APPENDIX J. PRACTICE PROBLEMS AND SOLUTIONS

This appendix contains problems to apply the principles learned in the NUREG with the FDT^s program. This appendix provides some additional practice to solve problems related to fire dynamics.

NUREG Chapter and Related Calculation Methods

Problem	**NUREG Chapter**	**FDT^s**
J-1	Chapter 2. Predicting Hot Gas Layer Temperature and Smoke Layer Height in a Room Fire with Natural and Forced Ventilation Method of McCaffrey, Quintiere, and Harkleroad (MQH) Compartment with Thermally Thick/Thin Boundaries	02.1_Temperature_NV.xls
J-2	Chapter 2. Predicting Hot Gas Layer Temperature and Smoke Layer Height in a Room Fire with Natural and Forced Ventilation Method of Foote, Pagni, and Alvares (FPA) Compartment with Thermally Thick/Thin Boundaries Method of Deal and Beyler Compartment with Thermally Thick/Thin Boundaries	02.2_Temperature_FV.xls
J-3	Chapter 2. Predicting Hot Gas Layer Temperature and Smoke Layer Height in a Room Fire with Natural and Forced Ventilation Method of McCaffrey, Quintiere, and Harkleroad (MQH) Compartment with Thermally Thick/Thin Boundaries Chapter 2. Method of Predicting Hot Gas Layer Temperature in Room Fire with Forced Ventilation Method of Foote, Pagni, and Alvares (FPA) Compartment with Thermally Thick/Thin Boundaries Method of Deal and Beyler Compartment with Thermally Thick/Thin Boundaries	02.1_Temperature_NV.xls 02.2_Temperature_FV.xls
J-4	Chapter 3. Estimating Burning Characteristics of Liquid Pool Fire, Heat Release Rate, Burning Duration and Flame Height Heat Release Rate, Burning Duration, and Flame Height	03_HRR_Flame_Height_Burning _ Duration_Calculations.xls

NUREG Chapter and Related Calculation Methods

Problem	NUREG Chapter	FDT[s]
J-5	Chapter 4. Estimating Wall Fire Flame Height, Line Fire Flame Height Against the Wall, and Corner Fire Flame Height	04_Flame_Height_Calculations.xls Wall_Line_Flame_Height Corner_Flame_Height Wall_Flame_Height
J-6	Chapter 2. Predicting Hot Gas Layer Temperature and Smoke Layer Height in a Room Fire with Natural and Forced Ventilation Method of Foote, Pagni, and Alvares (FPA) Compartment with Thermally Thick/Thin Boundaries Method of Deal and Beyler Compartment with Thermally Thick/Thin Boundaries	02.2_Temperature_FV.xls
J-7	Chapter 5. Estimating Radiant Heat Flux from Fire to a Target Fuel Solid Flame Radiation Model (Target Above Ground Level, with Wind)	05.2_Heat_Flux_Calculations_Wind_Free.xls (Solid Flame 2)
J-8	Chapter 6. Estimating the Ignition Time of a Target Fuel Exposed to a Constant Radiative Heat Flux Method of Estimating Piloted Ignition Time of Solid Materials Under Radiant Exposures. Method of (1) Mikkola and Wichman, (2) Quintiere and Harkleroad and, (3) Janssens	06_Ignition_Time_Calculations.xls (Ignition_Time_Calculations1)
J-9	Chapter 7. Estimating the Full-Scale Heat Release Rate of a Cable Tray Fire	07_Cable_HRR_Calculations.xls
J-10	Chapter 9. Estimating the Centerline Temperature of a Buoyant Fire Plume	09_Plume_Temperature_Calculations.xls
J-11	Chapter 10. Estimating Sprinkler Response Time	10_Detector_Activation_Time.xls (Sprinkler)
J-12	Chapter 12. Estimating Heat Detector Response Time	10_Detector_Activation_Time.xls (FTHDetector)

NUREG Chapter and Related Calculation Methods

Problem	NUREG Chapter	FDT[s]
J-13	Chapter 13. Predicting Compartment Flashover Compartment Post-Flashover Temperature. Method of Law. Minimum Heat Release Rate Required to Compartment Flashover. Method of (1) McCaffrey, Quintiere, and Harkleroad (MQH), (2) Babrauskas, and (3) Thomas	13_Compartment_Flashover_ Calculations.xls (Post_Flashover_Temperature) (Flashover-HRR)
J-14	Chapter 14. Estimating Pressure Rise Attributable to a Fire in a Closed Compartment	14_Compartment_Over_Pressure _Calculations.xls
J-15	Chapter 17. Calculating the Fire Resistance of Structural Steel Members Empirical Correlations	17.1_FR_Beams_Columns_Sub stitution_Correlation.xls (Beam)
J-16 (a)	Chapter 3. Estimating Burning Characteristics of Liquid Pool Fire, Heat Release Rate, Burning Duration, and Flame Height	03_HRR_Flame_Height_Burning _Duration_Calculations.xls
(b)	Chapter 2. Predicting Hot Gas Layer Temperature and Smoke Layer Height in a Room Fire with Natural and Forced Ventilation Method of McCaffrey, Quintiere, and Harkleroad (MQH) Compartment with Thermally Thick/Thin Boundaries	02.1_Temperature_NV.xls
(c)	Chapter 9. Estimating the Centerline Temperature of a Buoyant Fire Plume	09_Plume_Temperature_ Calculations.xls
(d & e)	Chapter 5. Estimating Radiant Heat Flux from Fire to a Target Fuel Wind-Free Condition Point Source Radiation Model (Target at Ground Level) Solid Flame Radiation Model (Target Above Ground Level)	05.1_Heat_Flux_Calculations_ Wind_Free.xls (Point Source) (Solid Flame 2)
(f)	Chapter 10. Estimating Sprinkler Response Time	10_Detector_Activation_Time.xls (Sprinkler)
(g)	Chapter 13. Predicting Compartment Flashover	13_Compartment_Flashover_ Calculations.xls (Flashover-HRR)

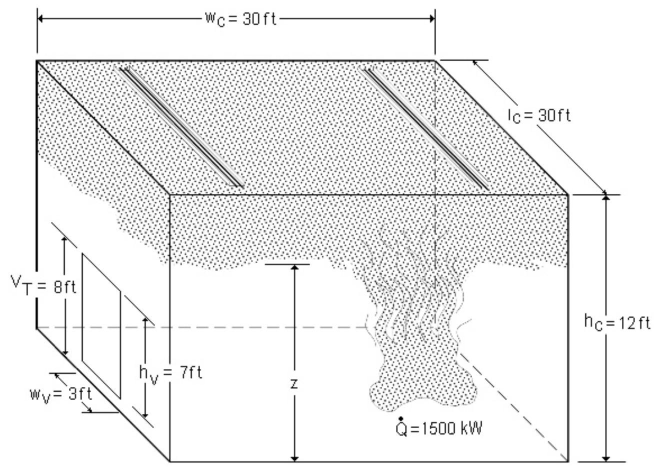
NUREG Chapter and Related Calculation Methods

Problem	NUREG Chapter	FDT^s
J-17	Chapter 3. Estimating Burning Characteristics of Liquid Pool Fire, Heat Release Rate, Burning Duration, and Flame Height Chapter 2. Predicting Hot Gas Layer Temperature and Smoke Layer Height in a Room Fire with Natural and Forced Ventilation Method of McCaffrey, Quintiere, and Harkleroad (MQH) Compartment with Thermally Thick/Thin Boundaries	03_HRR_Flame_Height_Burning_Duration_Calculations.xls 02.1_Temperature_NV.xls
J-18	Chapter 3. Estimating Burning Characteristics of Liquid Pool Fire, Heat Release Rate, Burning Duration, and Flame Height Chapter 8. Estimating Burning Duration of Solid Combustibles	03_HRR_Flame_Height_Burning_Duration_Calculations.xls 08_Burning_Duration_Solids.xls

Problem J-1

Problem Statement

Consider a compartment 9.0 m wide x 9.0 m long x 3.7 m high (30 ft wide x 30 ft long x 12 ft high) (w_c x l_c x h_c) with a door vent that is 0.92 m wide x 2.15 m high (3 ft wide x 7 ft high) (w_v x h_v). The fire is constant with an HRR of 1,500 kW (1,422 Btu/sec). Assume that the top of the vent is at 2.45 m (8 ft). Compute the hot gas temperature in the compartment, as well as the smoke layer height, at 5 minutes after the ignition, assuming that the compartment boundaries are made of 2.54 cm (1.0 in) thick gypsum board.



Problem 1: Compartment Fire with Natural Ventilation

Solution

Purpose:

(1) Determine the hot gas temperature in the compartment (T_g) at t = 5 min after ignition.
(2) Determine the smoke layer height (z) at t = 5 min after ignition.

Assumptions:

(1) Air properties (ambient) are at 25 °C (77 °F).
(2) The ceiling is unconfined, unobstructed, and flat.
(3) The heat flow through the compartment boundaries is one-dimensional.
(4) The heat release rate (HRR) is constant.
(5) The fire is located at the center of the compartment or away from the walls.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 02.1_Temperature_NV.xls

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

- Compartment Width (w_c) = 30 ft
- Compartment Length (l_c) = 30 ft
- Compartment Height (h_c) = 12 ft
- Vent Width (w_v) = 3 ft
- Vent Height (h_v) = 7 ft
- Top of Vent from Floor (V_T) = 8 ft
- Interior Lining Thickness (δ) = 1 in
- Select Material: select **Gypsum Board** from the combo box
- Fire Heat Release Rate $(\dot{Q})$ = 1,500 kW
- Time after Ignition (t) = 5 min

Note: When **Gypsum Board** is selected, its thermal properties are automatically selected from the table and entered in the corresponding input cells.

Results*

From the table of results of the spreadsheet at t = 5 minutes after ignition we obtain:

Hot Gas Layer Temperature T_g °C (°F)	Smoke Layer Height z m (ft)
351 (664)	2.44 (8.00) smoke is exiting through the vent

*spreadsheet calculations attached on next page

Spreadsheet Calculations

FDT[s]: 02.1_Temperature_NV.xls

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN A ROOM FIRE WITH NATURAL VENTILATION COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

Version 1805.0

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Parameter	Value	Unit	Converted
Compartment Width (w_c)	30.00	ft	9.144 m
Compartment Length (l_c)	30.00	ft	9.144 m
Compartment Height (h_c)	12.00	ft	3.6576 m
Vent Width (w_v)	3.00	ft	0.914 m
Vent Height (h_v)	7.00	ft	2.134 m
Top of Vent from Floor (V_T)	8.00	ft	2.438 m
Interior Lining Thickness (δ)	1.00	in	0.0254 m

AMBIENT CONDITIONS

Parameter	Value	Unit	Converted
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.18	kg/m³	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Parameter	Value	Unit
Interior Lining Thermal Inertia ($k\rho c$)	0.18	$(kW/m^2\text{-}K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K
Interior Lining Specific Heat (c)	1.1	kJ/kg-K
Interior Lining Density (ρ)	960	kg/m³

Note : Air density will automatically correct with Ambient Air Temperature (T_a) Input

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ $(kW/m^2\text{-}K)^2$-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m³)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Select Material: Gypsum Board

Scroll to desired material then Click the selection

Reference: Klote, J., J. Milke, Principles of Smoke Management, 2002, Page 270.

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	1500.00	kW
	Calculate	

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-175.

$\Delta T_g = 6.85\,[Q^2/(A_v(h_v)^{1/2})(A_T h_k)]^{1/3}$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)

Q = heat release rate of the fire (kW)

A_v = area of ventilation opening (m^2)

h_v = height of ventilation opening (m)

h_k = convective heat transfer coefficient (kW/m^2-K)

A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$A_v = (w_v)(h_v)$

Where A_v = area of ventilation opening (m^2)

w_v = vent width (m)

h_v = vent height (m)

A_v = 1.95 m^2

Thermal Penetration Time Calculation

$t_p = (\rho c_p/k)(\delta/2)^2$

Where t_p = thermal penetration time (sec)

ρ = interior construction density (kg/m^3)

c_p = interior construction heat capacity (kJ/kg-K)

k = interior construction thermal conductivity (kW/m-K)

δ = interior construction thickness (m)

t_p = 1001.90 sec

Heat Transfer Coefficient Calculation

$h_k = \sqrt{(k\rho c/t)}$ for $t < t_p$ or (k/δ) for $t > t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec

(a thermal property of material responsible for the rate of temperature rise)

t = time after ignition (sec)

See table below for results

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)] - A_v$

Where A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

w_c = compartment width (m)

l_c = compartment length (m)

h_c = compartment height (m)

A_v = area of ventilation opening (m^2)

A_T = 299.05 m^2

Compartment Hot Gas Layer Temperature With Natural Ventilation

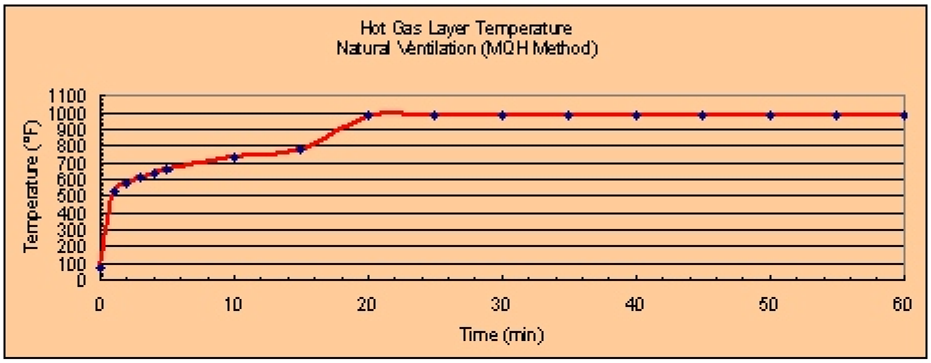
$\Delta T_g = 6.85\,[Q^2/(A_v(h_v)^{1/2})(A_T h_k)]^{1/3}$

$\Delta T_g = T_g - T_a$

$T_g = \Delta T_g + T_a$

Results

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0.00	-	-	298.00	25.00	77.00
1	60	0.05	249.29	547.29	274.29	525.73
2	120	0.04	279.82	577.82	304.82	580.68
3	180	0.03	299.39	597.39	324.39	615.90
4	240	0.03	314.09	612.09	339.09	642.36
5	300	0.02	325.99	623.99	350.99	663.79
10	600	0.02	365.91	663.91	390.91	735.65
15	900	0.01	391.50	689.50	416.50	781.69
20	1200	0.01	502.37	800.37	527.37	981.27
25	1500	0.01	502.37	800.37	527.37	981.27
30	1800	0.01	502.37	800.37	527.37	981.27
35	2100	0.01	502.37	800.37	527.37	981.27
40	2400	0.01	502.37	800.37	527.37	981.27
45	2700	0.01	502.37	800.37	527.37	981.27
50	3000	0.01	502.37	800.37	527.37	981.27
55	3300	0.01	502.37	800.37	527.37	981.27
60	3600	0.01	502.37	800.37	527.37	981.27



ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANA AND TANAKA

$z = ((2kQ^{1/3}t/3A_c) + (1/h_c^{(2/3)}))^{-3/2}$

Where z = smoke layer height (m)
Q = heat release rate of the fire (kW)
t = time after ignition (sec)
h_c = compartment height (m)
A_c = compartment floor area (m^2)
k = a constant given by $k = 0.076/\rho_g$
ρ_g = hot gas layer density (kg/m^3)
ρ_g is given by $\rho_g = 353/T_g$
T_g = hot gas layer temperature (K)

Compartment Area Calculation

$A_c = (w_c)(l_c)$

Where A_c = compartment floor area (m^2)
w_c = compartment width (m)
l_c = compartment length (m)

A_c = 83.61 m^2

Hot Gas Layer Density Calculation

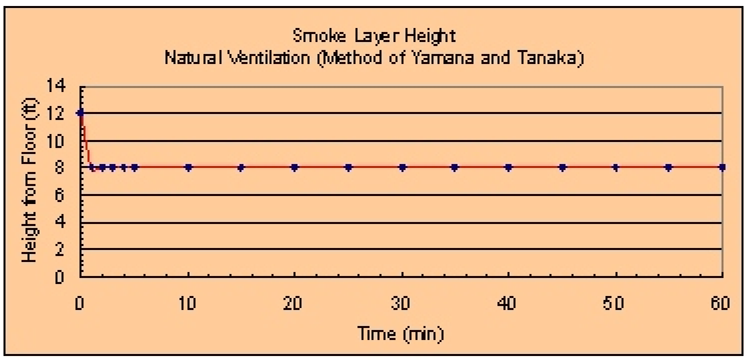
$\rho_g = 353/T_g$

Calculation for Constant K

Results

Caution! The smoke layer height is a conservative estimate and is only intended to provide an indication where the hot gas layer is located. Calculated smoke layer height below the vent height are not creditable since the calculation is not accounting for the smoke exiting the vent.

