Introduction to CFAST: Consolidated Model of Fire Growth and Smoke Transport

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Introduction

Overview

- CFAST is a two-zone fire model, developed by the National Institute of Standards and Technology (NIST), used to calculate the evolving distribution of smoke, fire gases, and temperature throughout compartments of a building during a fire. 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.

- The U.S. Department of Energy (DOE) provides guidance for use in supporting Documented Safety Analysis (DSA) applications for versions CFAST 3.1.7 and CFAST 5.1.1. The most current version is CFAST 6.0.10 and is presented here.

Guidance

DOE-EH-4.2.1.4-Final CFAST Code Guidance, “CFAST Computer Code Application Guidance for Documented Safety Analysis,” July 2004;

NIST Special Publication 1041 (December 2005) – CFAST User’s Guide for Version 6; and

NIST Special Publication 1026 (December 2005) – CFAST Technical Reference Guide for Version 6

Uses

- The timing of specific events in building fire performance, such as detector activation, sprinkler activation, and flashover, can be estimated using CFAST.
- The environmental conditions (e.g., temperature, combustion product concentrations, layer height) in the fire compartment and neighboring compartments can also be estimated.
- 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.

Heat Release Rate: The single most important variable in fire hazard

Heat Release Rate

- The heat release rate (HRR) is the single most important variable in describing fire hazard:

  The HRR is the driving force for the fire.

  Most other variables are correlated to the HRR (e.g., smoke, toxic gases, room temperatures, etc.)

  A high HRR indicates high threat to life as a high HRR causes high temperatures and high heat flux conditions.

Heat Release Rate (cont.)

- CFAST <u>does not</u> evaluate the HRR.
- CFAST accepts the HRR curve as an input that is reflected by three interrelated quantities: mass loss or pyrolysis rate (m), heat release rate (Q), and heat of combustion (ΔH_c).
- CFAST will calculate the third parameter as a function of time based on the last two parameters specified.

$$Q = \Delta H_c m$$

Heat Release Rate (cont.)

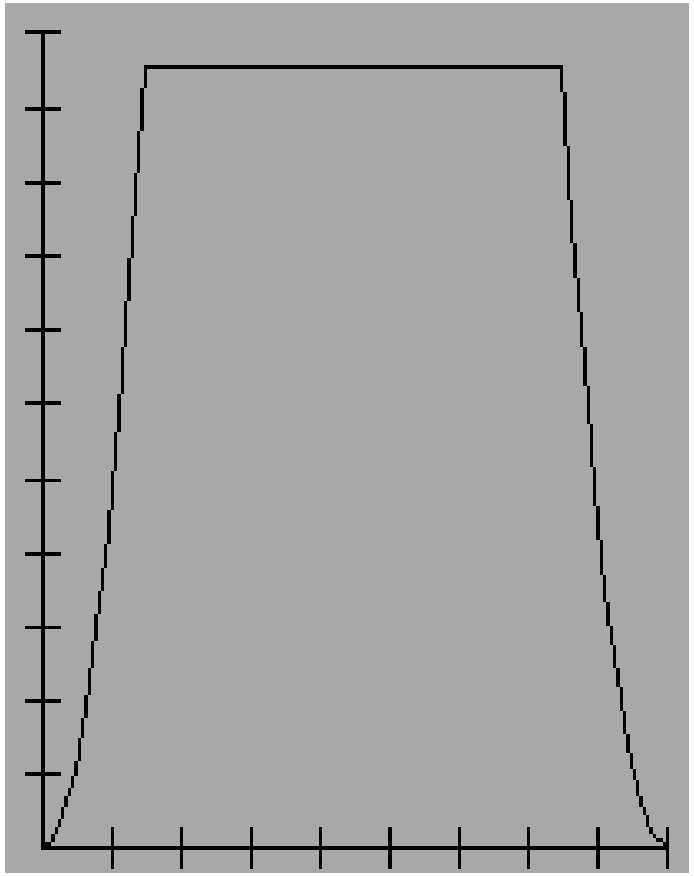
- CFAST uses the pyrolysis curve to define the fire history and the HRR curve to estimate the energy released.
- CFAST will limit the energy released to account for limited oxygen conditions.
- Because the pyrolysis curve is an input value, CFAST results do not account for increased pyrolysis due to radiative feedback from the flame or the compartment. The similarity of the input to the real fire problem of interest will determine the accuracy of the resulting calculation. The user must account for any interactions between the fire and the pyrolysis rate.

Heat Release Rate (cont.)

- There are limitations inherent in the assumptions used in application of the empirical models in CFAST. As a general guideline, the heat release should not exceed about 1 MW/m^3. This is a limitation on the numerical routines due to the coupling between gas flow and heat transfer through boundaries (conduction, convection, and radiation).

Heat Release Rate (cont.)

- The HRR curve can be characterized by a growth phase, a steady phase, and a decay phase



Heat Release Rate (cont.)

During the growth phase of a fire, the HRR, Q, is approximately expressed by:

$$Q = \alpha\, t^2$$

The growth phase is characterized by a growth time, t_g, which is the time for the fire to reach 1,000 Btu/s or 1,055 kW:

$$1{,}055 \text{ kW} = \alpha\, t_g^{\,2}$$

Combining these equations yields:

$$Q = 1{,}055\, (t/t_g)^2 \text{ kW}$$

where t = any time on the HRR curve.

Heat Release Rate (cont.)

The steady state phase of a fire is characterized by a constant heat release rate, Q_m, which is the maximum heat release rate of the fire:

$$Q_m = 1{,}055\ (t_m/t_g)^2\ \text{kW}$$

where t_m = the end of the growth phase and the beginning of the steady phase.

Heat Release Rate (cont.)

The duration of the steady phase, denoted by t_s, is determined as follows:

The total heat released, E_m, during the growth phase is:

$$E_m = 1/3\ (1{,}055/t_g^2)\ t_m^3$$

The mass burned during the growth phase, ΔM, is:

$$\Delta M = E_m / \Delta H_c$$

where ΔH_c is the heat of combustion.

Combining these two equations yields:

$$\Delta M = 1/3\ (1{,}055/t_g^2)\ t_m^3 / \Delta H_c$$

Heat Release Rate (cont.)

During the steady phase, the combustibles are consumed at a constant rate equivalent to the maximum heat release rate, Q_m. Therefore, the duration of the steady phase, t_s, is obtained by:

$$t_s = [(M - \Delta M)\ \Delta H_c]/Q_m$$

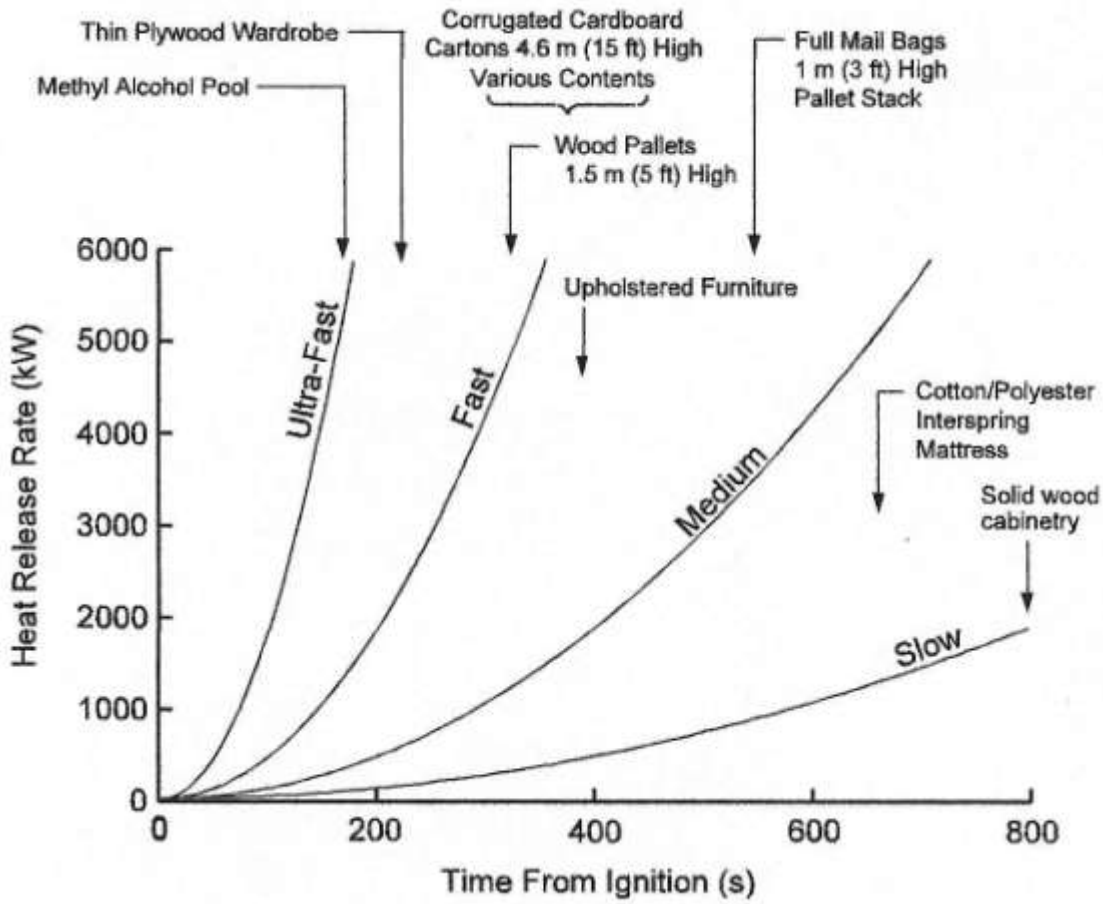
It is conservatively assumed that all combustible materials are consumed by the end of the steady phase, $t_m + t_s$. Therefore, for the purpose of calculating the maximal temperature of a fire, the decay phase is not important and is ignored.

Heat Release Rate (cont.)

- The growth rate approximately follows a relationship proportional to time squared for flaming and radially spreading fires: t-squared (t^2) fires. Such fires are classed by the speed of growth: slow, medium, fast, and ultra-fast with fire intensity coefficients (α) such that the fires reach an HRR of 1,055 kW (1,000 BTU/s) in 600 s, 300 s, 150 s, and 75 s, respectively.

Fire Growth	**Fire Intensity Coefficient α (kW/sec^2)**	**Growth Time t_g (sec)**	**Duration of fire prior to decay $t_m + t_s$ (sec)**
Slow	0.00293	600	1200
Medium	0.01172	300	900
Fast	0.0469	150	750
Ultra-fast	0.1876	75	150

Heat Release Rate (cont.)



Flashover: The fully developed fire and the ultimate signal of untenable conditions

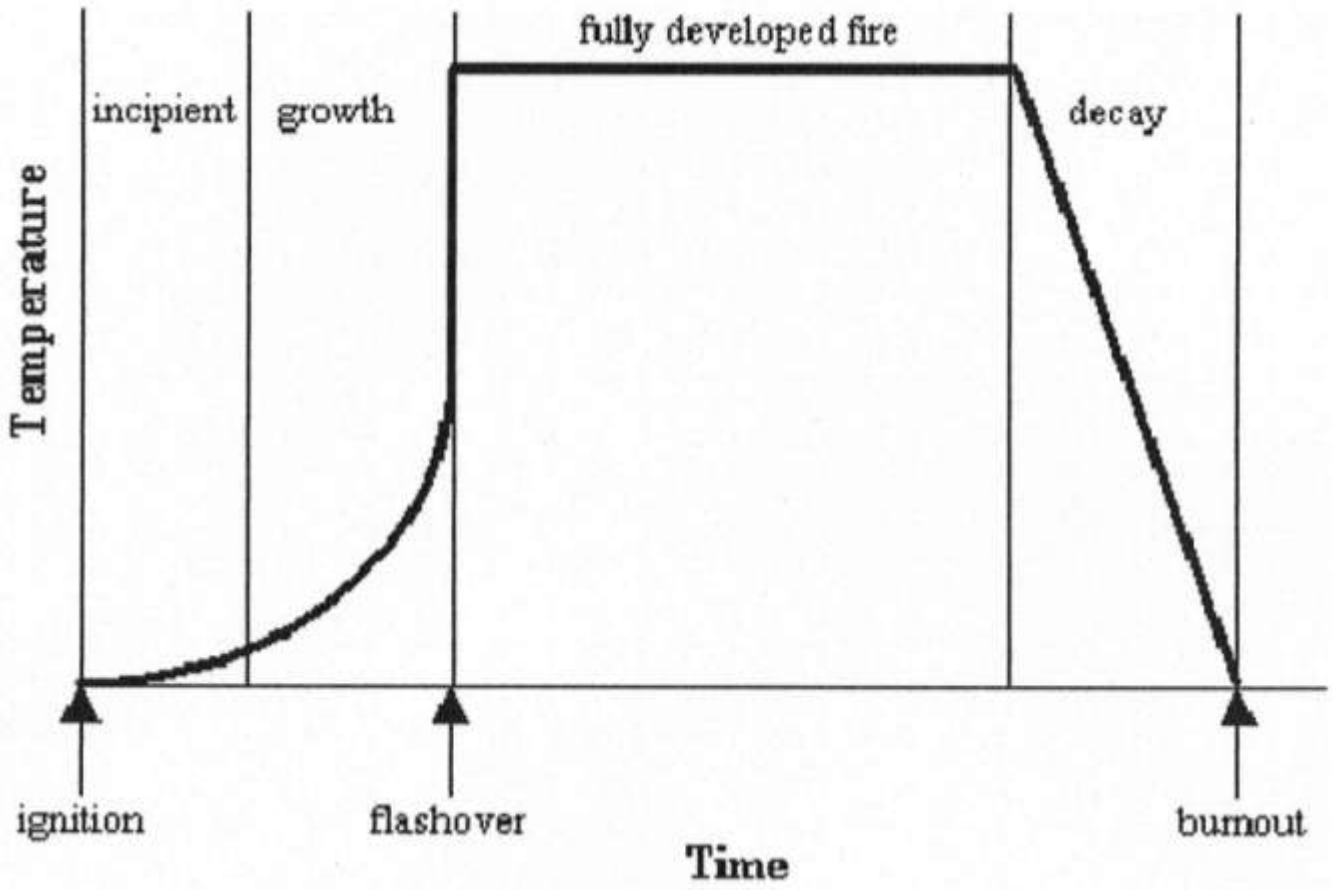
Definition

- Flashover is a transitional phase in the development of a compartment fire in which surfaces exposed to thermal radiation reach ignition temperature more or less simultaneously and fire spreads rapidly throughout the space resulting in full room involvement or total involvement of the compartment or enclosed area.
- 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.

