a DOS based program, the DOS naming convention applies.

THRMF specifies the input file provides the location and name of the thermal database. The thermal database specifies the thermo-physical properties of the enclosing surfaces and targets by specifying the thermal conductivity, specific heat, emissivity, density, and thickness of specific materials that are then identified as enclosing surfaces or targets in the structure settings.

        THRMF WSMSTH04.DF

The default thermal database file as provided by NIST is initially THERMAL.DF (not THERMAL.TPF or THERMAL.DAT as identified in (Peacock, 2000), Section A.6). An alternate thermal database file can be entered in the configuration file. For analyses that support a DSA it is recommended that a site-specific or facility specific database file be established. For the sample problem the database selected is titled WSMSTH04.DF. This approach was used to ensure that the physical property information in the database was traceable to a source document.

7.2.3   Ambient Conditions

TAMB specifies the initial the internal ambient temperature (K), internal ambient pressure (Pa) and station elevation (m) of the location at which the ambient temperature and pressure are measured.

        TAMB 293.150   101300. 0.000000

EAMB specifies the initial external ambient temperature (K), internal ambient pressure (Pa) and station elevation (m) of the point at which the ambient temperature and pressure are measured.

        EAMB 293.150   101300. 0.000000

Documentation ((Peacock, 2000), Section A.4) identifies the default ambient pressure as 101300 Pa and the default ambient temperature as 300 K. However, the default ambient temperature for CFAST is 288 K. The default ambient temperature for FAST is 293.15 K.

7.2.4   Compartment (Descriptions)

The size and location of every compartment in the structure must be described. In a structure with *n* compartments, *n+1* denotes outside.

HI/F is the absolute height (in meters) of the floor of the compartment with respect to the station elevation and is specified when defining each compartment. HI/F is a required input. The default setting is zero. A structure with *n* compartments will have *n* data entries for this parameter. Since there are three compartments for the sample problem there are three numerical entries for the Compartment Description keywords.

        HI/F   0.000000 0.000000 0.000000

WIDTH specifies the width (from left wall to right wall [y], in meters) of each compartment. (See Figure 7-3.) As with the HI/F keyword and the remaining keywords in this section a data file with *n* compartments will have *n* data entries.

        WIDTH   3.0000   2.00000   3.00000

DEPTH specifies the depth (from rear wall forward [x], in meters) of each compartment. (See Figure 7-3.)

        DEPTH   3.0000   2.00000   15.0000

HEIGH specifies the height [z] (in meters) of each compartment. (See Figure 7-3.)

        HEIGH   2.4400   2.44000   2.44000
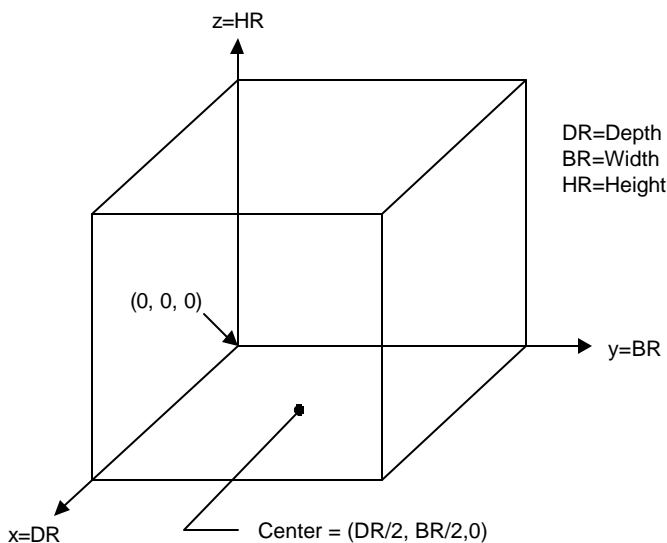
Figure 7-3. Orientation

CEILI specifies the name of the material accessed from the thermal database file for the ceiling of each compartment.

```
CEILI GYPSUM    GYPSUM    GYPSUM
#CEILI GYPSUM    GYPSUM    GYPSUM
```

WALLS specifies the name of the material accessed from the thermal database file for the walls of each compartment.

```
WALLS GYPSUM    GYPSUM    GYPSUM
#WALLS GYPSUM    GYPSUM    GYPSUM
```

FLOOR specifies the name of the material accessed from the thermal database file for the floor of each compartment.

```
FLOOR CONC003   CONC003   CONC003
#FLOOR CONC003   CONC003   CONC003
```

7.2.5   Horizontal Flow

HVENT specifies natural flow horizontal vents. The first three integers specify the "From Compartment", "To Compartment", and the sequential vent number (i.e., from Compartment 1 to Compartment 2 - Vent number 1 for the line below). The next three of numbers define the opening width, soffit height and sill height (m) of the vent. For the line presented below, the door width is 0.91 meters, with a 2.13 meter height and a sill even with the bottom of the floor. The next parameter defines the wind coefficient, and the remaining two establish the horizontal distance between the centerline of the vent and the respective reference point in the "From" and "To" compartments.

```
HVENT  1   2   1 0.910000   2.130000 0.000000 0.000000
       0.000000 0.000000
```

It is possible to define a total of four (4) horizontal flow connections between any pair of compartments. Location of the connection (i.e., sill height, soffit height) is given with respect to the floor of the "from" compartment.

CVENT specifies the opening/closing parameter for the natural flow horizontal vents. As with the HVENT keyword, the first three integers define the compartments and the vent number. The remaining values are the opening/closing parameters corresponding to each point on the specified fire timeline. The default value of one corresponds to an open vent and a fractional value represents the ratio of the opening (i.e., 0.5 would specify a vent which is halfway open). The height of the soffit and sill are not affected by this keyword. The time increments corresponding to these opening/closing factors are specified in FTIME below.

```
CVENT  1   2   1        0.00000        0.00000        0.00000
      0.00000        0.00000       0.00000        0.00000
      0.00000        0.00000       0.00000        0.00000
      0.00000        0.00000       0.00000        0.00000
```

```
        0.00000         0.00000         0.00000         0.00000
        0.00000
```

7.2.6 Ventilation System Settings

MVDCT specifies a duct that exists between two defined nodes. The first two values define the nodes. The next three establish the duct length (m), diameter (m) and absolute roughness (m). The remaining values describe the inlet flow coefficient, inlet area (m^2), outlet flow coefficient and outlet area (m^2).

```
    MVDCT  1   2  20.0000 0.120000 0.000150000   2.00000 0.120000
        4.000000 0.120000
```

MVFAN specifies the location of a fan in the ventilation network and the fan curve. The first two values are the nodes that the fan is connected to. The third and fourth values are the minimum and maximum pressures (Pa) respectively. Below the minimum pressure the fan flow is assumed to be constant. Above the maximum pressure the fan flow is assumed to stop

```
    MVFAN  2   3 0.000000   500.000   0.038 0.00000 0.00000
        0.000000 0.000000
```

The remaining five values specify the fan curve as:

$$(9) \quad F = A_1 + A_2 \, \Delta p + A_3 \, \Delta p^2 + A_4 \, \Delta p^3 + A_5 \, \Delta p^4$$

where: F is the flow [m^3/s]

A_i is the respective flow coefficient

Δp is the pressure increase across the fan [Pa]

MVOPN specifies a connection between a compartment and the ventilation system network. The first value is the compartment number and the second is the node number. (Note: For this sample problem compartment number 4 is the outside.) The opening orientation is specified as horizontal (H) or vertical (V). The remaining values represent the height of the duct above the floor (m) and the area of the opening into the compartment (m^2).

```
    MVOPN  1   1 V   1.00000 0.100000

    MVOPN  4   3 H   10.0000 0.400000
```

INELV specifies the height of a ventilation node with respect to the height of the reference datum. The first value specifies the node number; the second the elevation (m).

```
    INELV  2   1.00000
```

7.2.7 Main Fire Specifications

CHEMI specifies the parameters for fire kinetics as follows: the molar weight (molecular weight of the fuel vapor used for conversion to ppm), relative humidity (%), lower oxygen limit (%), heat of combustion (J/kg), initial fuel temperature (K), gaseous ignition temperature (K), and radiative fraction.

```
     CHEMI  28.0000  50.0000  12.0000 4.00000E+007  293.150
         393.150 0.300000
```

The molar weight (28.0) is the value for polyethylene (SFPE, 2002). The default when using FAST is 16.0. The relative humidity (50%) was assigned based on the FAST default value of 50 percent. (Note: Relative humidity is specified within the environment settings.)

The lower oxygen limit (12%) is applicable only to Type 2 fires (see LFBT below). A Type 2 fire models the condition where the quantity of air entering the fire compartment is constrained by the ventilation openings. Under such conditions the HRR will be limited and excess pyrolysis gases will occur. The oxygen concentration threshold for this condition is in the range of 8 to 15 percent by volume (Babrauskas, 1992). FAST has a default value of 10 percent. The 12 percent value used in the sample problem has been accepted as good practice by the *International Collaborative Project to Evaluate Fire Models for Nuclear Power Plant Applications* (NRC, 2002).

The net heat of combustion for polyethylene is 43 MJ/kg (SFPE, 2002). It has been rounded down to 40 MJ/kg since trash is seldom a uniform material. The default heat of combustion for FAST, which is based on wood, is 1.95E+07 J/kg (not 5.0E+07 as indicated in Peacock, 2000, Section A.10).

The initial fuel temperature (293.15 K) was selected from the initial room condition of 20°C. This value is consistent with the FAST default initial fuel temperature.

The gaseous ignition temperature (393.15 K) was set at 100 K higher than the initial fuel temperature. The default value in FAST is 100 K higher than the initial fuel temperature. There is sometimes discussion that the gaseous ignition temperature should be set at the spontaneous or autoignition temperature (AIT) of the pyrolysis gases. In addition to the information previously discussed in Section 5.2.1 there are two additional shortcomings to this: (1) the pyrolysis gases are seldom well understood, (2) if an ignition source exists (e.g., spark, brand, hot object) then ignition could occur at a temperature below the AIT. Polyethylene is known to decompose into propane, propene, ethane, ethene, butene, hexene-1 and butene-1 (Beyler, 2002). The flashpoint and AIT for these materials, where available, range from 138 to 193 K and 658 to 745 K, respectively (Kanury, 2002). The 393.15 K value is above the flashpoint value, but below the AIT for the available data.

The HRR from a fire is the total energy release rate, which consists of both radiation and convective terms. Typically, the radiation term is 20 to 40 percent of the total energy release rate (Karlsson, 2000). The radiative fraction (0.3) is the midpoint of this range.

LFBO is the compartment of fire origin (i.e., Compartment 1).

```
        LFBO 1
```

LFBT is the type of fire (0 = Off, 1 = Unconstrained, 2 = Constrained/Constrained with Flashover)

```
        LFBT 2
```

CJET indicates for which surfaces convective heating will be determined. Setting selections are *OFF*, *CEILING*, *WALLS* and *ALL*.

```
        CJET ALL
```

FPOS defines the position of the fire (X, Y, Z). Note: -1.0 indicates position is centered on that axis.

```
        FPOS -1.00000 -1.00000 0.000000
```

Where: X   is the position of the fire (in meters) as a distance from the rear wall of the
             compartment (See Figure 7-3 for orientation)

         Y   is the position of the fire (in meters) as a distance from the left wall of the
             compartment

         Z   is the height of the fire above the floor (in meters).

FTIME specifies the times that correspond to the pyrolysis and heat release rate curves. Because the 0.0 time is not listed in this keyword, there is one numeric entry less than in the fire descriptor keywords (e.g., FMASS). The units of time are seconds.

```
        FTIME          50.000        100.000        150.000
           200.000        250.000        300.000        350.000
           400.000        450.000        500.000        550.000
           600.000        650.000        700.000        800.000
           900.000       1000.000       1100.000       1200.000
```

Initial entry of this curve specifies the mass loss rate, heat release rate, and if applicable the heat of combustion curve (see discussion below on over specifying fire curves). It also specifies the time step for various other parameters (CVENT, HCR, HCN, etc.). Note that after initial entry, any adjustment to this curve will affect all the time-related curves.

FMASS specifies the mass loss rate (e.g., fuel pyrolysis rate) corresponding to each point of the specified fire. The units of the mass loss rate are kg/s.

```
        FMASS   0.000E+000  4.861E-004  1.944E-003  4.375E-003
           7.778E-003  1.215E-002  1.250E-002  1.250E-002  1.250E-
           002  1.250E-002  1.250E-002  1.250E-002  1.250E-002
           1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.167E-
           002  5.833E-003  0.000E+000
```

FQDOT specifies the heat release rate corresponding to each point of the specified fire. The units of the heat release rate are Watts.

```
FQDOT   0.000E+000  1.944E+004  7.778E+004  1.750E+005
   3.111E+005  4.861E+005  5.000E+005  5.000E+005
   5.000E+005  5.000E+005  5.000E+005  5.000E+005
   5.000E+005  5.000E+005  5.000E+005  5.000E+005
   5.000E+005  4.667E+005  2.333E+005  0.000E+000
```

> **Over specifying Fire Curves:** Since the heat of combustion, heat release rate, and mass loss rate are inter-related, it is possible to over-specify the fire curve. The FAST GUI editor accounts for this by using the two most recently entered to calculate the third parameter. If CFAST is executed from the DOS command prompt the model will use the mass loss rate and the HRR. The heat of combustion will not be reflected in the simulation.

HCR specifies the hydrogen to carbon ratio (kg/kg) corresponding to each point of the specified fire timeline. Polyethylene is C_2H_4, thus the hydrogen to carbon ratio is 0.167. The default value when using FAST for this ratio is 0.08.

```
HCR       0.1670000       0.1670000       0.1670000
    0.1670000       0.1670000       0.1670000       0.1670000
    0.1670000       0.1670000       0.1670000       0.1670000
    0.1670000       0.1670000       0.1670000       0.1670000
    0.1670000       0.1670000       0.1670000       0.1670000
    0.1670000
```

7.2.8   Graphics

The remaining keywords (e.g., SELECT, DEVICE, etc.) support the run time graphics associated with CFAST. The reader is directed to Jones, 2003, for a description of these keywords

7.3   Output Files

The Input File, CAB042.DAT, which is discussed above and presented in Appendix B directs CFAST to prepare two output files. In addition, a third output file can be created if CFAST is executed from the DOS command line. Each of these files is discussed below.

7.3.1   Spreadsheet File

The comma delimited spreadsheet file is CAB042.CSV. It contains the normal (n) outputs (layer temperatures, interface height, and fire size), the vent flows (f) and the species concentrations (s). The specific entries, and their respective units, are listed in Appendix H. With the exception of the HRR values, which were generated from the history file, all of the plots presented in this section are based on the spreadsheet files.

7.3.2   History File

The history file name is CAB042.HI. For the sample problem the size of this file should be about 6093 kB. The file is accessed by the routine CPlot, which was discussed earlier. The spreadsheet file contains most of the data that is in the history file, however there is some important information that is not exported to the spreadsheet file. While the spreadsheet file contains the main fire HRR, it does not provide the HRR for the other rooms.

The HRR for the three compartments and the outside were obtained from the history file using CPlot.

7.3.3   Text File

When CFAST is executed from the DOS prompt with the command line

```
CFAST CAB042.DAT CAB043.LST /rinfs
```

a text file is generated. As stated previously the name of the data file associated with this command line is "CAB042.DAT." The name of the text file is "CAB043.LST." The options selected by this line direct that the text file should contain the model initial conditions and scenario description (i), the standard output data (n), the vent flow data (f), and the layer species concentrations (s). Appendix G provides the *.lst file for the sample problem base case where only the initial conditions were requested.

7.4   Sample Results

The base case results are presented graphically in Figure 7-4 through Figure 7-9. The spreadsheet data for this case is summarized in Appendix H. The data for layer height (Figure 7-6), room pressure (Figure 7-6), and oxygen content (Figure 7-9) are plotted directly from the respective spreadsheet columns. The temperatures were converted from K to °C prior to preparing Figure 7-4. The flows, which are presented in Figure 7-7, were derived by combining the four respective mass flow values for each opening. Where there were multiple openings between two rooms, the net flow for each opening was combined. For example, for flow through opening 1 from compartment 2 to compartment 1:

$$(10) \quad \text{Flow}_{\text{net},2\text{-}1,1} = \text{Flow}_{1-2,\text{upper,in}} - \text{Flow}_{1-2,\text{upper,out}} + \text{Flow}_{1-2,\text{lower,in}} - \text{Flow}_{1-2,\text{lower,out}}$$

The net flow from compartment 2 to compartment 1 is:

$$(11) \quad \text{Flow}_{\text{net},2\text{-}1} = \text{Flow}_{\text{net},2\text{-}1,1} + \text{Flow}_{\text{net},2\text{-}1,2} + \text{Flow}_{\text{net},2\text{-}1,3}$$

The HRR data for compartment 1 may be obtained from the spreadsheet (CAB042.CSV) or the history file (CAB042.HI). The HRR values for compartment 2, 3, and the outside are not available in the spreadsheet (CAB042.CSV). For this scenario, since the HRR values in the remaining compartments are negligible, this data would normally be sufficient. However the HRR results for these compartments are not negligible for CAB043.DAT, so the method to obtain them is presented here.