Time (min)	ρ_g (kg/m^3)	Constant(k) (kW/m-K)	Smoke Layer height z (m)	Smoke Layer height z (ft)	
0	1.18	0.084	3.66	12.00	
1	0.64	0.118	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
2	0.61	0.124	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
3	0.59	0.129	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
4	0.58	0.132	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
5	0.57	0.134	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
10	0.53	0.143	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
15	0.51	0.148	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
20	0.44	0.172	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
25	0.44	0.172	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
30	0.44	0.172	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
35	0.44	0.172	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
40	0.44	0.172	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
45	0.44	0.172	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
50	0.44	0.172	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
55	0.44	0.172	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
60	0.44	0.172	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT



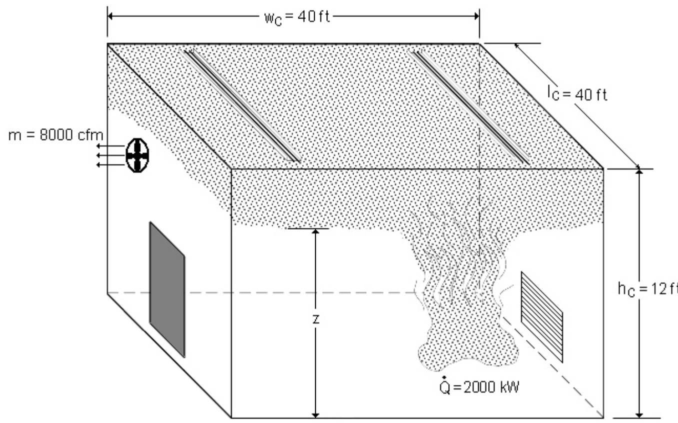
NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov.

Problem J-2

Problem Statement

Consider a compartment 12.0 m wide x 12.0 m long x 3.7 m high (40.0 ft wide x 40.0 ft long x 12.0 ft high) (w_c x l_c x h_c) with a forced ventilation rate of 3.78 m^3/s (8,000 cfm). Calculate the hot gas layer temperature in the compartment for a fire size $(\dot{Q})$ of 2,000 kW (1,896 Btu/sec) at 5 minutes after ignition, assuming that the compartment boundaries are made of 5.10 cm (2.0 in) thick gypsum board.



Problem 2: Compartment Fire with Forced Ventilation

Solution

Purpose:

(1) Determine the hot gas temperature in the compartment (T_g) at t = 5 min after ignition.

Assumptions:

(1) Air properties (ambient) are at 25 °C (77 °F).
(2) The ceiling is unconfined, unobstructed, and flat.
(3) The heat flow through the compartment boundaries is one-dimensional.
(4) The heat release rate (HRR) is constant.
(5) The fire is located at the center of the compartment or away from the walls.
(6) The compartment is open to the outside at the inlet (pressure =1 atm).

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 02.2_Temperature_FV.xls

FDT[s] Input Parameters:

Enter the following parameters in both spreadsheets (values only):

- Compartment Width (w_c) = 40 ft
- Compartment Length (l_c) = 40 ft
- Compartment Height (h_c) = 12 ft
- Interior Lining Thickness (δ) = 2 in
- Select Material: select **Gypsum Board** from the combo box
- Compartment Ventilation Rate $(\dot{m})$ = 8,000 cfm
- Fire Heat Release Rate $(\dot{Q})$ = 2,000 kW

Note: When **Gypsum Board** is selected, its thermal properties are automatically selected from the table and entered in the corresponding input cells.

Results

From the table of results of the spreadsheet at t = 5 minutes after ignition we obtain:

Hot Gas Layer Temperature* T_g °C (°F)	
Method of Foot, Pagni, and Alvares (FPA)	Method of Deal & Beyler
203 (398)	244 (471)

*spreadsheet calculations attached on next page

Spreadsheet Calculations
FDT2: 02.2_Temperature_FV.xls

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION
COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

Version 1805.0

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	40.00	ft	12.19 m
Compartment Length (l_c)	40.00	ft	12.19 m
Compartment Height (h_c)	12.00	ft	3.66 m
Interior Lining Thickness (δ)	2.00	in	0.0508 m

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.18	kg/m^3	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia (kρc)	0.18	(kW/m^2-K)^2-sec
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K
Interior Lining Specific Heat (c)	1.1	kJ/kg-K
Interior Lining Density (ρ)	960	kg/m^3

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	kρc (kW/m^2-K)^2-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: *Klote, J., J. Milke, Principles of Smoke Management, 2002 Page 270.*

Select Material
Gypsum Board
Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m) | 8000.00 cfm | 3.776 m^3/sec
4.472 kg/sec

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) | 2000.00 kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-177.

$\Delta T_g/T_a = 0.63(Q/m c_p T_a)^{0.72}(h_k A_T/m c_p)^{-0.36}$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)

T_a = ambient air temperature (K)

Q = heat release rate of the fire (kW)

m = compartment mass ventilation flow rate (kg/sec)

c_p = specific heat of air (kJ/kg-K)

h_k = convective heat transfer coefficient (kW/m^2-K)

A_T = total area of the compartment enclosing surface boundaries (m^2)

Thermal Penetration Time Calculation

$t_p = (\rho c_p/k)(\delta/2)^2$

Where t_p = thermal penetration time (sec)

ρ = interior construction density (kg/m^3)

c_p = interior construction heat capacity (kJ/kg-K)

k = interior construction thermal conductivity (kW/m-K)

δ = interior construction thickness (m)

t_p = 4007.58 sec

Heat Transfer Coefficient Calculation

$h_k = \sqrt{(k\rho c/t)}$ for $t < t_p$ or (k/δ) for $t > t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec

(a thermal property of material responsible for the rate of temperature rise)

t = time after ignition (sec)

See table below for results

Area of Compartment Enclosing Surface Boundaries

$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$

Where A_T = total area of the compartment enclosing surface boundaries (m^2)

w_c = compartment width (m)

l_c = compartment length (m)

h_c = compartment height (m)

A_o = area of ventilation opening (m^2)

A_T = 475.66 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

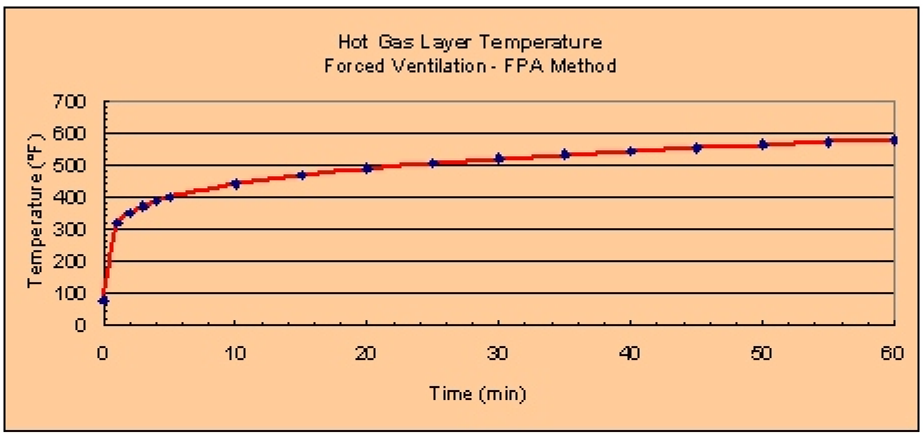
$\Delta T_g/T_a = 0.63(Q/m c_p T_o)^{0.72}(h_k A_T/m c_p)^{-0.36}$

$\Delta T_g = T_g - T_a$

$T_g = \Delta T_g + T_a$

Results

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	$(kW/m^2\text{-}K)$		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.05	0.45	133.34	431.34	158.34	317.01
2	120	0.04	0.51	151.06	449.06	176.06	348.90
3	180	0.03	0.55	162.49	460.49	187.49	369.49
4	240	0.03	0.57	171.13	469.13	196.13	385.04
5	300	0.02	0.60	178.14	476.14	203.14	397.66
10	600	0.02	0.68	201.82	499.82	226.82	440.27
15	900	0.01	0.73	217.10	515.10	242.10	467.77
20	1200	0.01	0.77	228.64	526.64	253.64	488.54
25	1500	0.01	0.80	238.01	536.01	263.01	505.41
30	1800	0.01	0.83	245.95	543.95	270.95	519.70
35	2100	0.01	0.85	252.87	550.87	277.87	532.16
40	2400	0.01	0.87	259.02	557.02	284.02	543.23
45	2700	0.01	0.89	264.57	562.57	289.57	553.22
50	3000	0.01	0.90	269.63	567.63	294.63	562.34
55	3300	0.01	0.92	274.30	572.30	299.30	570.74
60	3600	0.01	0.93	278.63	576.63	303.63	578.53



METHOD OF DEAL AND BEYLER

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-178.

Heat Transfer Coefficient Calculation

$h_k = 0.4\,\sqrt{(k\rho c / t)}$ for $t < t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec

(a thermal property of material responsible for the rate of temperature rise)

δ = thickness of interior lining (m)

h_k = 0.022 kW/m^2-K

Area of Compartment Enclosing Surface Boundaries

$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$

A_T = 475.66 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

$\Delta T_g = Q / (m\, c_p + h_k A_T)$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)

T_a = ambient air temperature (K)

Q = heat release rate of the fire (kW)

m = compartment mass ventilation flow rate (kg/sec)

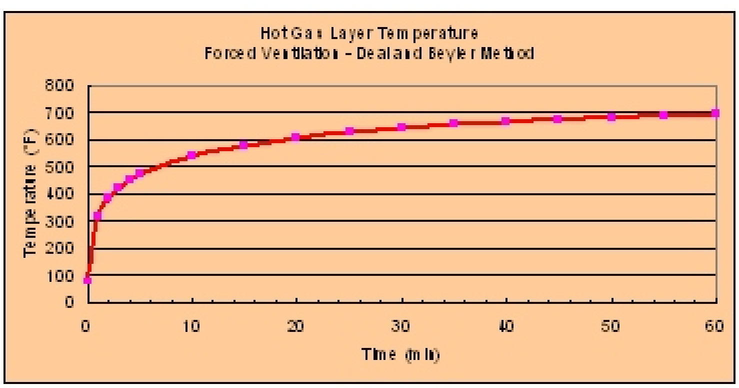
c_p = specific heat of air (kJ/kg-K)

h_k = convective heat transfer coefficient (kW/m^2-K)

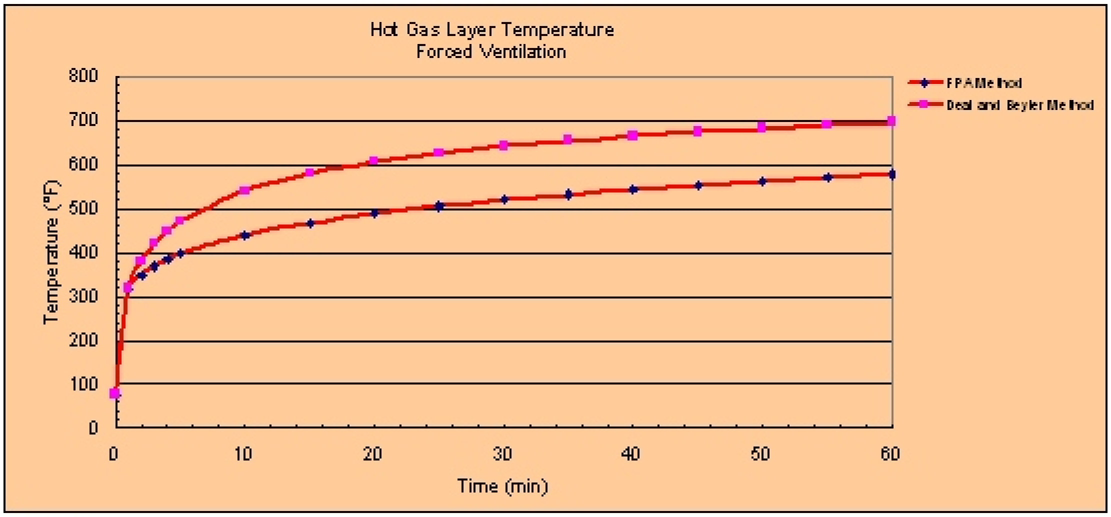
A_T = total area of the compartment enclosing surface boundaries (m^2)

Results

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.02	134.29	432.29	159.29	318.71
2	120	0.02	168.90	466.90	193.90	381.02
3	180	0.01	190.67	488.67	215.67	420.21
4	240	0.01	206.55	504.55	231.55	448.78
5	300	0.01	218.99	516.99	243.99	471.18
10	600	0.01	257.47	555.47	282.47	540.45
15	900	0.01	279.21	577.21	304.21	579.57
20	1200	0.00	294.00	592.00	319.00	606.20
25	1500	0.00	305.03	603.03	330.03	626.06
30	1800	0.00	313.72	611.72	338.72	641.70
35	2100	0.00	320.82	618.82	345.82	654.48
40	2400	0.00	326.79	624.79	351.79	665.22
45	2700	0.00	331.90	629.90	356.90	674.42
50	3000	0.00	336.35	634.35	361.35	682.43
55	3300	0.00	340.27	638.27	365.27	689.49
60	3600	0.00	343.77	641.77	368.77	695.79



Summary of Result:



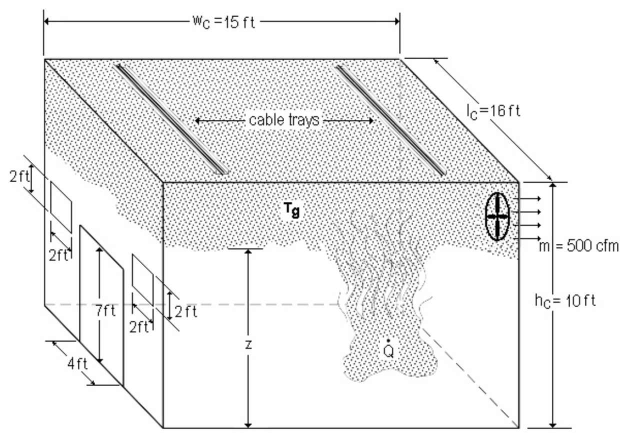
NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-3

Problem Statement
Consider a compartment 4.6 m wide x 4.9 m long x 3.0 m high (15 ft wide x 16 ft long x 10 ft high) with multiple vents and 15.24 cm (6 in.) of gypsum board as interior boundary material. The compartment has two vents of 0.6 m wide x 0.6 m high (2 ft wide x 2 ft high) and one vent of 1.2 m wide x 2.1 m high (4 ft wide x 7 ft high), all located on the same wall. The top of the highest vent is at 2.4 m (8 ft) above the floor. If the ventilation system is not operating (natural ventilation) and at 10 minutes after a fire ignition the hot gas layer temperature reaches the failure temperature of the IEEE-383 unqualified cable [assume T_g = 218 °C (T_g = 425 °F) as failure for this example], what minimum HRR might cause this failure? Is the smoke exiting the compartment at the time of cable failure?

Consider the same compartment with a mechanical ventilation rate of 0.236 m^3/s (500 cfm) and a fire with an intensity equal to the HRR of the natural ventilation scenario. What would be the hot gas layer temperature around the cable trays at 10 minutes after ignition? (Use method of FPA and method of Deal & Beyler). What is the effect of the ventilation system on the hot gas layer temperature? Compare the results of the forced ventilation scenario as a function of time after ignition and explain the discrepancy between methods.