Stages of Compartment Fire

1. Growth or pre-flashover stage: The average compartment temperature is relatively low and the fire is localized in the vicinity of its origin.
2. Fully developed or post-flashover fire: All combustible items in the compartment are involved and flames appear to fill the entire volume.
3. Decay period: Often identified as that stage of the fire after the average temperature has fallen to 80% of its peak value.

Stages of Compartment Fire



Fully-Developed Stage

- Rate of heat release reaches a maximum and threat to neighboring compartments – and perhaps adjacent buildings – is greatest.
- Flames may emerge from any ventilation opening, spreading fire to the rest of the building, either internally (through open doorways) or externally (through windows).
- Structural damage may occur, perhaps leading to partial or total collapse of the building.
- Once flashover has occurred in one compartment, the occupants of the rest of the building can be threatened directly.

Flashover and Structural Integrity

- The fire resistance of a building may be defined as:

  (1) Its ability to withstand exposure to fire without losing its load bearing function; and

  (2) Its ability to act as a barrier to the spread of fire.
- Before a fire is in the fully-developed stage, temperatures are relatively low and have a negligible influence on the fire resistance of building elements.
- During the fully-developed stage (post-flashover), the risk that structural members or fire barriers will fail begins.
- The risk of failure of structural members or fire barriers continues to exist during the decay period of the fire.

DOE Recommended Logic

- Flashover is not expected if the maximum predicted upper layer temperatures resulting from iterated ventilation conditions do not exceed 450°C.
- If the maximum predicted upper layer temperatures resulting from iterated ventilation conditions exceed 600°C, flashover should be expected.
- If the maximum predicted upper layer temperatures resulting from iterated ventilation conditions are between 450 and 600°C, the occurrence of flashover is indeterminate.

DOE Guidance

DOE Recommended Approach

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.
5. Iterate the HRR curve to produce a peak HRR 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 peak HRR 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.

An Overview of CFAST

Data Libraries

- thermal.csv – This data library provides the typical heat transfer data used to describe walls and other objects. This data library may be used as is or modified to meet the needs of the analysis.
- object.o – Multiple object files (e.g., sofa.o) are included with this version of CFAST. Object files are selected to define the fire or fires. Defaults may be used or new objects may be created.

Simulation Files

- *.in – input file
- *.out – text output file
- *.csv – spreadsheet output files (n-normal output, s-species output, f-flow output, w-wall surface temperatures and targets and sprinklers)
- *.smv – Smokeview geometry file
- *.plt – Smokeview plot file
- *.hi – binary output file

Example 1

Office Fire

Results Used to Determine Combustible Loading Limits

Necessary Information

The following information (as a minimum) will need to be determined by walkdown, review of literature, or calculation prior to beginning input into CFAST for this example:

- How many compartments will be modeled
- Dimensions of compartments
- Composition of floor, ceiling, and walls
- Location and dimensions of doorways and vents
- Location and quantities of combustibles
- Characteristics of the HRR curve

Compartments

Two compartments and a corridor will be modeled in this example.

Compartment 1 (Office): 12 ft W x 12 ft L x 15 ft H; ceiling and floor – 6 in. concrete, normal weight; walls – 1/8 in. steel plate (plain carbon steel)

Compartment 2 (Laboratory): 12 ft W x 24 ft L x 10 ft H; ceiling – 5/8 in. gypsum; floor – 6 in. concrete, normal weight; walls – 1/8 in. steel plate (plain carbon steel)

Compartment 3 (Corridor): 6 ft W x 12 ft L x 10 ft H; ceiling – 5/8 in. gypsum; floor – 6 in. concrete, normal weight; walls – 1/8 in. steel plate (plain carbon steel)

Doorways and Vents

Compartment 1 (Office): 1 door open to the corridor – 3 ft W x 7 ft H

Compartment 2 (Laboratory): 1 door open to the corridor – 5 ft W x 7 ft H

Compartment 3 (Corridor): In addition to the office and laboratory doors, 2 doors open to the outside (at either end of the corridor) – each 6 ft W x 10 ft H

Heat Release Rate Curve

The types of combustibles present are used to estimate the growth time, t_g, of a fire involving those or similar combustibles:

> *Office* - Paper loosely placed on a desk, books on a bookshelf, chairs, etc.

In most cases, data will not be found for the specific combustibles that may be present; therefore, combustibles for which there is data available should be selected to best represent what combustibles are actually present. Tables B.2.3.2.6.2(a) and (e) in NFPA 72 will be used to estimate the growth time (t_g) of a fire by selecting combustibles similar to those found in the office.

Heat Release Rate Curve (cont.)

- Paper loosely placed on a desk will be represented by mail bags, filled, stored 5 ft high – t_g = 190 s
- Books on a bookshelf will be represented by paper products, densely packed in cartons, rack storage, 20 ft high – t_g = 470 s
- Chairs will be represented by chair, metal frame, padded seat and back, 34.26 lb – t_g = 350 s

Heat Release Rate Curve (cont.)

The growth time, t_g, of the combined combustible materials in the office is taken as the average value of the above selected data:

$$\text{Office} - t_g = (190 + 470 + 350)/3 \text{ s} = 337 \text{ s}$$

This growth time represents the time it will take for the fire to reach 1 MW.

(Inputs for a custom t-square growth fire will be used to generate the HRR curve.)

Heat Release Rate Curve (cont.)

The second input required for specifying a custom t-square growth fire is the level off time of the fire (i.e., the time at which the fire achieves the maximum or peak HRR, Q_m).

The maximum HRR, Q_m, is expressed as:

$$Q_m = q_m A$$

where q_m is the heat release density and A is the space occupied by the combustibles

Heat Release Rate Curve (cont.)

The heat release density, q_m, is taken again from tables B.2.3.2.6.2(a) and (e) in NFPA 72. The heat release density, for this example, is considered to be represented by the average of the mail bag and ½ of cartons, compartmented, stacked 15 ft high:

$$q_m = (35 + 200/2)/2 \text{ Btu/s-ft}^2 = 67.5 \text{ Btu/s-ft}^2$$

Heat Release Rate Curve (cont.)

The space occupied by the combustibles in the office is taken to be 25 percent of the floor area; therefore, the maximum HRR, Q_m, is:

$$Q_m = 67.5 \text{ Btu/s-ft}^2 \times 0.25 \times 144 \text{ ft}^2 = 2.57 \text{ MW}$$

$$(2{,}430 \text{ Btu/s} / 9.480 \times 10^{-4} = 2.57 \times 10^6 \text{ J/s})$$

The time at which the fire achieves the maximum HRR, Q_m, is determined by:

$$Q_m = 1{,}055 \, (t_m/t_g)^2 \text{ kW}$$

$$2.57 \times 10^3 \text{ kW} = 1{,}055 \, (t_m/337 \text{ s})^2 \text{ kW}$$

$$t_m = 526 \text{ s}$$

Heat Release Rate Curve (cont.)

The third input required for specifying a custom t-square growth fire is the time that the decay phase starts, marking the end of the steady phase. The duration of the steady phase, t_s, is dependent upon the mass remaining to be burned following the growth phase. The mass burned during the growth phase is:

$$\Delta M = 0.3333\ (1{,}055/337^2)\ (526)^3 / 16.2\ \text{MJ/kg} = 27.8\ \text{kg}$$

(All combustible materials were converted into equivalent quantities of ordinary combustibles with the heat of combustion of 16.2 MJ/kg.)

Heat Release Rate Curve (cont.)

Because the purpose of this example is to determine combustible loading limits, 1-, 2-, and 3-lb/ft^2 will be modeled.

$$M = 1\ \text{lb/ft}^2 \times 144\ \text{ft}^2 = 65.5\ \text{kg}$$

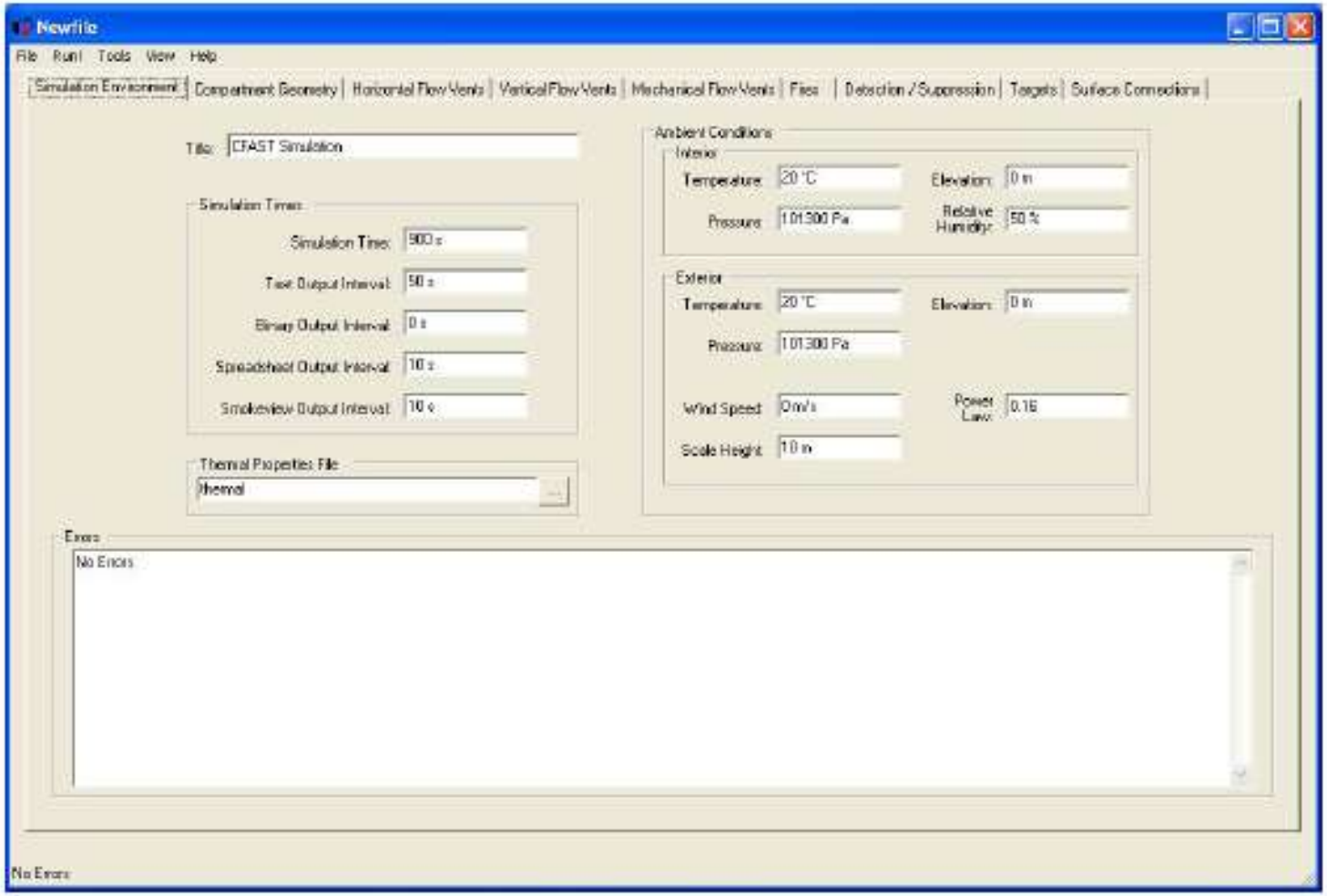
$$t_s = (M - \Delta M)\ \Delta H_c/Q_m$$

$$t_s = (65.5 - 27.8\ \text{kg})(16.2\ \text{MJ/kg})/2.57\ \text{MW} = 238\ \text{s}$$