From the DOS command prompt start the program CPlot with the following entry:

```
CPLOT
```

When prompted from CPlot, enter:

```
File
```

This will direct CPlot to access the appropriate history file. Enter the respective file name

```
CAB042.HI
```

Prompt CPlot to read the appropriate data with the command:

```
ADD
```

CPlot will then request the keyword name, which is HEAT. Once entered indicate the fire compartment: 1. Repeat this for compartments 2, 3 and 4. When the data has been read into memory it may be saved to an ASCII file with the following command:

```
SAVE
```

When prompted, provide the appropriate file name. This file can be imported into Microsoft Excel and plotted as shown in Figure 7-8.
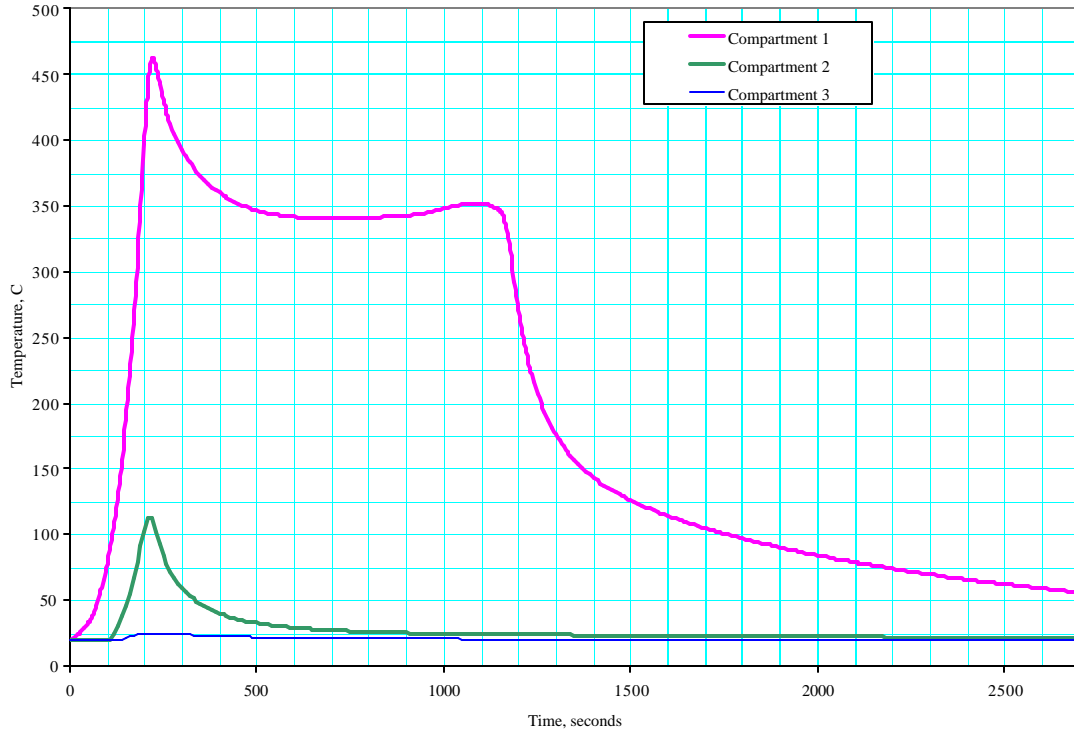
Figure 7-4. Upper Layer Temperatures For Base Case (CAB042.DAT)
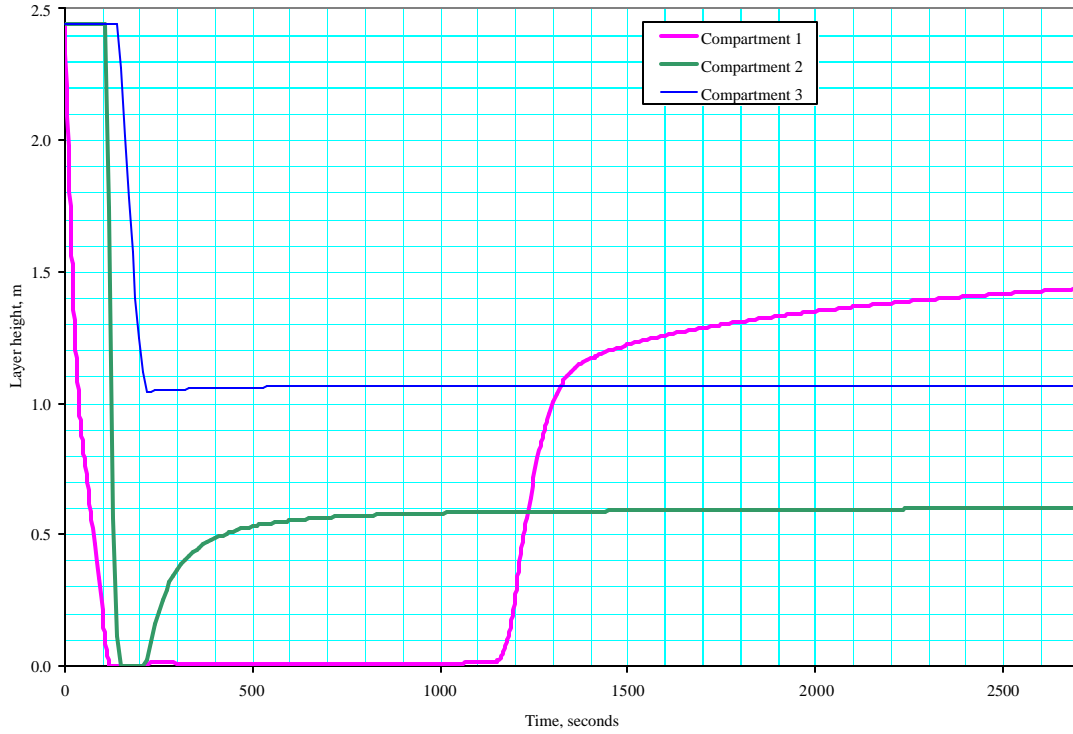
Figure 7-5. Layer Heights For Base Case (CAB042.DAT)
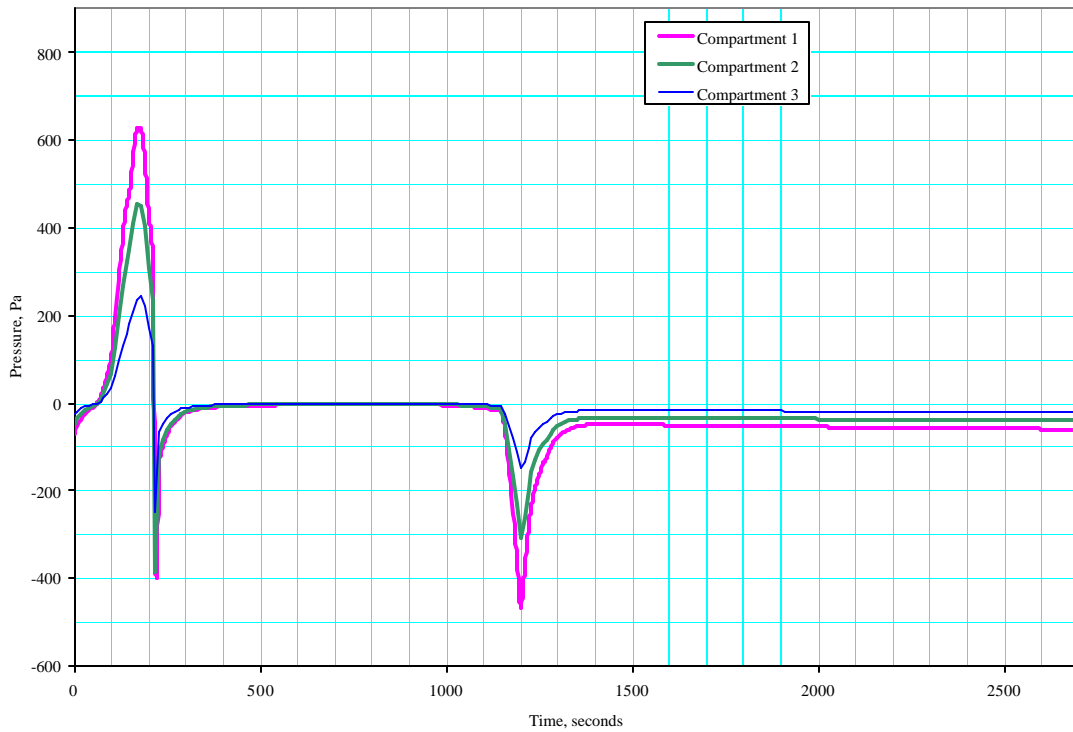
Figure 7-6. Room Pressures For Base Case (CAB042.DAT)
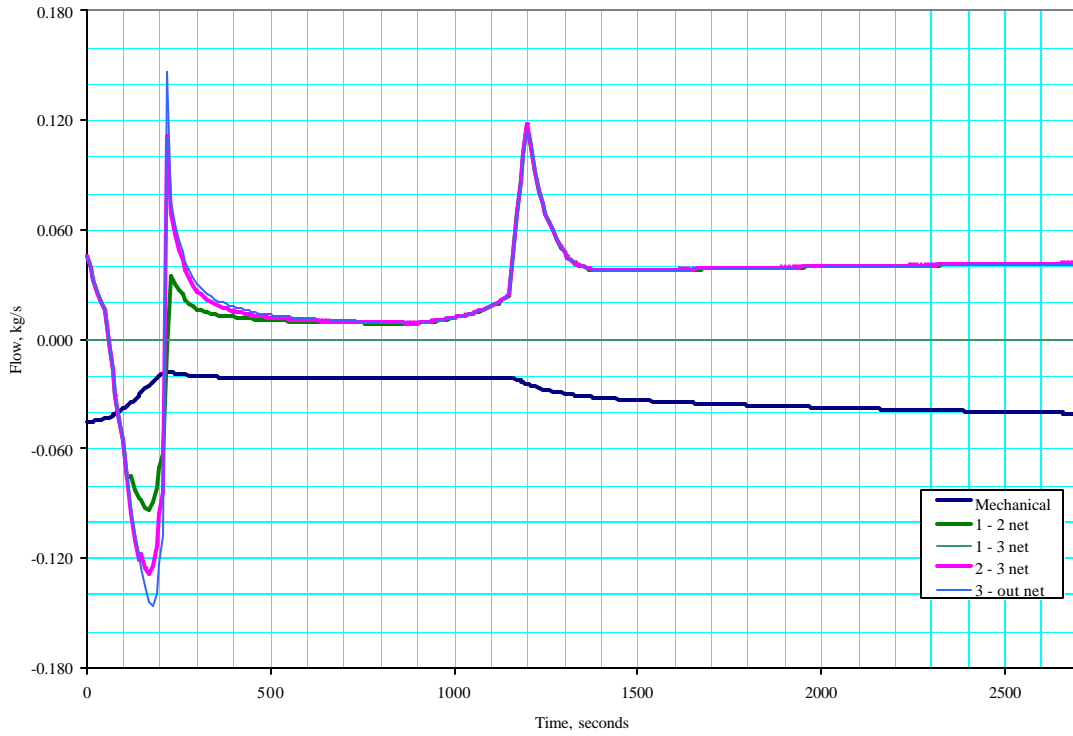
Figure 7-7. Ventilation Flows For Base Case (CAB042.DAT)
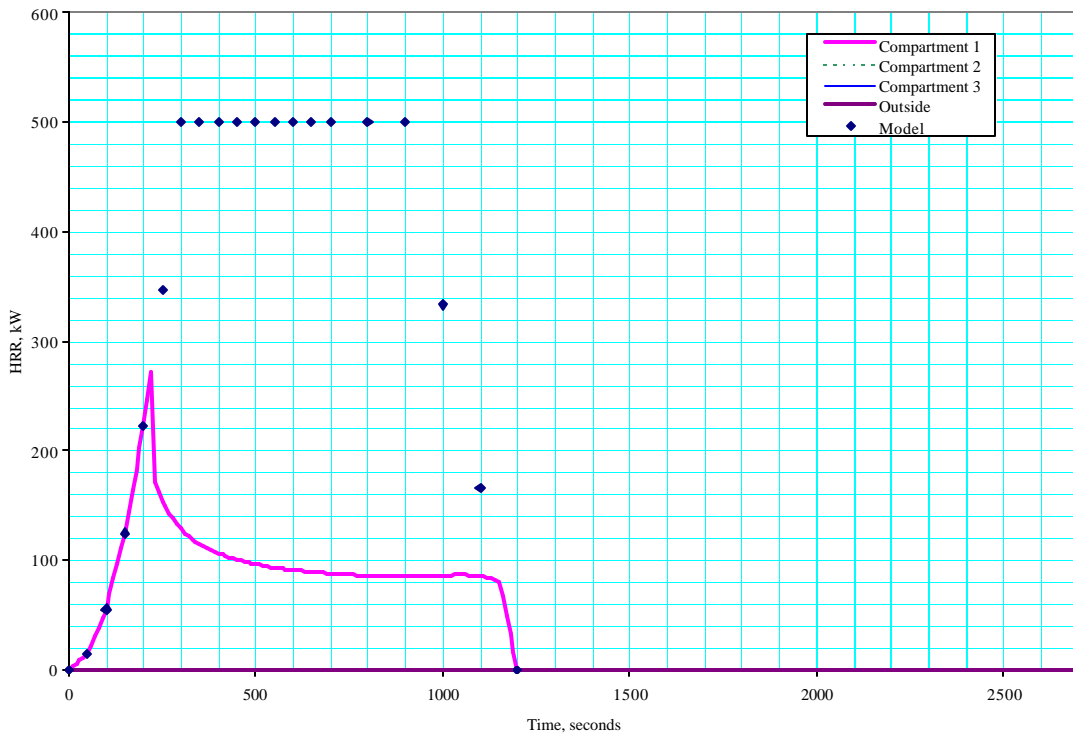
Figure 7-8. Heat Release Rates For Base Case (CAB042.DAT)
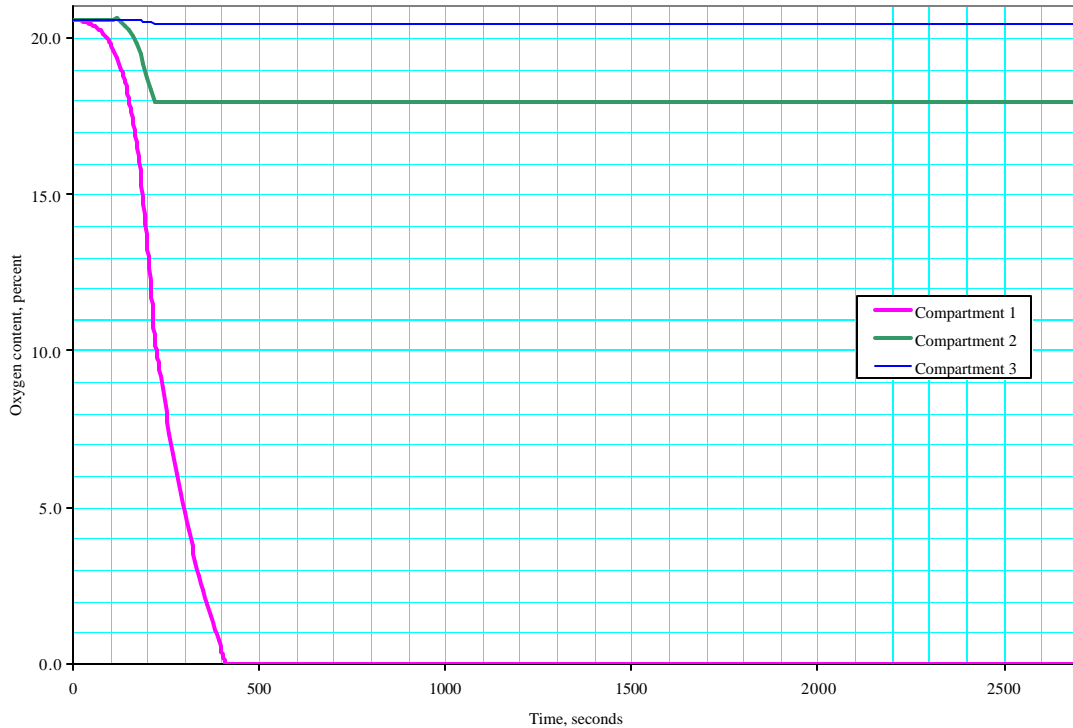
Figure 7-9. Oxygen Contents For Base Case (CAB042.DAT)

In addition to the base case (CAB042.DAT), there are several additional data files in the appendices. These include a no-fire case (Appendix C), which is a good diagnostic tool, and a case that involves breaking of the window between compartment 1 and 3 (Appendix D). Such breakage can occur during a fire where the temperature difference between the center of a glass pane and the glass, which is embedded in the window frame, exceeds 70°C (NFPA, 2001). These cases represent a subset of the potential scenarios that must be evaluated in establishing the most severe fire descriptions using the solution method presented in Section 4.4.

7.5 Discussion

Since the upper layer temperature in compartment 1, as shown in Figure 7-4, exceeds 450°C, there is the potential that flashover could occur. However for this particular scenario since the temperature does not exceed 600°C, flashover may not necessarily occur. Since the temperature is below 800°C and the high-temperature duration is less than 30 minutes (1800 seconds), material that is in shipping containers that are certified to 10 CFR 71.73(CFR, 2001a) will not be released (i.e., $DR = 0$). The integrity of steel containers that will not pressurize and are not in direct flame contact will also not be compromised. The room temperatures are such that storage containers that may contain moisture will require a structural analysis to determine if they will fail.

Figure 7-5 provides the layer heights for each compartment. For compartment 1 (process room) and compartment 2 (airlock) the layer height drops to the floor about 2 minutes after the fire starts. Such conditions will prevent operators from safely entering to manually suppress the fire. The layer height in the corridor (approximately 1 meter at 3.5 minutes) will limit operator actions

in compartment 3 (corridor). The conclusion, based solely on the temperature and layer height profiles, is that there is little a facility occupant can do to safely intervene in the scenario unless equipped with turnout gear.

Figure 7-6 presents the room pressures for the three compartments. At the start of the fire the pressures were slightly negative for each room as compared with ambient. At 60 seconds into the fire the pressures reverse. This occurs because of thermal expansion as the fire heats the air in compartment 1. The pressure peaks in all three compartments at 170 seconds. These pressures indicate that a flow reversal occurs in all of the compartments. This reversal lasts until 220 seconds. Following the initial flow reversal, the decrease in fire HRR allows the room atmosphere to cool, thus creating a thermal contraction that pulls air into the room. This repeats at the end of the HRR curve.

The flow rates in Figure 7-7 mirror the pressure behaviors in Figure 7-6. Initially flow is from compartment 3, through compartment 2 and into compartment 1 where it is exhausted through the mechanical ventilation system. As the fire HRR increases the mechanical exhaust will decrease. For this scenario the ventilation system moves air out of compartment 1 throughout the entire scenario.

Figure 7-8 provides the HRR curves for the three fire compartments, the outside, and the model input file. Early in the fire the predicted HRR fire in compartment 1 follows the model input. At about 220 seconds the HRR rapidly drops. This is fairly typical for fire compartments with limited ventilation. As can be seen in Figure 7-9 this coincides with the oxygen level in the upper layer of compartment 1 reaching 10.4 percent. As represented in CFAST, the mass loss rate will continue at the model input rate, but the HRR will be limited by the available oxygen. This effect continues until the predicted HRR curve intersects with the decay portion of the input HRR curve.

Figure 7-9 presents the oxygen content in the three compartments. The oxygen concentration in the upper layer of compartment 1 decreases to zero at 420 seconds. The concentration in the upper layer of the airlock decreases to 18 percent. For compartment 3 the upper layer concentration decreases to 20.5 percent.

It is possible to predict the leakpath factor (LPF) using the CFAST results. To do this explicitly is a straightforward, but time consuming process. A simplified method is presented in Appendix I. The estimate is based on the following assumptions:

1. All of the contamination is released into compartment 1 at the start of the fire.

2. Any contamination exiting compartment 1 goes directly outside. (This avoids the need to track concentrations in compartments 2 and 3.)

3. Once contamination leaves compartment 1, it does not reenter compartment 1.

4. The contamination is uniformly distributed in a layer.

Figure 7-10 shows the total contamination as a percent of the original release. The figure also provides the contamination that travels through the mechanical ventilation system, and

presumably is trapped on a filter. From this figure it is implied that the LPF is no greater than 0.42.