Problem 3: Compartment Fire with Multiple Vents

Solution

Purpose:

(1) Determine the minimum HRR that could cause the IEEE-383 unqualified cable failure at 10 min after ignition in a natural ventilation scenario.
(2) Determine if the smoke is exiting the compartment at 10 min after ignition.
(3) Determine the hot gas layer temperature (T_g) at 10 min after ignition if the mechanical ventilation system is activated and the HRR is equal to the HRR of the natural ventilation scenario (i.e., use the answer of purpose **1**).
(4) Evaluate the effect of the ventilation system in the hot gas layer temperature (i.e., increase, decrease, etc.).
(5) Analyze the discrepancy between the methods of FPA and Deal & Beyler, and mention possible causes of that discrepancy.

Assumptions:

(1) Air properties (ambient) are at 25 °C (77 °F).
(2) The ceiling is unconfined, unobstructed and flat.
(3) The heat flow through the compartment boundaries is one-dimensional.
(4) The HRR is constant.
(5) The fire is located at the center of the compartment or away from the walls.
(6) The compartment is open to the outside at the inlet (pressure = 1 atm).

Pre FDT^s Calculations:

Equivalent Vent

Since the FDT^s are designed to calculate the hot gas layer temperature and smoke layer height based in only one vent compartment, we need to calculate an equivalent vent that represents the three vent openings.

Vent Opening Characteristics			
Width w_v (ft)	Height h_v (ft)	Are A_o (ft^2)	MQH Factor $A_o \sqrt{h_v}$ ($ft^{5/2}$)
2	2	4	5.66
2	2	4	5.66
4	7	28	74.08
Total		36	84.4

The equivalent vent dimensions must satisfy the following conditions in order to have the same effect of the actual multiple vents:

Condition 1: $A_o \sqrt{h_v} = 85.4\ ft^{5/2}$

$36\ ft^2 \sqrt{h_v} = 85.4\ ft^{5/2}$

$h_v = 5.63\ ft = 5.6\ ft$

Condition 2: $w_v \times h_v = 36\ ft^2$

$w_v \times 5.63\ ft = 36\ ft^2$

$w_v = 6.39\ ft = 6.4\ ft$

Spreadsheet (FDT^s) Solution Procedure:

Natural Ventilation Scenario

Use the following FDT^s:

(a) 02.1_Temperature_NV.xls

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

- Compartment Width (w_c) = 15 ft
- Compartment Length (l_c) = 16 ft
- Compartment Height (h_c) = 10 ft
- Vent Width (w_v) = 6.4 ft
- Vent Height (h_v) = 5.6 ft
- Top of Vent from Floor (V_T) = 8 ft
- Interior Lining Thickness (δ) = 6 in
- Select Material: select **Gypsum Board** from the combo box
- Fire Heat Release Rate $(\dot{Q})$ = 410 kW*

Note: When **Gypsum Board** is selected, its thermal properties are automatically selected from the table and entered in the corresponding input cells.

*The HRR value is a starting value for the trial and error procedure explained below.

Because we are looking for an HRR value that could generate a hot gas layer temperature of 218 °C (425 °F), we need to enter HRR values on the spreadsheet until get a temperature close to 218 °C (425 °F) at 10 min after ignition. This trial and error procedure is shown in the following table.

Trial and error procedure to determine the HRR Target: T_g = 425 °F for natural ventilation scenario		
Trial	Heat Release Rate $(\dot{Q})$ (kW)	Hot Gas Layer Temperature (T_g) at 10 min after Ignition (°C) (°F)
1	100	100 (213)
2	200	145 (293)
3	300	182 (360)
4	400	215 (420)
5*	410	219 (425)

*spreadsheet calculations attached on next page for last trial at t = 10 min

Results

According to the method of McCaffrey, Quintiere, and Harkleroad (MQH), an HRR of approximate **410 kW** could generate a hot gas layer temperature of 218 °C (425 °F) at 10 minutes after ignition. But, what is important for practical purposes is that for the given compartment and ventilation conditions, a fire power of about **400 kW (379 Btu/sec)** may generate a hot gas layer temperature of **204+°C (400+°F)**. Also, the smoke layer height at 10 minutes after ignition is approximately **z = 0.39 m (1.27 ft)**, based on the method of Yamana and Tanaka. That means that the smoke could be exiting the compartment because z is less than the height of the vent top (V_T).

Spreadsheet Calculations

FDT^{s}: 02.1_Temperature_NV.xls (*Temperature_NV Thermally Thick*)

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN A ROOM FIRE WITH NATURAL VENTILATION COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

Version 1805.0

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Parameter	Value	Unit	Converted
Compartment Width (w_c)	15.00	ft	4.572 m
Compartment Length (l_c)	16.00	ft	4.8768 m
Compartment Height (h_c)	10.00	ft	3.048 m
Vent Width (w_v)	6.40	ft	1.951 m
Vent Height (h_v)	5.60	ft	1.707 m
Top of Vent from Floor (V_T)	8.00	ft	2.438 m
Interior Lining Thickness (δ)	6.00	in	0.1524 m

AMBIENT CONDITIONS

Parameter	Value	Unit	Converted
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.18	kg/m^3	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Parameter	Value	Unit
Interior Lining Thermal Inertia ($k\rho c$)	0.18	(kW/m^2-K)^2-sec
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K
Interior Lining Specific Heat (c)	1.1	kJ/kg-K
Interior Lining Density (ρ)	960	kg/m^3

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ (kW/m^2-K)^2-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Select Material
Gypsum Board
Scroll to desired material then Click the selection

Reference: Klote, J., J. Milke, Principles of Smoke Management, 2002, Page 270.

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) | 410.00 | kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-175.

$\Delta T_g = 6.85\,[Q^2/(A_v(h_v)^{1/2})(A_T h_k)]^{1/3}$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)

Q = heat release rate of the fire (kW)

A_v = area of ventilation opening (m^2)

h_v = height of ventilation opening (m)

h_k = convective heat transfer coefficient (kW/m^2-K)

A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$A_v = (w_v)(h_v)$

Where A_v = area of ventilation opening (m^2)

w_v = vent width (m)

h_v = vent height (m)

A_v = 3.33 m^2

Thermal Penetration Time Calculation

$t_p = (\rho c_p/k)(\delta/2)^2$

Where t_p = thermal penetration time (sec)

ρ = interior construction density (kg/m^3)

c_p = interior construction heat capacity (kJ/kg-K)

k = interior construction thermal conductivity (kW/m-K)

δ = interior construction thickness (m)

t_p = 36068.24 sec

Heat Transfer Coefficient Calculation

$h_k = \sqrt{(k\rho c/t)}$ for $t < t_p$ or (k/δ) for $t > t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia ($(kW/m^2\text{-}K)^2$-sec)

(a thermal property of material responsible for the rate of temperature rise)

t = time after ignition (sec)

See table below for results

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)] - A_v$

Where A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

w_c = compartment width (m)

l_c = compartment length (m)

h_c = compartment height (m)

A_v = area of ventilation opening (m^2)

A_T = 98.86 m^2

Compartment Hot Gas Layer Temperature With Natural Ventilation

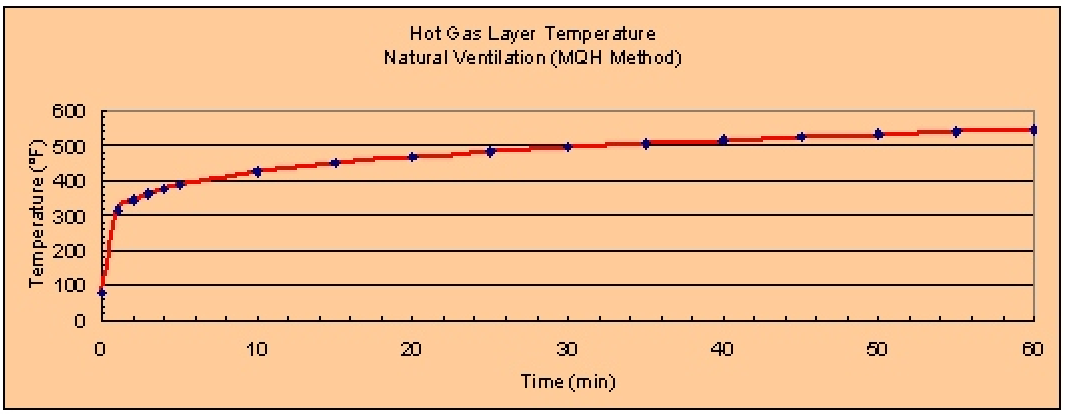
$\Delta T_g = 6.85\,[Q^2/(A_v(h_v)^{1/2})(A_T h_k)]^{1/3}$

$\Delta T_g = T_g - T_a$

$T_g = \Delta T_g + T_a$

Results

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m²-K)	(K)	(K)	(°C)	(°F)
0	0.00	-	-	298.00	25.00	77.00
1	60	0.05	131.88	429.88	156.88	314.39
2	120	0.04	148.03	446.03	173.03	343.46
3	180	0.03	158.38	456.38	183.38	362.08
4	240	0.03	166.16	464.16	191.16	376.09
5	300	0.02	172.46	470.46	197.46	387.42
10	600	0.02	193.57	491.57	218.57	425.43
15	900	0.01	207.11	505.11	232.11	449.79
20	1200	0.01	217.28	515.28	242.28	468.10
25	1500	0.01	225.51	523.51	250.51	482.92
30	1800	0.01	232.47	530.47	257.47	495.45
35	2100	0.01	238.52	536.52	263.52	506.34
40	2400	0.01	243.89	541.89	268.89	516.00
45	2700	0.01	248.72	546.72	273.72	524.70
50	3000	0.01	253.13	551.13	278.13	532.63
55	3300	0.01	257.18	555.18	282.18	539.93
60	3600	0.01	260.94	558.94	285.94	546.69



ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANA AND TANAKA

$z = ((2kQ^{1/3}\,t/3A_c) + (1/h_c^{(2/3)}))^{-3/2}$

Where
- z = smoke layer height (m)
- Q = heat release rate of the fire (kW)
- t = time after ignition (sec)
- h_c = compartment height (m)
- A_c = compartment floor area (m^2)
- k = a constant given by $k = 0.076/\rho_g$
- ρ_g = hot gas layer density (kg/m^3)
- ρ_g is given by $\rho_g = 353/T_g$
- T_g = hot gas layer temperature (K)

Compartment Area Calculation

$A_c = (w_c)\,(l_c)$

Where
- A_c = compartment floor area (m^2)
- w_c = compartment width (m)
- l_c = compartment length (m)

$A_c =$ 22.30 m^2

Hot Gas Layer Density Calculation

$\rho_g = 353/T_g$

Calculation for Constant K

$k = 0.076/\rho_g$

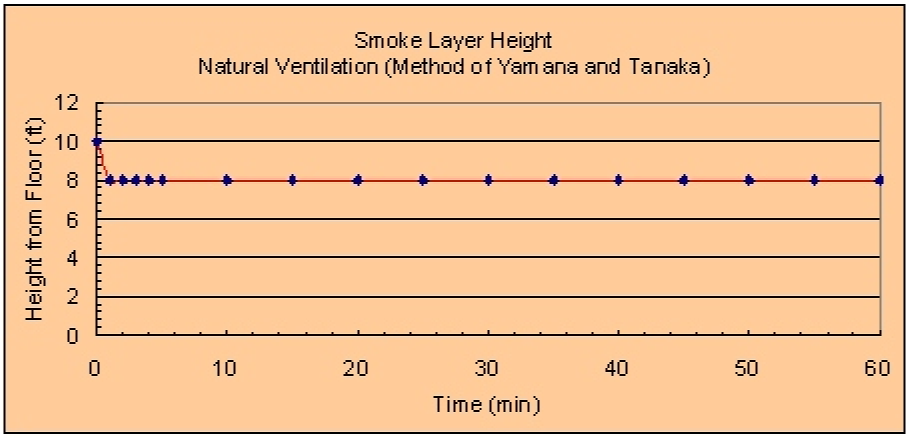
Smoke Gas Layer Height With Natural Ventilation

$z = [(2kQ^{1/3}\,t/3A_c] + (1/h_c^{2/3}))^{-3/2}$

Results

Caution! The smoke layer height is a conservative estimate and is only intended to provide an indication where the hot gas layer is located. Calculated smoke layer height below the vent height are not creditable since the calculation is not accounting for the smoke exiting the vent.

Time (min)	ρ_g (kg/m^3)	Constant (k) (kW/m-K)	Smoke Layer height z (m)	Smoke Layer height z (ft)	
0	1.18	0.064	3.05	10.00	
1	0.82	0.093	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
2	0.79	0.096	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
3	0.77	0.098	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
4	0.76	0.100	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
5	0.75	0.101	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
10	0.72	0.106	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
15	0.70	0.109	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
20	0.69	0.111	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
25	0.67	0.113	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
30	0.67	0.114	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
35	0.66	0.116	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
40	0.65	0.117	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
45	0.65	0.118	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
50	0.64	0.119	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
55	0.64	0.120	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT
60	0.63	0.120	2.44	8.00	CAUTION: SMOKE IS EXITING OUT VENT



NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov.

Spreadsheet (FDT^s) Solution Procedure:

Forced Ventilation Scenario

Use the following FDT^s:

(a) 02.2_Temperature_FV.xls

FDT^s Input Parameters:

Enter the following parameters in both spreadsheets (values only):

- Compartment Width (w_c) = 15 ft
- Compartment Length (l_c) = 16 ft
- Compartment Height (h_c) = 10 ft
- Interior Lining Thickness (δ) = 6 in
- Material: select **Gypsum Board** from the combo box
- Compartment Ventilation Rate $(\dot{m})$ = 500 cfm
- Fire Heat Release Rate $(\dot{Q})$ = 410 kW

Note: When **Gypsum Board** is selected, its thermal properties are automatically selected from the table and entered in the corresponding input cells.

Results

From the table of results of the spreadsheet at t = 10 minutes after ignition we obtain:

Hot Gas Layer Temperature* T_g °C (°F)	
Method of Foot, Pagni, and Alvares (FPA)	Method of Deal & Beyler
329 (625)	440 (824)

*spreadsheet calculations attached on next page

These results demonstrate that the ventilation system is able to increase the hot gas layer temperature. That is, for a specific compartment and heat release rate, the ventilation system can drastically increase the hot gas layer temperature due to the oxygen supply.

Spreadsheet Calculations
FDT[s]: 02.2_Temperature_FV.xls

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

Version 1805.0

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	15.00	ft	4.57 m
Compartment Length (l_c)	16.00	ft	4.88 m
Compartment Height (h_c)	10.00	ft	3.05 m
Interior Lining Thickness (δ)	6.00	in	0.1524 m

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.18	kg/m³	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia ($k\rho c$)	0.18	$(kW/m^2-K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K
Interior Lining Specific Heat (c)	1.1	kJ/kg-K
Interior Lining Density (ρ)	960	kg/m³

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ $(kW/m^2-K)^2$-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m³)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: *Klote, J., J. Milke, Principles of Smoke Management, 2002 Page 270.*

Select Material
Gypsum Board
Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m)	500.00	cfm	0.236 m^3/sec
			0.280 kg/sec

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	410.00	kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-177.