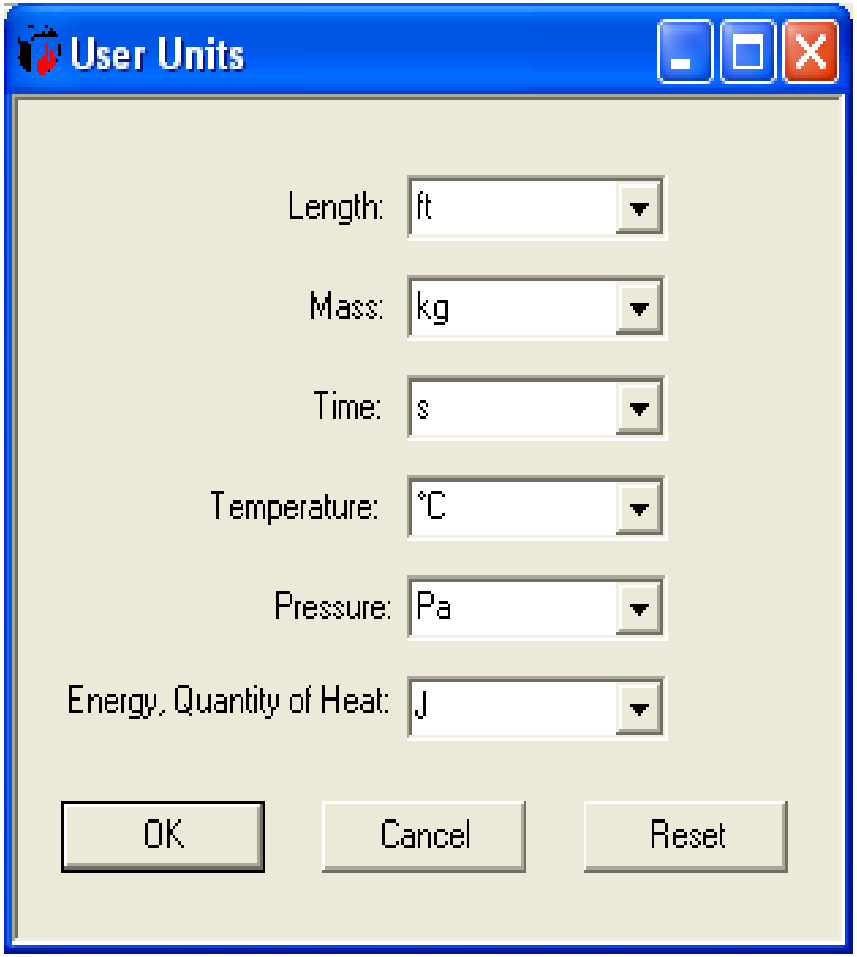
$$t_{tot} = (t_m + t_s) = (526 + 238)\text{s} = 764\ \text{s}$$

764 s is the time the steady phase ends and the decay phase begins for the 1 lb/ft^2 model. Likewise, 1,177s will be used for the 2 lb/ft^2 model and 1,586 s will be used for the 3 lb/ft^2 model.

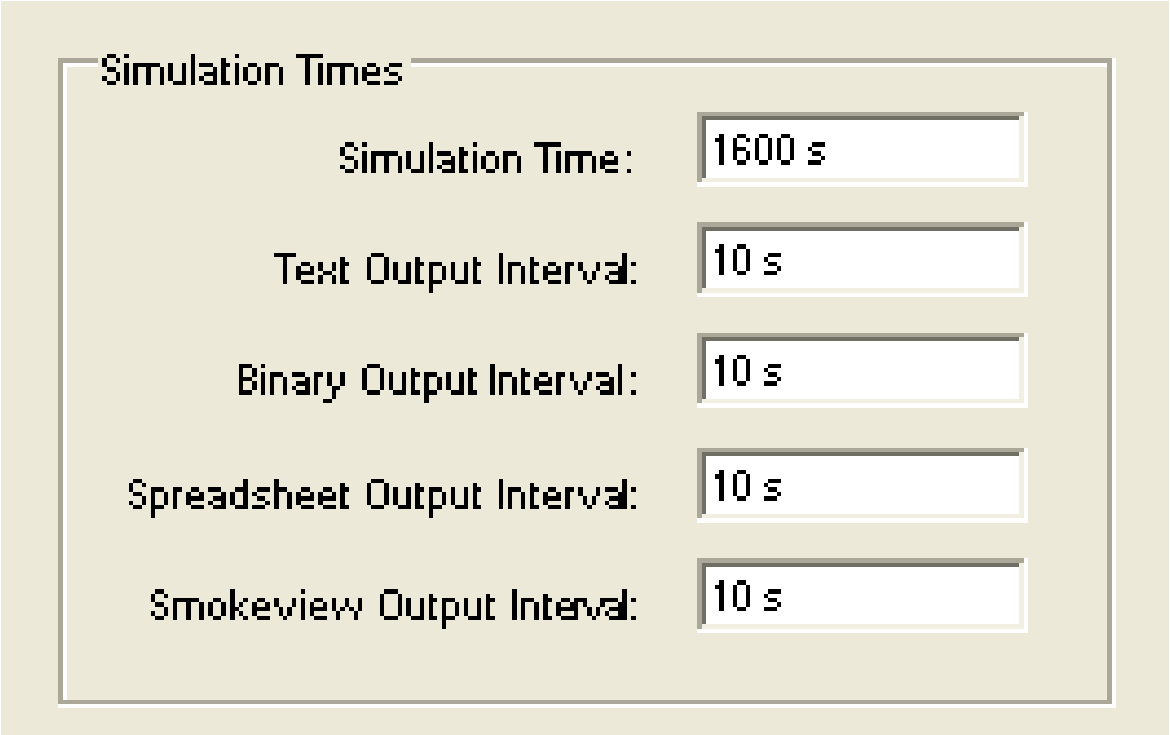
CFAST Window



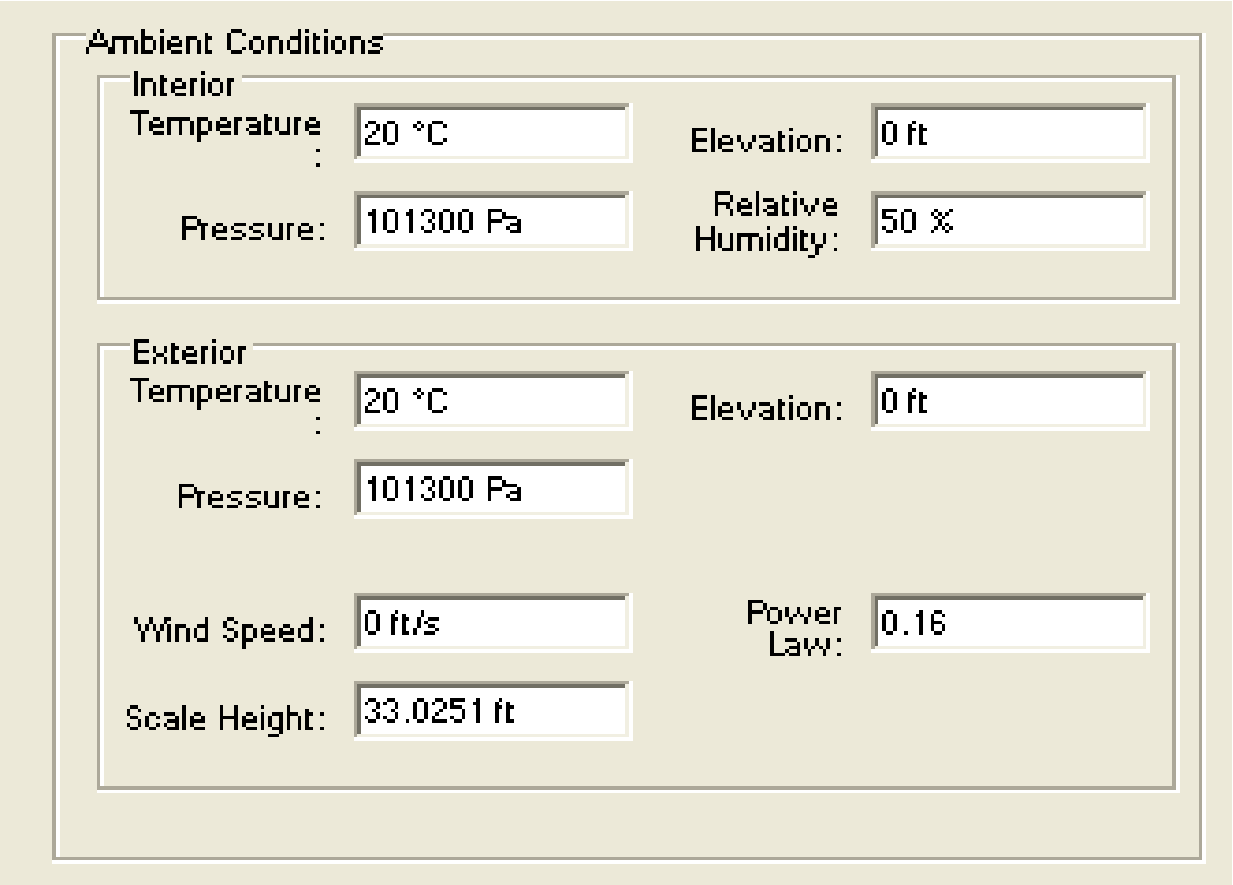
Specifying Units



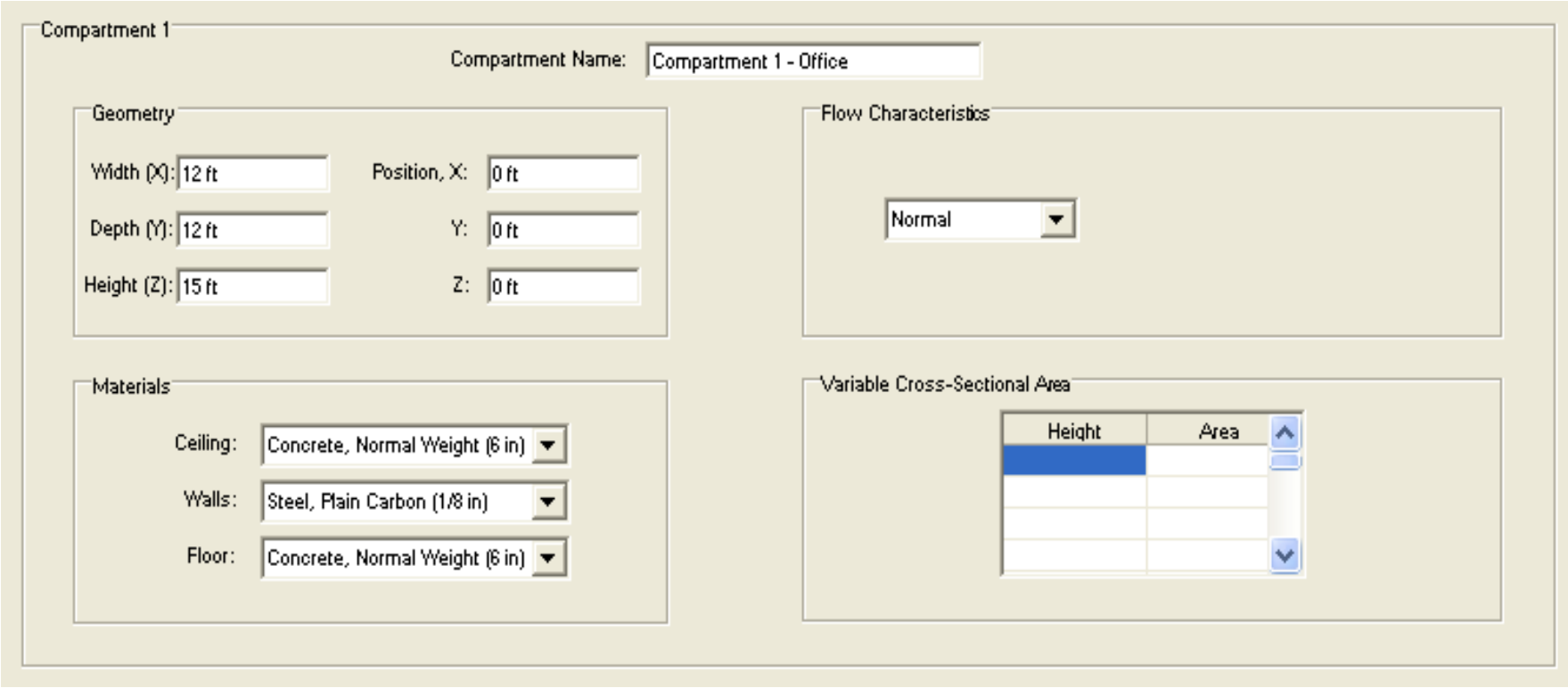
Simulation Environment



Simulation Environment



Compartment 1 Geometry



Compartment 2 Geometry

Compartment 2

Compartment Name: Compartment 2 - Corridor

Geometry

Width (X): 6 ft
Position, X: 0 ft
Depth (Y): 12 ft
Y: 0 ft
Height (Z): 10 ft
Z: 0 ft

Flow Characteristics

Normal

Materials

Ceiling: Gypsum Board (5/8 in)
Walls: Steel, Plain Carbon (1/8 in)
Floor: Concrete, Normal Weight (6 in)

Variable Cross-Sectional Area

Height	Area

Compartment 3 Geometry

Compartment 3

Compartment Name: Compartment 3 - Laboratory

Geometry

Width (X): 12 ft

Position, X: 0 ft

Depth (Y): 24 ft

Y: 0 ft

Height (Z): 10 ft

Z: 0 ft

Flow Characteristics

Normal

Materials

Ceiling: Gypsum Board (5/8 in)

Walls: Steel, Plain Carbon (1/8 in)

Floor: Concrete, Normal Weight (6 in)

Variable Cross-Sectional Area

Height	Area

Horizontal Flow Vents (1)

Vent 1 (of 4) Geometry

First Compartment

Compartment 1 - Office

Vent Offest: 0 ft

Second Compartment

Compartment 2 - Corridor

Vent Offest: 0 ft

Sill: 0 ft

Soffit: 7 ft

Width: 3 ft

Initial Opening Fraction: 1

Change Fraction At: 0 s

Final Opening Fraction: 1

Wind Angle: 0 °

Face: Front

Horizontal Flow Vents (2)