The temperature predictions for data file CAB043.DAT (Appendix D) are provided in Figure 7-11. The only difference between this case and the base case (CAB042.DAT) is the window between compartment 1 and compartment 3, which is assumed to fail at 700 seconds. The timing of the window failure was determined iteratively with the intent of maximizing the temperature in compartment 1. Immediately after this postulated event, the upper layer temperatures in compartment 1 and compartment 3 rise. The temperature in compartment 1 reaches 608°C, while in compartment 3 the temperature is predicted to be 530°C. Thus, for compartment 1 flashover (via a backdraft) is expected. Thus, the MAR for this scenario would include any radiological material that could be in compartment 3, in addition to the material in compartment 1.

The HRR rate also significantly increases after window failure as shown in Figure 7-12. In this scenario flames are also predicted in compartment 3. The flames in compartment 3 will last for about 2 minutes. Based on these results, ignition of some materials in compartment 3 would be expected. Thus, the DSA would need to address a multi-room fire, which would be more severe than is presented in this sample problem. (i.e., The sample problem neglects combustibles outside of compartment 1.)

The severity of the fire associated with CAB043.DAT is very severe. The damage ratio for most containers should be taken as unity unless a mechanistic structural model is developed. In addition to the thermal loads, the temperatures are sufficiently high to initiate failure of structural steel. As such, glove boxes may tip and spill their contents. If radiological material is in powder form several release mechanisms will exist (e.g., pressurized release from storage container failure, spillage when glove box supports fail, and air entrainment). In addition, lamps and similar devices that are hung from the ceiling or wall may fall and impact power that is exposed.

CFAST 3.1.7 room representations are limited to rectangular parallelepipeds. Thus, when presenting a model involving a non-rectangular room a compromise must be made: balance the free room volume and the wall surface area. In addition, if the contents of a room are significant (e.g., glove box), the effective room volume may be substantially less than the space that the room displaces. Accounting for these effects explicitly in CFAST is difficult. To account for non-rectangular geometries, non-uniform wall construction, and large building contents, a sensitivity analysis approach is recommended. This can be accomplished by bracketing the expected condition with two similar models. If the conclusions of the bracketing models are similar, then the need to demonstrate that a specific model explicitly represents the facility is alleviated. The data file CAB044.DAT (Appendix E) provides an alternate model to the base case in CAB042.DAT. For this case the compartment depth is reduced from 3 to 2 meters.

CFAST 5.1.1 has keywords that permit the evaluation of non-rectilinear compartments. The keywords supporting this are ROOMA and ROOMH. The analyst can use this approach when using CFAST 5.1.1 rather than that suggested for CFAST 3.1.7 above.

As with the base case (CAB042.DAT) the upper layer temperature in compartment 1, as shown in Figure 7-13, exceeds 450°C. In terms of timing, this high temperature occurs earlier for the

reduced-volume model, although the difference is not significant. The HRR reduction limitation occurs earlier for the reduced-volume model as shown in Figure 7-14. There is also a brief recovery after the initial drop, although the overall effect is minimal.

The data file CAB045.DAT (Appendix F) uses an alternate HRR curve as the input. In this case, the PHRR is increased from 500 kW to 750 kW. The temperature and HRR predictions for this data file are presented in Figure 7-15 and Figure 7-16. There is no significant difference in the conclusions for this high PHRR scenario as compared with the base case.
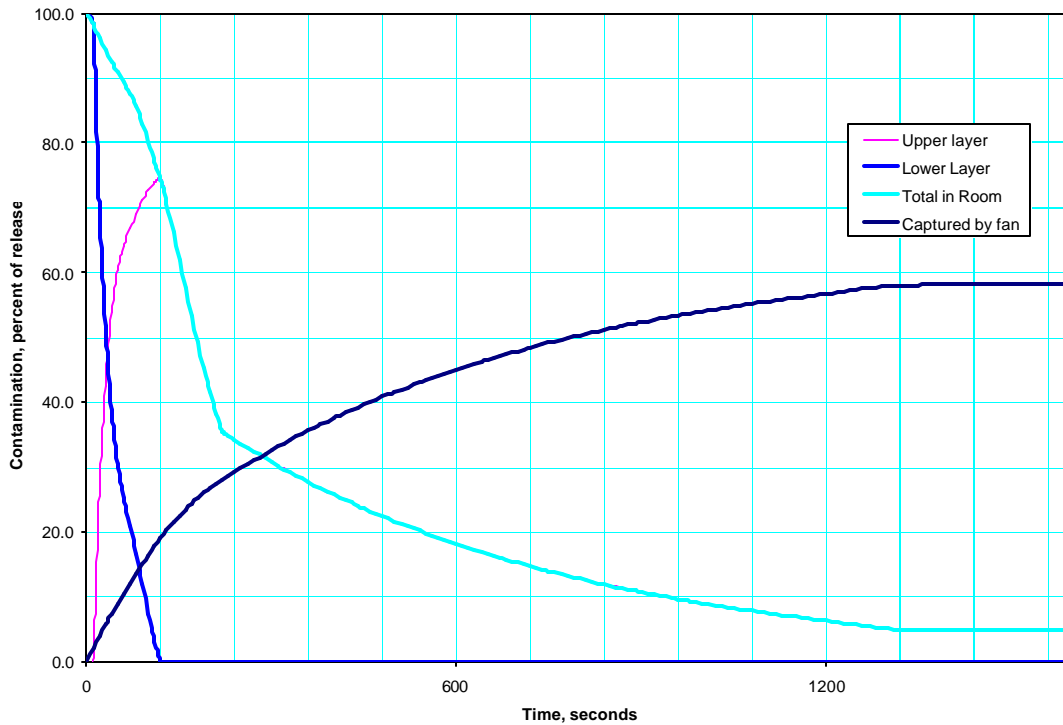
Figure 7-10. Contamination Location For Base Case (CAB042.DAT)
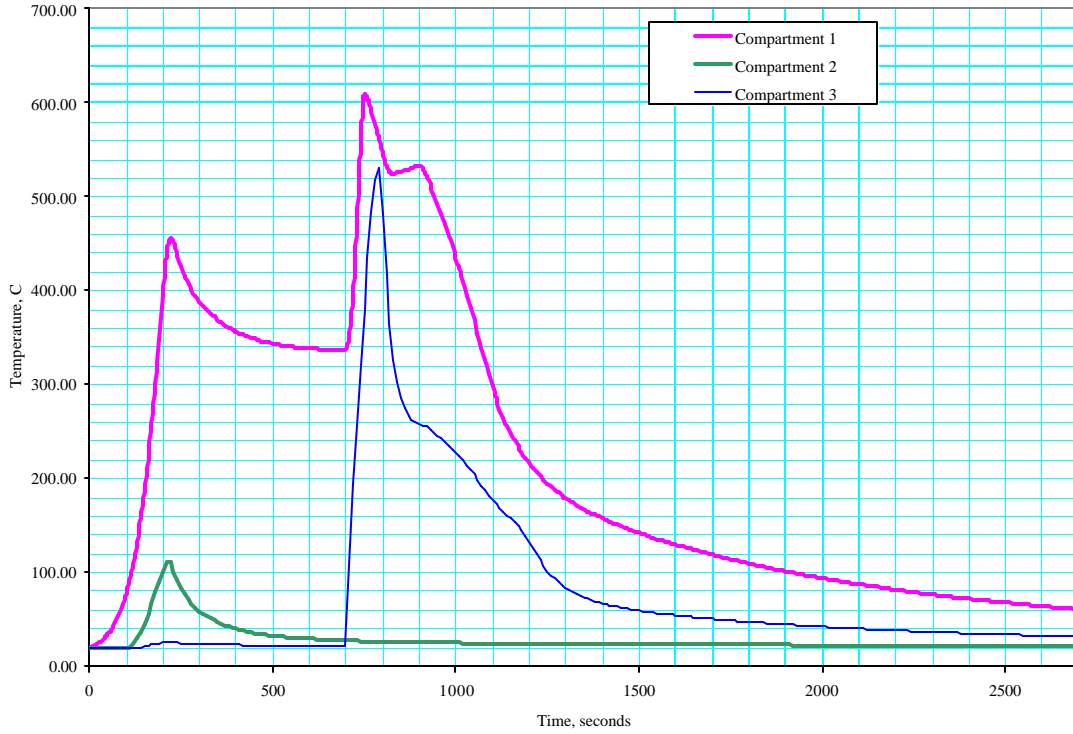
Figure 7-11. Upper Layer Temperatures For Window Failure Fire (CAB043.DAT)
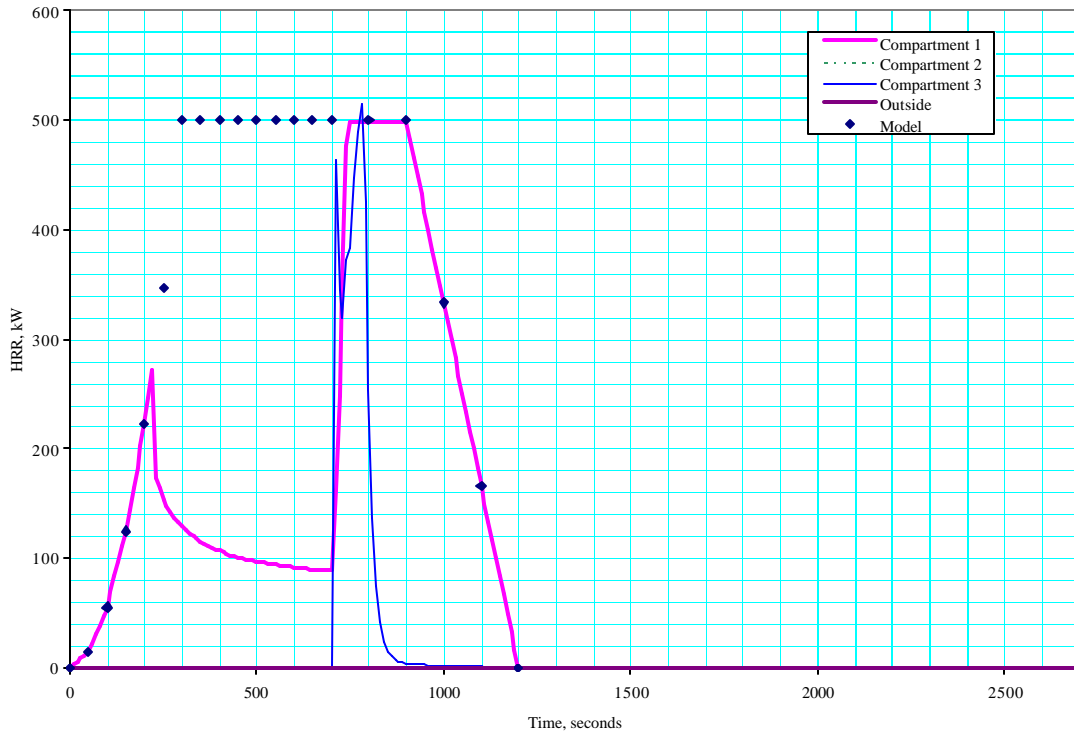
Figure 7-12. Heat Release Rates For Window Failure Fire (CAB043.DAT)
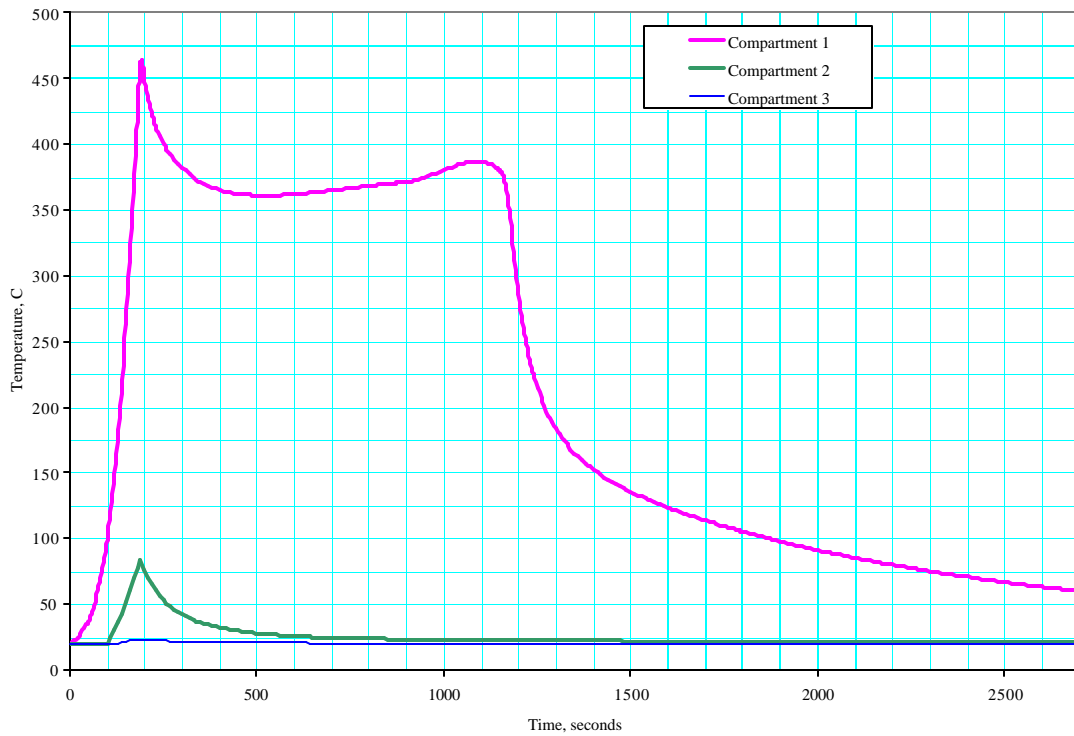
Figure 7-13. Upper Layer Temperatures For Reduced Room Size (CAB044.DAT)
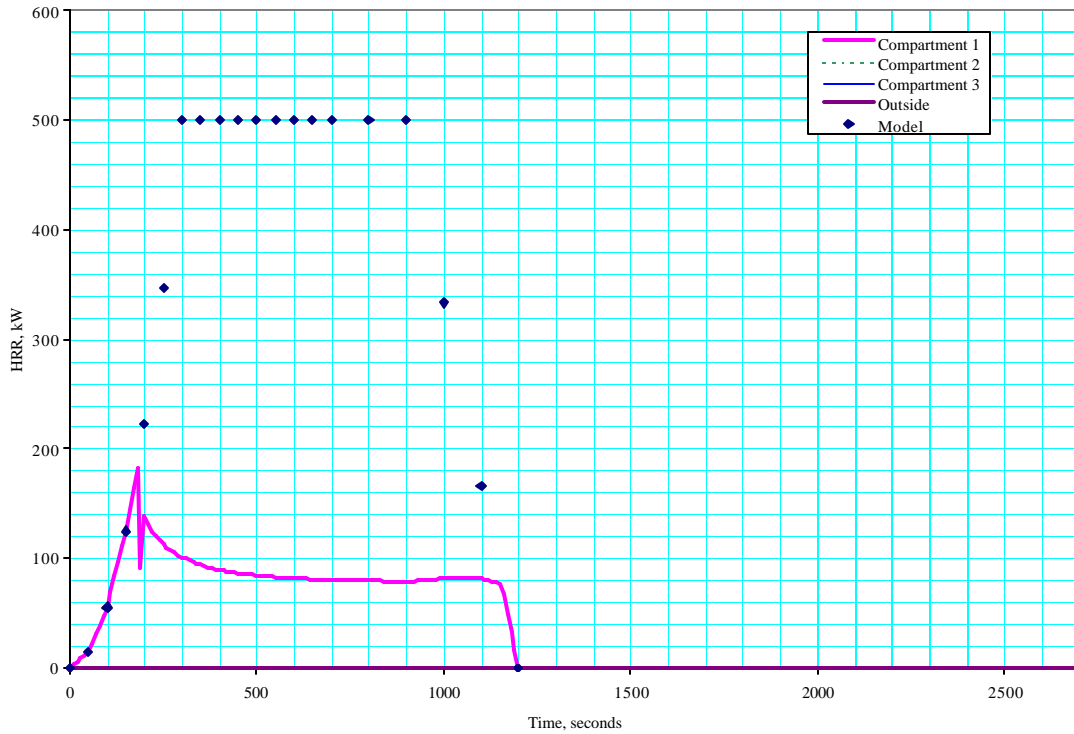
Figure 7-14. Heat Release Rates For Reduced Room Size (CAB044.DAT)
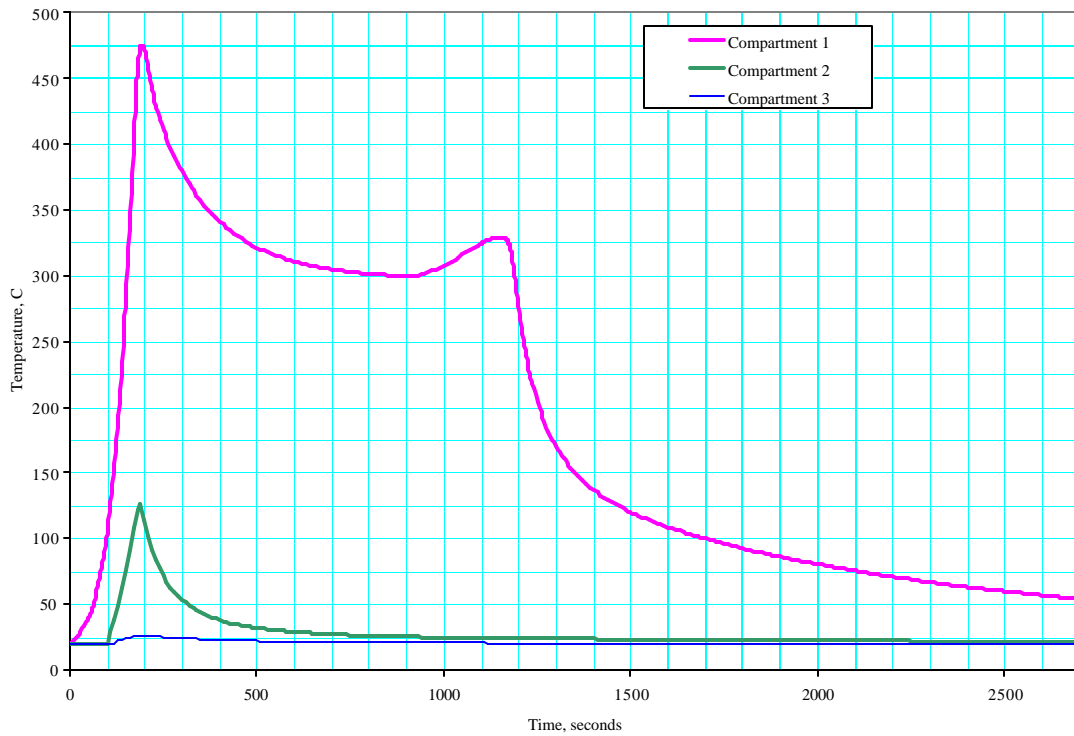
Figure 7-15. Upper Layer Temperatures For 750kw Fire (CAB045.DAT)
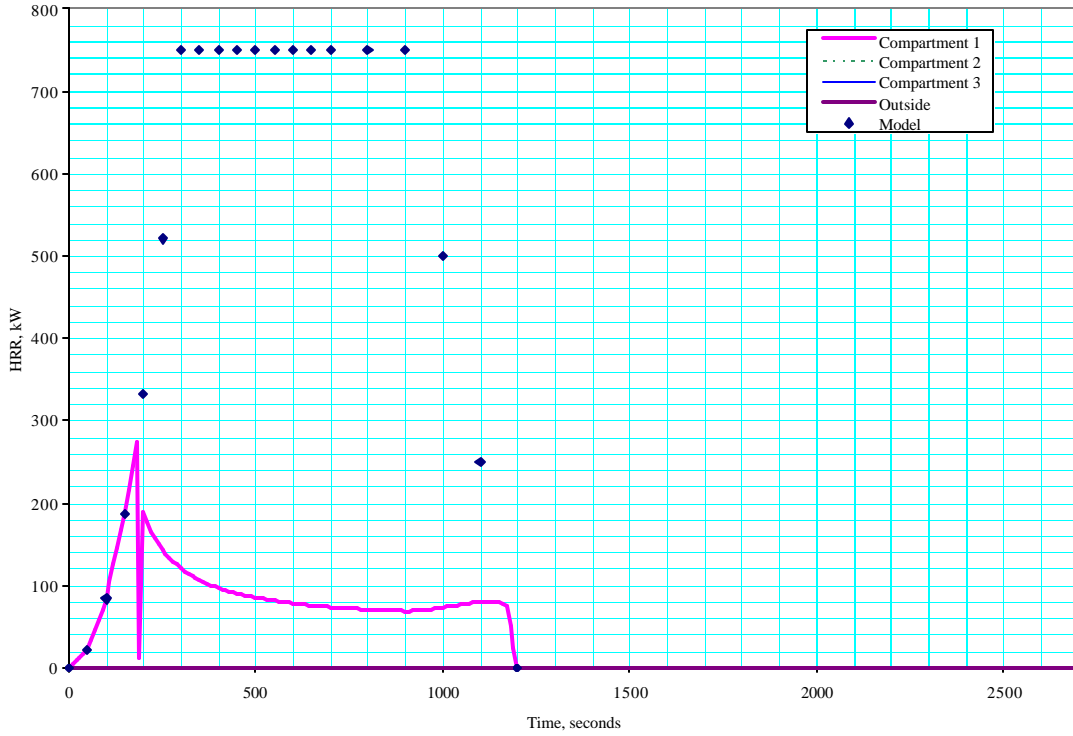
Figure 7-16. Heat Release Rates For 750kw Fire (CAB045.DAT)