$\Delta T_g/T_a = 0.63(Q/m c_p T_a)^{0.72}(h_k A_T/m c_p)^{-0.36}$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)

T_a = ambient air temperature (K)

Q = heat release rate of the fire (kW)

m = compartment mass ventilation flow rate (kg/sec)

c_p = specific heat of air (kJ/kg-K)

h_k = convective heat transfer coefficient (kW/m^2-K)

A_T = total area of the compartment enclosing surface boundaries (m^2)

Thermal Penetration Time Calculation

$t_p = (\rho c_p/k)(\delta/2)^2$

Where t_p = thermal penetration time (sec)

ρ = interior construction density (kg/m^3)

c_p = interior construction heat capacity (kJ/kg-K)

k = interior construction thermal conductivity (kW/m-K)

δ = interior construction thickness (m)

t_p = 36068.24 sec

Heat Transfer Coefficient Calculation

$h_k = \sqrt{(k\rho c/t)}$ for $t < t_p$ or (k/δ) for $t > t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec

(a thermal property of material responsible for the rate of temperature rise)

t = time after ignition (sec)

See table below for results

Area of Compartment Enclosing Surface Boundaries

$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$

Where A_T = total area of the compartment enclosing surface boundaries (m^2)

w_c = compartment width (m)

l_c = compartment length (m)

h_c = compartment height (m)

A_0 = area of ventilation opening (m^2)

A_T = 102.19 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

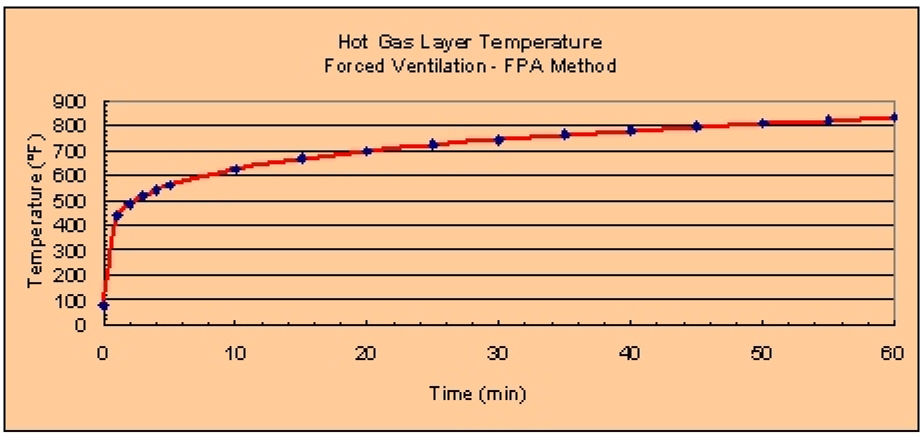
$\Delta T_g/T_a = 0.63(Q/m c_p T_0)^{0.72}(h_k A_T/m c_p)^{-0.36}$

$\Delta T_g = T_g - T_a$

$T_g = \Delta T_g + T_a$

Results

Time After Ignition (t)		h_k (kW/m^2-K)	$\Delta T_g/T_a$	ΔT_g (K)	T_g (K)	T_g (°C)	T_g (°F)
(min)	(sec)						
0	0	-	-	-	298.00	25.00	77.00
1	60	0.05	0.67	201.07	499.07	226.07	438.92
2	120	0.04	0.76	227.78	525.78	252.78	487.01
3	180	0.03	0.82	245.03	543.03	270.03	518.06
4	240	0.03	0.87	258.05	556.05	283.05	541.50
5	300	0.02	0.90	268.63	566.63	293.63	560.53
10	600	0.02	1.02	304.33	602.33	329.33	624.79
15	900	0.01	1.10	327.37	625.37	352.37	666.26
20	1200	0.01	1.16	344.77	642.77	369.77	697.58
25	1500	0.01	1.20	358.90	656.90	383.90	723.01
30	1800	0.01	1.24	370.87	668.87	395.87	744.57
35	2100	0.01	1.28	381.30	679.30	406.30	763.35
40	2400	0.01	1.31	390.58	688.58	415.58	780.04
45	2700	0.01	1.34	398.95	696.95	423.95	795.11
50	3000	0.01	1.36	406.59	704.59	431.59	808.86
55	3300	0.01	1.39	413.62	711.62	438.62	821.52
60	3600	0.01	1.41	420.15	718.15	445.15	833.27



METHOD OF DEAL AND BEYLER

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-178.

Heat Transfer Coefficient Calculation

$h_k = 0.4 \sqrt{(k\rho c / t)}$ for $t < t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec

(a thermal property of material responsible for the rate of temperature rise)

δ = thickness of interior lining (m)

h_k = 0.022 kW/m^2-K

Area of Compartment Enclosing Surface Boundaries

$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$

A_T = 102.19 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g = Q / (m\, c_p + h_k A_T)$$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)

T_a = ambient air temperature (K)

Q = heat release rate of the fire (kW)

m = compartment mass ventilation flow rate (kg/sec)

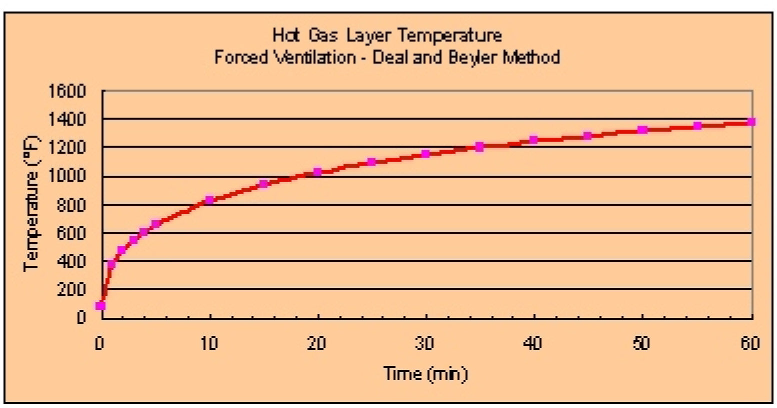
c_p = specific heat of air (kJ/kg-K)

h_k = convective heat transfer coefficient (kW/m^2-K)

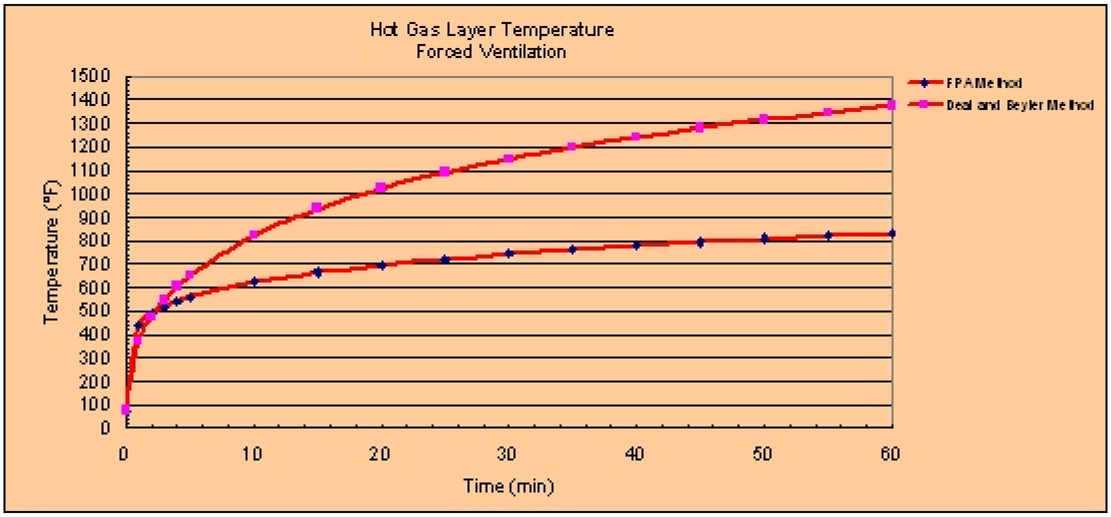
A_T = total area of the compartment enclosing surface boundaries (m^2)

Results

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.02	162.80	460.80	187.80	370.04
2	120	0.02	220.11	518.11	245.11	473.20
3	180	0.01	260.78	558.78	285.78	546.41
4	240	0.01	293.07	591.07	318.07	604.52
5	300	0.01	320.11	618.11	345.11	653.20
10	600	0.01	415.17	713.17	440.17	824.31
15	900	0.01	478.07	776.07	503.07	937.52
20	1200	0.00	525.53	823.53	550.53	1022.95
25	1500	0.00	563.72	861.72	588.72	1091.69
30	1800	0.00	595.67	893.67	620.67	1149.21
35	2100	0.00	623.12	921.12	648.12	1198.62
40	2400	0.00	647.16	945.16	672.16	1241.89
45	2700	0.00	668.53	966.53	693.53	1280.35
50	3000	0.00	687.73	985.73	712.73	1314.92
55	3300	0.00	705.16	1003.16	730.16	1346.30
60	3600	0.00	721.10	1019.10	746.10	1374.99



Summary of Result:

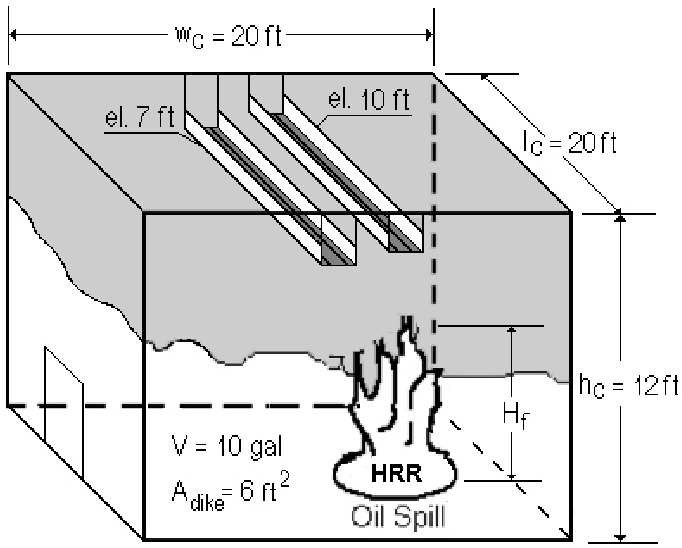


NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-4

Problem Statement
Consider a pool fire caused by a 38.0 liters (10 gallons) spill combustible liquid (kerosine oil) in a 0.55-m^2 (6.0-ft^2) dike area in a compartment with a concrete floor. The kerosine oil is ignited and spread rapidly over the surface, reaching steady burning almost instantly. Compute the HRR, burning duration, and flame height of the pool fire. The dimensions of the compartment are 6.0 m wide x 6.0 m long x 3.7 m high (20.0 ft wide x 20.0 ft long x 12.0 ft). Two cable trays are located above the pool fire at heights of 2.15 m (7.0 ft) and 3.0 m (10.0 ft), respectively. Determine whether flame will impinge upon the cable trays. Assume instantaneous, complete involvement of the liquid pool with no fire growth and no intervention by the plant fire department or automatic suppression systems.



Problem 4: Compartment with Liquid Pool Fire Scenario

Solution

Purpose:

(1) Determine the HRR of the liquid pool fire.
(2) Determine the flame duration.
(3) Determine flame height (H_f).
(4) Determine if the flame will impinge the cable trays.

Assumptions:

(1) There is instantaneous and complete involvement of the liquid in the pool fire.
(2) The pool fire is burning in the open.
(3) The pool is circular or nearly circular and contains a fixed mass of liquid volume.
(4) The pool fire is in the center of the compartment or away from the walls.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

- Fuel spill volume (V) = 10 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 6.0 ft^2
- Select Fuel Type: select **Kerosine** from the combo box

Note: When **Kerosine** is selected, its properties are automatically selected from the table and entered in the corresponding input cells.

Results

Heat Release Rate* $\dot{Q}$ kW (Btu/sec)	Burning Duration* t_b (min)	Pool Fire Flame Height* H_f m (ft)	
		Method of Heskestad	Method of Thomas
890 kW (843 Btu/sec)	24	2.7 m (8.8 ft)	2.3 m (7.6 ft)

*spreadsheet calculations attached on next page

Both methods for pool fire flame height estimation show that the flame could impinge upon the cable trays.

Spreadsheet Calculations

FDT^s: 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

CHAPTER 3. ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE,
HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT

Version 1805.0

The following calculations estimate the heat release rate, burning duration, and flame height for liquid pool fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	10.00	gallons	0.0379 m^3
Fuel Spill Area or Dike Area (A_{dike})	6.00	ft^2	0.557 m^2
Mass Burning Rate of Fuel (m'')	0.039	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	43200	kJ/kg	
Fuel Density (ρ)	820	kg/m^3	
Empirical Constant ($k\beta$)	3.5	m^{-1}	
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K
Gravitational Acceleration (g)	9.81	m/sec^2	
Ambient Air Density (ρ_a)	1.18	kg/m^3	

Calculate

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m'' (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Density ρ (kg/m^3)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	796	100
Ethanol	0.015	26,800	794	100
Butane	0.078	45,700	573	2.7
Benzene	0.085	40,100	874	2.7
Hexane	0.074	44,700	650	1.9
Heptane	0.101	44,600	675	1.1
Xylene	0.09	40,800	870	1.4
Acetone	0.041	25,800	791	1.9
Dioxane	0.018	26,200	1035	5.4
Diethy Ether	0.085	34,200	714	0.7
Benzine	0.048	44,700	740	3.6
Gasoline	0.055	43,700	740	2.1
Kerosine	0.039	43,200	820	3.5
Diesel	0.045	44,400	918	2.1
JP-4	0.051	43,500	760	3.6
JP-5	0.054	43,000	810	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	760	0.7
561 Silicon Transformer Fluid	0.005	28,100	960	100
Fuel Oil, Heavy	0.035	39,700	970	1.7
Crude Oil	0.0335	42,600	855	2.8
Lube Oil	0.039	46,000	760	0.7
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-26.

Select Fuel Type

Scroll to desired fuel type
Click on selection

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference : *SFPE Handbook of Fire Protection Engineering*, 3[rd] Edition, 2002, Page 3-25.

$Q = \dot{m}''\Delta H_{c,eff}(1 - e^{-k\beta D})\,A_{dike}$

Where Q = pool fire heat release rate (kW)

$\dot{m}''$ = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

$k\beta$ = empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

Where A_{dike} = surface area of pool fire (m^2)

D = pool fire diamter (m)

$D = \sqrt{(4A_{dike}/\pi)}$

D = 0.842 m

Heat Release Rate Calculation

$Q = \dot{m}''\Delta H_{c,eff}(1-e^{-k\beta D})\,A_{dike}$

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

Q =	889.91 kW	843.48 Btu/sec	Answer

ESTIMATING POOL FIRE BURNING DURATION

Reference : *SFPE Handbook of Fire Protection Engineering*, 2[nd] Edition, 1995, Page 3-197.

$t_b = 4V / \pi D^2 v$

Where t_b = burning duration of pool fire (sec)

V = volume of liquid (m^3)

D = pool diameter (m)

v = regression rate (m/sec)

Calculation for Regression Rate

$v = \dot{m}''/\rho$

Where v = regression rate (m/sec)

$\dot{m}''$ = mass burning rate of fuel (kg/m^2-sec)

ρ = liquid fuel density (kg/m^3)

v = 0.000048 m/sec

Burning Duration Calculation

$t_b = 4V/\pi D^2 v$

t_b =	1427.85 sec	23.80 minutes	Answer

Note that a liquid pool fire with a given amount of fuel can burn for long periods of time over small area or for short periods of time over a large area.

ESTIMATING POOL FIRE FLAME HEIGHT
METHOD OF HESKESTAD

Reference : *SFPE Handbook of Fire Protection Engineering*, 2[nd] Edition, 1995, Page 2-10.

$H_f = 0.235\,Q^{2/5} - 1.02\,D$

Where H_f = pool fire flame height (m)

Q = pool fire heat release rate (kW)

D = pool fire diameter (m)

Pool Fire Flame Height Calculation

$H_f = 0.235\,Q^{2/5} - 1.02\,D$

H_f =	2.70 m	8.84 ft	Answer

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-204.

$H_f = 42\, D\, (\dot{m}'' / \rho_a \sqrt{g D})^{0.61}$

Where H_f = pool fire flame height (m)

$\dot{m}''$ = mass burning rate of fuel per unit surface area (kg/m^2-sec)

ρ_a = ambient air density (kg/m^3)

D = pool fire diameter (m)

g = gravitational acceleration (m/sec^2)

Pool Fire Flame Height Calculation

$H_f = 42\, D\, (\dot{m}'' / \rho_a \sqrt{g D})^{0.61}$

H_f =	2.32 m	7.60 ft	Answer

Flame Height Calculation - Summary of Results

Calculation Method	Flame Height (ft)
METHOD OF HESKESTAD	8.84
METHOD OF THOMAS	7.60

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	148.32	8567.07	4.54	4.08
2	0.19	0.49	296.64	4283.54	5.89	5.19
3	0.28	0.60	444.96	2855.69	6.85	5.97
4	0.37	0.69	593.28	2141.77	7.61	6.60
5	0.46	0.77	741.60	1713.41	8.27	7.13
6	0.56	0.84	889.91	1427.85	8.84	7.60
7	0.65	0.91	1038.23	1223.87	9.36	8.02
8	0.74	0.97	1186.55	1070.88	9.83	8.40
9	0.84	1.03	1334.87	951.90	10.26	8.75
10	0.93	1.09	1483.19	856.71	10.67	9.07
11	1.02	1.14	1631.51	778.82	11.05	9.38
12	1.11	1.19	1779.83	713.92	11.40	9.67
13	1.21	1.24	1928.15	659.01	11.74	9.94
14	1.30	1.29	2076.47	611.93	12.06	10.20
15	1.39	1.33	2224.79	571.14	12.37	10.45
20	1.86	1.54	2966.38	428.35	13.73	11.55
25	2.32	1.72	3707.98	342.68	14.89	12.48
50	4.65	2.43	7415.95	171.34	19.10	15.87
75	6.97	2.98	11123.93	114.23	22.06	18.28
100	9.29	3.44	14831.91	85.67	24.43	20.20

Caution: The purpose of this random spill size chart is to aid the user in evaluating the hazard of random sized spills. Please note that the calculation doe not take into account the viscosity or volatility of the liquid, or the absorptivity of the surface. The results generated for small volume spills over large areas should be used with extreme caution.