Vent 2 (of 4) Geometry

First Compartment

Compartment 3 - Laboratory

Vent Offest: 0 ft

Second Compartment

Compartment 2 - Corridor

Vent Offest: 0 ft

Sill: 0 ft

Soffit: 7 ft

Width: 5 ft

Initial Opening Fraction: 1

Change Fraction At: 0 s

Final Opening Fraction: 1

Wind Angle: 0 °

Face: Rear

Horizontal Flow Vents (3)

Vent 3 (of 4) Geometry

First Compartment

Compartment 2 - Corridor

Vent Offset: 0 ft

Second Compartment

Outside

Vent Offset: 0 ft

Sill: 0 ft

Soffit: 10 ft

Width: 6 ft

Initial Opening Fraction: 1

Change Fraction At: 0 s

Final Opening Fraction: 1

Wind Angle: 0 °

Face: Right

Horizontal Flow Vents (4)

Vent 4 (of 4) Geometry

First Compartment

Compartment 2 - Corridor

Vent Offest: 0 ft

Second Compartment

Outside

Vent Offest: 0 ft

Sill: 0 ft

Soffit: 10 ft

Width: 6 ft

Initial Opening Fraction: 1

Change Fraction At: 0 s

Final Opening Fraction: 1

Wind Angle: 0 °

Face: Left

Defining Main Fire

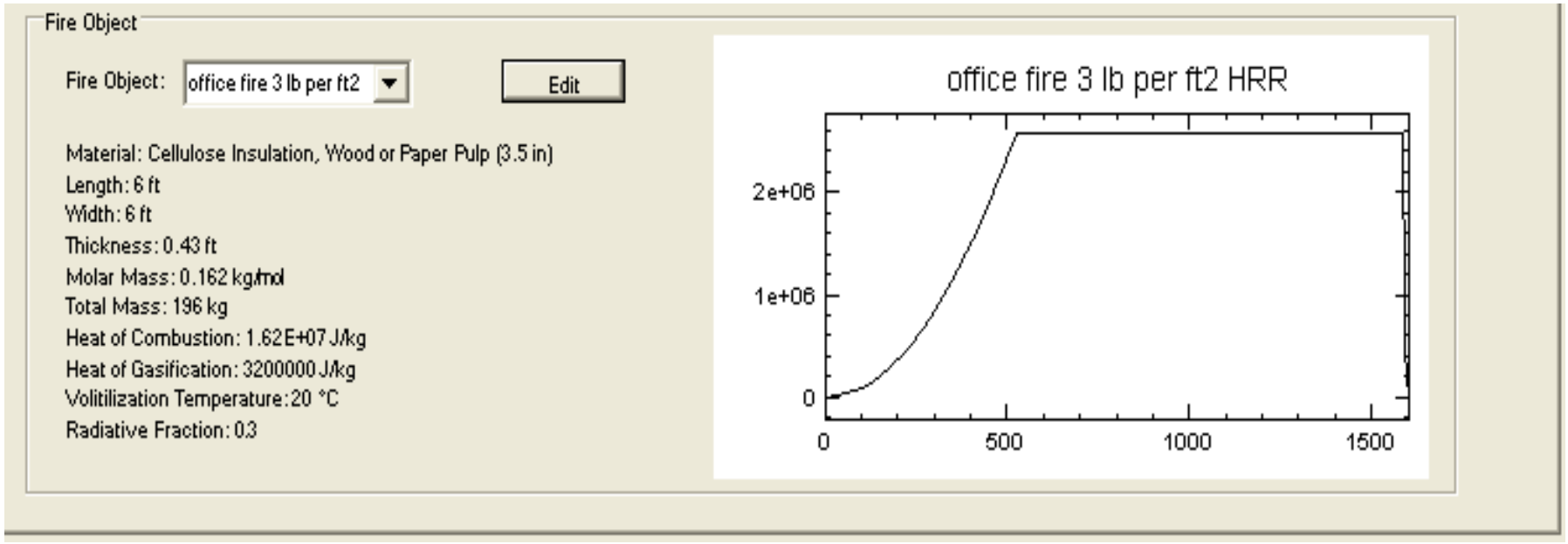
Fire 1

Compartment: Compartment 1 - Office

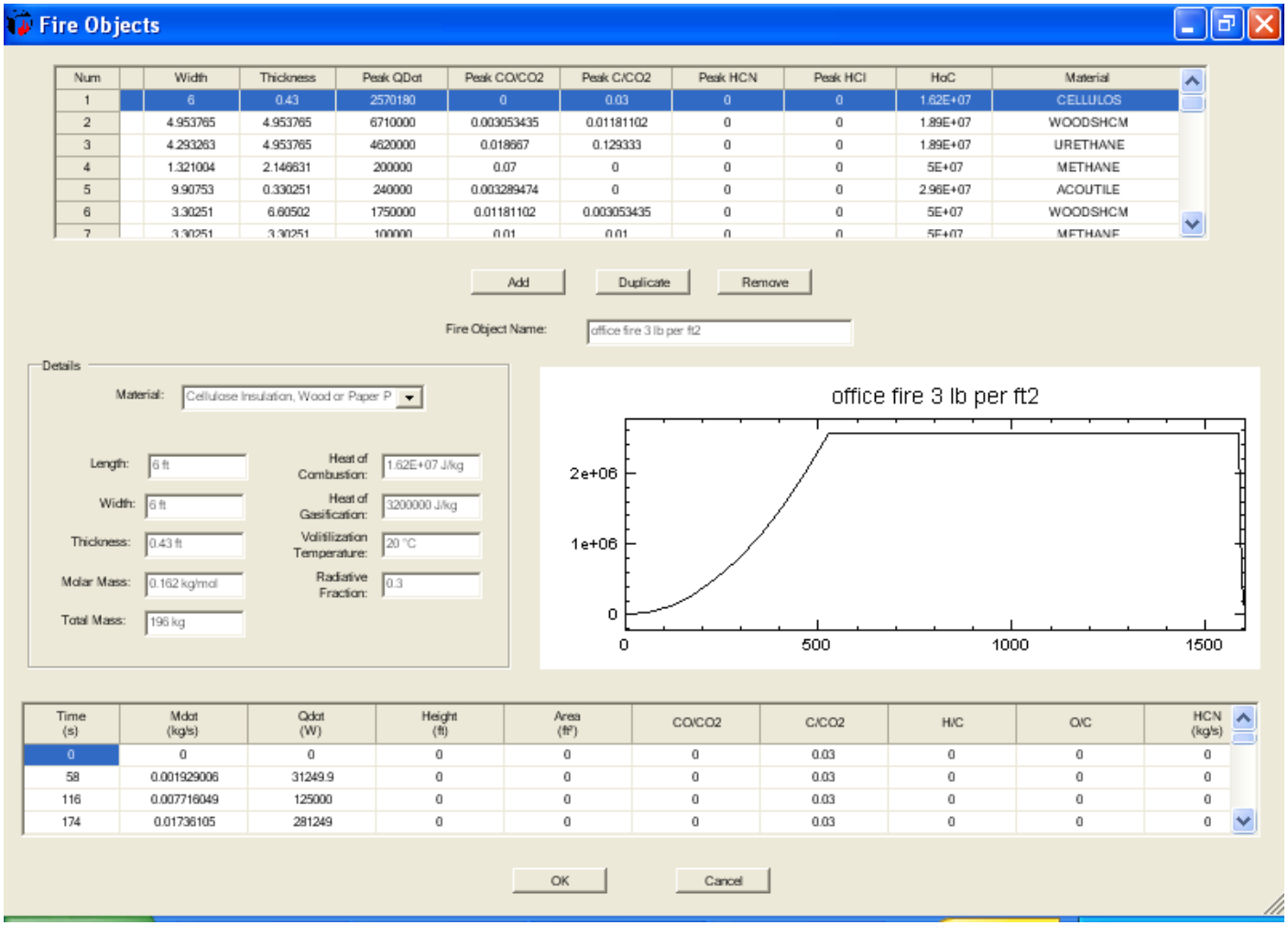
Type: Constrain | Position, X: 6 ft | Position Y: 6 ft | Position Z: 0 ft | Ignition Criterion: Time

Normal, X: 1 | Normal, Y: 1 | Normal, Z: 0 | Plume: McCaffre | Ignition Value: 0 s

Defining Main Fire



Defining Main Fire

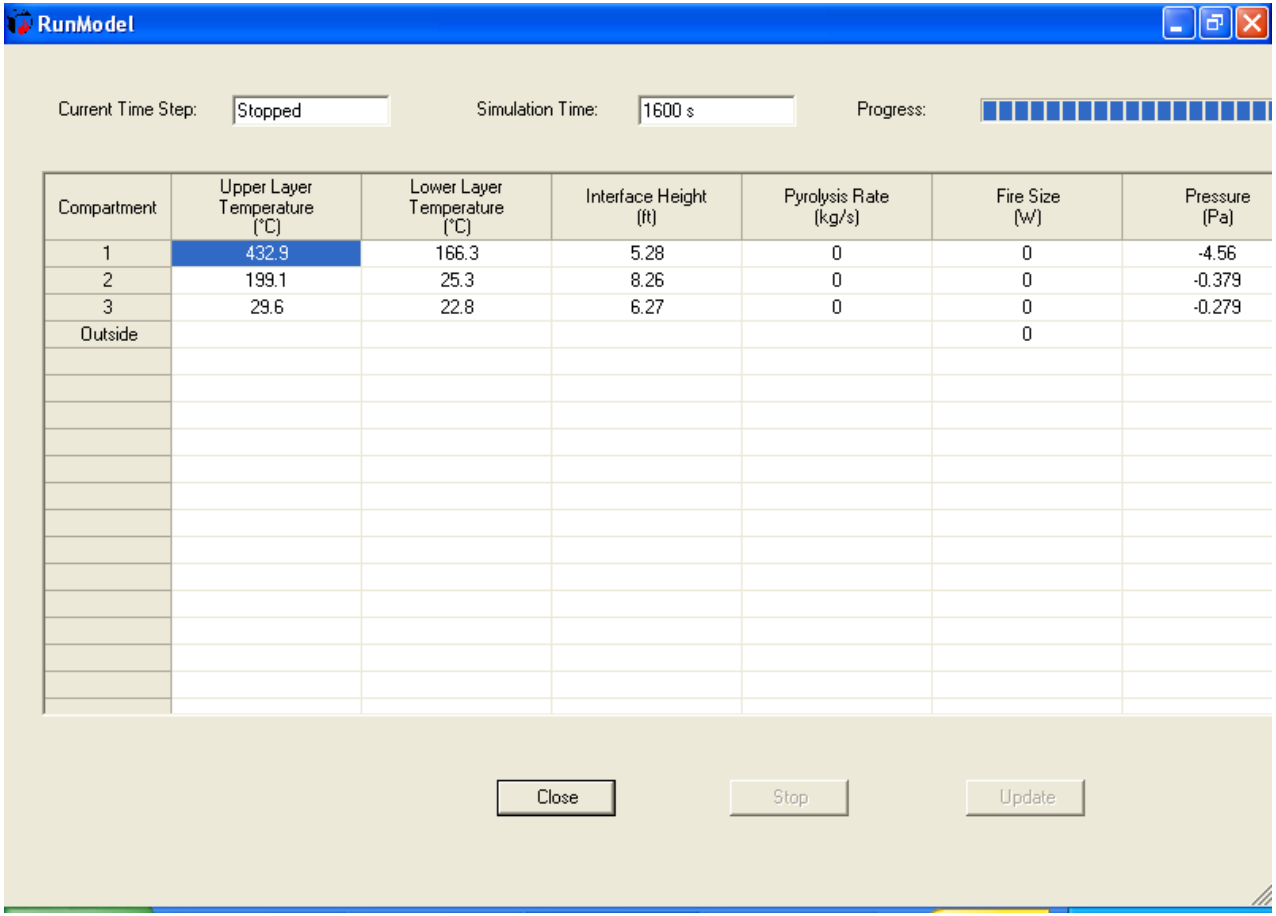


Num	Width	Thickness	Peak QDot	Peak CO/CO2	Peak C/CO2	Peak HCN	Peak HCl	HoC	Material
1	6	0.43	2570180	0	0.03	0	0	1.62E+07	CELLULOS
2	4.953765	4.953765	6710000	0.003053435	0.01181102	0	0	1.89E+07	WOODSHCM
3	4.293263	4.953765	4620000	0.018867	0.129333	0	0	1.89E+07	URETHANE
4	1.321004	2.146631	200000	0.07	0	0	0	5E+07	METHANE
5	9.90753	0.330251	240000	0.003289474	0	0	0	2.96E+07	ACOUTILE
6	3.30251	6.60502	1750000	0.01181102	0.003053435	0	0	5E+07	WOODSHCM
7	3.30251	3.30251	100000	0.01	0.01	0	0	5E+07	METHANE

Time (s)	Mdot (kg/s)	Qdot (W)	Height (ft)	Area (ft²)	CO/CO2	C/CO2	H/C	O/C	HCN (kg/s)
0	0	0	0	0	0	0.03	0	0	0
58	0.001929006	31249.9	0	0	0	0.03	0	0	0
116	0.007716049	125000	0	0	0	0.03	0	0	0
174	0.01736105	281249	0	0	0	0.03	0	0	0