8.0   ACRONYMS AND DEFINITIONS

ACRONYMS:

AHJ	Authority Having Jurisdiction
ALOHA	Areal Locations of Hazardous Atmospheres (designated toolbox software)
ANSI	American National Standards Institute
ARF	Airborne Release Fraction
ARR	Airborne Release Rate
BR	Breathing Rate
CEDE	Committed Effective Dose Equivalent (see definition below)
CFAST	Consolidated Fire and Smoke Transport Model (designated toolbox software)
CFR	Code of Federal Regulations
DBA	Design Basis Accident
DCF	Dose Conversion Factor
DNFSB	Defense Nuclear Facilities Safety Board
DoD	Department of Defense
DOE	Department of Energy
DR	Damage Ratio
DSA	Documented Safety Analysis
EFCOG	Energy Facility Contractors Group
EH	DOE Office of Environment, Safety and Health
EM	DOE Office of Environmental Management
EPIcode	Emergency Prediction Information code (designated toolbox software)
GENII	Generalized Environmental Radiation Dosimetry Software System - Hanford Dosimetry System (Generation II) (designated toolbox software)
ICRP	International Commission for Radiological Protection
IDCF	Inhalation Dose Conversion Factor
IEEE	Institute of Electrical and Electronics Engineers
IP	Implementation Plan
ISO	International Organization for Standardization
LPF	Leak Path Factor
MACCS2	MELCOR Accident Consequence Code System 2 (designated toolbox software)
MAR	Material at Risk
MELCOR	Methods for Estimation of Leakages and Consequences of Releases (designated toolbox software)
NIST	National Institute of Standards and Technology
NNSA	National Nuclear Security Administration
NRC	Nuclear Regulatory Commission
RF	Respirable Fraction
SASG	Safety Analysis Software Group (see definition below)
SQA	Software Quality Assurance
ST	Source Term
TEDE	Total Effective Dose Equivalent (see definition below)
V&V	Verification and Validation
WSMS	Washington Safety Management Solutions

Selected Terms and Definitions

Committed Dose Equivalent ($H_{T,50}$) – The dose equivalent calculated to be received by a tissue or organ over a 50-year period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed dose equivalent is expressed in units of rem (or sievert) (1 rem = 0.01 sievert).

Committed Effective Dose Equivalent (CEDE) – The sum of the committed dose equivalents ($H_{T,50}$) over a fifty-year period to various organs or tissues in the body, each multiplied by the appropriate weighting factor (w_T) -- that is $H_{E,50} = \Sigma \; w_T \; H_{T,50}$. CEDE is applicable to exposure from internally deposited radionuclides.

Piloted ignition – Ignition of combustible gases or vapors by a pilot source of ignition (ASTM, 1999a).

Safety Analysis Software Group (SASG) – A group of technical experts formed by the Deputy Secretary in October 2000 in response to Technical Report 25 issued by the Defense Nuclear Facilities Safety Board (DNFSF). This group is responsible for determining the safety analysis and instrument and control (I&C) software needs to be fixed or replaced, establishing plans and cost estimates for remedial work, providing recommendations for permanent storage of the software and coordinating with the Nuclear Regulatory Commission on code assessment as appropriate.

Spontaneous ignition – Unpiloted ignition caused by an internal exothermic reaction (ASTM, 1999a).

Toolbox Codes – A small number of standard computer models (codes) supporting DOE safety analysis, having widespread use, and of appropriate qualification that are maintained, managed, and distributed by a central source. Toolbox codes meet minimum quality assurance criteria. They may be applied to support 10 CFR 830 DSAs provided the application domain and input parameters are valid. In addition to public domain software, commercial or proprietary software may also be considered. In addition to safety analysis software, design codes may also be included if there is a benefit to maintain centralized control of the codes [modified from DOE N 411.1].

Total Effective Dose Equivalent (TEDE) – The sum of the deep dose equivalent (from external exposure) and the committed effective dose equivalent (from internal exposure). Note that the TEDE is equivalent to the EDE. For purposes of compliance, deep dose equivalent to the whole body may be used as effective dose equivalent for external exposures.

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Appendix A　Fire Severity

Fire severity has historically been defined as the room average temperature as a function of time. This approach was developed in the early 1920s based on testing by Ingberg.[1] Based on this approach, a building with a combustible contents equivalent to 10 pounds of wood equivalent* would be expected to have an equivalent fire severity of 1 hour as defined in ASTM E-119.[2] If the loading were 20-psf, the equivalent severity would be 2-hours. The fire protection community still sometimes uses this approach as a fire severity metric[3] and for most fire-resistant construction materials the simplification provides reasonable results. (i.e., For a given structural element, the maximum internal temperature at the critical depth does not depend significantly on the temporal variation of the heat flux penetrating the element.) For metals and surfaces that are covered with metal, which are the more common situation in safety evaluations, the method is not appropriate and an alternate severity metric should be applied.[4] Thus, for most DSA work fire severity predications should be developed based on engineering fundamentals.

In defining the fire severity within a fire compartment the effect of the ventilation must be understood. The nominal effect is illustrated in Figure A-1. For relatively low ventilation rates, the temperature in the fire compartment decreases with decreasing ventilation. This occurs because the less air entering the compartment, the lower the combustion rate (i.e., chemical energy released in the compartment by combustion processes). Under such conditions the fire is described as ventilation limited and the energy release will be limited to approximately 3 MJ per kg of air entering the compartment.[5] As the ventilation rate is increased there is an optimum combustion state where the temperature is maximized. For flow rates above this optimum rate, the room temperature, and hence the fire severity, is lower. This lower severity occurs because the excess airflow tends to dilute the hot fire gases.

Fires occurring in an enclosure exhibit the interaction of several complicated phenomena. As shown Figure A-2 energy exits the compartment through the enclosure perimeter (walls, ceiling and floor), by convection with the combustion products through the door and other openings. Fresh air will enter the compartment through open doors, windows, ventilation systems and other leak paths. This fresh air will be relatively cool and will then to move towards the floor. The fire will tend to draw in this cooler air, thus supporting continued combustion and will pump combustion products and heated air towards the ceiling in a well-defined plume. The development of two distinct layers occurs in many fire enclosure fires, where the upper layer is relatively hot. Mass enters the hot layer via the fire plume and exits through doors and other openings. The lower layer is relatively cool and is maintained by the in flow of fresh air and the loss via the fire plume. With the exception of the plume, there is usually little exchange between the layers except where countercurrent flow is occurring at the enclosure boundaries.

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*　pounds of wood equivalent is an energy unit. It is equal to 8,000 Btu/pound or 19 MJ/kg.
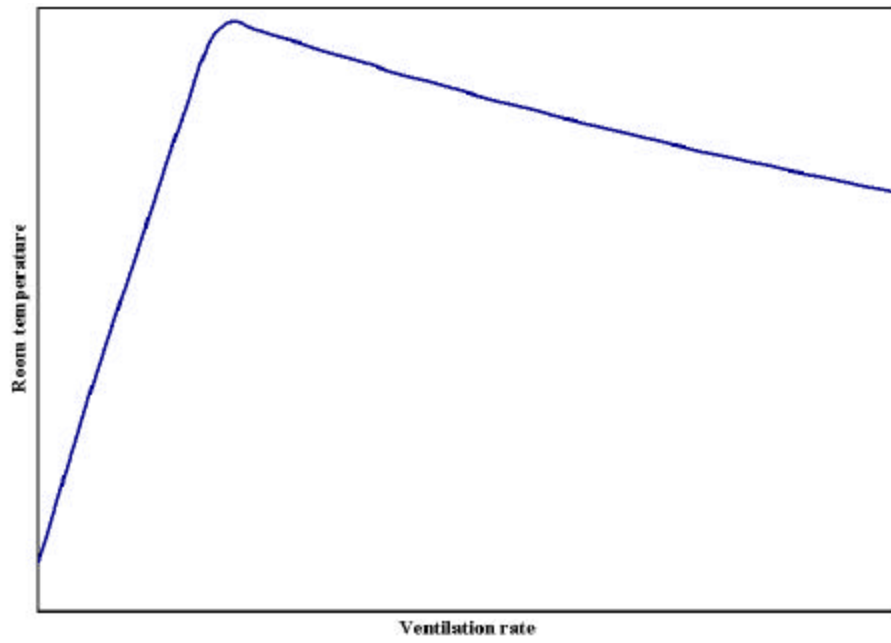
Figure A-1. Ventilation Effect On Fire Conditions
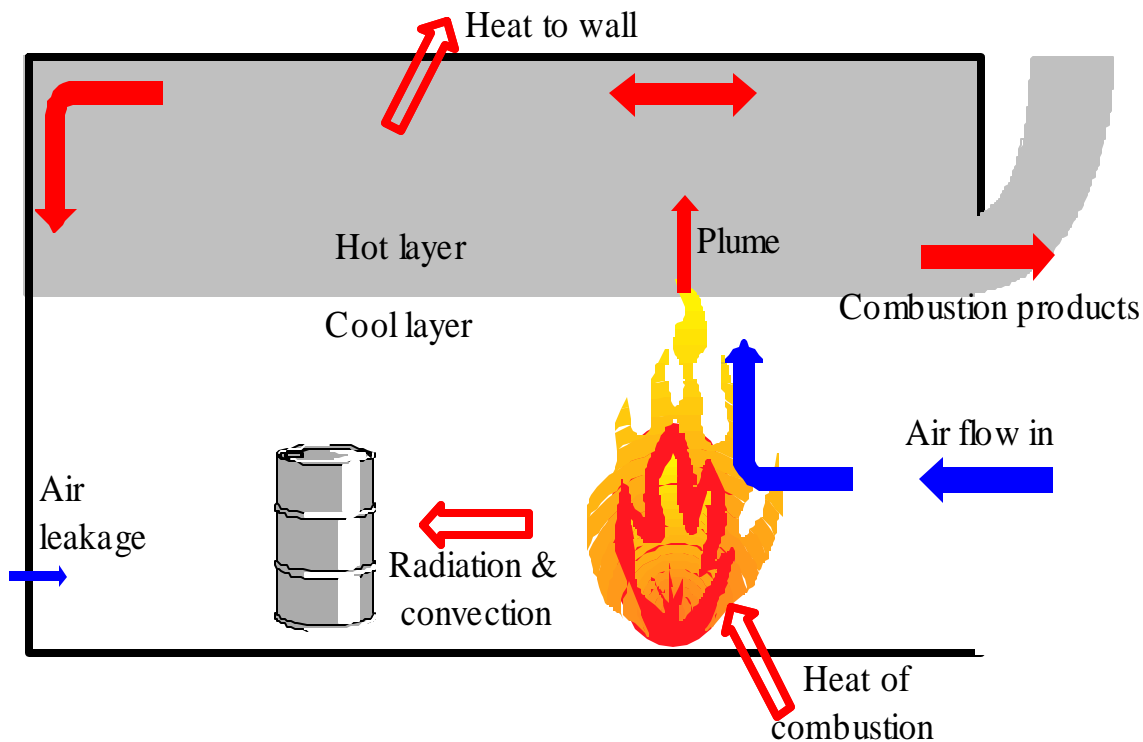
Figure A-2. Energy And Mass Flow Diagram For Compartment Fire

The height of the interface between the two layers is dependent on the combustion rate, the room ventilation (forced and natural) and the enclosure heat transfer properties. The greater the combustion rate, the lower the interface height will descend. If the interface height descends to contain the fire, the combustion rate in the compartment could decrease, however the pyrolysis rate will likely be unaffected. Under such conditions the excess pyrolate will often burn outside the compartment. (e.g., The luminous flames often observed above windows and doors).

The above discussion did not introduce the concept of multiple fire sources in the compartment. There are several mechanisms that can lead to ignition of secondary fires in the enclosure. Two will be presented. The first is ignition by thermal heating between the first burning object and a second "fuel package." There are many publications that discuss this ignition mechanism.[6] This will be the dominant propagation mechanism early in the fire prior to flashover, and in large rooms where flashover, backdraft and similar rapid ignition behaviors do not occur.

Flashover is the other predominate ignition mechanism. It is defined as "the rapid transition to a state of total surface involvement in a fire of combustible materials within an enclosure."[7] It is essentially a thermal instability phenomenon. There are multiple criteria that have been defined to predict flashover. These criteria will be discussed in a later section. The behavior of a compartment fire prior to flashover is very different from that observed after flashover. Prior to flashover the fuel type and geometry usually limit the combustion rate. In a post-flashover fire the combustion rate is limited by the ventilation rate. During the fully developed portion of a post-flashover the average air temperature in the enclosure is typically 700 to 1200°C. In

addition there will be regions in the room where combustion is occurring. In these localized areas flame temperatures will occur. These temperatures may range from 900 to 1500°C.[8, 9] Any DSA efforts should be careful to not confuse the widely published average room temperatures with the flame temperatures.

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Appendix B   Example Problem Input Data

BASE Case Fire (CAB042.DAT)

```
VERSN     3BASE CASE FOR EXAMPLE - FIRE
#VERSN 3 BASE CASE FOR EXAMPLE - FIRE
TIMES   2710     10      10      20      0
DUMPR CAB042.HI
ADUMP CAB042.CSV NFS
TAMB  293.150         101300. 0.000000
EAMB  293.150         101300. 0.000000
THRMF WSMSTH04.DF
HI/F  0.000000 0.000000 0.000000
WIDTH  3.0000  2.00000  3.00000
DEPTH  3.0000  2.00000  15.0000
HEIGH  2.4400  2.44000  2.44000
CEILI GYPSUM    GYPSUM    GYPSUM
WALLS GYPSUM    GYPSUM    GYPSUM
FLOOR CONC003  CONC003   CONC003
#CEILI GYPSUM   GYPSUM    GYPSUM
#WALLS GYPSUM   GYPSUM    GYPSUM
#FLOOR CONC003  CONC003   CONC003
HVENT  1  2  1 0.910000  2.130000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  1      0.00000       0.00000       0.00000       0.00000       0.00000
    0.00000       0.00000       0.00000       0.00000      0.00000      0.00000
    0.00000       0.00000       0.00000       0.00000      0.00000      0.00000
    0.00000       0.00000       0.00000
HVENT  1  2  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  2      1.00000       1.00000       1.00000       1.00000       1.00000
    1.00000       1.00000       1.00000       1.00000      1.00000      1.00000
    1.00000       1.00000       1.00000       1.00000      1.00000      1.00000
    1.00000       1.00000       1.00000
HVENT  1  3  3 1.20000  1.80000   0.90000 0.000000 0.000000 0.000000
CVENT  1  3  3      0.00000       0.00000       0.00000       0.00000       0.00000
    0.00000       0.00000       0.00000       0.00000      0.00000      0.00000
    0.00000       0.00000       0.00000       0.00000      0.00000      0.00000
    0.00000       0.00000       0.00000
HVENT  2  3  1 0.910000  2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  2  3  1      0.00000       0.00000       0.00000       0.00000       0.00000
    0.00000       0.00000       0.00000       0.00000      0.00000      0.00000
    0.00000       0.00000       0.00000       0.00000      0.00000      0.00000
    0.00000       0.00000       0.00000
HVENT  2  3  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  2  3  2      1.00000       1.00000       1.00000       1.00000       1.00000
    1.00000       1.00000       1.00000       1.00000      1.00000      1.00000
    1.00000       1.00000       1.00000       1.00000      1.00000      1.00000
    1.00000       1.00000       1.00000
HVENT  3  4  1 0.910000  2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  3  4  1      0.00000       0.00000       0.00000       0.00000       0.00000
    0.00000       0.00000       0.00000       0.00000      0.00000      0.00000
    0.00000       0.00000       0.00000       0.00000      0.00000      0.00000
    0.00000       0.00000       0.00000
HVENT  3  4  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  3  4  2      1.00000       1.00000       1.00000       1.00000       1.00000
    1.00000       1.00000       1.00000       1.00000      1.00000      1.00000
    1.00000       1.00000       1.00000       1.00000      1.00000      1.00000
    1.00000       1.00000       1.00000
MVDCT  1  2  20.0000 0.120000 0.000150000   2.00000 0.120000 4.000000 0.120000
MVFAN  2  3 0.000000  500.000   0.038 0.00000 0.00000 0.000000 0.000000
MVOPN  1  1 V  1.00000 0.100000
MVOPN  4  3 H  10.0000 0.400000
```

```
INELV  2  1.00000
CHEMI  28.0000  50.0000  12.0000 4.00000E+007  293.150   393.150 0.300000
LFBO 1
LFBT 2
CJET ALL
FPOS -1.00000 -1.00000 0.000000
FTIME        50.000        100.000       150.000       200.000       250.000
       300.000       350.000       400.000       450.000       500.000       550.000
       600.000       650.000       700.000       800.000       900.000      1000.000
      1100.000      1200.000
FMASS   0.000E+000  3.472E-004  1.389E-003  3.125E-003  5.556E-003  8.681E-003
      1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.250E-002
      1.250E-002  1.250E-002  1.250E-002  1.250E-002  8.333E-003  4.167E-003  0.000E+000
FQDOT   0.000E+000  1.389E+004  5.556E+004  1.250E+005  2.222E+005  3.472E+005
      5.000E+005  5.000E+005  5.000E+005  5.000E+005  5.000E+005  5.000E+005  5.000E+005
      5.000E+005  5.000E+005  5.000E+005  5.000E+005  3.333E+005  1.667E+005  0.000E+000
HCR       0.1670000       0.1670000       0.1670000       0.1670000       0.1670000
       0.1670000       0.1670000       0.1670000       0.1670000       0.1670000       0.1670000
       0.1670000       0.1670000       0.1670000       0.1670000       0.1670000       0.1670000
       0.1670000       0.1670000       0.1670000
SELECT 1 2 3
#GRAPHICS ON
DEVICE 1
WINDOW    0.     0. -100. 1280. 1024. 1100.
LABEL  1 970.  960.    0. 1231. 1005.   10. 15 00:00:00 0.00  0.00
GRAPH  1 100.   50.    0.  600.  475.   10. 3 TIME HEIGHT
GRAPH  2 100.  550.    0.  600.  940.   10. 3 TIME CELSIUS
GRAPH  3 720.   50.    0. 1250.  475.   10. 3 TIME FIRE_SIZE(kW)
GRAPH  4 720.  550.    0. 1250.  940.   10. 3 TIME O|D2|O()
HEAT    0 0 0 0 3   1 U
HEAT    0 0 0 0 3   2 U
HEAT    0 0 0 0 3   3 U
TEMPE   0 0 0 0 2   1 U
TEMPE   0 0 0 0 2   2 U
TEMPE   0 0 0 0 2   3 U
INTER   0 0 0 0 1   1 U
INTER   0 0 0 0 1   2 U
INTER   0 0 0 0 1   3 U
O2      0 0 0 0 4   1 U
O2      0 0 0 0 4   2 U
O2      0 0 0 0 4   3 U
```