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

UNITED STATES NUCLEAR REGULATORY COMMISSION

Problem J-5

Problem Statement
Consider a compartment with cable trays at 4.60 m (15 ft) above the floor. The cable trays are very close to the compartment walls. If 7.6 liters (2 gallons) of lube oil spills covering an area of 1.4 m^2 (15 ft^2), what location type of fire source will allow the fire flame to impinge on the cable trays?

Solution

Purpose:

(1) Determine what type of fire source will impinge upon the cable tray.

Assumptions:

(1) Air is entrained only from one side during the combustion process.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 04_Flame_Height_Calculations.xls
select *Wall_Flame _Height* for wall fire analysis
select *Corner_Flame _Height* for corner fire analysis
select *Wall_Line_Flame _Height* for line fire analysis

FDT^s Input Parameters:

Enter the following parameters in all spreadsheets (values only):

- Fuel spill volume (V) = 2 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 15 ft^2
- Select Fuel Type: select **Lube Oil** from the combo box

Note: When **Lube Oil** is selected, its properties are automatically selected from the table and entered in the corresponding input cells.

Results

Fire Source	Flame Height* H_f m (ft)
Wall Fire	4.02 (13.18)
Corner Fire	6.07 (19.93)
Line Fire	2.01 (6.59)

*spreadsheet calculations attached on next page

Spreadsheet Calculations

FDT[s]: 04_Flame_Height_Calculations.xls (Wall_Flame _Height)

CHAPTER 4. ESTIMATING WALL FIRE FLAME HEIGHT

Version 1805.0

The following calculations estimate the wall fire flame height.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	2.00	gallons	0.0076 m^3
Fuel Spill Area or Dike Area (A_{dike})	15.00	ft^2	1.394 m^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg	
Empirical Constant (kβ)	0.7	m^{-1}	

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzene	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosene	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.034	42,600	2.8
Lube Oil	0.039	46,000	0.7
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.*

Select Fuel Type

Lube Oil

Scroll to desired fuel type then Click on selection

Heat Release Rate Calculation

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-25.*

$Q = \dot{m}''\Delta H_{c,eff}(1 - e^{-k\beta D})A_{dike}$

Where Q = pool fire heat release rate (kW)

$\dot{m}''$ = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

$k\beta$ = empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

(Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{4A_{dike}/\pi}$

Where A_{dike} = surface area of pool fire (m^2)

D = pool fire diamter (m)

D = 1.332 m

Heat Release Rate Calculation

$Q = \dot{m}''\Delta H_{c,eff}(1-e^{-k\beta D})A_{dike}$

Q = 1516.02 kW 1436.91 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$Q' = Q/L$

Where Q' = heat release rate per unit length (kW/m)

Q = fire heat release rate of the fire (kW)

L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

L x W = 1.394 m^2

L = 1.180 m

$Q' = Q/L$

Q' = 1284.23 kW/m

ESTIMATING WALL FIRE FLAME HEIGHT

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.*

$H_{(wall)} = 0.034\, Q'^{2/3}$

Where $H_{(wall)}$ = wall fire flame height (m)

Q' = rate of heat release per unit length of the fire (kW/m)

$H_{(wall)} = 0.034\, Q'^{2/3}$

$H_{(wall)}$ =	4.02 m	13.18 ft	Answer

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and NFPA Fire Protection Handbook, 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

CHAPTER 4. ESTIMATING CORNER FIRE FLAME HEIGHT

Version 1805.0

The following calculations estimate the corner fire flame height.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	2.00	gallons	0.0076 m^3
Fuel Spill Area or Dike Area (A_{dike})	15.00	ft^2	1.394 m^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg	
Empirical Constant (kβ)	0.7	m^{-1}	

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzene	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosene	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.034	42,600	2.8
Lube Oil	0.039	46,000	0.7
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.*

Select Fuel Type

Lube Oil

Scroll to desired fuel type then Click on selection

Heat Release Rate Calculation

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-25.

$Q = \dot{m}'' \Delta H_{c,eff} (1 - e^{-k\beta D}) A_f$

Where Q = pool fire heat release rate (kW)

$\dot{m}''$ = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

$k\beta$ = empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

(Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4A_{dike}/\pi)}$

Where A_{dike} = surface area of pool fire (m^2)

D = pool fire diamter (m)

D = 1.332 m

Heat Release Rate Calculation

$Q = \dot{m}'' \Delta H_{c,eff} (1 - e^{-k\beta D}) A_{dike}$

Q = 1516.02 kW 1436.91 Btu/sec

ESTIMATING CORNER FIRE FLAME HEIGHT

Reference: *Hesemi and Tokunaga, "Modeling of Turbulent Diffusion Flames and Fire Plumes for the Analysis of Fire Growth," Growth," Proceeding of the 21st National Heat Transfer Conference, American Society of Mechanical Engineers (ASME), 1983.*

$H_{f(corner)} = 0.075\ Q^{2/5}$

Where Q = heat release rate of the fire (kW)

$H_{f(corner)} = 0.075\ Q^{2/5}$

$H_{f(corner)}$ = 6.07 m 19.93 ft **Answer**

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002 and Hesemi and Tokunage, 1983.

Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.

Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

CHAPTER 4. ESTIMATING LINE FIRE FLAME HEIGHT AGAINST THE WALL

Version 1805.0

The following calculations estimate the line fire flame height against the wall.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	2.00	gallons	0.0076 m^3
Fuel Spill Area or Dike Area (A_{dike})	15.00	ft^2	1.394 m^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg	
Empirical Constant (kβ)	0.7	m^{-1}	

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzene	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosene	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.034	42,600	2.8
Lube Oil	0.039	46,000	0.7
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.*

Select Fuel Type

Lube Oil

Scroll to desired fuel type then Click on selection

Heat Release Rate Calculation

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-25.*

$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_f$

Where Q = pool fire heat release rate (kW)

m'' = mass burning rate of fuel per unit surface area (kg/m²-sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m²)

$k\beta$ = empirical constant (m⁻¹)

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

(Liquids with relatively high flash point, like transformer oil require localized heating to achieve ignition)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4A_{dike}/\pi)}$

Where A_{dike} = surface area of pool fire (m²)

D = pool fire diameter (m)

D = 1.332 m

Heat Release Rate Calculation

$Q = m''\Delta H_{c,eff} (1-e^{-k\beta D}) A_{dike}$

Q = 1516.02 kW 1436.91 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$Q' = Q/L$

Where Q' = heat release rate per unit length (kW/m)

Q = fire heat release rate of the fire (kW)

L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

L x W = 1.394 m²

L = 1.180 m

$Q' = Q/L$

Q' = 1284.23 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.*

$H_{f(wall\ line)} = 0.017\ Q'^{2/3}$

Where $H_{f(wall\ line)}$ = wall fire flame height (m)

Q' = rate of heat release per unit length of the fire (kW/m)

$H_{f(wall\ line)} = 0.017\ Q'^{2/3}$

$H_{f(wall\ line)}$ =	2.01 m	6.59 ft	Answer

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and NFPA Fire Protection Handbook, 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

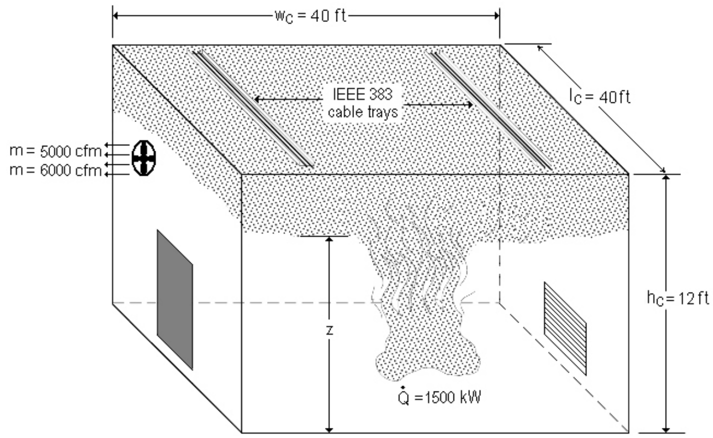
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.

Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-6

Problem Statement

Consider a compartment that is 15.2 m wide x 12.20 m long x 3.70 m height (50 ft wide x 40 ft long x 12 ft height) with two forced ventilation rates: 2.4 m^3/s and 2.8 m^3/s (5,000 cfm and 6,000 cfm). If a fire scenario arises with a fire power of 1,500 kW (1,422 Btu/sec), find the average hot gas layer temperature for gypsum board (boundary material) that is ½, ⅝, ¾, 1, 1½, and 2 inch(es) thick at 15 min after ignition.



Problem 6: Compartment Fire with Forced Ventilation

Solution

Purpose:

(1) Determine the average hot gas layer temperature for two ventilation rates (5,000 cfm and 6,000 cfm) at 15 minutes after ignition.

Assumptions:

(1) Air properties (ambient) are at 25 °C (77 °F).
(2) Neglect the effect of the cable trays on the plume profile.
(3) The heat flow through the compartment boundaries is one-dimensional.
(4) The HRR is constant.
(5) The fire is located at the center of the compartment or away from the walls.
(6) The compartment is open to the outside at the inlet (pressure = 1 atm).

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 02.2_Temperature_FV.xls

FDT[s] Input Parameters:

Enter the following parameters in both spreadsheets (values only):

- Compartment Width (w_c) = 50 ft
- Compartment Length (l_c) = 40 ft
- Compartment Height (h_c) = 12 ft
- Interior Lining Thickness = 0.5 in
- Select Material: select **Gypsum Board** from the combo box
- Compartment ventilation rate $(\dot{m})$ = 5,000 cfm and 6,000 cfm
- Fire Heat Release Rate $(\dot{Q})$ = 1,500 kW

Note: When **Gypsum Board** is selected, its thermal properties are automatically selected from the table and entered in the corresponding input cells.

Results

This problem is solved using the two different ventilation rates and varying wall thicknesses at 15 minutes after ignition. The following table summarizes the results.

Ventilation rate $\dot{m}$ (cfm)	Trial	Material Thickness (in)	Hot Gas Layer Temperature T_g [°C (°F)]	
			Method of FPA	Method of Deal & Beyler
5,000	1	0.5	225 (436)	274 (525)
	2	0.63	241 (467)	274 (525)
	3	0.75	256 (492)	274 (525)
	4	1.0	220 (429)	274 (525)
	5	1.5	220 (429)	274 (525)
	6	2.0	220 (429)	274 (525)
6,000	1	0.5	212 (413)	253 (487)
	2	0.63	228 (442)	253 (487)
	3	0.75	241 (466)	253 (487)
	4	1.0	208 (407)	253 (487)
	5	1.5	208 (407)	253 (487)
	6	2.0	208 (407)	253 (487)

*spreadsheet calculations attached on next page

Following the results of the FPA and Deal & Beyler method, we see how the two methods respond to different inputs. This problem can be rerun varying time to explore the differences in methods.

Spreadsheet Calculations

Note: The following spreadsheets show the final result of the solution process. Only the 6,000 cfm case is shown; spreadsheet calculations for the 5,000 cfm scenario are similar.

FDT[s]: 02.2_Temperature_FV.xls

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION
COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

Version 1805.0

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	50.00	ft	15.24 m
Compartment Length (l_c)	40.00	ft	12.19 m
Compartment Height (h_c)	12.00	ft	3.66 m
Interior Lining Thickness (δ)	1.50	in	0.0381 m

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.18	kg/m³	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia ($k\rho c$)	0.18	(kW/m²-K)²-sec
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K
Interior Lining Specific Heat (c)	1.1	kJ/kg-K
Interior Lining Density (ρ)	960	kg/m³

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ (kW/m²-K)²-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m³)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Select Material: Gypsum Board
Scroll to desired material then Click on selection

Reference: *Klote, J., J. Milke, Principles of Smoke Management, 2002 Page 270.*

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m) | 6000.00 cfm | 2.832 m^3/sec | 3.354 kg/sec

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) | 1500.00 kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-177.

$\Delta T_g/T_a = 0.63(Q/mc_pT_a)^{0.72}(h_kA_T/mc_p)^{-0.36}$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)

T_a = ambient air temperature (K)

Q = heat release rate of the fire (kW)

m = compartment mass ventilation flow rate (kg/sec)

c_p = specific heat of air (kJ/kg-K)

h_k = convective heat transfer coefficient (kW/m^2-K)

A_T = total area of the compartment enclosing surface boundaries (m^2)

Thermal Penetration Time Calculation

$t_p = (\rho c_p/k)(\delta/2)^2$

Where t_p = thermal penetration time (sec)

ρ = interior construction density (kg/m^3)

c_p = interior construction heat capacity (kJ/kg-K)

k = interior construction thermal conductivity (kW/m-K)

δ = interior construction thickness (m)

t_p = 2254.26 sec

Heat Transfer Coefficient Calculation

$h_k = \sqrt{(k\rho c/t)}$ for $t < t_p$ or (k/δ) for $t > t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec

(a thermal property of material responsible for the rate of temperature rise)

t = time after ignition (sec)

See table below for results

Area of Compartment Enclosing Surface Boundaries

$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$

Where A_T = total area of the compartment enclosing surface boundaries (m^2)

w_c = compartment width (m)

l_c = compartment length (m)

h_c = compartment height (m)

A_v = area of ventilation opening (m^2)

A_T = 572.28 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

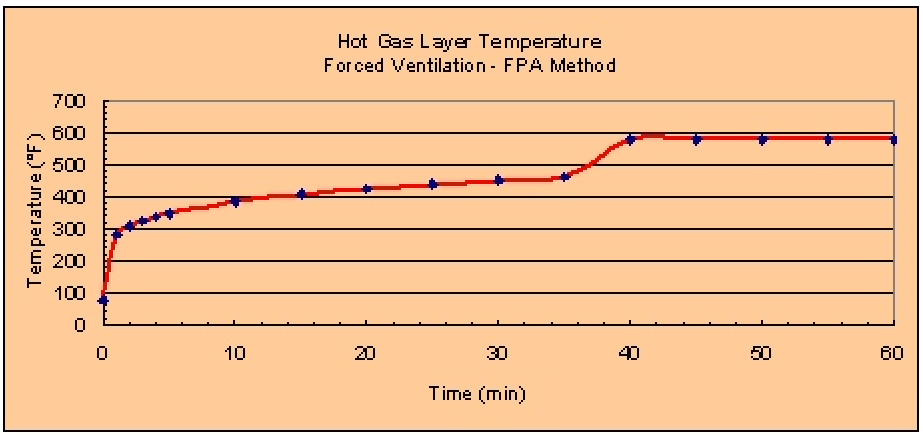
$\Delta T_g/T_a = 0.63(Q/mc_pTo)^{0.72}(h_kA_T/mc_p)^{-0.36}$

$\Delta T_g = T_g - T_a$

$T_g = \Delta T_g + T_a$

Results

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.05	0.38	112.48	410.48	137.48	279.46
2	120	0.04	0.43	127.42	425.42	152.42	306.36
3	180	0.03	0.46	137.07	435.07	162.07	323.73
4	240	0.03	0.48	144.36	442.36	169.36	336.84
5	300	0.02	0.50	150.27	448.27	175.27	347.49
10	600	0.02	0.57	170.24	468.24	195.24	383.44
15	900	0.01	0.61	183.13	481.13	208.13	406.64
20	1200	0.01	0.65	192.86	490.86	217.86	424.16
25	1500	0.01	0.67	200.77	498.77	225.77	438.38
30	1800	0.01	0.70	207.47	505.47	232.47	450.44
35	2100	0.01	0.72	213.30	511.30	238.30	460.95
40	2400	0.00	0.93	277.41	575.41	302.41	576.34
45	2700	0.00	0.93	277.41	575.41	302.41	576.34
50	3000	0.00	0.93	277.41	575.41	302.41	576.34
55	3300	0.00	0.93	277.41	575.41	302.41	576.34
60	3600	0.00	0.93	277.41	575.41	302.41	576.34



METHOD OF DEAL AND BEYLER

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-178.