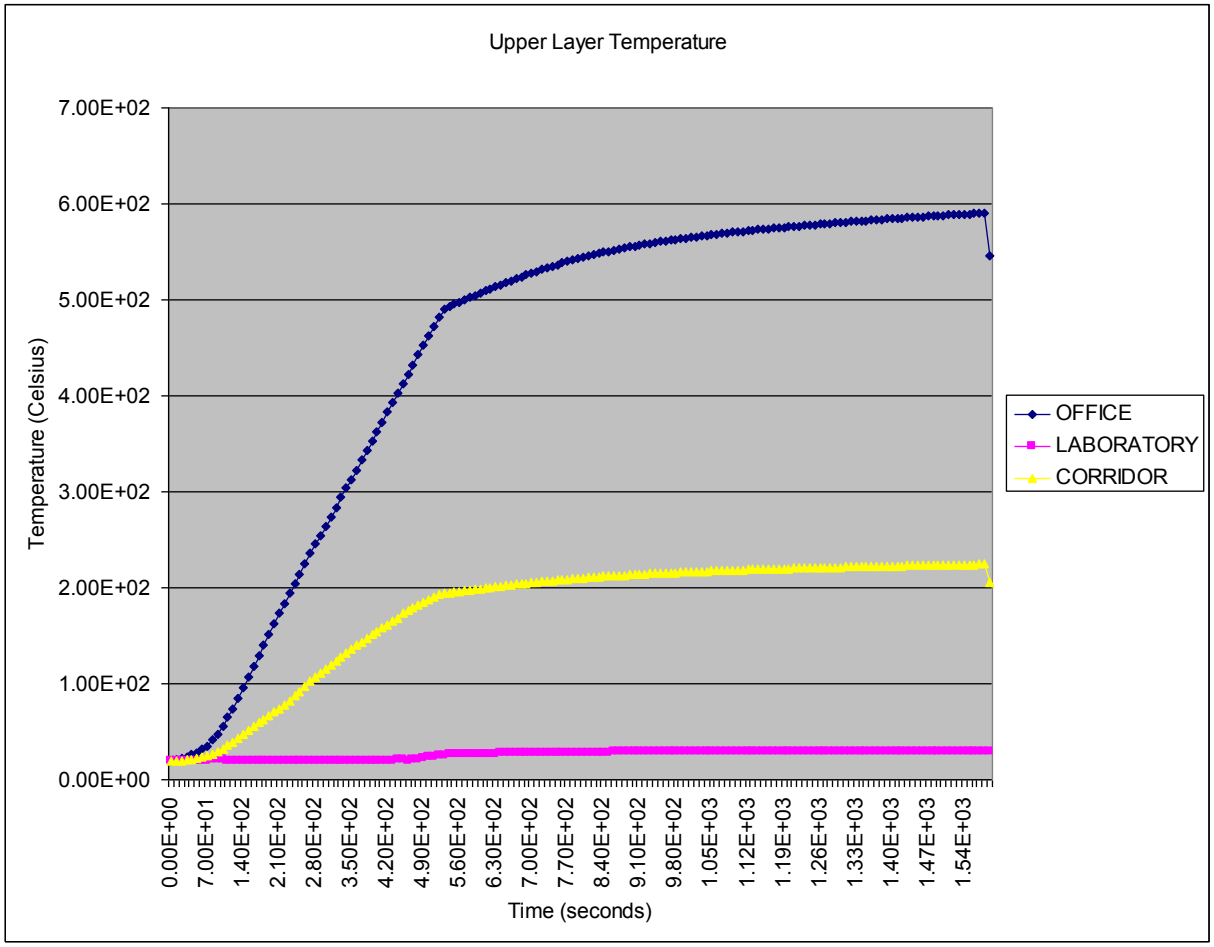
Running the Model

- Select Run! And Model Simulation, CFAST

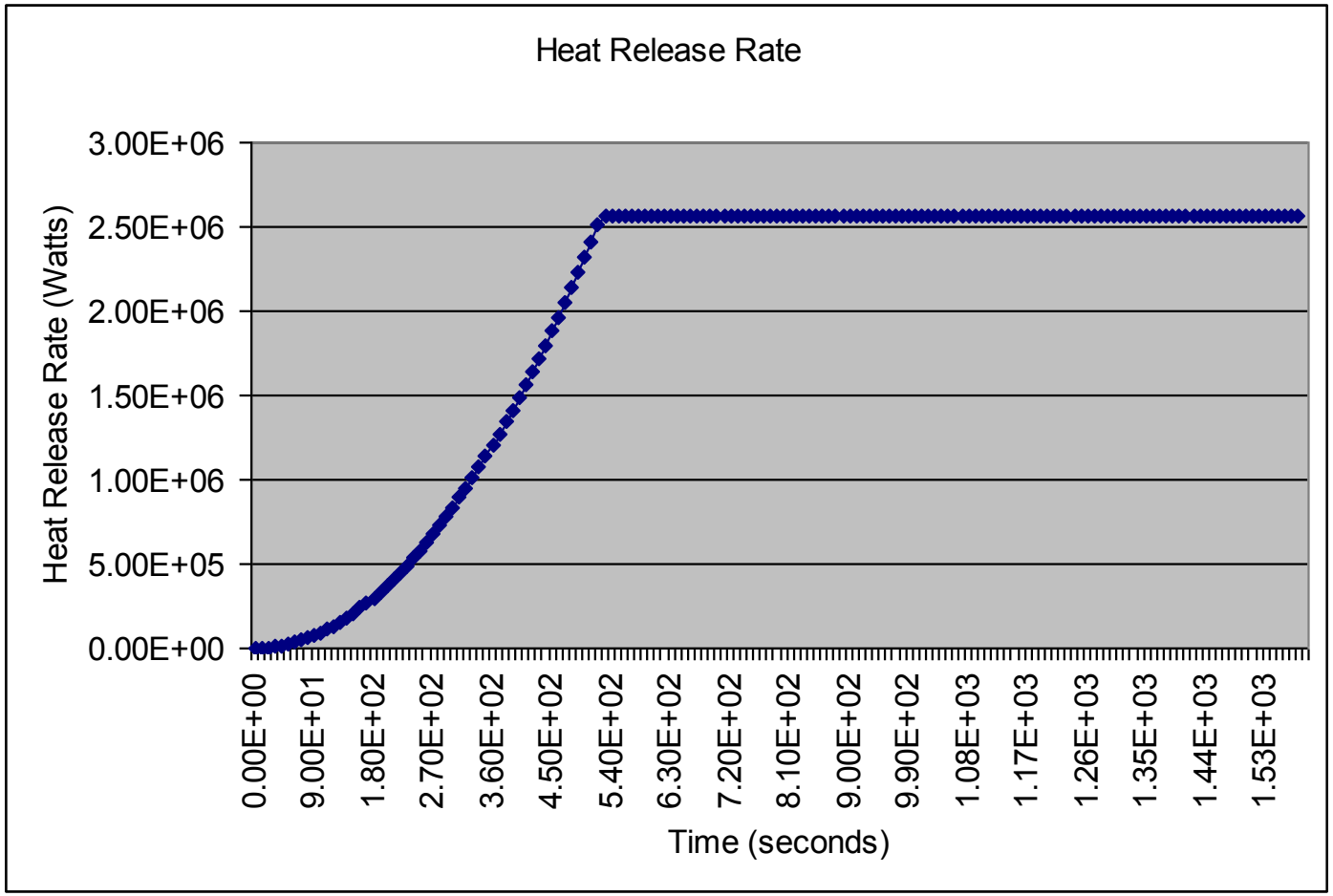


Compartment	Upper Layer Temperature (°C)	Lower Layer Temperature (°C)	Interface Height (ft)	Pyrolysis Rate (kg/s)	Fire Size (W)	Pressure (Pa)
1	432.9	166.3	5.28	0	0	-4.56
2	199.1	25.3	8.26	0	0	-0.379
3	29.6	22.8	6.27	0	0	-0.279
Outside					0	

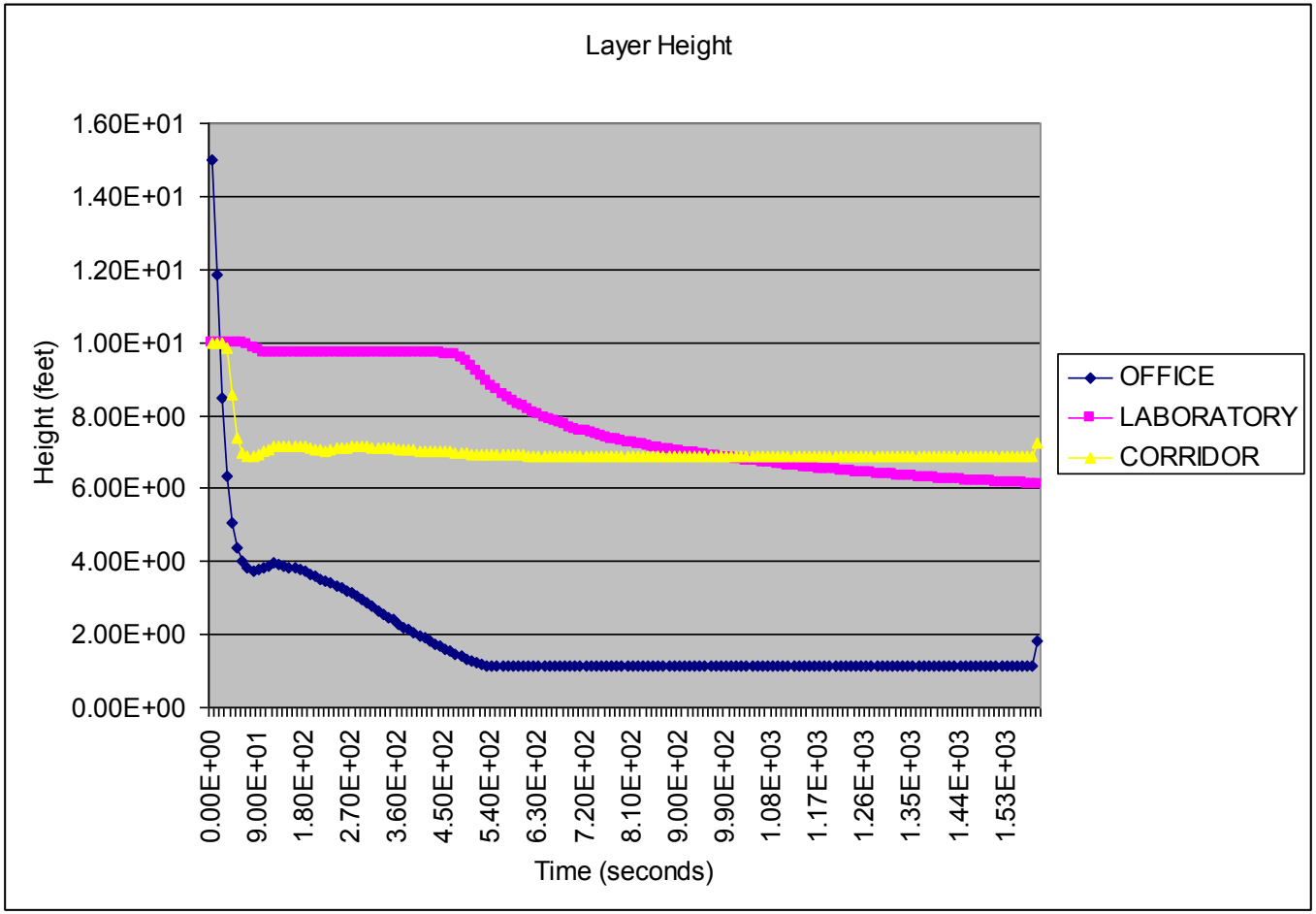
Upper Layer Temperature



Heat Release Rate Curve



Layer Height



Interpreting the Results

- Using the flashover logic given in the DOE CFAST guidance document, the occurrence of flashover is indeterminate. Iterating the ventilation conditions and the HRR curve will likely result in an upper layer temperature greater than 600°C and an expectation of flashover given 3 lbs/ft^2 of combustibles.
- Run multiple models with varying parameters to ensure that the results are conservative and bounding.
- Assume a certain degree of uncertainty even after multiple models have been run.