Appendix C   Example Problem Input Data, No-Fire Solution (CAB041.DAT)

```
VERSN    3BASE CASE FOR EXAMPLE - NO FIRE
#VERSN 3 BASE CASE FOR EXAMPLE - NO FIRE
TIMES  2710    10    10    20    0
DUMPR CAB041.HI
ADUMP CAB041.CSV NFS
TAMB  293.150        101300. 0.000000
EAMB  293.150        101300. 0.000000
THRMF WSMSTH04.DF
HI/F 0.000000 0.000000 0.000000
WIDTH  3.0000  2.00000  3.00000
DEPTH  3.0000  2.00000  15.0000
HEIGH  2.5000  2.44000  2.44000
CEILI GYPSUM    GYPSUM    GYPSUM
WALLS GYPSUM    GYPSUM    GYPSUM
FLOOR CONC003   CONC003  CONC003
#CEILI GYPSUM    GYPSUM    GYPSUM
#WALLS GYPSUM    GYPSUM    GYPSUM
#FLOOR CONC003  CONC003   CONC003
HVENT  1  2  1 0.910000  2.130000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  1      0.00000      0.00000      0.00000      0.00000      0.00000
    0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
    0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
    0.00000      0.00000      0.00000
HVENT  1  2  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  2      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000
HVENT  1  3  3 1.20000  1.80000  0.90000 0.000000 0.000000 0.000000
CVENT  1  3  3      0.00000      0.00000      0.00000      0.00000      0.00000
    0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
    0.00000      0.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000
HVENT  2  3  1 0.910000  2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  2  3  1      0.00000      0.00000      0.00000      0.00000      0.00000
    0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
    0.00000      0.00000      0.00000      0.00000      0.00000      0.00000
    0.00000      0.00000      0.00000
HVENT  2  3  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  2  3  2      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000
HVENT  3  4  1 0.910000  2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  3  4  1      0.00000      0.00000      0.00000      0.00000      0.00000
    0.00000      0.00000      0.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000
HVENT  3  4  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  3  4  2      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000      1.00000      1.00000      1.00000
    1.00000      1.00000      1.00000
MVDCT  1  2  20.0000 0.120000 0.000150000  2.00000 0.120000 4.000000 0.120000
MVFAN  2  3 0.000000  500.000  0.038 0.00000 0.00000 0.000000 0.000000
MVOPN  1  1 V  1.00000 0.100000
MVOPN  4  3 H  10.0000 0.400000
```

```
INELV  2  1.00000
CHEMI  28.0000  50.0000  12.0000 4.00000E+007  293.150  393.150 0.300000
LFBO 1
LFBT 2
CJET ALL
FPOS -1.00000 -1.00000 0.000000
FTIME         50.000        100.000        150.000        200.000        250.000
        300.000        350.000        400.000        450.000        500.000        550.000
        600.000        650.000        700.000        800.000        900.000       1000.000
       1100.000       1200.000
FMASS   0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000
        0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000
        0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000
FQDOT   0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000
        0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000
        0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000  0.000E+000
HCR        0.1670000      0.1670000       0.1670000       0.1670000       0.1670000
        0.1670000      0.1670000      0.1670000      0.1670000      0.1670000      0.1670000
        0.1670000      0.1670000      0.1670000      0.1670000      0.1670000      0.1670000
        0.1670000      0.1670000      0.1670000
SELECT 1 2 3
#GRAPHICS ON
DEVICE 1
WINDOW    0.     0. -100. 1280. 1024. 1100.
LABEL  1 970.  960.    0. 1231. 1005.   10. 15 00:00:00 0.00  0.00
GRAPH  1 100.   50.    0.  600.  475.   10. 3 TIME HEIGHT
GRAPH  2 100.  550.    0.  600.  940.   10. 3 TIME CELSIUS
GRAPH  3 720.   50.    0. 1250.  475.   10. 3 TIME FIRE_SIZE(kW)
GRAPH  4 720.  550.    0. 1250.  940.   10. 3 TIME O|D2|O()
HEAT   0 0 0 0 3    1 U
HEAT   0 0 0 0 3    2 U
HEAT   0 0 0 0 3    3 U
TEMPE  0 0 0 0 2    1 U
TEMPE  0 0 0 0 2    2 U
TEMPE  0 0 0 0 2    3 U
INTER  0 0 0 0 1    1 U
INTER  0 0 0 0 1    2 U
INTER  0 0 0 0 1    3 U
O2     0 0 0 0 4    1 U
O2     0 0 0 0 4    2 U
O2     0 0 0 0 4    3 U
```

Appendix D   Example Problem Input Data, Window Failure Fire (CAB043.DAT)

```
VERSN    3BASE CASE FOR EXAMPLE - WINDOW BREAKS
#VERSN 3 BASE CASE FOR EXAMPLE - WINDOW BREAKS
TIMES  2710    10     10     20      0
DUMPR CAB043.HI
ADUMP CAB043.CSV NFS
TAMB  293.150        101300. 0.000000
EAMB  293.150        101300. 0.000000
THRMF WSMSTH04.DF
HI/F 0.000000 0.000000 0.000000
WIDTH  3.0000  2.00000  3.00000
DEPTH  3.0000  2.00000  15.0000
HEIGH  2.4400  2.44000  2.44000
CEILI GYPSUM    GYPSUM    GYPSUM
WALLS GYPSUM    GYPSUM    GYPSUM
FLOOR CONC003  CONC003  CONC003
#CEILI GYPSUM    GYPSUM    GYPSUM
#WALLS GYPSUM    GYPSUM    GYPSUM
#FLOOR CONC003  CONC003  CONC003
HVENT  1  2  1 0.910000  2.130000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  1       0.00000       0.00000       0.00000       0.00000       0.00000
      0.00000        0.00000       0.00000       0.00000      0.00000      0.00000
      0.00000        0.00000       0.00000       0.00000      0.00000      0.00000
      0.00000        0.00000       0.00000
HVENT  1  2  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  2       1.00000       1.00000       1.00000       1.00000       1.00000
      1.00000        1.00000       1.00000       1.00000      1.00000      1.00000
      1.00000        1.00000       1.00000       1.00000      1.00000      1.00000
      1.00000        1.00000       1.00000
HVENT  1  3  3 1.20000  1.80000  0.90000 0.000000 0.000000 0.000000
CVENT  1  3  3       0.00000       0.00000       0.00000       0.00000       0.00000
      0.00000        0.00000       0.00000       0.00000      0.00000      0.00000
      0.00000        0.00000       0.00000       0.00000      1.00000      1.00000
      1.00000        1.00000       1.00000
HVENT  2  3  1 0.910000  2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  2  3  1       0.00000       0.00000       0.00000       0.00000       0.00000
      0.00000        0.00000       0.00000       0.00000      0.00000      0.00000
      0.00000        0.00000       0.00000       0.00000      0.00000      0.00000
      0.00000        0.00000       0.00000
HVENT  2  3  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  2  3  2       1.00000       1.00000       1.00000       1.00000       1.00000
      1.00000        1.00000       1.00000       1.00000      1.00000      1.00000
      1.00000        1.00000       1.00000       1.00000      1.00000      1.00000
      1.00000        1.00000       1.00000
HVENT  3  4  1 0.910000  2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  3  4  1       0.00000       0.00000       0.00000       0.00000       0.00000
      0.00000        0.00000       1.00000       1.00000      1.00000      1.00000
      1.00000        1.00000       1.00000       1.00000      1.00000      1.00000
      1.00000        1.00000       1.00000
HVENT  3  4  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  3  4  2       1.00000       1.00000       1.00000       1.00000       1.00000
      1.00000        1.00000       1.00000       1.00000      1.00000      1.00000
      1.00000        1.00000       1.00000       1.00000      1.00000      1.00000
      1.00000        1.00000       1.00000
MVDCT  1  2  20.0000 0.120000 0.000150000  2.00000 0.120000 4.000000 0.120000
MVFAN  2  3 0.000000  500.000  0.038 0.00000 0.00000 0.000000 0.000000
MVOPN  1  1 V  1.00000 0.100000
MVOPN  4  3 H  10.0000 0.400000
```

```
INELV  2  1.00000
CHEMI  28.0000  50.0000  12.0000 4.00000E+007  293.150   393.150 0.300000
LFBO 1
LFBT 2
CJET ALL
FPOS -1.00000 -1.00000 0.000000
FTIME         50.000         100.000         150.000         200.000         250.000
      300.000         350.000         400.000         450.000         500.000         550.000
      600.000         650.000         700.000         800.000         900.000        1000.000
     1100.000        1200.000
FMASS   0.000E+000  3.472E-004  1.389E-003  3.125E-003  5.556E-003  8.681E-003
      1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.250E-002
      1.250E-002  1.250E-002  1.250E-002  1.250E-002  8.333E-003  4.167E-003  0.000E+000
FQDOT   0.000E+000  1.389E+004  5.556E+004  1.250E+005  2.222E+005  3.472E+005
      5.000E+005  5.000E+005  5.000E+005  5.000E+005  5.000E+005  5.000E+005  5.000E+005
      5.000E+005  5.000E+005  5.000E+005  5.000E+005  3.333E+005  1.667E+005  0.000E+000
HCR        0.1670000       0.1670000       0.1670000       0.1670000       0.1670000
      0.1670000       0.1670000       0.1670000       0.1670000       0.1670000       0.1670000
      0.1670000       0.1670000       0.1670000       0.1670000       0.1670000       0.1670000
      0.1670000       0.1670000       0.1670000
SELECT 1 2 3
#GRAPHICS ON
DEVICE 1
WINDOW    0.    0. -100. 1280. 1024. 1100.
LABEL  1 970.  960.    0. 1231. 1005.   10. 15 00:00:00 0.00   0.00
GRAPH  1 100.   50.    0.  600.  475.   10. 3 TIME HEIGHT
GRAPH  2 100.  550.    0.  600.  940.   10. 3 TIME CELSIUS
GRAPH  3 720.   50.    0. 1250.  475.   10. 3 TIME FIRE_SIZE(kW)
GRAPH  4 720.  550.    0. 1250.  940.   10. 3 TIME O|D2|O()
HEAT   0 0 0 0 3   1 U
HEAT   0 0 0 0 3   2 U
HEAT   0 0 0 0 3   3 U
TEMPE  0 0 0 0 2   1 U
TEMPE  0 0 0 0 2   2 U
TEMPE  0 0 0 0 2   3 U
INTER  0 0 0 0 1   1 U
INTER  0 0 0 0 1   2 U
INTER  0 0 0 0 1   3 U
O2     0 0 0 0 4   1 U
O2     0 0 0 0 4   2 U
O2     0 0 0 0 4   3 U
```

Appendix E   Example Problem Input Data, Reduced Room Size Fire (CAB044.DAT)

```
VERSN    3BASE CASE FOR EXAMPLE - REDUCED VOLUME
#VERSN 3 BASE CASE FOR EXAMPLE - REDUCED VOLUME
TIMES   2710     10     10      20      0
DUMPR CAB044.HI
ADUMP CAB044.CSV NFS
TAMB  293.150          101300. 0.000000
EAMB  293.150          101300. 0.000000
THRMF WSMSTH04.DF
HI/F  0.000000 0.000000 0.000000
WIDTH  3.0000   2.00000   3.00000
DEPTH  2.0000   2.00000   15.0000
HEIGH  2.4400   2.44000   2.44000
CEILI GYPSUM    GYPSUM    GYPSUM
WALLS GYPSUM    GYPSUM    GYPSUM
FLOOR CONC003   CONC003   CONC003
#CEILI GYPSUM    GYPSUM    GYPSUM
#WALLS GYPSUM    GYPSUM    GYPSUM
#FLOOR CONC003   CONC003   CONC003
HVENT  1   2   1 0.910000   2.130000 0.000000 0.000000 0.000000 0.000000
CVENT  1   2   1       0.00000        0.00000        0.00000        0.00000        0.00000
      0.00000         0.00000        0.00000        0.00000       0.00000       0.00000
      0.00000         0.00000        0.00000        0.00000       0.00000       0.00000
      0.00000         0.00000        0.00000
HVENT  1   2   2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  1   2   2       1.00000        1.00000        1.00000        1.00000        1.00000
      1.00000         1.00000        1.00000        1.00000       1.00000       1.00000
      1.00000         1.00000        1.00000        1.00000       1.00000       1.00000
      1.00000         1.00000        1.00000
HVENT  1   3   3 1.20000   1.80000   0.90000 0.000000 0.000000 0.000000
CVENT  1   3   3       0.00000        0.00000        0.00000        0.00000        0.00000
      0.00000         0.00000        0.00000        0.00000       0.00000       0.00000
      0.00000         0.00000        0.00000        0.00000       0.00000       0.00000
      0.00000         0.00000        0.00000
HVENT  2   3   1 0.910000   2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  2   3   1       0.00000        0.00000        0.00000        0.00000        0.00000
      0.00000         0.00000        0.00000        0.00000       0.00000       0.00000
      0.00000         0.00000        0.00000        0.00000       0.00000       0.00000
      0.00000         0.00000        0.00000
HVENT  2   3   2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  2   3   2       1.00000        1.00000        1.00000        1.00000        1.00000
      1.00000         1.00000        1.00000        1.00000       1.00000       1.00000
      1.00000         1.00000        1.00000        1.00000       1.00000       1.00000
      1.00000         1.00000        1.00000
HVENT  3   4   1 0.910000   2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  3   4   1       0.00000        0.00000        0.00000        0.00000        0.00000
      0.00000         0.00000        0.00000        0.00000       0.00000       0.00000
      0.00000         0.00000        0.00000        0.00000       0.00000       0.00000
      0.00000         0.00000        0.00000
HVENT  3   4   2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  3   4   2       1.00000        1.00000        1.00000        1.00000        1.00000
      1.00000         1.00000        1.00000        1.00000       1.00000       1.00000
      1.00000         1.00000        1.00000        1.00000       1.00000       1.00000
      1.00000         1.00000        1.00000
MVDCT  1   2  20.0000 0.120000 0.000150000  2.00000 0.120000 4.000000 0.120000
MVFAN  2   3 0.000000  500.000  0.038 0.00000 0.00000 0.000000 0.000000
MVOPN  1   1 V  1.00000 0.100000
MVOPN  4   3 H  10.0000 0.400000
```

```
INELV  2  1.00000
CHEMI  28.0000  50.0000  12.0000 4.00000E+007  293.150   393.150 0.300000
LFBO 1
LFBT 2
CJET ALL
FPOS -1.00000 -1.00000 0.000000
FTIME         50.000        100.000        150.000       200.000        250.000
     300.000        350.000        400.000       450.000        500.000        550.000
     600.000        650.000        700.000       800.000        900.000       1000.000
     1100.000       1200.000
FMASS   0.000E+000  3.472E-004  1.389E-003  3.125E-003  5.556E-003  8.681E-003
     1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.250E-002  1.250E-002
     1.250E-002  1.250E-002  1.250E-002  1.250E-002  8.333E-003  4.167E-003  0.000E+000
FQDOT   0.000E+000  1.389E+004  5.556E+004  1.250E+005  2.222E+005  3.472E+005
     5.000E+005  5.000E+005  5.000E+005  5.000E+005  5.000E+005  5.000E+005  5.000E+005
     5.000E+005  5.000E+005  5.000E+005  5.000E+005  3.333E+005  1.667E+005  0.000E+000
HCR       0.1670000      0.1670000      0.1670000      0.1670000      0.1670000
        0.1670000      0.1670000      0.1670000      0.1670000      0.1670000      0.1670000
        0.1670000      0.1670000      0.1670000      0.1670000      0.1670000      0.1670000
        0.1670000      0.1670000      0.1670000
SELECT 1 2 3
#GRAPHICS ON
DEVICE 1
WINDOW    0.    0. -100. 1280. 1024. 1100.
LABEL  1 970.  960.    0. 1231. 1005.   10. 15 00:00:00 0.00  0.00
GRAPH  1 100.   50.    0.  600.  475.   10. 3 TIME HEIGHT
GRAPH  2 100.  550.    0.  600.  940.   10. 3 TIME CELSIUS
GRAPH  3 720.   50.    0. 1250.  475.   10. 3 TIME FIRE_SIZE(kW)
GRAPH  4 720.  550.    0. 1250.  940.   10. 3 TIME O|D2|O()
HEAT   0 0 0 0 3   1 U
HEAT   0 0 0 0 3   2 U
HEAT   0 0 0 0 3   3 U
TEMPE  0 0 0 0 2   1 U
TEMPE  0 0 0 0 2   2 U
TEMPE  0 0 0 0 2   3 U
INTER  0 0 0 0 1   1 U
INTER  0 0 0 0 1   2 U
INTER  0 0 0 0 1   3 U
O2     0 0 0 0 4   1 U
O2     0 0 0 0 4   2 U
O2     0 0 0 0 4   3 U
```