Heat Transfer Coefficient Calculation

$h_k = 0.4 \sqrt{(k\rho c / t)}$ for $t < t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)

h_k = 0.022 kW/m^2-K

Area of Compartment Enclosing Surface Boundaries

$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$

A_T = 572.28 m^2

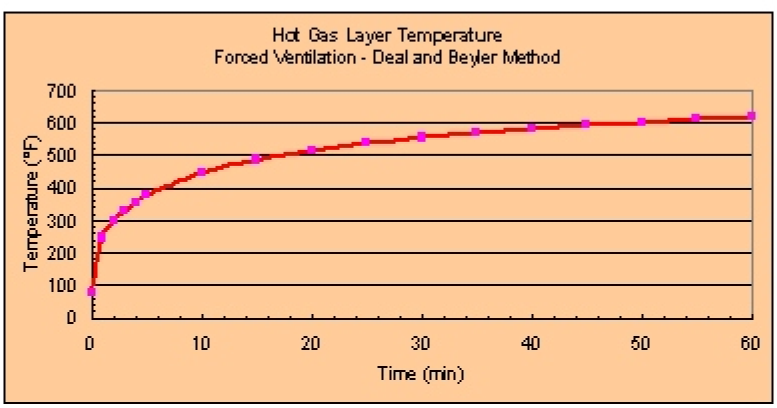
Compartment Hot Gas Layer Temperature With Forced Ventilation

$\Delta T_g = Q / (m\, c_p + h_k A_T)$

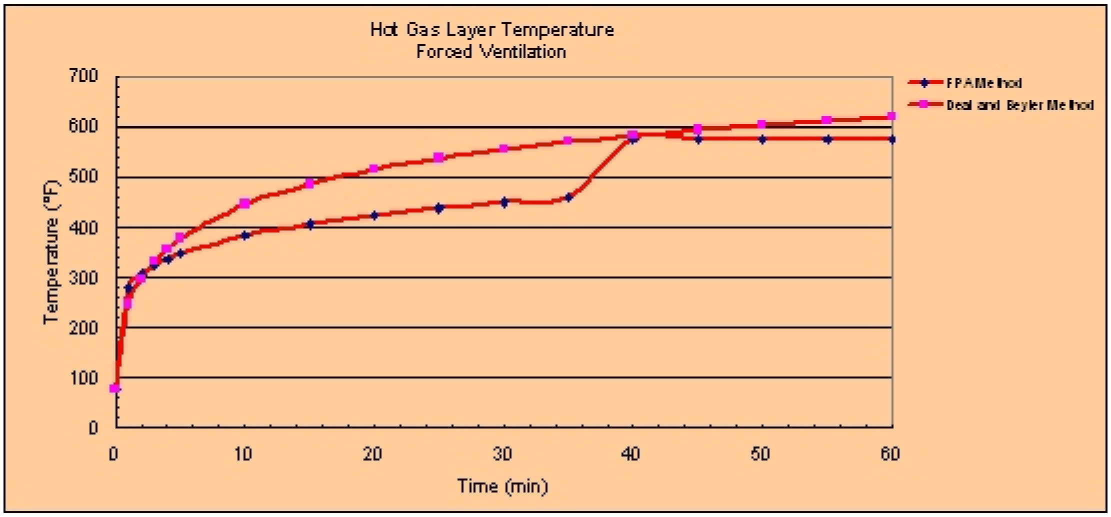
Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_p = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Results

Time After Ignition (t) (min)	(sec)	h_k (kW/m^2-K)	ΔT_g (K)	T_g (K)	T_g (°C)	T_g (°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.02	94.38	392.38	119.38	246.89
2	120	0.02	122.75	420.75	147.75	297.95
3	180	0.01	141.60	439.60	166.60	331.88
4	240	0.01	155.87	453.87	180.87	357.57
5	300	0.01	167.38	465.38	192.38	378.29
10	600	0.01	204.94	502.94	229.94	445.89
15	900	0.01	227.56	525.56	252.56	486.61
20	1200	0.00	243.59	541.59	268.59	515.46
25	1500	0.00	255.89	553.89	280.89	537.60
30	1800	0.00	265.80	563.80	290.80	555.43
35	2100	0.00	274.04	572.04	299.04	570.27
40	2400	0.00	281.07	579.07	306.07	582.93
45	2700	0.00	287.17	585.17	312.17	593.91
50	3000	0.00	292.54	590.54	317.54	603.58
55	3300	0.00	297.33	595.33	322.33	612.19
60	3600	0.00	301.63	599.63	326.63	619.93



Summary of Result:



NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-7

Problem Statement
Consider a compartment with an open vent that allows the air entrance at 3.60 m/s (700 ft/min). Assume that heptane from a tank spills on the concrete floor forming a 1.86 m^2 (20 ft^2) pool. The edge to edge distance from the pool fire to a certain target is about 9.0 m (30 ft). The target is 3 m (10 ft) above ground. Calculate the flame radiative heat flux at ground level using the solid flame model.

Solution

Purpose:

(1) Calculate the radiant heat flux from the pool fire to the target using the solid flame radiation model and considering the effect of the wind.

Assumptions:

(1) The pool is circular or nearly circular.
(2) The correlation for solid flame radiation model is suitable for heptane.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 05.2_Heat_Flux_Calculations_Wind.xls (select *Solid Flame 2*)

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

- Fuel Spill Area or Dike Area (A_{dike}) = 20 ft^2
- Distance between Fire and Target (L) = 30 ft
- Vertical Distance of Target from Ground Level (H_1 = H_{f1}) = 10 ft
- Wind Speed or Velocity (u_w) = 700 ft/min
- Select Fuel Type: select **Heptane** from the combo box

Note: When **Heptane** is selected, its thermal properties are automatically selected from the table and entered in the corresponding input cells.

Results

Radiation Model	Radiant Heat Flux* $\dot{q}''$ kW/m^2 (Btu/ft^2-sec)
Solid Flame	4.06 (0.36)

*spreadsheet calculations attached on next page

Spreadsheet Calculations
FDT[s]: 05.2_Heat_Flux_Calculations_Wind.xls (Solid Flame 2)

CHAPTER 5. ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL ABOVE GROUND LEVEL IN PRESENCE OF WIND (TILTED FLAME) SOLID FLAME RADIATION MODEL

Version 1805.0

The following calculations estimate the radiative heat flux from a pool fire to a target fuel in the presence of wind.
The purpose of this calculation is to estimate the radiation transmitted from a burning fuel array to a target fuel positioned some distance from the fire above ground level to determine if secondary ignitions are likely in presence of wind.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Parameter	Value	Unit		
Mass Burning Rate of Fuel (m'')	0.101	kg/m^2-sec		
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	44600	kJ/kg		
Empirical Constant ($k\beta$)	1.1	m^{-1}		
Fuel Area or Dike Area (A_{dike})	20.00	ft^2	1.86	m^2
Distance between Fire and Target (L)	30.00	ft	9.144	m
Vertical Distance of Target from Ground Level ($H_1 = H_T$)	10.00	ft	3.048	m
Wind Speed or Velocity (u_w)	700	ft/min	3.56	m/sec
Ambient Air Temperature (T_a)	77.00	°F	25.00	°C
			298.00	K
Gravitational Acceleration (g)	9.81	m/sec^2		
Ambient Air Density (ρ_a)	1.18	kg/m^3		

Calculate

Note: Air density will automatically correct with Ambient Air Temperature (T_a) input

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m'' (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-26.

Select Fuel Type

Heptane

Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL IN PRESENCE OF WIND

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-272.

SOLID FLAME RADIATION MODEL IN PRESENCE OF WIND

$q'' = EF_{1\to2}$

Where q'' = incident radiative heat flux on the target (kW/m²)
E = emissive power of the pool fire flame (kW/m²)
$F_{1\to2}$ = view factor between target and the flame in presence of wind

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4 A_{dike}/\pi)}$

Where A_{dike} = surface area of pool fire (m²)
D = pool fire diameter (m)

$D =$ 1.64 m

Pool Fire Radius Calculation

$r =$ D/2

$r =$ 0.77 m

Flame Emissive Power Calculation

$E = 58 (10^{-0.00823 D})$

Where E = emissive power of the pool fire flame (kW/m²)
D = diameter of the pool fire (m)

$E =$ 56.33 (kW/m²)

View Factor Calculation in Presence of Wind

$\pi F_{1\to2,V1} =$ $(a_1 \cos\theta/(b - a_1 \sin\theta)) (a_1^2 + (b+1)^2 - 2b(1 + a_1 \sin\theta))/(A_1B_1)^{0.5} (\tan^{-1} (A_1/B_1)^{0.5} ((b-1)/(b+1))^{0.5} + \cos\theta/(C)^{0.5} ((\tan^{-1}(a_1b - (b^2-1)\sin\theta)/((b^2-1)(C)^{0.5} + \tan^{-1}(b^2-1)\sin\theta/(b^2-1)^{0.5}$

$\pi F_{1\to2,V2} =$ $(a_2 \cos\theta/(b - a_2 \sin\theta)) (a_2^2 + (b+1)^2 - 2b(1 + a_2 \sin\theta))/(A_2B_2)^{0.5} (\tan^{-1} (A_2/B_2)^{0.5} ((b-1)/(b+1))^{0.5} + \cos\theta/(C)^{0.5} ((\tan^{-1}(a_2b - (b^2-1)\sin\theta)/((b^2-1)(C)^{0.5} + \tan^{-1}(b^2-1)\sin\theta/(b^2-1)^{0.5}$

$A_1 =$ $a_1^2 + (b+1)^2 - 2a_1 (b+1) \sin\theta$

$A_2 =$ $a_2^2 + (b+1)^2 - 2a_2 (b+1) \sin\theta$

$B_1 =$ $a_1^2 + (b-1)^2 - 2a_1 (b-1) \sin\theta$

$B_2 =$ $a_2^2 + (b-1)^2 - 2a_2 (b-1) \sin\theta$

$C =$ $1 + (b^2 - 1) \cos^2\theta$

$a_1 =$ $2H_{f1}/r = 2H_t/r$

$a_2 =$ $2H_{f2}/r = 2(H_f - H_t)/r$

$b =$ R/r

$F_{1\to2,V} = F_{1\to2,V1} + F_{1\to2,V2}$

Where $F_{1\to2,V}$ = total vertical view factor in presence of wind
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
r = pool fire radius (m)
θ = flame tilt or angle of deflection (radians)

Distance from Center of the Pool Fire to Edge of the Target Calculation

$R = L + r =$ 9.91 m

Where
- R = distance from center of the pool fire to edge of the target (m)
- L = Distance between Fire and Target
- r = pool fire radius (m)

Heat Release Rate Calculation

$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_{dike}$

Where
- Q = pool fire heat release rate (kW)
- m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
- ΔH_c = effective heat of combustion of fuel (kJ/kg)
- A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
- $k\beta$ = empirical constant (m^{-1})
- D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

$Q =$ 6828.38 kW

Pool Fire Flame Height Calculation

$H_f = 55\, D\, (m''/\rho_a \sqrt{(g\, D)})^{0.67} (u^*)^{-0.21}$

Where
- H_f = flem height (m)
- m'' = mass burning rate of fuel (kg/m^2-sec)
- D = pool fire diameter (m)
- ρ_a = ambient air density (kg/m^3)
- g = gravitational acceleration (m/sec^2)
- u^* = nondimensional wind velocity

Nondimensional Wind Velocity Calculation

$u^* = u_w/(g\, m''\, D/\rho_a)^{1/3}$

Where
- u^* = nondimensional wind velocity
- u_w = wind velocity (m/sec)
- g = gravitational acceleration (m/sec^2)
- m'' = mass burning rate of fuel (kg/m^2-sec)
- D = pool fire diameter (m)
- ρ_a = ambient air density (kg/m^3)

$u^* = u_w/(g\, m''\, D/\rho_a)^{1/3}$

$u^* =$ 3.270

$H_f = 55\, D\, (m''/\rho_a (\sqrt{g\, D}))^{0.67} (u^*)^{-0.21}$

$H_f =$ 5.11 m

Flame Tilt or Angle of Deflection Calculation

COS θ = 1 for u* ≤ 1

COS θ = 1 / (u*) for u* ≥ 1

Since u* ≥ 1

θ = ACOS(1/(u*)^0.5) =	0.986 Rad		56.42 degree
	0.986 Rad		56.42 degree
	0 Rad		0.00 degree

$A_1 = a_1^2 + (b+1)^2 - 2a_1 (b+1) \sin\theta =$	72.30
$A_2 = a_2^2 + (b+1)^2 - 2a_2 (b+1) \sin\theta =$	97.71
$B_1 = a_1^2 + (b-1)^2 - 2a_1 (b-1) \sin\theta =$	47.16
$B_2 = a_2^2 + (b-1)^2 - 2a_2 (b-1) \sin\theta =$	68.98
$C = 1 + (b^2 - 1) \cos^2\theta =$	61.61
$a_1 = 2H_{f1}/r = 2H_1/r =$	7.93
$a_2 = 2H_{f2}/r = 2(H - H_1)/r =$	6.36
$b = R/r =$	12.89

$F_{1\to2,V1}$	0.04306
$F_{1\to2,V2}$	0.02899
$F_{1\to2} = F_{1\to2,V1} + F_{1\to2,V2} =$	0.07204

F_{V1}	F_{V2}	F_{V3}	F_{V4}	F_{V5}	F_{V6}	F_{V7}	$F_{1\to2,V1}$
0.697	1.023	0.853	0.077	-0.367	0.980	0.521	0.048061

F_{V1}	F_{V2}	F_{V3}	F_{V4}	F_{V5}	F_{V6}	F_{V7}	$F_{1\to2,V2}$
0.351	1.022	0.852	0.077	-0.367	0.980	0.262	0.028991

Radiative Heat Flux Calculation in Presence of Wind

$\dot{q}'' = EF_{1\to2}$

q" =	4.06 kW/m²	0.36 Btu/ft²-sec		Answer

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-8

Problem Statement
Consider a compartment that has been insulated with 1.27 cm (½ in) of gypsum board, wallboard (S142M). If a pool fire scenario arises with a heat flux of 75 kW/m^2, what will be the ignition time of the gypsum board?

Solution

Purpose:

(1) Calculate the ignition time of Gypsum Board, Wallboard (S142M) for the given conditions.

Assumptions:

(1) The material is infinitely thick.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 06_Ignition_Time_Calculations.xls (select *Ignition_Time _Calculations1*)

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

-Exposure or External Radiative Heat Flux to Target Fuel $(\dot{q}_e'')$ = 75 kW/m^2

-Select Material: select **Gypsum Board, Wallboard (S142M)** from the combo box

Note: When **Gypsum Board, Wallboard (S142M)** is selected, its thermal properties are automatically selected from the table and entered in the corresponding input cells.