Effects of Varying Parameters

Hot Cell Example

Effects of Varying Parameters

An evaluation of a potential hot cell fire was performed to determine the impact of certain variables on the upper layer temperature. CFAST was utilized to determine the impact of the following variables:

- The packing density of the combustibles in the fire
- The heat release density of the combustibles in the fire
- The area the fire occupies
- The volume of the hot cell
- The fire growth rate
- The hole size chosen to represent the aggregate in-leakage into the hot cell

Scenario Information

- Fire initiates in an alpha box within the hot cell due to ignition of combustibles from a hot plate or heat lamp, is self-sustaining with no operator suppression, propagates to other combustibles within the alpha box, propagates to the hot cell, and fails the hot cell HEPA filter providing a transport pathway for MAR to the public.
- The ignition of additional combustibles contained within a 30-gallon waste drum located below the alpha box is conservatively assumed.
- Potential fire effect propagation mechanisms from the alpha box to the hot cell which could ignite combustibles contained in the 30-gallon waste drum are:

  (1) An open port in the alpha box and an open lid of the 30-gallon waste drum

  (2) Failure of the alpha box windows which allows for the transport of heat and smoke to the hot cell

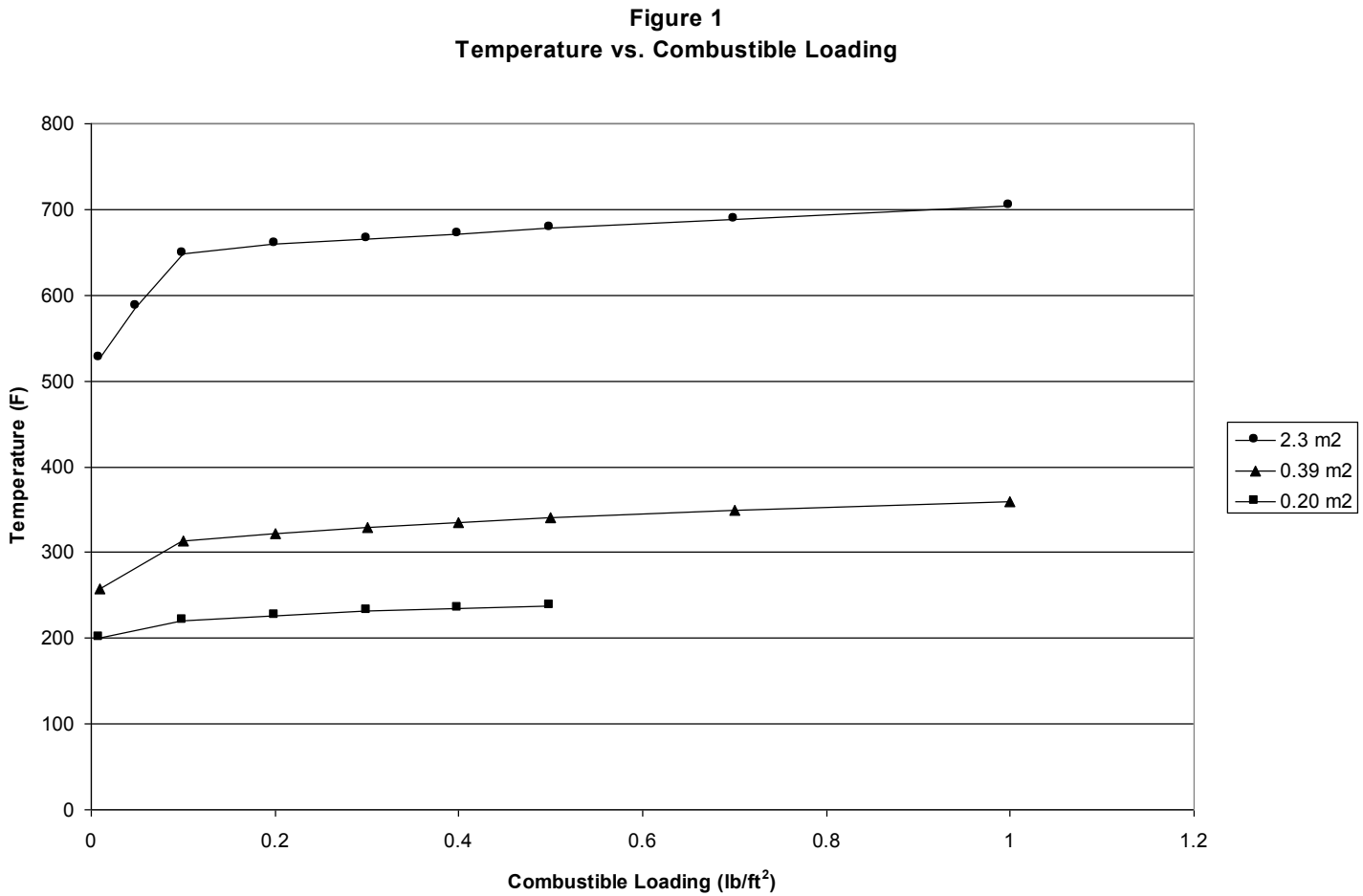
  (3) Transport of heat and smoke from the alpha box through penetrations to the hot cell, which ignites the combustibles within the 30-gallon waste drum

Packing Density of Combustibles

Three fire sizes were considered: 0.20 m^2, 0.39 m^2, and 2.30 m^2, representing one 30-gallon waste container, two 30-gallon waste containers, and 38 percent of the floor area, respectively. To analyze the impact of combustible quantity on the hot layer temperature, packing densities of the three fires were varied.

<u>Results:</u> The peak hot layer temperature attained in a fire is affected more strongly by the area which the fire occupies than by the total combustibles burned by the fire.

Packing Density (cont.)

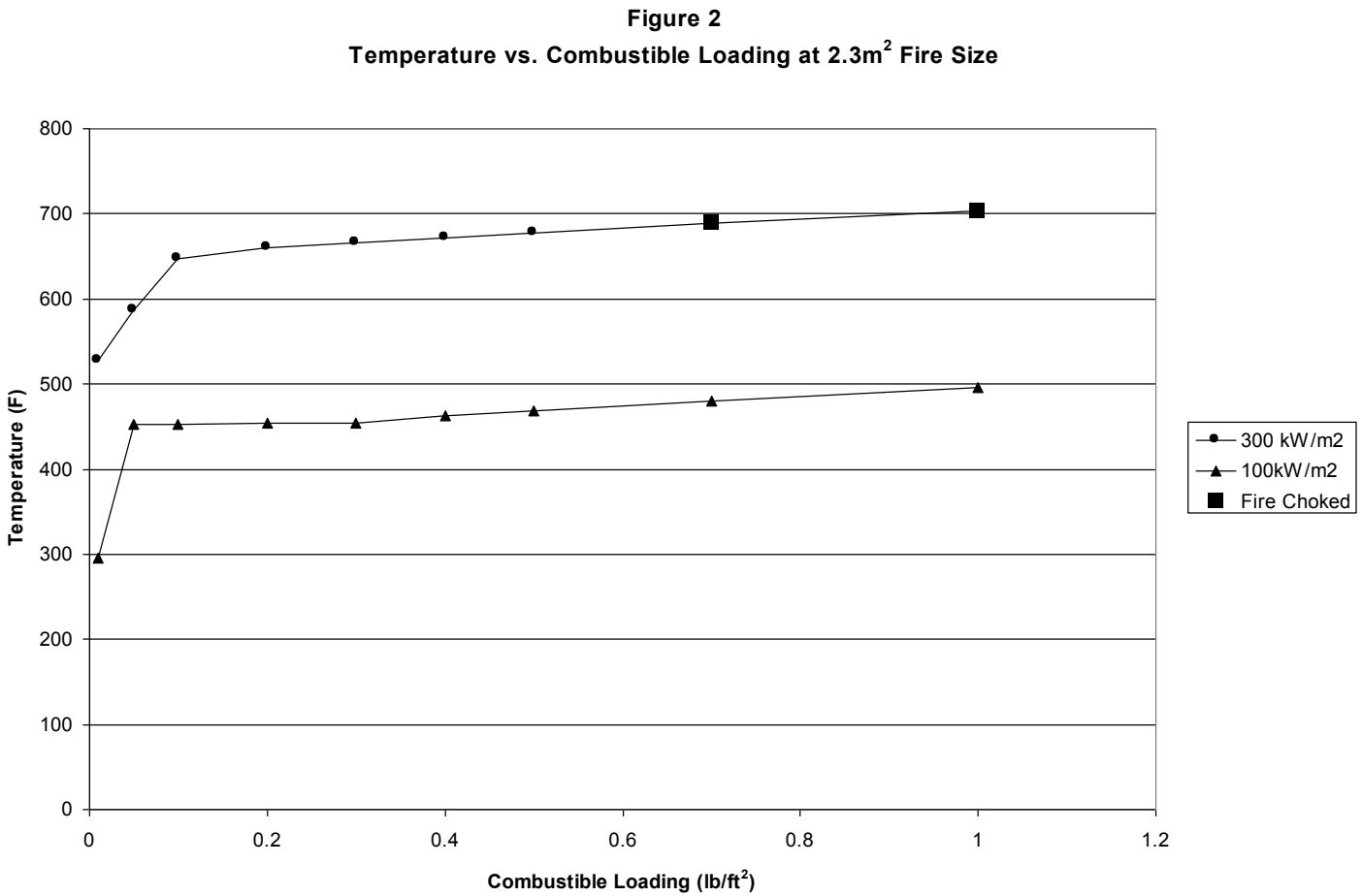


Heat Release Density of the Combustibles

The heat release density is determined by the type of combustibles burned. For this parametric analysis, heat release densities of 300 kW/m^2 and 100 kW/m^2 were used, while keeping the fire size constant at 2.3 m^2. Using heat release densities of 100 and 300 kW/m^2 bounds possible combustible types which may be found in the hot cell.

<u>Results:</u> The type of combustibles burned has a significant impact on hot layer temperature.

Heat Release Density of the Combustibles (cont.)

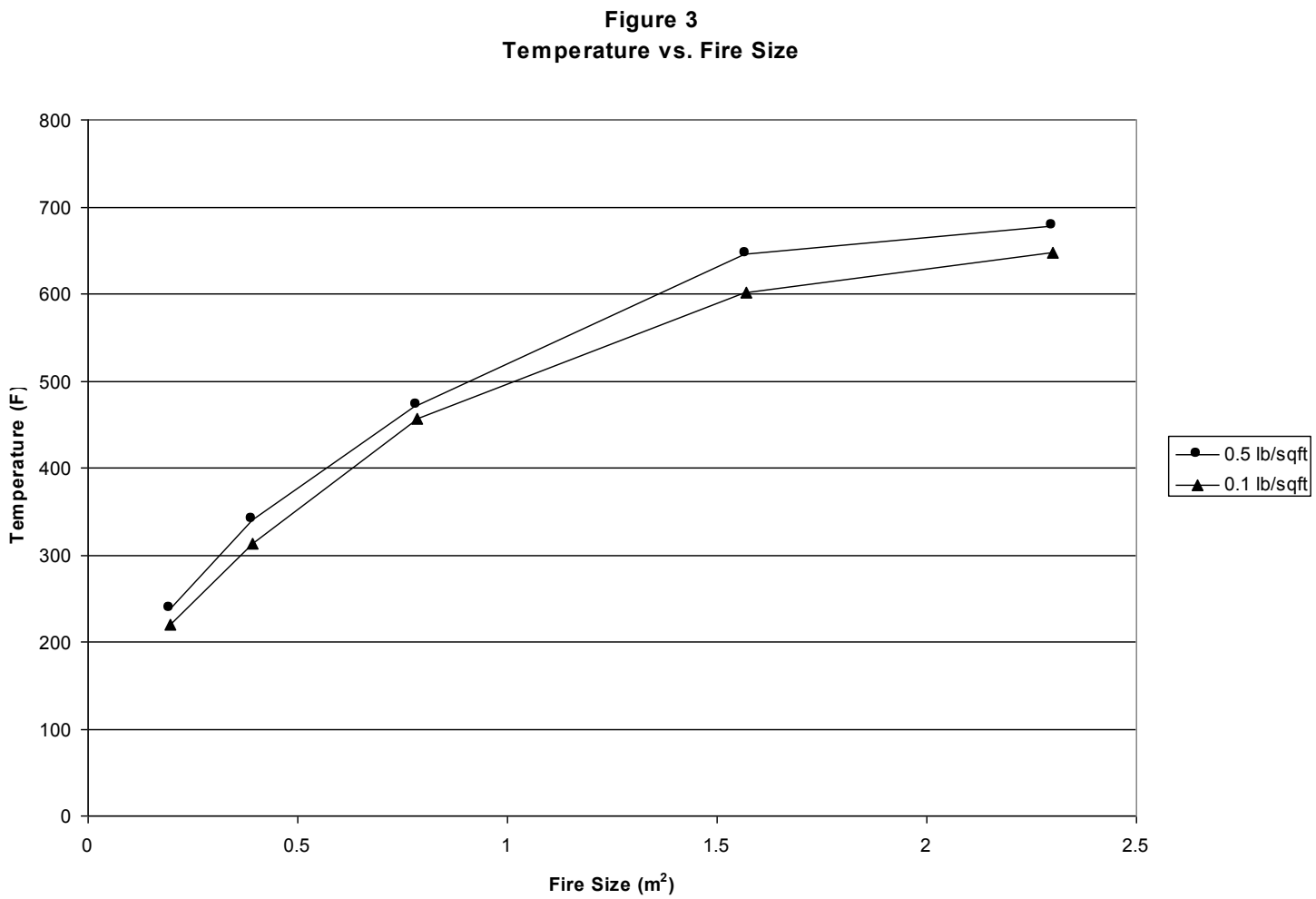


Area Occupied by the Fire

Fire sizes of 0.20 m^2, 0.39 m^2, 0.80 m^2, 1.57 m^2, and 2.30 m^2, representing one 30-gallon waste container, two 30-gallon waste containers, four 30-gallon waste containers, eight 30-gallon waste containers, and 38 percent of the hot cell floor area, respectively, were modeled. Combustible loading was held constant.

<u>Result:</u> For any combustible loading, the size of the fire has a significant impact on the hot layer temperature. Also, combustible loading has little impact on hot layer temperature, or temperature profile.

Area Occupied (cont.)