Appendix F   Example Problem Input Data, 750 kW Fire (CAB045.DAT)

```
VERSN     3BASE CASE FOR EXAMPLE - HIGH FIRE
#VERSN 3 BASE CASE FOR EXAMPLE - HIGH FIRE
TIMES  2710     10     10     20      0
DUMPR CAB045.HI
ADUMP CAB045.CSV NFS
TAMB  293.150          101300. 0.000000
EAMB  293.150          101300. 0.000000
THRMF WSMSTH04.DF
HI/F  0.000000 0.000000 0.000000
WIDTH  3.0000  2.00000  3.00000
DEPTH  3.0000  2.00000  15.0000
HEIGH  2.4400  2.44000  2.44000
CEILI GYPSUM    GYPSUM    GYPSUM
WALLS GYPSUM    GYPSUM    GYPSUM
FLOOR CONC003   CONC003   CONC003
#CEILI GYPSUM    GYPSUM    GYPSUM
#WALLS GYPSUM    GYPSUM    GYPSUM
#FLOOR CONC003   CONC003   CONC003
HVENT  1  2  1 0.910000   2.130000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  1       0.00000        0.00000        0.00000        0.00000        0.00000
     0.00000        0.00000        0.00000        0.00000      0.00000      0.00000
     0.00000        0.00000        0.00000        0.00000      0.00000      0.00000
     0.00000        0.00000        0.00000
HVENT  1  2  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  1  2  2       1.00000        1.00000        1.00000        1.00000        1.00000
     1.00000        1.00000        1.00000        1.00000      1.00000      1.00000
     1.00000        1.00000        1.00000        1.00000      1.00000      1.00000
     1.00000        1.00000        1.00000
HVENT  1  3  3 1.20000   1.80000   0.90000 0.000000 0.000000 0.000000
CVENT  1  3  3       0.00000        0.00000        0.00000        0.00000        0.00000
     0.00000        0.00000        0.00000        0.00000      0.00000      0.00000
     0.00000        0.00000        0.00000        0.00000      0.00000      0.00000
     0.00000        0.00000        0.00000
HVENT  2  3  1 0.910000   2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  2  3  1       0.00000        0.00000        0.00000        0.00000        0.00000
     0.00000        0.00000        0.00000        0.00000      0.00000      0.00000
     0.00000        0.00000        0.00000        0.00000      0.00000      0.00000
     0.00000        0.00000        0.00000
HVENT  2  3  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  2  3  2       1.00000        1.00000        1.00000        1.00000        1.00000
     1.00000        1.00000        1.00000        1.00000      1.00000      1.00000
     1.00000        1.00000        1.00000        1.00000      1.00000      1.00000
     1.00000        1.00000        1.00000
HVENT  3  4  1 0.910000   2.13000 0.000000 0.000000 0.000000 0.000000
CVENT  3  4  1       0.00000        0.00000        0.00000        0.00000        0.00000
     0.00000        0.00000        0.00000        0.00000      0.00000      0.00000
     0.00000        0.00000        0.00000        0.00000      0.00000      0.00000
     0.00000        0.00000        0.00000
HVENT  3  4  2 0.910000 0.0095000 0.000000 0.000000 0.000000 0.000000
CVENT  3  4  2       1.00000        1.00000        1.00000        1.00000        1.00000
     1.00000        1.00000        1.00000        1.00000      1.00000      1.00000
     1.00000        1.00000        1.00000        1.00000      1.00000      1.00000
     1.00000        1.00000        1.00000
MVDCT  1  2  20.0000 0.120000 0.000150000  2.00000 0.120000 4.000000 0.120000
MVFAN  2  3 0.000000   500.000   0.038 0.00000 0.00000 0.000000 0.000000
MVOPN  1  1 V  1.00000 0.100000
MVOPN  4  3 H  10.0000 0.400000
```

```
INELV  2  1.00000
CHEMI  28.0000  50.0000  12.0000 4.00000E+007  293.150  393.150 0.300000
LFBO 1
LFBT 2
CJET ALL
FPOS -1.00000 -1.00000 0.000000
FTIME         50.000         100.000         150.000         200.000         250.000
      300.000        350.000        400.000        450.000        500.000        550.000
      600.000        650.000        700.000        800.000        900.000       1000.000
     1100.000       1200.000
FMASS   0.000E+000  5.208E-004  2.083E-003  4.688E-003  8.333E-003  1.302E-002
      1.875E-002  1.875E-002  1.875E-002  1.875E-002  1.875E-002  1.875E-002  1.875E-002
      1.875E-002  1.875E-002  1.875E-002  1.875E-002  1.250E-002  6.250E-003  0.000E+000
FQDOT   0.000E+000  2.083E+004  8.333E+004  1.875E+005  3.333E+005  5.208E+005
      7.500E+005  7.500E+005  7.500E+005  7.500E+005  7.500E+005  7.500E+005  7.500E+005
      7.500E+005  7.500E+005  7.500E+005  7.500E+005  5.000E+005  2.500E+005  0.000E+000
HCR       0.1670000      0.1670000      0.1670000      0.1670000      0.1670000
      0.1670000      0.1670000      0.1670000      0.1670000      0.1670000      0.1670000
      0.1670000      0.1670000      0.1670000      0.1670000      0.1670000      0.1670000
      0.1670000      0.1670000      0.1670000
SELECT 1 2 3
#GRAPHICS ON
DEVICE 1
WINDOW    0.    0. -100. 1280. 1024. 1100.
LABEL  1 970.  960.    0. 1231. 1005.   10. 15 00:00:00 0.00  0.00
GRAPH  1 100.   50.    0.  600.  475.   10. 3 TIME HEIGHT
GRAPH  2 100.  550.    0.  600.  940.   10. 3 TIME CELSIUS
GRAPH  3 720.   50.    0. 1250.  475.   10. 3 TIME FIRE_SIZE(kW)
GRAPH  4 720.  550.    0. 1250.  940.   10. 3 TIME O|D2|O()
HEAT   0 0 0 0 3    1 U
HEAT   0 0 0 0 3    2 U
HEAT   0 0 0 0 3    3 U
TEMPE  0 0 0 0 2    1 U
TEMPE  0 0 0 0 2    2 U
TEMPE  0 0 0 0 2    3 U
INTER  0 0 0 0 1    1 U
INTER  0 0 0 0 1    2 U
INTER  0 0 0 0 1    3 U
O2     0 0 0 0 4    1 U
O2     0 0 0 0 4    2 U
O2     0 0 0 0 4    3 U
```

Appendix G   Example Problem Text File Results, Base Case Fire (CAB042.LST)

```
**      CFAST  Version   3.1.7  Run  8/28/ 2    **
**                                              **
**           A contribution of the              **
**  National Institute of Standards and Technology **
**           Gaithersburg, MD  20899            **
**           Not subject to Copyright           **
**                                              **
**      DOS/4GW Memory Manager Copyright (c)     **
**           Rational System, Inc (1993)        **

CFAST Version   3.1.7    BASE CASE FOR EXAMPLE - FIRE

Data file is cab042.dat    (Checksum 000000000)


OVERVIEW

Compartments   Doors, ...   Ceil. Vents, ...   MV Connects

     3             7               0                 2

Simulation   Print     History    Restart
Time         Interval  Interval   Interval
(s)          (s)       (s)        (s)

2710         10        10         0

Ceiling jet is on for all
History file is CAB042.HI

AMBIENT CONDITIONS

Interior      Interior    Exterior      Exterior    Station     Wind      Wind          Wind
Temperature   Pressure    Temperature   Pressure    Elevation   Speed     Ref. Height   Power
(K)           (Pa)        (K)           (Pa)        (m)         (m/s)     (m)

293.          101300.     293.          101300.     0.00        0.0       10.0          0.16
```

COMPARTMENTS

Compartment	Width (m)	Depth (m)	Height (m)	Area (m^2)	Volume (m^3)	Ceiling Height (m)	Floor Height (m)
1	3.00	3.00	2.44	9.00	21.96	2.44	0.00
2	2.00	2.00	2.44	4.00	9.76	2.44	0.00
3	3.00	15.00	2.44	45.00	109.80	2.44	0.00

VENT CONNECTIONS

Horizontal Natural Flow Connections (Doors, Windows, ...)

From Compartment	To Compartment	Vent Number (m)	Width (m)	Sill Height (m)	Soffit Height (m)	Abs. Sill (m)	Abs. Soffit (m)	Area (m^2)
1	2	1	0.91	0.00	2.13	0.00	2.13	1.94
1	2	2	0.91	0.00	0.01	0.00	0.01	0.01
1	3	3	1.20	0.90	1.80	0.90	1.80	1.08
2	3	1	0.91	0.00	2.13	0.00	2.13	1.94
2	3	2	0.91	0.00	0.01	0.00	0.01	0.01
3	Outside	1	0.91	0.00	2.13	0.00	2.13	1.94
3	Outside	2	0.91	0.00	0.01	0.00	0.01	0.01

There are no vertical natural flow connections

Mechanical Flow Connections (Fans, Ducts, ...)

Connections and Ducts

System	From	To	From Elev. (m)	To Elev. (m)	Length (m)	Area (m^2)	Rough (mm)
1	Comp 1	Node 1	1.00	1.00		0.10	

Fans

System	From	To	From Elev. (m)	To Elev. (m)	Fan Number	Minimum (Pa)	Maximum (Pa)	Fan Curve
1	Node 2	Node 3	1.00	10.00	1	0.00	500.00	3.80E-02 0.00E+00
0.00E+00 0.00E+00	Node 3	Outside	10.00	10.00		0.40		

THERMAL PROPERTIES

Compartment	Ceiling	Wall	Floor
1	GYPSUM	GYPSUM	CONC003
2	GYPSUM	GYPSUM	CONC003
3	GYPSUM	GYPSUM	CONC003

Thermal data base used: WSMSTH04.DF

Name	Conductivity	Specific heat	Density	Thickness	Emissivity	HCL B's (1->5)
GYPSUM	0.200	1.000E+03	700.	1.600E-02	0.900	0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00
CONC003	1.75	1.000E+03	2.200E+03	0.152	0.940	0.00E+00 0.00E+00 0.00E+00 0.00E+00 0.00E+00

TARGETS

Target	Compartment	Position (x, y, z)	Direction (x, y, z)	Material	
1	1	1.50 1.50 0.00	0.00 0.00 1.00	CONC003	Floor, compartment 1
2	2	1.00 1.00 0.00	0.00 0.00 1.00	CONC003	Floor, compartment 2
3	3	7.50 1.50 0.00	0.00 0.00 1.00	CONC003	Floor, compartment 3

Compartment	Fire Type	Position (x,y,z)	Relative Humidity	Lower O2 Limit	Pyrolysis Temperature
1	Constrained	1.50 1.50 0.00	50.0	12.00	293.

Time (s)	Fmass (kg/s)	Hcomb (J/kg)	Fqdot (W)	Fhigh (m)	C/CO2 (kg/kg)	CO/CO2 (kg/kg)	H/C (kg/kg)	O/C (kg/kg)	HCN (kg/kg)	HCL (kg/kg)
0.	0.00E+00	4.00E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
50.	3.47E-04	4.00E+07	1.39E+04	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
100.	1.39E-03	4.00E+07	5.56E+04	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
150.	3.13E-03	4.00E+07	1.25E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
200.	5.56E-03	4.00E+07	2.22E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
250.	8.68E-03	4.00E+07	3.47E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
300.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
350.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
400.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
450.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
500.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
550.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
600.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
650.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
700.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
800.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
900.	1.25E-02	4.00E+07	5.00E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
1000.	8.33E-03	4.00E+07	3.33E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
1100.	4.17E-03	4.00E+07	1.67E+05	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00
1200.	0.00E+00	4.00E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.33	0.00E+00	0.00E+00	0.00E+00

Appendix H   Example Problem Comma -Delimitated Entries, Base Case Fire (CAB042.CSV)

Output Parameter	Spreadsheet Output Selection	Units	Description
TIME	Normal	seconds	Time
Upper Layer Temp(1)	Normal	K	Upper layer temperature in compartment 1
Lower Layer Temp(1)	Normal	K	Lower layer temperature in compartment 1
Layer Height(1)	Normal	m	Height from floor to bottom of upper layer in compartment 1
Upper Layer Volume(1)	Normal	m^3	Volume of upper layer in compartment 1
Pressure(1)	Normal	Pa	Gauge pressure in compartment 1
Ambient Target(1)	Normal	W/m^2	Undefined
Floor Target(1)	Normal	W/m^2	Undefined
Upper Layer Temp(2)	Normal	K	Upper layer temperature in compartment 2
Lower Layer Temp(2)	Normal	K	Lower layer temperature in compartment 2
Layer Height(2)	Normal	m	Height from floor to bottom of upper layer in compartment 2
Upper Layer Volume(2)	Normal	m^3	Volume of upper layer in compartment 2
Pressure(2)	Normal	Pa	Gauge pressure in compartment 2
Ambient Target(2)	Normal	W/m^2	Undefined
Floor Target(2)	Normal	W/m^2	Undefined
Upper Layer Temp(3)	Normal	K	Upper layer temperature in compartment 3
Lower Layer Temp(3)	Normal	K	Lower layer temperature in compartment 3
Layer Height(3)	Normal	m	Height from floor to bottom of upper layer in compartment 3
Upper Layer Volume(3)	Normal	m^3	Volume of upper layer in compartment 3
Pressure(3)	Normal	Pa	Gauge pressure in compartment 3
Ambient Target(3)	Normal	W/m^2	Undefined
Floor Target(3)	Normal	W/m^2	Undefined
Main Plume Flow	Normal	kg/s	Plume mass flow rate for main fire
Main Pyrolysis Rate	Normal	kg/s	Fuel mass loss rate for main fire
Main Fire Size	Normal	W	Heat release rate (HRR)
Main Flame Height	Normal	m	Flame height
Main Convec. Size	Normal	W	Flame convection energy
Upper N2(1)	Species	%	mass concentration of nitrogen in the upper layer of compartment 1
Upper O2(1)	Species	%	mass concentration of oxygen in the upper layer of compartment 1
Upper CO2(1)	Species	%	mass concentration of carbon dioxide in the upper layer of compartment 1
Upper CO(1)	Species	ppm	mass concentration of carbon monoxide in the upper layer of compartment 1
Upper HCN(1)	Species	ppm	mass concentration of hydrogen cyanide in the upper layer of compartment 1
Upper HCL(1)	Species	ppm	mass concentration of hydrogen chloride in the upper layer of compartment 1
Upper TUHC(1)	Species	%	mass concentration of total unburned hydrocarbons in the upper layer of compartment 1
Upper H2O(1)	Species	%	mass concentration of water in the upper layer of compartment 1
Upper OD(1)	Species	m^{-1}	mass concentration of soot in the upper layer of compartment 1
HCl c(1)	Species	mg/m^2	Undefined
HCl uw(1)	Species	mg/m^2	Undefined
HCl lw(1)	Species	mg/m^2	Undefined
HCl f(1)	Species	mg/m^2	Undefined
Upper N2(2)	Species	%	
Upper O2(2)	Species	%	
Upper CO2(2)	Species	%	
Upper CO(2)	Species	ppm	
Upper HCN(2)	Species	ppm	
Upper HCL(2)	Species	ppm	
Upper TUHC(2)	Species	%	
Upper H2O(2)	Species	%	
Upper OD(2)	Species	m^{-1}	
HCl c(2)	Species	mg/m^2	
HCl uw(2)	Species	mg/m^2	
HCl lw(2)	Species	mg/m^2	
HCl f(2)	Species	mg/m^2	

Output Parameter	Spreadsheet Output Selection	Units	Description
Upper N2(3)	Species	%	
Upper O2(3)	Species	%	
Upper CO2(3)	Species	%	
Upper CO(3)	Species	ppm	
Upper HCN(3)	Species	ppm	
Upper HCL(3)	Species	ppm	
Upper TUHC(3)	Species	%	
Upper H2O(3)	Species	%	
Upper OD(3)	Species	m^{-1}	
HCl c(3)	Species	mg/m^2	
HCl uw(3)	Species	mg/m^2	
HCl lw(3)	Species	mg/m^2	
HCl f(3)	Species	mg/m^2	
Lower N2(1)	Species	%	mass concentration of nitrogen in the lower layer of compartment 1
Lower O2(1)	Species	%	mass concentration of oxygen in the lower layer of compartment 1
Lower CO2(1)	Species	%	mass concentration of carbon dioxide in the lower layer of compartment 1
Lower CO(1)	Species	ppm	mass concentration of carbon monoxide in the lower layer of compartment 1
Lower HCN(1)	Species	ppm	mass concentration of hydrogen cyanide in the lower layer of compartment 1
Lower HCL(1)	Species	ppm	mass concentration of hydrogen chloride in the lower layer of compartment 1
Lower TUHC(1)	Species	%	mass concentration of total unburned hydrocarbons in lower layer
Lower H2O(1)	Species	%	mass concentration of water in the lower layer of compartment 1
Lower OD(1)	Species	m^{-1}	mass concentration of soot in the lower layer of compartment 1
HCl c(1)	Species	mg/m^2	Undefined
HCl uw(1)	Species	mg/m^2	Undefined
HCl lw(1)	Species	mg/m^2	Undefined
HCl f(1)	Species	mg/m^2	Undefined
Lower N2(2)	Species	%	
Lower O2(2)	Species	%	
Lower CO2(2)	Species	%	
Lower CO(2)	Species	ppm	
Lower HCN(2)	Species	ppm	
Lower HCL(2)	Species	ppm	
Lower TUHC(2)	Species	%	
Lower H2O(2)	Species	%	
Lower OD(2)	Species	m^{-1}	
HCl c(2)	Species	mg/m^2	
HCl uw(2)	Species	mg/m^2	
HCl lw(2)	Species	mg/m^2	
HCl f(2)	Species	mg/m^2	
Lower N2(3)	Species	%	
Lower O2(3)	Species	%	
Lower CO2(3)	Species	%	
Lower CO(3)	Species	ppm	
Lower HCN(3)	Species	ppm	
Lower HCL(3)	Species	ppm	
Lower TUHC(3)	Species	%	
Lower H2O(3)	Species	%	
Lower OD(3)	Species	m^{-1}	
HCl c(3)	Species	mg/m^2	
HCl uw(3)	Species	mg/m^2	
HCl lw(3)	Species	mg/m^2	
HCl f(3)	Species	mg/m^2	
Upper Inflow 1- 2(1)	Flow Field	kg/s	mass flow rate into upper layer of compartment 1 from compartment 2 for vent 1.