Results

Calculation Method	Ignition Time* t_{ig} (min)
Mikkola and Wichmann	0.34 min
Quintiere and Harkleroad	0.20 min
Janssens	0.86 min

*spreadsheet calculations attached on next page

Spreadsheet Calculations

FDT[s]: 06_Ignition_Time_Calculations.xls (Ignition_Time _Calculations1)

CHAPTER 6. ESTIMATING THE IGNITION TIME OF A TARGET FUEL EXPOSED TO A CONSTANT RADIATIVE HEAT FLUX

Version 1805.0

The following calculations estimate time to ignition for flame spread of solid fuels exposed to a constant external radiative heat flux.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters.
This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

MATERIAL FLAME SPREAD PROPERTIES

Material Ignition Temperature (T_{ig})	412.00	°C
Material Thermal Inertia (kρc)	0.57	$(kW/m^2\text{-}K)^2\text{-sec}$
Material Critical Heat Flux for Ignition ($q''_{critical}$)	18.00	kW/m^2
Flame Spread Parameter b	0.07	$(s)^{-1/2}$
Exposure or External Radiative Heat Flux (q''_e)	75.00	kW/m^2
Ambient Air Temperature (T_a)	77.00	°F
Heat Transfer Coefficient at Ignition (h_{ig})	0.0275	$kW/m^2\text{-}K$
	Calculate	

FLAME SPREAD PROPERTIES OF COMMON MATERIALS

Materials	Ignition Temperature T_{ig} (°C)	Thermal Inertia kρc $(kW/m^2\text{-}K)^2\text{-sec}$	Critical Heat Flux for Ignition $q''_{critical}$ (kW/m^2)	Flame Spread Parameter b $(s)^{-1/2}$
PMMA Polycast (1.59mm)	278	0.73	9	0.04
Hardboard (6.35mm)	298	1.87	10	0.03
Carpet (Acrylic)	300	0.42	10	0.06
Fiber Insulation Board	355	0.46	14	0.07
Hardboard (3.175mm)	365	0.88	14	0.05
PMMA Type G (1.27 cm)	378	1.02	15	0.05
Asphalt Shingle	378	0.7	15	0.06
Douglas Fire Particle Board (1.27 cm)	382	0.94	16	0.05
Plywood Plain (1.27 cm)	390	0.54	16	0.07
Plywood Plain (0.635 cm)	390	0.46	16	0.07
Foam Flexible (2.54cm)	390	0.32	16	0.09
GRP (2.24 mm)	390	0.32	16	0.09
Hardboard (Gloss Paint) (3.4 mm)	400	1.22	17	0.05
Hardboard Nitrocellulose Paint)	400	0.79	17	0.06
GRP (1.14 mm)	400	0.72	17	0.06
Particle Board (1.27 cm Stock)	412	0.93	18	0.05
Carpet (Nylon/Wool Blend)	412	0.68	18	0.06
Gypsum Board, Wallboard (S142M)	412	0.57	18	0.07
Carpet # 2 (Wool Untreated)	435	0.25	20	0.11
Foam Rigid (2.54 cm)	435	0.03	20	0.32
Fiberglass Shingle	445	0.5	21	0.08
Polyisoyanurate (5.08cm)	445	0.02	21	0.36
Carpet # 2 (Wool Treated)	455	0.24	22	0.12
Carpet # 1 (Wool, Stock)	465	0.11	23	0.18
Aircraft Panel Expoxy Fiberite	505	0.24	28	0.13
Gypsum Board FR (1.27 cm)	510	0.4	28	0.1
Polycarbonate (1.52 mm)	528	1.16	30	0.06
Gypsum Board (Common) (1.27 mm)	565	0.45	35	0.11
Plywood FR (1.27 cm)	620	0.76	44	0.1
Polystyrene (5.08cm)	630	0.38	46	0.14
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 74.

Select Material
Gypsum Board, Wallbo
Scroll to desired m
Click on selection

METHOD OF MIKKOLA AND WICHMAN
THERMALLY THICK MATERIALS

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 7.

$t_{ig} = \pi/4\ k\rho c\ (T_{ig} - T_a)^2 / (q_e'' - q_{critical}'')^2$

Where

t_{ig} = material ignition time (sec)
$k\rho c$ = material thermal inertia $(kW/m^2\text{-}K)^2\text{-sec}$
T_{ig} = material ignition temperature (°C)
T_a = ambient air temperature (°C)
q_e'' = exposure or external radiative heat flux (kW/m^2)
$q''_{critical}$ = material critical heat flux for ignition (kW/m^2)

$t_{ig} = \pi/4\ k\rho c\ (T_{ig} - T_a)^2 / (q_e'' - q_{critical}'')^2$

t_{ig} =	20.64 sec	0.34 minute	Answer

METHOD OF QUINTIERE AND HARKLEROAD
THERMALLY THICK MATERIALS

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 12.

$t_{ig} = (q_{critical}'' / b\ q_e'')^2$

Where

t_{ig} = material ignition time (sec)
$q''_{critical}$ = material critical heat flux for ignition (kW/m^2)
b = flame spread parameter $(s)^{-1/2}$
q_e'' = exposure or external radiative heat flux (kW/m^2)

$t_{ig} = (q_{critical}'' / b\ q_e'')^2$

t_{ig} =	11.76 sec	0.20 minute	Answer

METHOD OF JANSSENS
THERMALLY THICK MATERIALS

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 15.

$t_{ig} = 0.563\ (k\rho c / h_{ig}^2)\ ((q_e'' / q_{critical}'') - 1)^{-1.83}$

Where

t_{ig} = material ignition time (sec)
$k\rho c$ = material thermal inertia $(kW/m^2\text{-}K)^2\text{-sec}$
h_{ig} = heat transfer coefficient at ignition $(kW/m^2\text{-}K)$
q_e'' = exposure or external radiative heat flux (kW/m^2)
$q''_{critical}$ = material critical heat flux for ignition (kW/m^2)

$t_{ig} = 0.563\ (k\rho c / h_{ig}^2)\ ((q_e'' / q_{critical}'') - 1)^{-1.83}$

t_{ig} =	51.48 sec	0.86 minute	Answer

Summary of Result

Calculation Method	Time to Ignition (minute)
MIKKOLA AND WICHMAN	0.34
QUINTIERE AND HARKLEROAD	0.20
JANSSENS	0.86

NOTE

The above calculations are based on principles developed in the SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," January 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-9

Problem Statement
A 75.0-liter (20-gallon) trash bag exposure fire source is located 3.0 m (10.0 ft) beneath a horizontal cable tray. Assume that the trash fire ignites an area of approximately 1.0 m^2 (11.0 ft^2) of the cable tray, and the cables in the tray are IEEE-383-qualified XPE/FRXPE cables. Compute the full-scale HRR, $(\dot{Q}_{fs})$ of the XPE/FRXPE cable insulation. The bench scale HRR $(\dot{Q}''_{bs})$ of the XPE/FRXPE is 475 kW/m^2.

Solution

Purpose:

(1) Calculate the full-scale HRR of the XPE/FRXPE for the given scenario.

Assumptions:

(1) Lee's correlation is valid for this fire scenario.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 07_Cable_HRR_Calculations.xls

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

-Exposure Cable Tray Burning Area (A_f) = 11 ft^2

-Select Cable Typel: select **XPE/FRXPE** from the combo box

Note: When **XPE/FRXPE** is selected, its thermal properties are automatically selected from the table and entered in the corresponding input cells.

Results

Cable Insulation	Full Scale HRR $\dot{Q}_{fs}$ kW (Btu/sec)
XPE/FRXPE	218 (207)

*spreadsheet calculations attached on next page.

Spreadsheet Calculations
FDT[s]: 07_Cable_HRR_Calculations.xls

CHAPTER 7. ESTIMATING THE FULL-SCALE HEAT RELEASE RATE OF A CABLE TRAY FIRE

Version 1805.0
The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Cable Bench-Scale HRR ($\dot{Q}''_{bs}$)	475	kW/m²	
Exposed Floor Area (Length x Width) of Burning Cable Tray (A)	11.00	ft²	1.022 m²

Calculate

HEAT RELEASE RATE DATA FOR CABLE TRAY FIRE

BENCH-SCALE HRR OF CABLE TRAY FIRE

Cable Type	Bench-Scale HRR per Unit Floor Area (L x W) $\dot{Q}''_{bs}$ (kW/m²)
XPE	1071
PE/PVC	589
XPE/FRXPE	475
PE/PVC	395
PE/PVC	359
XPE/Neoprene	354
PE, PP/Cl.S.PE	345
PE/PVC	312
XPE/Neoprene	302
PE, PP/Cl.S.PE	299
PE, PP/Cl.S.PE	271
FRXPE/Cl.S.PE	258
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218
XPE/Cl.S.PE	204
Silicone, glass braid, asbestos	182
XPE/XPE	178
PE, PP/Cl.S.PE	177
Silicone, glass braid	128
Teflon	98
User Specified Value	Enter Value

Select Cable Type
XPE/FRXPE
Scroll to desired cable type then Click on selection

Reference: "*Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters,*" EPRI Research Project 1165-1, NP-1200, Part 1.

ESTIMATING FULL-SCALE CABLE TRAY HEAT RELEASE RATE

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition 2002, Page 3-16.*

$Q_{fs} = 0.45\ Q_{bs}\ A$

Where Q_{fs} = cable tray full-scale HRR (kW)

Q_{bs} = cable tray bench-scale HRR (kW)

A = exposed floor area (length x width) of burning cable tray (m^2)

Heat Release Rate Calculation

$Q_{fs} = 0.45\ Q_{bs}\ A$

Q_{fs} =	218.44 kW	207.04 Btu/sec	Answer

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.

Calculations are based on certain assumptions and has inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.

Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-10

Problem Statement

Estimate the maximum plume temperature ($T_{p(centerline)}$) at the ceiling of a 6.0-m (20.0-ft) high compartment above a 1,420 kW fire involving a 1½ ft high stack of wood pallets in a 0.92 m^2 (10.0 ft^2) pallet area. Assume that the ambient temperature is 25 °C (77 °F).

Solution

Purpose:

(1) Estimate the maximum plume temperature for the given fire scenario.

Assumptions:

(1) All heat is released at a point.

(2) Buoyant forces are more significant than momentum forces.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 09_Plume_Temperature_Calculations.xls

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

-Heat Release Rate $(\dot{Q})$ = 1,420 kW

-Distance from the Top of the Fuel to the Ceiling (z) = 20 ft

-Area of Combustible Fuel = 10 ft^2

Results

Heat Release Rate $\dot{Q}$ (kW)	Plume Centerline Temperature $T_{p(centerline)}$ °C (°F)
1,420	164 (328)

*spreadsheet calculations attached on next page.

Spreadsheet Calculations

FDT^s: 09_Plume_Temperature_Calculations.xls

CHAPTER 9. ESTIMATING CENTERLINE TEMPERATURE OF A BUOYANT FIRE PLUME

Version 1805.0

The following calculations estimate the centerline plume temperature in a compartment fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Heat Release Rate of the Fire (Q)	1420.00	kW	
Elevation Above the Fire Source (z)	20.00	ft	6.10 m
Area of Combustible Fuel (A_c)	10.00	ft^2	0.93 m^2
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
	Calculate		298.00 K

AMBIENT CONDITIONS

Specific Heat of Air (c_p)	1.00	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3
Acceleration of Gravity (g)	9.81	m/sec^2
Convective Heat Release Fraction (χ_c)	0.70	

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

ESTIMATING PLUME CENTERLINE TEMPERATURE

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 2-6.

$T_{p(centerline)} - T_a = 9.1\,(T_a/g\,c_p^2\,\rho_a^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$

Where $T_{p(centerline)}$ = plume centerline temperature (°C)
Q_c = convective portion of the heat release rate (kW)
T_a = ambient air temperature (K)
g = acceleration of gravity (m/sec^2)
c_p = specific heat of air (kJ/kg-K)
ρ_a = ambient air density (kg/m^3)
z = distance from the top of the fuel package to the ceiling (m)
z_0 = hypothetical virtual origin of the fire (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c\,Q$

Where Q_c = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χ_c = convective heat release fraction

Q_c = 994 kW

Fire Diameter Calculation

$A_c = \pi D^2/4$

Where A_c = area of combustible fuel (m^2)
D = fire diameter (m)

$D = \sqrt{(4\,A_c/\pi)}$

D = 1.09 m

Hypothetical Virtual Origin Calculation

$z_o/D = -1.02 + 0.083\,(Q^{2/5})/D$

Where z_o = virtual origin of the fire (m)

Q = heat release rate of fire (kW)

D = fire diameter (m)

z_o/D = 0.37

z_o = **0.40** m

Centerline Plume Temperature Calculation

$T_{p(centerline)} - T_a = 9.1\,(T_a/g\,c_p^2\,\rho_a^2)^{1/3}\,Q_c^{2/3}\,(z - z_o)^{-5/3}$

$T_{p(centerline)} - T_a$ = **139.22**

$T_{p(centerline)}$ = **437.22** K

$T_{p(centerline)}$ =	**164.22** °C	**327.59** °F	**Answer**

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.

Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

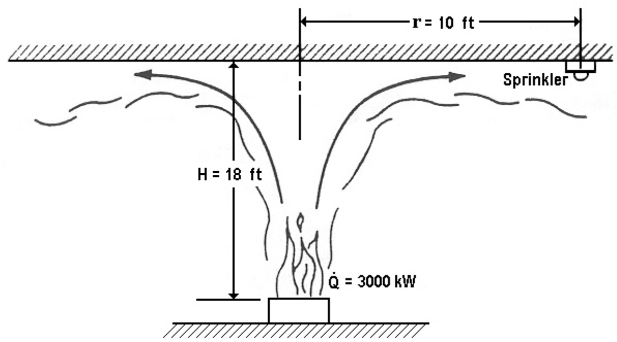
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.

Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-11

Problem Statement

A fire with $\dot{Q}$ = 3,000 kW occurs in a makeup pump room protected with sprinkler protection. The sprinklers are rated at 74 °C (165 °F) [standard response bulb with RTI 235 $(m\text{-}sec)^{1/2}$ and located 3.0 m (10.0 ft) from the center of the fire source. The height from the top of the fuel package to the ceiling is 5.5 m (18.0 ft). Determine whether the sprinklers would activate and, if so, how long it would take for them to activate.



Problem 11: Fire Scenario with Sprinkler Protection

Solution

Purpose:

(1) Determine if the sprinklers will be activated for the given fire scenario.
(2) If the sprinkles are activated, determine how long it takes for the activation.

Assumptions:

(1) The fire is located away from walls and corners.
(2) The fire is steady state
(3) The ceiling is unconfined, unobstructed, and flat.
(4) Only convective heat transfer from the hot fire gases is considered.
(5) There is heavily obstructed overhead.
(6) The ambient temperature before the fire ignition is 70 °F

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 10_Detector_Activation_Time.xls (select *Sprinkler*)

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

- Heat Release Rate of the Fire $(\dot{Q})$ = 3,000 kW
- Distance from the Top of the Fuel Package to the Ceiling (H) = 18 ft
- Radial Distance from the Plume Centerline to the Sprinkler (r) = 10 ft
- Ambient Air Temperature (T_a) = 70 °F
- Select Type of Sprinkler = select **Standard response bulb** from the combo box
- Select Sprinkler Classification = select **Ordinary** from the combo box

Note: Ordinary classification is selected because the rated value for the sprinklers in this problem (165 °F) is within the range of temperature ratings for ordinary sprinklers (135 °F–170 °F).

Note: When the **sprinkler type** and **classification** are selected, their respective values are automatically selected from the table and entered in the corresponding input cells.

Results

Sprinkler Type	Sprinkler Activation Time* $t_{activation}$ (min.)
Standard response bulb	2.47

*spreadsheet calculations attached on next page.

Spreadsheet Calculations
FDT^s: 10_Detector_Activation_Time.xls (Sprinkler)

CHAPTER 10. ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.0

The following calculations estimate sprinkler activation time.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Sprinkler Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	3000.00	kW	
Sprinkler Response Time Index (RTI)	235	(m-sec)$^{1/2}$	
Activation Temperature of the Sprinkler ($T_{activation}$)	165	°F	73.89 °C
Height of Ceiling above Top of Fuel (H)	18.00	ft	5.49 m
Radial Distance to the Detector (r) **never more than 0.707 or 1/2v2 of the listed spacing**	10.00	ft	3.05 m
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K
Convective Heat Release Rate Fraction (χ_c)	0.70		

r/H = 0.56

Calculate

GENERIC SPRINKLER RESPONSE TIME INDEX (RTI)*

Common Sprinkler Type	Generic Response Time Index (RTI) (m-sec)$^{1/2}$
Standard response bulb	235
Standard response link	130
Quick response bulb	42
Quick response link	34
User Specified Value	Enter Value

Select Type of Sprinkler
Standard response bulb
Scroll to desired sprinkler type then Click on selection

Reference: *Madrzykowski, D., "Evaluation of Sprinkler Activation Prediction Methods" ASIAFLAM95, International Conference on Fire Science and Engineering, 1st Proceeding, March 15-16, 1995, Kowloon, Hong Kong, pp. 211-218.*
*Note: The actual RTI should be used when the value is available.