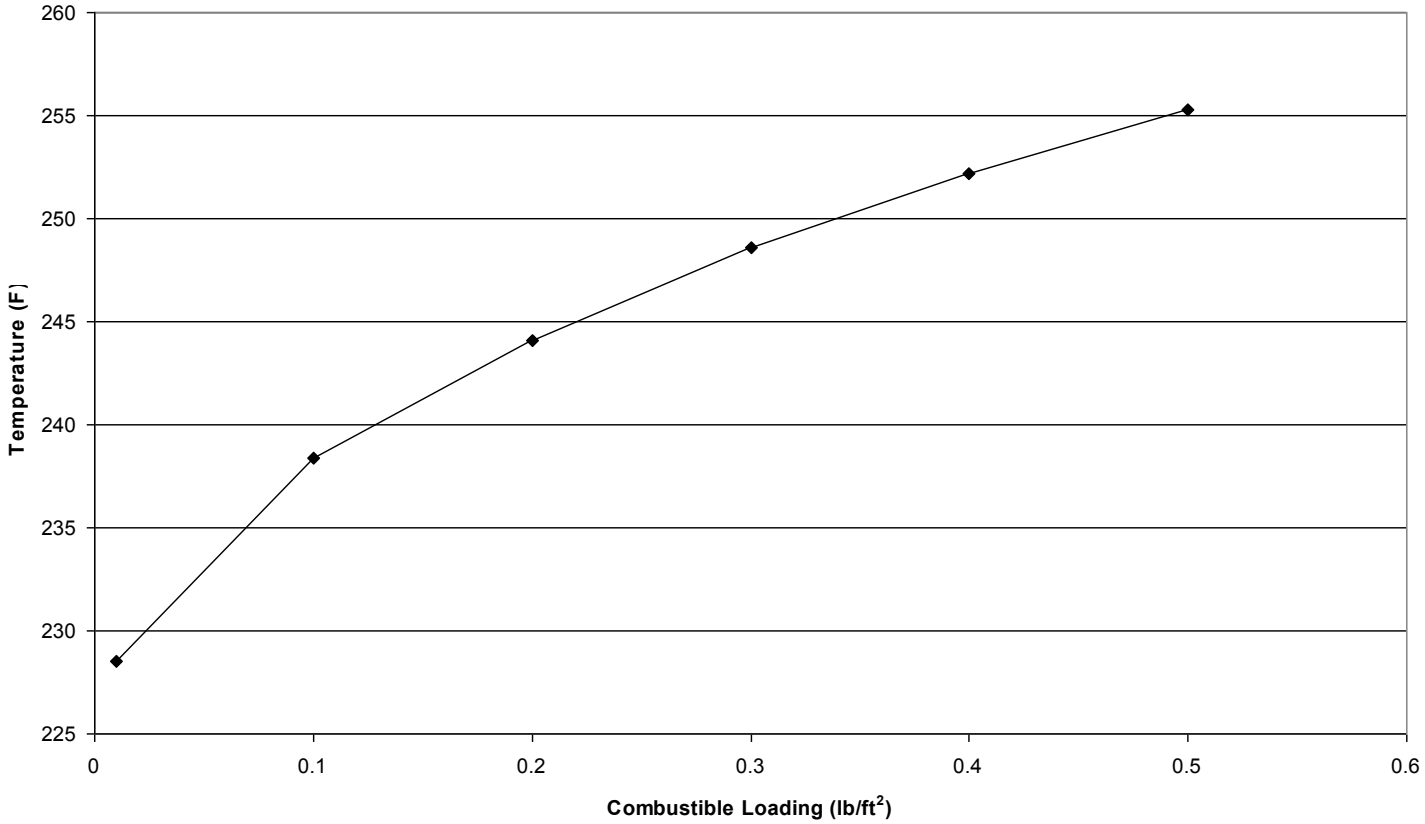
Volume of the Hot Cell

An analysis was performed to determine the impact of removing the volume occupied by the alpha box from the hot cell. For this parametric analysis, a fire size corresponding to one waste container (0.20 m^2) was used. Combustible loadings were varied from 0.01 lb/ft^2 to 0.5 lb/ft^2.

<u>Results:</u> For a smaller volume, the hot layer temperature increases, but if the fire is limited to a single waste drum, the hot layer temperature will not exceed the HEPA filter failure temperature.

Volume of the Hot Cell (cont.)

Figure 4
Temperature vs. Combustible Loading for a Hot Cell, with the Volume of an Alpha Box Removed, for a 0.20 m^2 Fire



Fire Growth Rate

A parametric analysis was performed which changed the growth rate of the fire from medium (the fire reaches 1 MW in 300 seconds) to fast (the fire reaches 1 MW in 150 seconds), while holding all other variables constant. The choice of a medium growth rate represents combustibles such as paper and wood products, while a fast growth rate represents a fire composed of substances that burn more readily, such as the isopropyl alcohol and acetone which are to be used within the alpha box. For this parametric analysis, a two 30-gallon waste drum fire size was evaluated. The heat release density for the two 30-gallon waste drums was held constant at 300 kW/m^2.

Results: Since the same total mass of combustibles are burned in both cases, the hot layer temperature is not dependent upon growth rate.

Fire Growth Rate (cont.)

Growth Rate	Equivalent hot cell combustible loading, lb/ft^2	Quantity, lb	Effective diameter, ft.	Peak heat release rate, kW	Growth time, s	Fire duration, s	Hot layer temperature, ^oF
Fast	0.1	6.4	2.32	117.8	50.1	432.7	314.3
Medium	0.1	6.4	2.32	117.8	100.2	466.1	313.7
Fast	0.5	32.0	2.32	117.8	50.1	2030.0	340.3
Medium	0.5	32.0	2.32	117.8	100.2	2063.4	340.3
Fast	1.0	64.0	2.32	117.8	50.1	4027.0	359.2
Medium	1.0	64.0	2.32	117.8	100.2	4060.0	359.3

Hole Size Chosen to Represent the Aggregate In-Leakage into the Hot Cell

Hole sizes of 0.5 ft^2, 1.0 ft^2, and 2.0 ft^2 were analyzed, with a fire size of two 30-gallon waste drums. The heat release density for the two 30-gallon waste drums was held constant at 300 kW/m^2.

<u>Results:</u> With the in-leakage flow in balance with the outlet ventilation flow rate, the size of the leak path into the room does not affect the hot layer temperature.

Hole Size (cont.)

Leak size, ft^2	Equivalent hot cell combustible loading, lb/ft^2	Quantity, lb	Fire duration, s	Hot layer temperature, ^oF
0.5	0.1	6.4	466.1	313.7
1.0	0.1	6.4	466.1	313.7
2.0	0.1	6.4	466.1	313.7
0.5	0.5	32.0	2063.4	340.3
1.0	0.5	32.0	2063.4	340.3
2.0	0.5	32.0	2063.4	340.3
0.5	1.0	64.0	4060.0	359.3
1.0	1.0	64.0	4060.0	359.3
2.0	1.0	64.0	4060.0	359.3

Conclusions

The size of the fire significantly impacts the hot cell temperature:

- A fire constrained to a 30-gallon waste drum does not produce a hot cell temperature approaching 300°F, even with a fire duration of greater than one hour
- For fire sizes equivalent to two 30-gallon waste drums and larger, hot cell temperature exceeds 300°F, except for extremely low combustible loadings (approximately 0.5 lbs total)

Conclusions (cont.)

The combustible type also significantly impacts the hot cell temperature:

- Heat release densities from 300 kW/m^2 to 100 kW/m^2 bound the range of combustible types and configurations which would be expected in the hot cell
- For fire sizes of approximately 38 percent of the hot cell area, hot cell temperature exceeds 300°F, except for extremely low combustible loadings independent of the heat release density

Conclusions (cont.)

The combustible loading does not significantly impact the hot cell temperature given that the fire area is constant:

- For a given fire size, combustible loading can increase by a factor of five and the hot cell temperature increases by no greater than 45°F
- The hot cell temperature profile versus fire size is independent of the combustible loading

Conclusions (cont.)

The growth rate of the fire does not impact the hot cell temperature if the combustibles are assumed to burn to completion:

- Fire growth times from 150 seconds to 300 seconds bound the range of combustible types which would be expected in the hot cell
- For the two 30-gallon waste drum fire utilized in this sensitivity analysis, the hot cell temperature exceeds 300°F in 90 seconds and 130 seconds for the fast growth and medium growth fire models, respectively. If the fire size is larger the HEPA filter failure temperature will be reached even more quickly

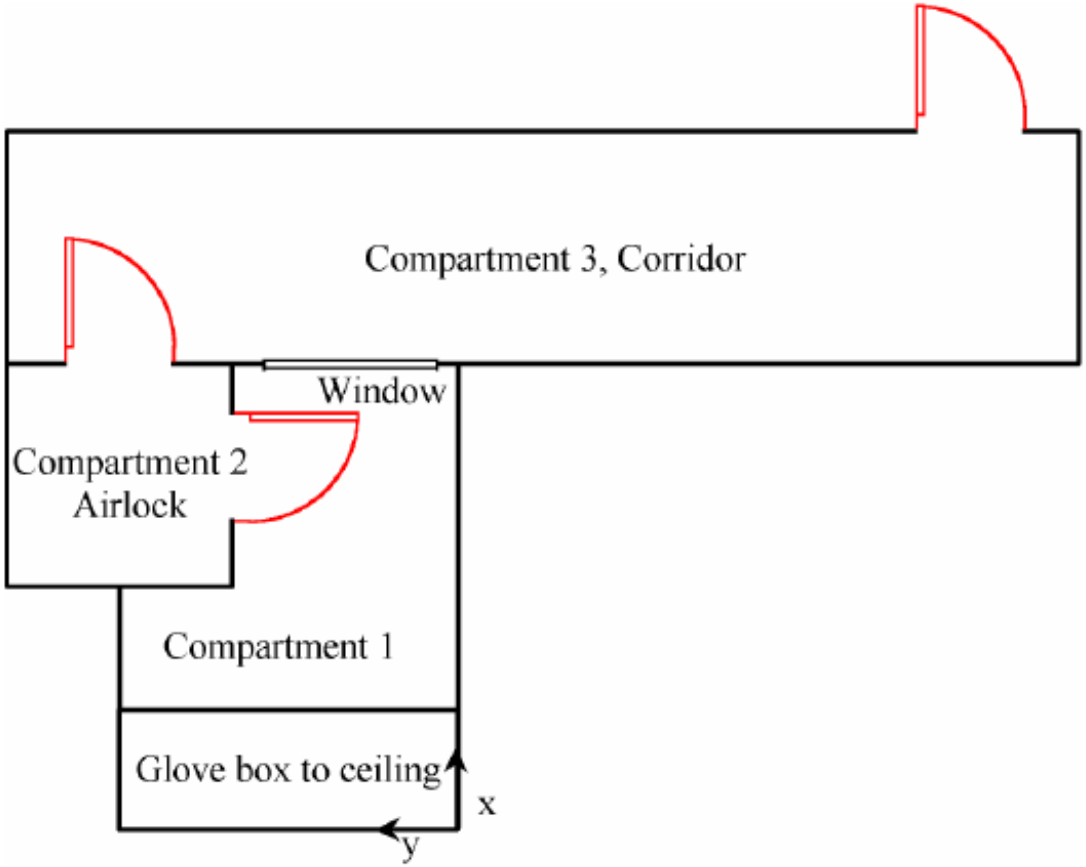
The hot cell in-leakage area does not impact the hot cell temperature for any combustible loading.

Example 2

DOE Guidance Document Example

Description of Example

- Two compartments (laboratory and airlock) and a corridor will be modeled



Description of Example (cont.)

- *Compartment 1 (Laboratory):* 3.0 m W x 3.0 m D x 2.44 m H; ceiling and walls – gypsum, floor – concrete; one closed door with a gap under the door and one closed viewing window will be modeled
- *Compartment 2 (Airlock):* 2.0 m W x 2.0 m D x 2.44 m H; ceiling and walls – gypsum, floor – concrete; two closed doors with gaps under the doors will be modeled
- *Compartment 3 (Corridor):* 3.0 m W x 15.0 m D x 2.44 m H; ceiling and walls – gypsum, floor – concrete; one closed viewing window, two closed doors with gaps under the doors will be modeled

Description of Example (cont.)

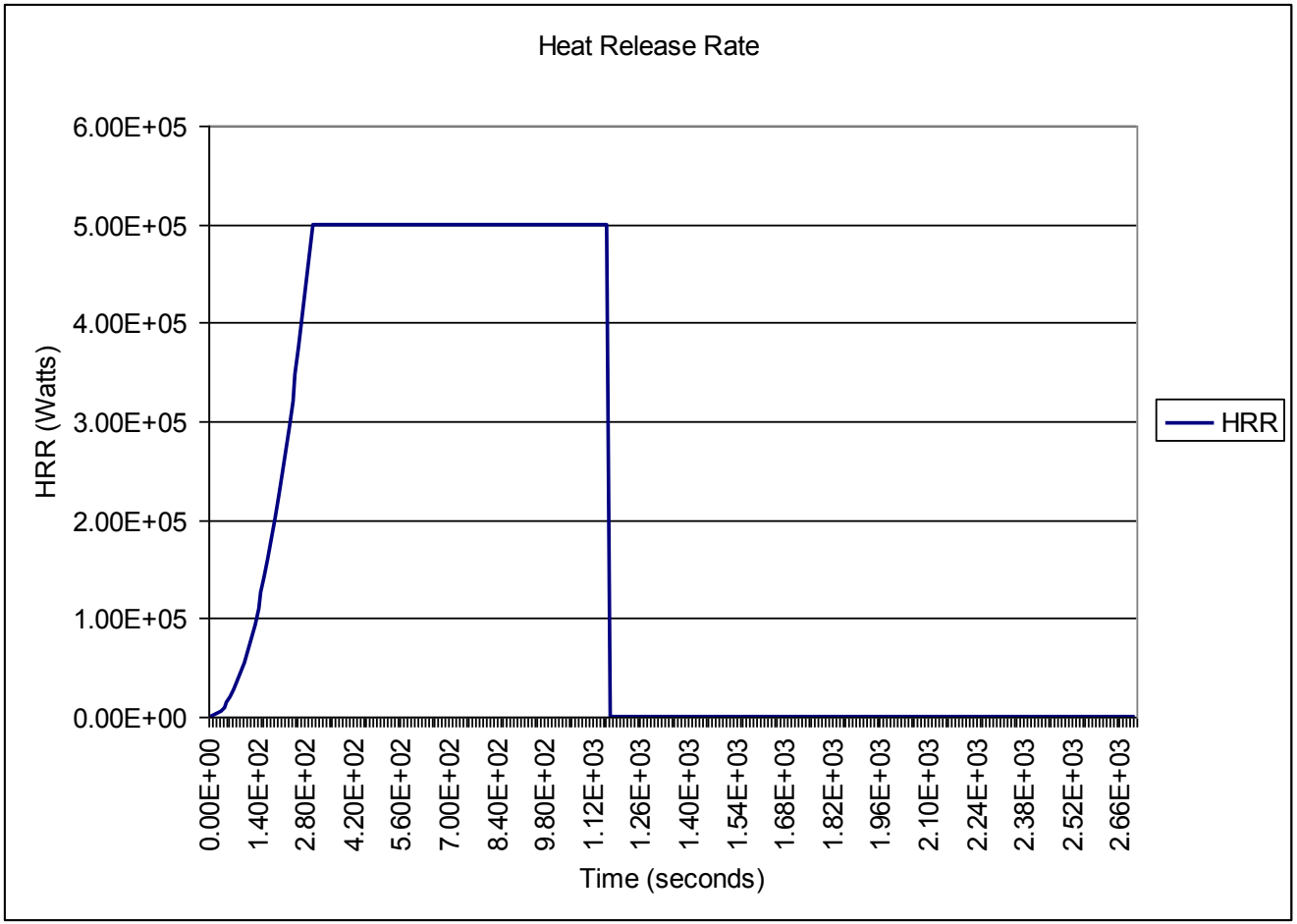
- The fire is limited to several trash bags containing a total of 12 kg of contaminated polyethylene waste located in the lab
- ΔH_c of polyethylene = 40 MJ/kg
- The fire is taken to be a slow to medium growth fire ($Q = 0.00556\ t^2$)
- The peak HRR is given as 500 kW
- The HRR curve defined in the DOE example is based on a linear fire decay occurring between 900 and 1200 seconds
- The total available energy is 516 MJ, of which 430 MJ is released in this fire
- The HRR is judged to be reasonably bounding since slightly more than 80 percent of the total available energy was released