Output Parameter	Spreadsheet Output Selection	Units	Description
Upper Outflow 1- 2(1)	Flow Field	kg/s	mass flow rate out of the upper layer of compartment 1 to compartment 2 for vent 1.
Lower Inflow 1- 2(1)	Flow Field	kg/s	mass flow rate into lower layer of compartment 1 from compartment 2 for vent 1.
Lower Outflow 1- 2(1)	Flow Field	kg/s	mass flow rate out of the lower layer of compartment 1 to compartment 2 for vent 1.
Mixing to Upper 1- 2(1)	Flow Field	kg/s	
Mixing to Lower 1- 2(1)	Flow Field	kg/s	
Upper Inflow 1- 2(2)	Flow Field	kg/s	
Upper Outflow 1- 2(2)	Flow Field	kg/s	
Lower Inflow 1- 2(2)	Flow Field	kg/s	
Lower Outflow 1- 2(2)	Flow Field	kg/s	
Mixing to Upper 1- 2(2)	Flow Field	kg/s	
Mixing to Lower 1- 2(2)	Flow Field	kg/s	
Upper Inflow 1- 3(3)	Flow Field	kg/s	
Upper Outflow 1- 3(3)	Flow Field	kg/s	
Lower Inflow 1- 3(3)	Flow Field	kg/s	
Lower Outflow 1- 3(3)	Flow Field	kg/s	
Mixing to Upper 1- 3(3)	Flow Field	kg/s	
Mixing to Lower 1- 3(3)	Flow Field	kg/s	
MV Upper Inflow 5	Flow Field	kg/s	
MV Upper Outflow 5	Flow Field	kg/s	
MV Lower Inflow 5	Flow Field	kg/s	
M V Lower Outflow 5	Flow Field	kg/s	
Upper Inflow 2- 1(1)	Flow Field	kg/s	
Upper Outflow 2- 1(1)	Flow Field	kg/s	
Lower Inflow 2- 1(1)	Flow Field	kg/s	
Lower Outflow 2- 1(1)	Flow Field	kg/s	
Mixing to Upper 2- 1(1)	Flow Field	kg/s	
Mixing to Lower 2- 1(1)	Flow Field	kg/s	
Upper Inflow 2- 1(2)	Flow Field	kg/s	
Upper Outflow 2- 1(2)	Flow Field	kg/s	
Lower Inflow 2- 1(2)	Flow Field	kg/s	
Lower Outflow 2- 1(2)	Flow Field	kg/s	
Mixing to Upper 2- 1(2)	Flow Field	kg/s	
Mixing to Lower 2- 1(2)	Flow Field	kg/s	
Upper Inflow 2- 3(1)	Flow Field	kg/s	
Upper Outflow 2- 3(1)	Flow Field	kg/s	
Lower Inflow 2- 3(1)	Flow Field	kg/s	
Lower Outflow 2- 3(1)	Flow Field	kg/s	
Mixing to Upper 2- 3(1)	Flow Field	kg/s	
Mixing to Lower 2- 3(1)	Flow Field	kg/s	
Upper Inflow 2- 3(2)	Flow Field	kg/s	
Upper Outflow 2- 3(2)	Flow Field	kg/s	
Lower Inflow 2- 3(2)	Flow Field	kg/s	
Lower Outflow 2- 3(2)	Flow Field	kg/s	
Mixing to Upper 2- 3(2)	Flow Field	kg/s	
Mixing to Lower 2- 3(2)	Flow Field	kg/s	
Upper Inflow 3- 1(3)	Flow Field	kg/s	
Upper Outflow 3- 1(3)	Flow Field	kg/s	
Lower Inflow 3- 1(3)	Flow Field	kg/s	
Lower Outflow 3- 1(3)	Flow Field	kg/s	
Mixing to Upper 3- 1(3)	Flow Field	kg/s	
Mixing to Lower 3- 1(3)	Flow Field	kg/s	
Upper Inflow 3- 2(1)	Flow Field	kg/s	
Upper Outflow 3- 2(1)	Flow Field	kg/s	
Lower Inflow 3- 2(1)	Flow Field	kg/s	
Lower Outflow 3- 2(1)	Flow Field	kg/s	
Mixing to Upper 3- 2(1)	Flow Field	kg/s	

Output Parameter	Spreadsheet Output Selection	Units	Description
Mixing to Lower 3- 2(1)	Flow Field	kg/s	
Upper Inflow 3- 2(2)	Flow Field	kg/s	
Upper Outflow 3- 2(2)	Flow Field	kg/s	
Lower Inflow 3- 2(2)	Flow Field	kg/s	
Lower Outflow 3- 2(2)	Flow Field	kg/s	
Mixing to Upper 3- 2(2)	Flow Field	kg/s	
Mixing to Lower 3- 2(2)	Flow Field	kg/s	
Upper Inflow 3-Outside(1)	Flow Field	kg/s	
Upper Outflow 3-Outside(1)	Flow Field	kg/s	
Lower Inflow 3-Outside(1)	Flow Field	kg/s	
Lower Outflow 3-Outside(1)	Flow Field	kg/s	
Upper Inflow 3-Outside(2)	Flow Field	kg/s	
Upper Outflow 3-Outside(2)	Flow Field	kg/s	
Lower Inflow 3-Outside(2)	Flow Field	kg/s	
Lower Outflow 3-Outside(2)	Flow Field	kg/s	

Appendix I   Example Problem Leak Path Estimate Spreadsheet, BASE CASE Fire (CAB042.xls)

Mass flow calculation for a contaminate

	A	B	C	D	E	F	G	H
1	Time (s)	Mass flow (kg/s)						
2	TIME	Main Plume Flow	Upper fan	Lower fan	Upper inflow	Lower inflow	Mixing upper to lower	Mixing lower to upper
3	0	0.00E+00	0.0000	-0.0454	0.0000	0.0454	0.0000	0.0000
4	10	5.48E-01	0.0000	-0.0451	0.0000	0.0390	0.0000	0.0000
5	20	3.98E-01	0.0000	-0.0448	0.0000	0.0324	0.0000	0.0000
6	30	2.79E-01	0.0000	-0.0445	0.0000	0.0260	0.0000	0.0000
7	40	2.01E-01	-0.0253	-0.0187	0.0000	0.0208	0.0000	0.0000
8	50	1.54E-01	-0.0435	0.0000	0.0000	0.0163	0.0000	0.0000
9	60	1.27E-01	-0.0428	0.0000	0.0000	-0.0014	0.0000	0.0000
10	70	1.13E-01	-0.0418	0.0000	0.0000	-0.0171	0.0000	0.0000
11	80	1.06E-01	-0.0406	0.0000	0.0000	-0.0314	0.0000	0.0000
12	90	8.96E-02	-0.0393	0.0000	0.0000	-0.0443	0.0000	0.0000
13	100	7.75E-02	-0.0380	0.0000	0.0000	-0.0555	0.0000	0.0000
14	110	5.58E-02	-0.0365	0.0000	0.0000	-0.0765	0.0000	0.0000
15	120	2.08E-03	-0.0348	0.0000	-0.0692	-0.0060	0.0000	0.0000
273	2700	0.00E+00	0.0000	-0.0404	0.0000	0.0418	0.0000	0.0000

	A	I	J	K	L	M	N
1	Time (s)	Temperature (K)		Densities (kg/m^3)		Layer Volumes (m^3)	
2	TIME	Upper	Lower	Upper	Lower	Upper	Lower
3	0	293.2	293.2	1.189	1.189	0.0	22.0
4	10	295.0	293.2	1.181	1.189	4.1	17.8
5	20	297.0	293.2	1.174	1.189	8.2	13.8
6	30	299.5	293.2	1.164	1.189	11.1	10.8
7	40	302.6	293.3	1.152	1.189	13.2	8.8
8	50	306.2	293.3	1.139	1.188	14.5	7.4
9	60	311.3	293.4	1.120	1.188	15.7	6.3
10	70	318.8	293.5	1.094	1.188	16.7	5.3
11	80	327.9	293.7	1.063	1.187	17.8	4.1
12	90	338.4	294.0	1.030	1.186	18.9	3.0
13	100	350.3	294.4	0.995	1.184	20.1	1.9
14	110	364.5	295.0	0.956	1.181	21.2	0.8
15	120	382.5	297.8	0.911	1.171	22.0	0.0
273	2700	329.2	310.4	1.059	1.123	9.0	12.9

Mass flow calculation for a contaminate (con't)

	A	O	P	Q	R	S	T	U
1	Time (s)	Volume flow (m³/s)						
2	TIME	Plume lower to upper	Upper fan	Lower fan	Upper inflow	Lower inflow	Mixing upper to lower	Mixing lower to upper
3	0	0.0000	0.0000	-0.0382	0.0000	0.0000	0.0000	0.0000
4	10	0.4611	0.0000	-0.0379	0.0000	0.0000	0.0000	0.0000
5	20	0.3351	0.0000	-0.0377	0.0000	0.0000	0.0000	0.0000
6	30	0.2348	0.0000	-0.0374	0.0000	0.0000	0.0000	0.0000
7	40	0.1689	-0.0219	-0.0157	0.0000	0.0000	0.0000	0.0000
8	50	0.1293	-0.0382	0.0000	0.0000	0.0000	0.0000	0.0000
9	60	0.1065	-0.0382	0.0000	0.0000	-0.0012	0.0000	0.0000
10	70	0.0950	-0.0382	0.0000	0.0000	-0.0144	0.0000	0.0000
11	80	0.0892	-0.0382	0.0000	0.0000	-0.0265	0.0000	0.0000
12	90	0.0756	-0.0382	0.0000	0.0000	-0.0373	0.0000	0.0000
13	100	0.0654	-0.0382	0.0000	0.0000	-0.0469	0.0000	0.0000
14	110	0.0472	-0.0382	0.0000	0.0000	-0.0647	0.0000	0.0000
15	120	0.0018	-0.0382	0.0000	-0.0759	-0.0051	0.0000	0.0000
273	2700	0.0000	0.0000	-0.0360	0.0000	0.0000	0.0000	0.0000

	A	V	W	X	Y	Z	AA	AB	AC
1	Time (s)	Contaminate mass (kg)			Contaminate concentration (kg/m³)		Mass collected at fan (kg)		
2	TIME	Upper layer	Lower Layer	Total in Room	Upper	Lower	Upper	Lower	Sum
3	0	0.0	100.0	100.0	0.00	4.55	0.0	0.0	0.0
4	10	0.0	98.3	98.3	0.00	5.51	0.0	-2.1	-2.1
5	20	25.4	70.7	96.2	3.11	5.13	0.0	-4.0	-4.0
6	30	42.6	51.6	94.2	3.84	4.76	0.0	-5.8	-5.8
7	40	53.8	38.7	92.5	4.08	4.40	-0.9	-6.5	-7.4
8	50	60.3	30.5	90.9	4.15	4.12	-2.5	-6.5	-9.0
9	60	64.1	25.2	89.3	4.09	4.00	-4.0	-6.5	-10.5
10	70	66.8	20.9	87.7	4.00	3.97	-5.6	-6.5	-12.1
11	80	69.0	16.6	85.6	3.87	4.00	-7.0	-6.5	-13.5
12	90	71.1	11.9	83.0	3.75	3.96	-8.5	-6.5	-15.0
13	100	72.7	7.5	80.1	3.62	3.93	-9.9	-6.5	-16.4
14	110	73.8	3.1	76.9	3.49	3.89	-11.2	-6.5	-17.7
15	120	74.3	0.0	74.3	3.39	0.00	-12.5	-6.5	-19.0
273	2700	4.7	0.0	4.7	0.52	0.00	-51.6	-6.5	58.1

Equations for mass flow calculation for a contaminate

	A	B	C	D	E	F	G	H
1	Time (s)	Mass flow (kg/s)						
2	TIME	Main Plume Flow	Upper fan	Lower fan	Upper inflow	Lower inflow	Mixing upper to lower	Mixing lower to upper
3	0	0.00E+00	0.0000	-0.0454	0.0000	0.0454	0.0000	0.0000
4	10	5.48E-01	0.0000	-0.0451	0.0000	0.0390	0.0000	0.0000
5	20	3.98E-01	0.0000	-0.0448	0.0000	0.0324	0.0000	0.0000
6	30	2.79E-01	0.0000	-0.0445	0.0000	0.0260	0.0000	0.0000
7	40	2.01E-01	-0.0253	-0.0187	0.0000	0.0208	0.0000	0.0000
8	50	1.54E-01	-0.0435	0.0000	0.0000	0.0163	0.0000	0.0000
9	60	1.27E-01	-0.0428	0.0000	0.0000	-0.0014	0.0000	0.0000
10	70	1.13E-01	-0.0418	0.0000	0.0000	-0.0171	0.0000	0.0000
11	80	1.06E-01	-0.0406	0.0000	0.0000	-0.0314	0.0000	0.0000
12	90	8.96E-02	-0.0393	0.0000	0.0000	-0.0443	0.0000	0.0000
13	100	7.75E-02	-0.0380	0.0000	0.0000	-0.0555	0.0000	0.0000
14	110	5.58E-02	-0.0365	0.0000	0.0000	-0.0765	0.0000	0.0000
15	120	2.08E-03	-0.0348	0.0000	-0.0692	-0.0060	0.0000	0.0000
273	2700	0.00E+00	0.0000	-0.0404	0.0000	0.0418	0.0000	0.0000

	A	I	J	K	L	M	N
1	Time (s)	Temperature (K)		Densities (kg/m^3)		Layer Volumes (m^3)	
2	TIME	Upper	Lower	Upper	Lower	Upper	Lower
3	0	293.2	293.2	=348.59/I3	=348.59/J3	0.0	=21.96-M3
4	10	295.0	293.2	=348.59/I4	=348.59/J4	4.1	=21.96-M4
5	20	297.0	293.2	=348.59/I5	=348.59/J5	8.2	=21.96-M5
6	30	299.5	293.2	=348.59/I6	=348.59/J6	11.1	=21.96-M6
7	40	302.6	293.3	=348.59/I7	=348.59/J7	13.2	=21.96-M7
8	50	306.2	293.3	=348.59/I8	=348.59/J8	14.5	=21.96-M8
9	60	311.3	293.4	=348.59/I9	=348.59/J9	15.7	=21.96-M9
10	70	318.8	293.5	=348.59/I10	=348.59/J10	16.7	=21.96-M10
11	80	327.9	293.7	=348.59/I11	=348.59/J11	17.8	=21.96-M11
12	90	338.4	294.0	=348.59/I12	=348.59/J12	18.9	=21.96-M12
13	100	350.3	294.4	=348.59/I13	=348.59/J13	20.1	=21.96-M13
14	110	364.5	295.0	=348.59/I14	=348.59/J14	21.2	=21.96-M14
15	120	382.5	297.8	=348.59/I15	=348.59/J15	22.0	=21.96-M15
273	2700	329.2	310.4	=348.59/I273	=348.59/J273	9.0	=21.96-M273

	A	O	P	Q	R	S	T	U
1	Time (s)	Volume flow (m^3/s)						
2	TIME	Plume lower to upper	Upper fan	Lower fan	Upper inflow	Lower inflow	Mixing upper to lower	Mixing lower to upper
3	0	=B3/L3	=C3/K3	=D3/L3	=IF(E3>0,0,E3)/K3	=IF(F3>0,0,F3)/L3	=G3/K3	=H3/L3
4	10	=B4/L4	=C4/K4	=D4/L4	=IF(E4>0,0,E4)/K4	=IF(F4>0,0,F4)/L4	=G4/K4	=H4/L4
5	20	=B5/L5	=C5/K5	=D5/L5	=IF(E5>0,0,E5)/K5	=IF(F5>0,0,F5)/L5	=G5/K5	=H5/L5
6	30	=B6/L6	=C6/K6	=D6/L6	=IF(E6>0,0,E6)/K6	=IF(F6>0,0,F6)/L6	=G6/K6	=H6/L6
7	40	=B7/L7	=C7/K7	=D7/L7	=IF(E7>0,0,E7)/K7	=IF(F7>0,0,F7)/L7	=G7/K7	=H7/L7
8	50	=B8/L8	=C8/K8	=D8/L8	=IF(E8>0,0,E8)/K8	=IF(F8>0,0,F8)/L8	=G8/K8	=H8/L8
9	60	=B9/L9	=C9/K9	=D9/L9	=IF(E9>0,0,E9)/K9	=IF(F9>0,0,F9)/L9	=G9/K9	=H9/L9
10	70	=B10/L10	=C10/K10	=D10/L10	=IF(E10>0,0,E10)/K10	=IF(F10>0,0,F10)/L10	=G10/K10	=H10/L10
11	80	=B11/L11	=C11/K11	=D11/L11	=IF(E11>0,0,E11)/K11	=IF(F11>0,0,F11)/L11	=G11/K11	=H11/L11
12	90	=B12/L12	=C12/K12	=D12/L12	=IF(E12>0,0,E12)/K12	=IF(F12>0,0,F12)/L12	=G12/K12	=H12/L12
13	100	=B13/L13	=C13/K13	=D13/L13	=IF(E13>0,0,E13)/K13	=IF(F13>0,0,F13)/L13	=G13/K13	=H13/L13
14	110	=B14/L14	=C14/K14	=D14/L14	=IF(E14>0,0,E14)/K14	=IF(F14>0,0,F14)/L14	=G14/K14	=H14/L14
15	120	=B15/L15	=C15/K15	=D15/L15	=IF(E15>0,0,E15)/K15	=IF(F15>0,0,F15)/L15	=G15/K15	=H15/L15
273	2700	=B273/L273	=C273/K273	=D273/L273	=IF(E273>0,0,E273)/K273	=IF(F273>0,0,F273)/L273	=G273/K273	=H273/L273

	A	V	W	X	Y	Z	AA	AB	AC
1	Time (s)	Contaminate mass (kg)			Contaminate concentration (kg/m³)		Mass collected at fan (kg)		
2	TIME	Upper layer	Lower Layer	Total in Room	Upper	Lower	Upper	Lower	Sum
3	0	0	100	=SUM(V3:W3)	=IF(M3=0,0,V3/M3)	=IF(N3=0,0,W3/N3)	0	0	=-SUM(AA3:AB3)
4	10	=IF(V3+(Y3*(P3+R3-T3)+Z3*(U3+O3))*10<=0,0,V3+(Y3*(P3+R3-T3)+Z3*(U3+O3))*10)	=IF(W3+(Z3*(Q3+S3-O3-U3)+T3*Y3)*10<=0,0,W3+(Z3*(Q3+S3-O3-U3)+T3*Y3)*10)	=SUM(V4:W4)	=IF(M4=0,0,V4/M4)	=IF(N4=0,0,W4/N4)	=Y4*P4*10+AA3	=Z4*Q4*10+AB3	=-SUM(AA4:AB4)
5	20	=IF(V4+(Y4*(P4+R4-T4)+Z4*(U4+O4))*10<=0,0,V4+(Y4*(P4+R4-T4)+Z4*(U4+O4))*10)	=IF(W4+(Z4*(Q4+S4-O4-U4)+T4*Y4)*10<=0,0,W4+(Z4*(Q4+S4-O4-U4)+T4*Y4)*10)	=SUM(V5:W5)	=IF(M5=0,0,V5/M5)	=IF(N5=0,0,W5/N5)	=Y5*P5*10+AA4	=Z5*Q5*10+AB4	=-SUM(AA5:AB5)
6	30	=IF(V5+(Y5*(P5+R5-T5)+Z5*(U5+O5))*10<=0,0,V5+(Y5*(P5+R5-T5)+Z5*(U5+O5))*10)	=IF(W5+(Z5*(Q5+S5-O5-U5)+T5*Y5)*10<=0,0,W5+(Z5*(Q5+S5-O5-U5)+T5*Y5)*10)	=SUM(V6:W6)	=IF(M6=0,0,V6/M6)	=IF(N6=0,0,W6/N6)	=Y6*P6*10+AA5	=Z6*Q6*10+AB5	=-SUM(AA6:AB6)
7	40	=IF(V6+(Y6*(P6+R6-T6)+Z6*(U6+O6))*10<=0,0,V6+(Y6*(P6+R6-T6)+Z6*(U6+O6))*10)	=IF(W6+(Z6*(Q6+S6-O6-U6)+T6*Y6)*10<=0,0,W6+(Z6*(Q6+S6-O6-U6)+T6*Y6)*10)	=SUM(V7:W7)	=IF(M7=0,0,V7/M7)	=IF(N7=0,0,W7/N7)	=Y7*P7*10+AA6	=Z7*Q7*10+AB6	=-SUM(AA7:AB7)
8	50	=IF(V7+(Y7*(P7+R7-T7)+Z7*(U7+O7))*10<=0,0,V7+(Y7*(P7+R7-T7)+Z7*(U7+O7))*10)	=IF(W7+(Z7*(Q7+S7-O7-U7)+T7*Y7)*10<=0,0,W7+(Z7*(Q7+S7-O7-U7)+T7*Y7)*10)	=SUM(V8:W8)	=IF(M8=0,0,V8/M8)	=IF(N8=0,0,W8/N8)	=Y8*P8*10+AA7	=Z8*Q8*10+AB7	=-SUM(AA8:AB8)
9	60	=IF(V8+(Y8*(P8+R8-T8)+Z8*(U8+O8))*10<=0,0,V8+(Y8*(P8+R8-T8)+Z8*(U8+O8))*10)	=IF(W8+(Z8*(Q8+S8-O8-U8)+T8*Y8)*10<=0,0,W8+(Z8*(Q8+S8-O8-U8)+T8*Y8)*10)	=SUM(V9:W9)	=IF(M9=0,0,V9/M9)	=IF(N9=0,0,W9/N9)	=Y9*P9*10+AA8	=Z9*Q9*10+AB8	=-SUM(AA9:AB9)

	A	V	W	X	Y	Z	AA	AB	AC
10	70	=IF(V9+(Y9*(P9+R9-T9)+Z9*(U9+O9))*10<=0,0,V9+(Y9*(P9+R9-T9)+Z9*(U9+O9))*10)	=IF(W9+(Z9*(Q9+S9-O9-U9)+T9*Y9)*10<=0,0,W9+(Z9*(Q9+S9-O9-U9)+T9*Y9)*10)	=SUM(V10:W10)	=IF(M10=0,0,V10/M10)	=IF(N10=0,0,W10/N10)	=Y10*P10*10+AA9	=Z10*Q10*10+AB9	=-SUM(AA10:AB10)
11	80	=IF(V10+(Y10*(P10+R10-T10)+Z10*(U10+O10))*10<=0,0,V10+(Y10*(P10+R10-T10)+Z10*(U10+O10))*10)	=IF(W10+(Z10*(Q10+S10-O10-U10)+T10*Y10)*10<=0,0,W10+(Z10*(Q10+S10-O10-U10)+T10*Y10)*10)	=SUM(V11:W11)	=IF(M11=0,0,V11/M11)	=IF(N11=0,0,W11/N11)	=Y11*P11*10+AA10	=Z11*Q11*10+AB10	=-SUM(AA11:AB11)
12	90	=IF(V11+(Y11*(P11+R11-T11)+Z11*(U11+O11))*10<=0,0,V11+(Y11*(P11+R11-T11)+Z11*(U11+O11))*10)	=IF(W11+(Z11*(Q11+S11-O11-U11)+T11*Y11)*10<=0,0,W11+(Z11*(Q11+S11-O11-U11)+T11*Y11)*10)	=SUM(V12:W12)	=IF(M12=0,0,V12/M12)	=IF(N12=0,0,W12/N12)	=Y12*P12*10+AA11	=Z12*Q12*10+AB11	=-SUM(AA12:AB12)
13	100	=IF(V12+(Y12*(P12+R12-T12)+Z12*(U12+O12))*10<=0,0,V12+(Y12*(P12+R12-T12)+Z12*(U12+O12))*10)	=IF(W12+(Z12*(Q12+S12-O12-U12)+T12*Y12)*10<=0,0,W12+(Z12*(Q12+S12-O12-U12)+T12*Y12)*10)	=SUM(V13:W13)	=IF(M13=0,0,V13/M13)	=IF(N13=0,0,W13/N13)	=Y13*P13*10+AA12	=Z13*Q13*10+AB12	=-SUM(AA13:AB13)
14	110	=IF(V13+(Y13*(P13+R13-T13)+Z13*(U13+O13))*10<=0,0,V13+(Y13*(P13+R13-T13)+Z13*(U13+O13))*10)	=IF(W13+(Z13*(Q13+S13-O13-U13)+T13*Y13)*10<=0,0,W13+(Z13*(Q13+S13-O13-U13)+T13*Y13)*10)	=SUM(V14:W14)	=IF(M14=0,0,V14/M14)	=IF(N14=0,0,W14/N14)	=Y14*P14*10+AA13	=Z14*Q14*10+AB13	=-SUM(AA14:AB14)

	A	V	W	X	Y	Z	AA	AB	AC
15	120	=IF(V14+(Y14*(P14+R14-T14)+Z14*(U14+O14))*10<=0,0,V14+(Y14*(P14+R14-T14)+Z14*(U14+O14))*10)	=IF(W14+(Z14*(Q14+S14-O14-U14)+T14*Y14)*10<=0,0,W14+(Z14*(Q14+S14-O14-U14)+T14*Y14)*10)	=SUM(V15:W15)	=IF(M15=0,0,V15/M15)	=IF(N15=0,0,W15/N15)	=Y15*P15*10+AA14	=Z15*Q15*10+AB14	=-SUM(AA15:AB15)
273	2700	=IF(V272+(Y272*(P272+R272-T272)+Z272*(U272+O272))*10<=0,0,V272+(Y272*(P272+R272-T272)+Z272*(U272+O272))*10)	=IF(W272+(Z272*(Q272+S272-O272-U272)+T272*Y272)*10<=0,0,W272+(Z272*(Q272+S272-O272-U272)+T272*Y272)*10)	=SUM(V273:W273)	=IF(M273=0,0,V273/M273)	=IF(N273=0,0,W273/N273)	=Y273*P273*10+AA272	=Z273*Q273*10+AB272	=-SUM(AA273:AB273)

Appendix J   CFAST History Summary

The information presented in this Appendix is reproduced from the website
http://cfast.nist.go v/versionhistory.html (May 10, 2004).

Version 5.1.1 (May 1, 2004)

There was an error in the HCR (hydrogen/carbon ratio) calculation. It introduced about a
6% error into the pyroloysis calculation. [Note: This only applies to calculations made
using Version 5.1.0.*]

Version 5.1.0 (March 1, 2004)

In version 5.0 and earlier, the oxygen calculation used the oxygen to fuel ratio, whereas
the technical reference manual states that it uses the oxygen to carbon ratio. The model
now matches the guide.

Version 5.0.1 (May 7, 2003)

Flow was not being reported correctly in some cases. The calculation was correct, but the
output from CFAST (/rf) was not updated when a vent opening decreased to zero.

The vertical flow calculation has been fixed. The symptom is that it the pressure in a
compartment connected by VVENT was never updated.

Version 5.0 (11/1/2001)

The number of points in a time history has been increased. This is to allow editing of the
examples, which default to 21 intervals.

Fix a printout error: the size of the fire was reported incorrectly in some cases. The
calculation was done correctly, but the output from Report and ReportSS was incorrect.
The problem occurs if there are two fires in a compartment, with one of them in the upper
layer, and one in the lower layer. Once again, the report was incorrect, but the value used
in subsequent calculations was correct.

The workspace for the solver was not dimensioned correctly, so CFAST could not do 30
compartments. This has been fixed.

(These fixes have been done in 3.1.7 as well and there is an update package available on
the website to implement the update.)

Version 4.0.1 (3/1/00)

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* Based on private communication with the NIST Subject Matter Expert for CFAST.

This release runs as an application under the Windows series of operating systems.

New phenomena: horizontal heat conduction (wall/wall) (HHEAT), horizontal smoke flow in corridors (HALL), variable geometry for compartments (ROOMA, ROOMH).

Fonts must be in the "font" directory off the "bin" folder.

Version 3.1.6 (11/1/99)

This is the last full GUI (FAST).
Add "constrained/with flashover" to FAST as a fire type (note, this is not carried into CFAST!)

Version 3.1.5 (4/1/99)

The program Build is included, along with sample files and documentation, which can be used to generate ".pic" files for the VIEW command.
Reportss has been fixed to include target temperatures in the output.
New phenomena: single zone switch (single layer model).

Version 3.1.4 (7/1/98)

Fix compatibility between FAST and CFAST. The history files were not compatible

Version 3.1.3 (4/1/98)

Fix fonts for FAST (remove wddraw from an explicit include in fast and fastlite), file naming error in the spreadsheet output, incorrect entrainment when the fire is in the upper layer and eliminate heat conduction thru the ceiling/floor connection to the outside (nputp)

Version 3.1.2 (1/1/98)

Fix boundary condition for vertical flow to the outside.
New phenomena: vertical heat flow.

Version 3.1.1 (10/1/97)

Fix font interface for metawindows. The FORTRAN-c interface could sometimes cause a page fault. Fonts are now names devfntnn.fnt where nn=1 to 24 (4 is the default). Note that font changes used in labels are permanent for the session, so the bracket |Hnn .... |H04 should be used. Removed O(n**2) data structures (about 40 arrays). Added a non-rectangular room option - roomhgt, roomarea are the key words.

Wind - wind now applies to vents rather than rooms (couldn't do from vs. back) - effect of wind was zero for ground floor rooms. wind induced pressure rise is now calculated at the average of the floor and ceiling elevation Initialize inside and outside pressure and temperature to the same lapse rate.

Output warning for excessive number of small time steps (set in solver.ini) (DTCHEK).

Add BLACK option to have atmosphere behave as a blackbody Note: rework SHAFT option to use only 3 equations per room. Modify hybrid code to conform to new FDS heat loss algorithm

Version 3.0 (1/3/96)

New user interface for CEdit. Add flame height calculation to report and flame spread algorithm to the model. New module, reportss, which uses the same format as report, but puts the output into a spread sheet (ASCII delimited text) output format. Added reporting option for wall and target heat flux printout. New output options are /r:winfstp. W is now wall and target heat fluxes and P is now wall temperature profiles.

New phenomena added: ceiling/floor heat transfer for inter-compartment heat transfer, CFAST keyword CFCON. and heat transfer to targets. Multiple objects in a desired position, orientation, and material.

Program calculation of object temperature and impinging heat fluxes can be printed. CFAST keyword is TARGET.

Improved stability of mechanical ventilation routines so that solution converges over a wider range of input values.

Modules in the release: CFAST (main model), fast (gui data editor), cplot (plotting package), report (report utility), reportss utility to generate spread sheet format, reportg to provide graphics playback, bintoasc to convert binary history files to ASCII text files, compare to compare two separate CFAST runs (using ASCII text files) and compinfo to summarize output from compare .

Version 2.1.1/ H1.2 "fix on fail" update (1/1/95)

Fixed optional ceiling jet calculation to not take into account lower wall surfaces. Too much energy was lost through the lower wall.

Corrected EXITT and SURVIVAL to access the layer interface height correctly. Prior to this fix, layer depth was always zero, making smoke detection (by detectors or "smell") inoperable.

Fixed thermal properties in several example data files to be consistent with current THERMAL.DF file.

Version 2.0.1 H 1.2 (7/1/94) This release did not get a new number!

Corrected write of vertical vent information to .DAT file in CEDIT. For large vent area, old format would merge two fields together resulting in read errors with the model. Tightened differential equation solver tolerances to correct calculated species

concentrations for one test case. This may make the model run slower when conditions are rapidly changing, but the answers should be more correct.

Corrected interaction between fire size and plume entrainment. Before the fix, CFAST calculated plume entrainment via a two step process:

 1) Determine the plume entrainment in FIRPLM via McCaffrey's method using the fire size unconstrained by the available oxygen.

 2) Once the actual fire size is calculated from the available oxygen in CHEMIE, a new estimate for the plume entrainment is determined by a simple linear correction. Since the plume entrainment is not a linear function of the fire size and the fire size depends on the oxygen entrained, this simple process can lead to an inconsistency between the fire size (calculated from the unconstrained plume entrainment) and the new estimate of the plume entrainment. For very large fires where the fire size is limited by the amount of oxygen entrained, this can lead to significant differences between the calculated fire size and the amount of oxygen actually available for the combustion. The fix is a simple one: when the fire is limited by the available oxygen entrained into the plume, the plume entrainment and fire size are both re-calculated by calling FIRPLM and CHEMIE a second time to get a better estimate of the actual oxygen available (and thus the actual fire size).

Version 2.0.1 (2/13/94) - H 1.2

 Corrected flow through horizontal openings (VVENT). In some test cases (where significant flow occurred from upper room to lower room), model would calculate extremely low temperatures in the lower room. Corrected species mass balance. For very large fires in small rooms, species mass fractions would not sum to unity when fire became oxygen limited. Printed output file is now placed in the data subdirectory along with the input data file.

Version 2.0 (August 23, 1993)

 Code restructured for future addition of a flame spread model. Consolidated calculation of hazardous conditions (and colors for plotting of them). Added a new THERMAL.DF file taken from Incorpera and DeWitt. New conduction routine. New convection routine. Use Watcom Fortran compiler. Printout routine has been totally rewritten to provide additional information with a consistent format.

Version 1.6.2 (December 1, 1992)

 Implement a faster initialization routine, and better selection rules for vertical flow. We now use the Pharlap memory expander which supports more display drivers. Mechanical ventilation is now tightly coupled with vertical and horizontal flow routines.

Version 1.5 (June, 1, 1992)

Added object specification (heat loss, ...), a more robust ODE solver (DASSL), restructured code to include physical interface routines for each physical phenomenon, and CEdit support for all modeling features.

Version 1.4 (February 1, 1992)

Added multiple fires, history file compression, extended memory, vertical flow, multiwall radiation model, distributed mechanical ventilation ducts, ceiling jet and 3D positioning of fires. The number of compartments was increased to 15.

CFAST Version 1.0 (May 1, 1990)

An amalgam of FAST 18.5 and CCFM -- functionally equivalent to FAST but more modular like CCFM.

FAST version 18.5 (May 1, 1990) HAZARD version 1.1 FAST version 18.3 (July 1988) HAZARD I version 1.0

Appendix K Error Messages

	Error No.	Error Message
	-11	ERROR IN RESID
	0	< Dassl error
1	1	Not an allowed fire type. (NPUTP)
2	2	Object no. XXX is in room XXX beyond the limit XXX rooms defined (NPUTP)
3	3	INTERNAL ERROR IN NPUTQ - RESTART OUT OF BOUNDS (NPUTQ)
4	4	No configuration and no data file (CFAST)
5	7	Error reading restart file (DREADIN)
6	6	Display area over written in view file read (DISPLAYC)
7	7	Error in accessing dump file (DUMPER)
8	-11	GASLOAD - Non numeric Token for display pointer (GASLOAD)
9	-11	GASLOAD - a pointer to a compartment must be a number (GASLOAD)
10	-11	GASLOAD - a pointer to a compartment must be a number (GASLOAD)
11	-11	GASLOAD - a layer must be specified (GASLOAD)
12	-11	HCLTRAN - H2O out of range (HCLTRAN)
13	-11	HVFRIC - I greater than 20 (HVFRIC)
14	14	HVINIT - Interior node has too many or too few connections (HVINIT)
15	15	LOADUP - Invalid number (LOADUP)
16	16	OFFSET - Node range exceeded for HVAC (OFFSET)
17	-11	RAD2 - Singular matrix (RAD2)
18	-11	RAD4 - Singular matrix (RAD4)
19	7	PACKOT - Overwrite, input and index = (WRITEOT)
20	20	UPDOBJ - Incorrectly defined object type (UPDOBJ)
21	21	INITTARG - Failure of target initialization (INITTARG)
22	22	NPUTP - Failure in nputp (NPUTP)
23	23	NPUTQ - Ignition criteria incorrect (NPUTQ)
24	24	NPUTQ - Invalid DETECTOR specification - room X is not a valid (NPUTQ)
25	25	NPUTQ - DETACT keyword must have at least 2 parameters (NPUTQ)
26	26	NPUTQ - Failure CFCON keyword (NPUTQ)
27	27	NPUTQ - Failure in SHAFT keyword (NPUTQ)
28	28	NPUTQ - Failure in TARGET keyword (NPUTQ)
29	29	NPUTQ - Failure in TARG keyword (NPUTQ)
30	30	OPENOBJ - Objects database file ',A,' does not exis t. (NPUTOB)
31	31	GETOBJ - Error in object definition in database (NPUTOB)
32	32	GETOBJ - Specified unsupported type. (NPUTOB)
33	33	GETOBJ - Too many targets (NPUTOB)
34	34	GETOBJ - Fatal error: too many flamespread type objects (NPUTOB)
35	35	SETFSM - Normal to the wall incorrectly defined (NPUTOB)
36	36	OPNTPF - Thermophysical properties file XXX does not exist. (NPUTT)
37	37	GETTTP - Failure in thermal physical properties definition. (NPUTT)
38	38	RSETVNTS - Adding too many time points. (RSETVNTS)
41	41	CFCON used to specify the outside. This is not an allowable specification.