Description of Example (cont.)

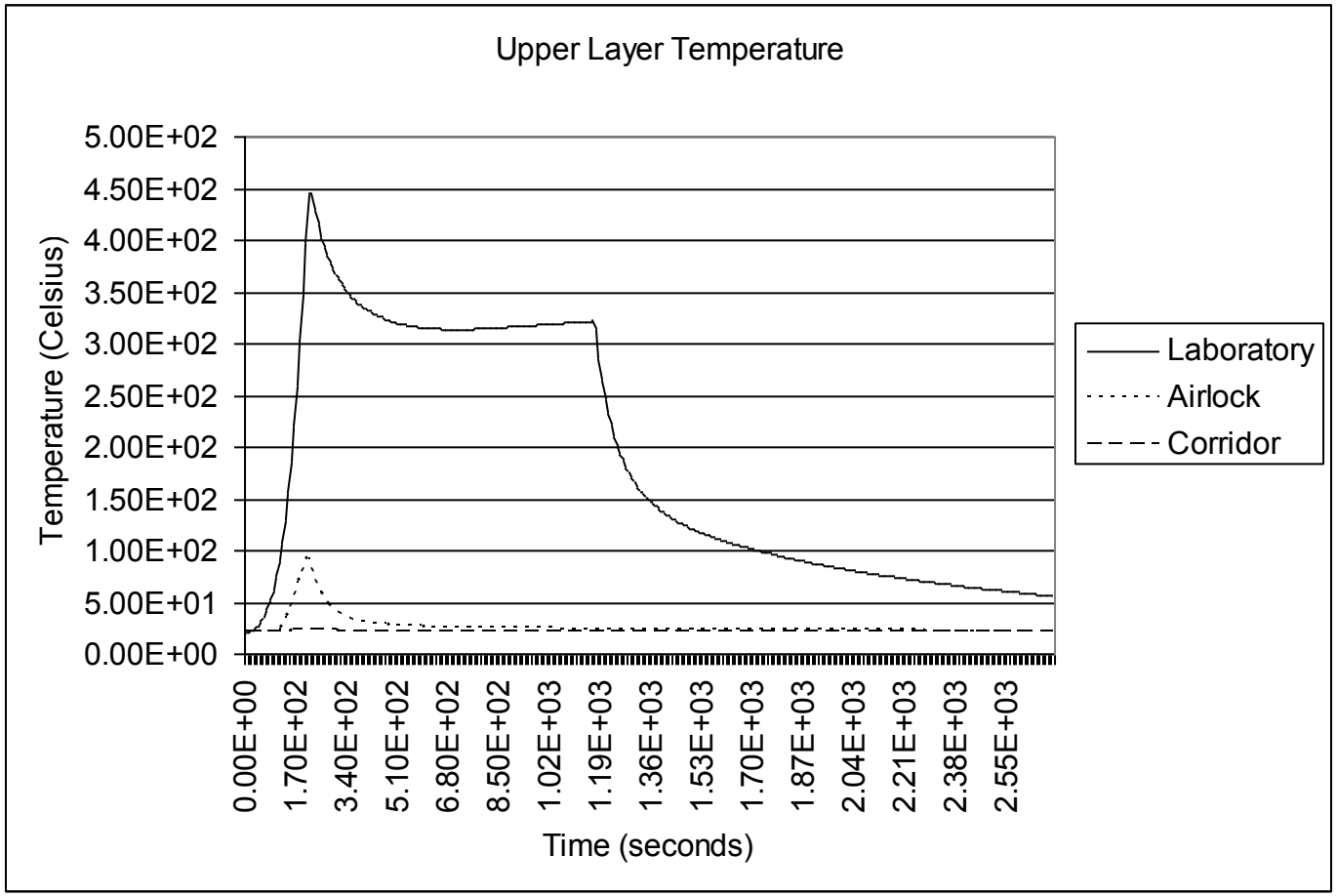
HRR curve input calculations:

- $t_g = (1{,}055\ kW / 0.00556\ kW/s^2)^{1/2} = 435.60\ s$
- $t_m = (500\ kW / 0.00556\ kW/s^2)^{1/2} = 299.88\ s$
- $E_m = 1/3(1{,}055\ kW / (435.60s)^2)(299.88s)^3 = 49{,}980.20\ kW/s$
- $\Delta M = 49{,}980.20\ kW/s / (40.0 \times 10^3\ kJ/kg) = 1.25\ kg$
- $t_s = [(12\ kg – 1.25\ kg)(40.0 \times 10^3\ kJ/kg)] / 500\ kW = 860\ s$
- $t_m + t_s = 860\ s + 299.88\ s = 1{,}159.88\ s$
- End of decay = 1,170 s

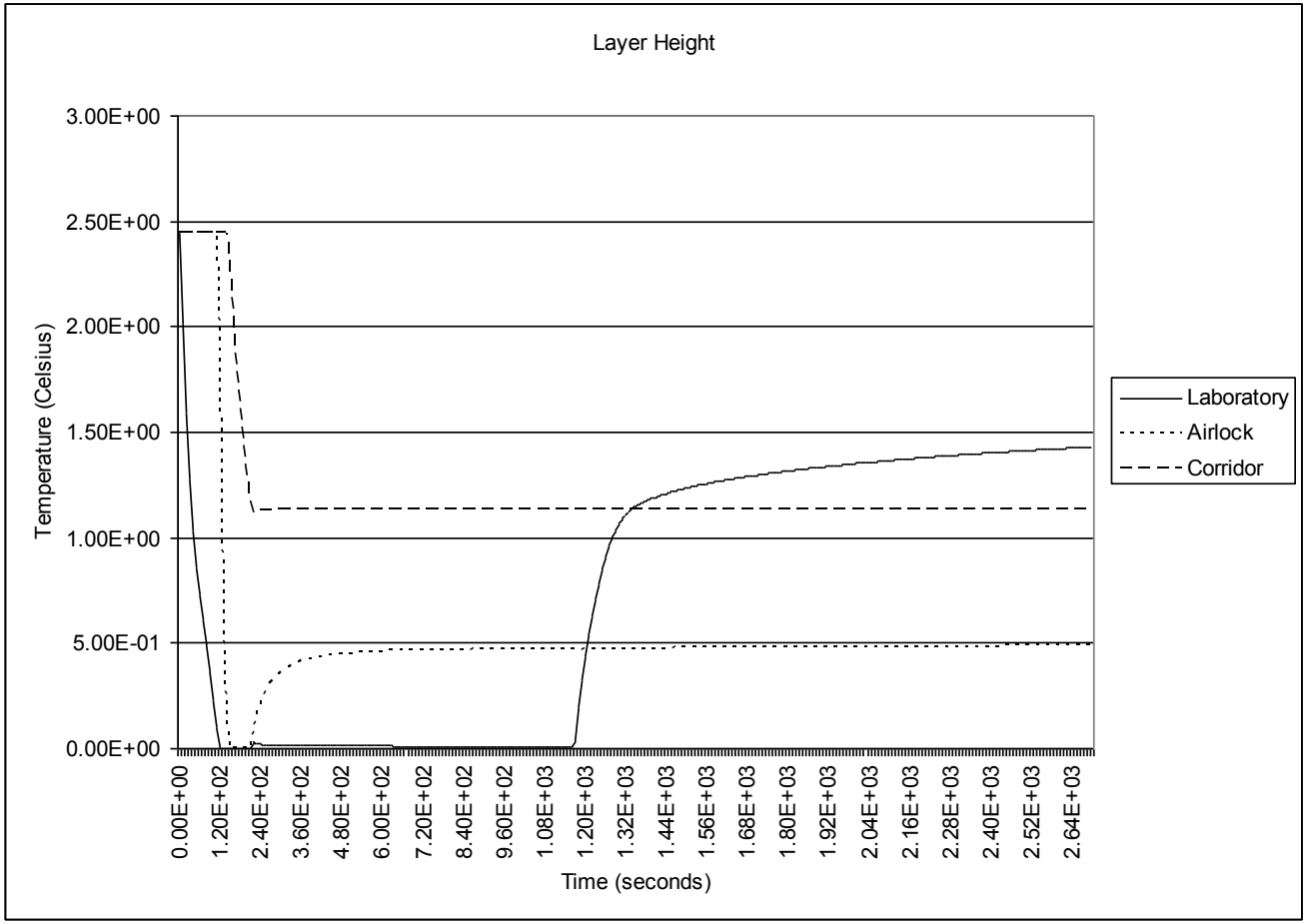
Results


Heat Release Rate
6.00E+05
5.00E+05
4.00E+05
3.00E+05
2.00E+05
1.00E+05
0.00E+00
HRR (Watts)
0.00E+00
1.40E+02
2.80E+02
4.20E+02
5.60E+02
7.00E+02
8.40E+02
9.80E+02
1.12E+03
1.26E+03
1.40E+03
1.54E+03
1.68E+03
1.82E+03
1.96E+03
2.10E+03
2.24E+03
2.38E+03
2.52E+03
2.66E+03
Time (seconds)
HRR

Results (cont.)



Results (cont.)



Interpreting the Results

- Flashover is indeterminate (450°C < upper layer temperature < 600°C) – iterate HRR curve
- Integrity of containers holding MAR and damage ratio can be assessed based on high-temperature and time
- Layer height and temperature indicate the ability (or lack thereof) for human intervention to control the fire

Iterations on this Example

- Assume viewing window fails at 700 seconds (iteration on ventilation conditions).
- Reduce Compartment 1 depth from 3 to 2 m to account for a reduction in room volume due to the presence of a glovebox (iteration on geometry).
- Increase peak HRR by 50% (from 500 kW to 750 kW) (iteration on HRR curve).

References and Resources

1. Office of Environment, Safety, and Health, “CFAST Computer Code Application Guidance for Documented Safety Analysis,” DOE-EH-4.2.1.4-Final CFAST Code Guidance. U.S. Department of Energy, Washington, D.C., July 2004.

2. R.D. Peacock, P.A. Reneke, W.W. Jones, and G.P. Forney, “CFAST-Consolidated Model of Fire Growth and Smoke Transport (Version 6) User’s Guide,” Special Publication 1041. National Institute of Standards and Technology, U.S. Department of Commerce, Washington, D.C., December 2005.

3. R.D. Peacock, G.P. Forney, P.A. Reneke, and W.W. Jones, “CFAST-Consolidated Model of Fire Growth and Smoke Transport (Version 6) Technical Reference Guide,” Special Publication 1026. National Institute of Standards and Technology, U.S. Department of Commerce, Washington, D.C, December 2005.

4. V. Babrauskas, “Heat release rate: a brief primer,” *Fire Science and Technology, Inc*., 1996, http://www.doctorfire.com/hrr_prmr.html.

5. P.M. Kennedy and K.C. Kennedy, “Flashover And Fire Analysis - A Discussion of The Practical Use of Flashover Analysis In Fire Investigations.” John A. Kennedy and Associates, Inc., Sarasota, FL, 2003.

6. D. Drysdale, “An Introduction to Fire Dynamics,” 2nd Edition, John Wiley and Sons, Ltd., West Sussex, England, 1998.

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7. N. Iqbal and M.H. Salley, “Fire Dynamics Tools (FDTs): Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program, Final Report,” NUREG-1805. U.S. Nuclear Regulatory Commission, Washington, D.C., December 2004.

8. “The SFPE Handbook of Fire Protection Engineering,” 2nd Edition. Society of Fire Protection Engineers, Boston, Massachusetts, 1995.

9. http://www.fast.nist.gov/