GENERIC SPRINKLER TEMPERATURE RATING ($T_{activation}$)*

Temperature Classification	Range of Temperature Ratings (°F)	Generic Temperature Ratings (°F)
Ordinary	135 to 170	165
Intermediate	175 to 225	212
High	250 to 300	275
Extra high	325 to 375	350
Very extra high	400 to 475	450
Ultra high	500 to 575	550
Ultra high	650	550
User Specified Value	–	Enter Value

Select Sprinkler Classification
Ordinary
Scroll to desired sprinkler class then Click on selection

Reference: *Automatic Sprinkler Systems Handbook, 6th Edition, National Fire Protection Association, Quincy, Massachusetts, 1994, Page 67.*
*Note: The actual temperature rating should be used when the value is available.

ESTIMATING SPRINKLER RESPONSE TIME

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-140.*

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

Where $t_{activation}$ = sprinkler activation response time (sec)

RTI = sprinkler response time index $(m\text{-}sec)^{1/2}$

u_{jet} = ceiling jet velocity (m/sec)

T_{jet} = ceiling jet temperature (°C)

T_a = ambient air temperature (°C)

$T_{activation}$ = activation temperature of sprinkler (°C)

Ceiling Jet Temperature Calculation

$T_{jet} - T_a = 16.9\ (Q_c)^{2/3}/H^{5/3}$ for r/H = 0.18

$T_{jet} - T_a = 5.38\ (Q_c/r)^{2/3}/H$ for r/H > 0.18

Where T_{jet} = ceiling jet temperature (°C)

T_a = ambient air temperature (°C)

Q_c = convective portion of the heat release rate (kW)

H = height of ceiling above top of fuel (m)

r = radial distance from the plume centerline to the sprinkler (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c\ Q$

Where Q_c = convective portion of the heat release rate (kW)

Q = heat release rate of the fire (kW)

χ_c = convective heat release rate fraction

Q_c = **2100** kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = **0.56** r/H > 0.15

$T_{jet} - T_a$ = (5.38 (Qc/r)^2/3)/H

$T_{jet} - T_a$ = 76.49

T_{jet}= **101.49** (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\ (Q/H)^{1/3}$ for r/H = 0.15

$u_{jet} = (0.195\ Q^{1/3}\ H^{1/2})/r^{5/6}$ for r/H > 0.15

Where u_{jet} = ceiling jet velocity (m/sec)

Q = heat release rate of the fire (kW)

H = height of ceiling above top of fuel (m)

r = radial distance from the plume centerline to the sprinkler (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.56 r/H > 0.15

u_{jet} = $(0.195\ Q^{1/3}\ H^{1/2})/r^{5/6}$

u_{jet} = 2.602 m/sec

Sprinkler Activation Time Calculation

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation}$ = 148.47 sec

The sprinkler will respond in approximately	2.47 minutes	**Answer**

NOTE: If $t_{activation}$ = "NUM" Sprinkler does not activate

NOTE

The above calculations are based on principles developed in the NFPA Fire Protection Handbook 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

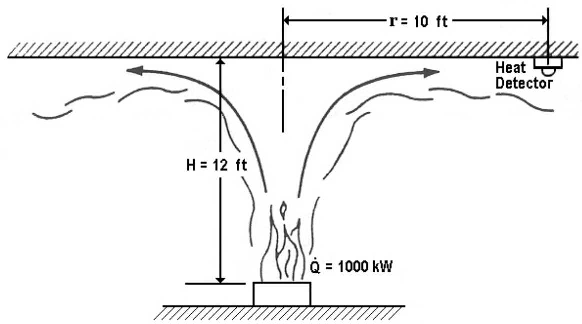
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.

Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-12

Problem Statement

A trash fire with an HRR ($\dot{Q}$) of 1,000 kW occurs in a battery room protected with fixed temperature heat detectors with an RTI of 306 $(m\text{-}sec)^{1/2}$. The distance from the top of the fuel package to the ceiling 3.7 m (12 ft) and the radial distance from the plume center to the heat detector location is 10 ft. Calculate the activation time ($t_{activation}$) for the detectors, using listed spacing of 4.6 m (15.0 ft). Assume that the detector activation temperature of 54 °C (128 °F), and the ambient temperature is 20 °C (68 °F).



Problem 12: Fire Scenario with Heat Detectors

Solution

Purpose:

(1) Determine the response time of the fixed-temperature heat detectors for the given fire scenario.

Assumptions:

(1) The fire is located away from walls and corners.
(2) The fire is steady state.
(3) The ceiling is unconfined, unobstructed, and flat.
(4) Only convective heat transfer from the hot fire gases is considered.
(5) There is heavily obstructed overhead.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 10_Detector_Activation_Time.xls (select *FTHDetectors*)

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

- Heat Release Rate of the Fire $(\dot{Q})$ = 1,000 kW
- Radial Distance to the Detector (r) = 10 ft
- Distance from the Top of the Fuel Package to the Ceiling (H) = 12 ft
- Ambient Air Temperature (T_a) = 68 °F
- Select the option button (⊙) for FTH detectors with $T_{activation}$ = 128 °F
- Select Detector Spacing: select **15** from the combo box

Note: When $\mathbf{T_{activation}}$ and **Detector Spacing** are selected, their respective values are automatically selected from the table and entered in the corresponding input cells.

Results

Detector Type	Heat Detector Activation Time $t_{activation}$ (min.)
Fixed Temperature	3.03

*spreadsheet calculations attached on next page.

Spreadsheet Calculations

FDT^s: 10_Detector_Activation_Time.xls (FTHDetectors)

CHAPTER 12. ESTIMATING HEAT DETECTOR RESPONSE TIME

Version 1805.0

The following calculations estimate fixed temperature heat detector activation time.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Detector Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Parameter	Value	Unit	Converted
Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW	
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	10.00	ft	3.05 m
Activation Temperature of the Fixed Temperature Heat Detector ($T_{activation}$)	128	°F	53.33 °C
Detector Response Time Index (RTI)	306.00	(m-sec)$^{1/2}$	
Height of Ceiling above Top of Fuel (H)	12.00	ft	3.66 m
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K
Convective Heat Release Fraction (χ_c)	0.70		

r/H = 0.83

Calculate

INPUT DATA FOR ESTIMATING HEAT DETECTOR RESPONSE TIME

Activation Temperature $T_{activation}$

◉ T= 128 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	490	128
15	306	128
20	325	128
25	152	128
30	116	128
40	87	128
50	72	128
70	44	128
User Specified Value	Enter Value	Enter Value

Select Detector Spacing: 15
Scroll to desired spacing then Click on selection

○ T= 135 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	404	135
15	233	135
20	165	135
25	123	135
30	98	135
40	70	135
50	54	135
70	20	135
User Specified Value	Enter Value	Enter Value

Select Detector Spacing
Scroll to desired spacing then Click on selection

○ T= 145 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	321	145
15	191	145
20	129	145
25	96	145
30	75	145
40	50	145
50	37	145
70	11	145
User Specified Value	Enter Value	Enter Value

Select Detector Spacing
Scroll to desired spacing then Click on selection

T= 160 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	239	160
15	135	160
20	86	160
25	59	160
30	44	160
40	22	160
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 170 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	196	170
15	109	170
20	64	170
25	39	170
30	27	170
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 196 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	119	196
15	55	196
20	21	196
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then

Click on selection

Reference: *NFPA Standard 72, National Fire Alarm Code, Appendix B, Table B-3.2.5.1, 1999, Edition.*

ESTIMATING FIXED TEMPERATURE HEAT DETECTOR RESPONSE TIME

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-140.*

$t_{activation} = (RTI/(\sqrt{u_{jet}}))(\ln(T_{jet} - T_a)/(T_{jet} - T_{activation}))$

Where $t_{activation}$ = detector activation time (sec)

RTI = detector response time index $(m\text{-}sec)^{1/2}$

u_{jet} = ceiling jet velocity (m/sec)

T_{jet} = ceiling jet temperature (°C)

T_a = ambient air temperature (°C)

$T_{activation}$ = activation temperature of detector (°C)

Ceiling Jet Temperature Calculation

$T_{jet} - T_a = 16.9\,(Q_c)^{2/3}/H^{5/3}$ for r/H = 0.18

$T_{jet} - T_a = 5.38\,(Q_c/r)^{2/3}/H$ for r/H > 0.18

Where T_{jet} = ceiling jet temperature (°C)

T_a = ambient air temperature (°C)

Q_c = convective portion of the heat release rate (kW)

H = height of ceiling above top of fuel (m)

r = radial distance from the plume centerline to the detector (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c\, Q$

Where Q_c = convective heat release rate (kW)

Q = heat release rate of the fire (kW)

χ_c = convective heat release fraction

Q_c = 700 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.83 r/H > 0.15

>0.15	55.16	<0.15	153.45

$T_{jet} - T_a$ = 5.38 ((Qc/r)^2/3)/H

$T_{jet} - T_a$ = 55.16

T_{jet} = 80.16 (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\,(Q/H)^{1/3}$ for r/H = 0.15

$u_{jet} = (0.195\,Q^{1/3}\,H^{1/2})/r^{5/6}$ for r/H > 0.15

Where u_{jet} = ceiling jet velocity (m/sec)

Q = heat release rate of the fire (kW)

H = height of ceiling above top of fuel (m)

r = radial distance from the plume centerline to the detector (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.83 r/H > 0.15

u_{jet} = (0.195 Q^1/3 H^1/2)/r^(5/6)

u_{jet} = 1.473 m/sec

Detector Activation Time Calculation

$t_{activation}$ = (RTI/(√u_{jet})) (ln (T_{jet} - T_a)/(T_{jet} - $T_{activation}$))

$t_{activation}$ = 181.72 sec

The detector will respond in approximately	3.03 minutes	Answer

NOTE: If $t_{activation}$ = "NUM" Detector does not activate

NOTE

The above calculations are based on principles developed in the NFPA Fire Protection Handbook 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations.
The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-13

Problem Statement

Calculate the HRR necessary for flashover $(\dot{Q}_{FO})$ and the post-flashover temperature in a long access corridor that is 30.5 m long x 5.5 m wide x 3.0 m high (100.0 ft long x 18.0 ft wide x 10.0 ft high), with an opening that is 0.91 m (3.0 ft) wide x 2.5 m (8.0 ft) high. Assume that corridor boundary material is 15 cm (6 in) thick concrete.

Solution

Purpose:

(1) Determine the HRR necessary for flashover and the post-flashover temperature for the given compartment

Assumptions:

(1) Natural Ventilation.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 13_Compartment_Flashover_Calculations.xls

select *Flashover-HRR* to calculate the HRR for flashover

select *Post_Flashover_Temperature* to calculate the post-flashover temperature

FDT^s Input Parameters:

Enter the following parameters in both spreadsheets (values only):

- Compartment Width (w_c) = 18 ft
- Compartment Length (l_c) = 100 ft
- Compartment Height (h_c) = 10 ft
- Vent Width (w_v) = 3 ft
- Vent Height (h_v) = 8 ft
- Interior Lining Thickness (δ) = 6 in (*Flashover-HRR* only)
- Select Material: select **Concrete** from the combo box (*Flashover-HRR only*)

Note: When **Concrete** is selected in *Flashover-HRR spreadsheet*, its respective properties are automatically selected from the table and entered in the corresponding input yellow cells.

Results

Post-Flashover Temperature $T_{PFO(max)}$ °C (°F)	Flashover HRR $\dot{Q}_{FO}$ kW (Btu/sec)		
Method of Law	Method of MQH	Method of Babrauskas	Method of Thomas
478 (892)	2,739 (2,596)	2,611 (2,475)	5,618 (5,325)

*spreadsheet calculations attached on next page

Spreadsheet Calculations

FDT[s]: 13_Compartment_Flashover_Calculations.xls (Post_Flashover_Temperature)

CHAPTER 13. PREDICTING COMPARTMENT POST-FLASHOVER TEMPERATURE

Version 1805.0

The following calculations estimate the compartment post-flashover temperature.
Parameters in YELLOW CELLS are Entered by the User.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	18.00	ft	5.4864 m
Compartment Length (l_c)	100.00	ft	30.48 m
Compartment Height (h_c)	10.00	ft	3.048 m
Vent Width (w_v)	3.00	ft	0.914 m
Vent Height (h_v)	8.00	ft	2.438 m

Calculate

PREDICTING COMPARTMENT POST-FLASHOVER TEMPERATURE
METHOD OF MARGARET LAW

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-183.

$T_{PFO\,(max)} = 6000\,(1 - e^{-0.1\Omega}) / (\sqrt{\Omega})$

Where $T_{PFO\,(max)}$ = maximum compartment post-flashover temperature (°C)
Ω = ventilation factor

Where $\Omega = (A_T - A_v) / A_v (\sqrt{h_v})$
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Area of Ventilation Opening Calculation
$A_v = (w_v)(h_v)$
Where A_v = area of ventilation opening (m^2)
w_v = vent width (m)
h_v = vent height (m)
A_v = 2.23 m^2

Area of Compartment Enclosing Surface Boundaries
$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)] - A_v$
Where A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)
A_v = area of ventilation opening (m^2)
A_T = 551.47 m^2

Ventilation Factor Calculation
$\Omega = (A_T - A_v) / A_v (\sqrt{h_v})$
Where Ω = ventilation factor
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = vent height (m)
Ω = 157.75 $m^{-1/2}$

Compartment Post-Flashover Temperature Calculation
$T_{PFO\,(max)} = 6000\,(1 - e^{-0.1\Omega}) / (\sqrt{\Omega})$

$T_{PFO\,(max)}$ = 477.71 °C 891.88 °F Answer

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

CHAPTER 13. PREDICTING COMPARTMENT FLASHOVER HEAT RELEASE RATE

Version 1805.0

The following calculations estimate the minimum heat release rate required to compartment flashover.

Parameters in YELLOW CELLS are Entered by the User.

Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	100.00	ft	30.48 m
Compartment Length (l_c)	18.00	ft	5.49 m
Compartment Height (h_c)	10.00	ft	3.048 m
Vent Width (w_v)	3.00	ft	0.914 m
Vent Height (h_v)	8.00	ft	2.44 m
Interior Lining Thickness (δ)	6.00	in	0.1524 m
Interior Lining Thermal Conductivity (k)	0.0016	kW/m-K	

Calculate

THERMAL PROPERTIES DATA

Material	Thermal Conductivity k (kW/m-K)
Aluminum (pure)	0.206
Steel (0.5% Carbon)	0.054
Concrete	0.0016
Brick	0.0008
Glass, Plate	0.00076
Brick/Concrete Block	0.00073
Gypsum Board	0.00017
Plywood	0.00012
Fiber Insulation Board	0.00053
Chipboard	0.00015
Aerated Concrete	0.00026
Plasterboard	0.00016
Calcium Silicate Board	0.00013
Alumina Silicate Block	0.00014
Glass Fiber Insulation	0.000037
Expanded Polystyrene	0.000034
User Specified Value	Enter Value

Select Material

Concrete

Scroll to desired material then Click on selection

Reference: *Klote, J., J. Milke, Principles of Smoke Management, 2002, Page 270.*

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-184.

$Q_{FO} = 610\ \sqrt{(h_k\ A_T\ A_o\ (\sqrt{h_v}))}$

Where
Q_{FO} = heat release rate necessary for flashover (kW)
h_k = effective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_o = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Heat Transfer Coefficient Calculation

$h_k = k/\delta$ — Assuming that compartment has been heated thoroughly before flashover, i.e., $t > t_p$.

Where
h_k = effective heat transfer coefficient (kW/m^2-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

h_k = 0.010 kW/m^2-K

Area of Ventilation Opening Calculation

$A_o = (w_v)(h_v)$

Where
A_o = area of ventilation opening (m^2)
w_v = vent width (m)
h_v = vent height (m)

A_o = 2.23 m^2

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)] - A_o$

Where
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)
A_o = area of ventilation opening (m^2)

A_T = 551.47 m^2

Minimum Heat Release Rate for Flashover

$Q_{FO} = 610\ \sqrt{(h_k\ A_T\ A_o\ (\sqrt{h_v}))}$

Q_{FO} = 2738.77 kW **Answer**

METHOD OF BABRAUSKAS

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-184.

$Q_{FO} = 750\, A_v \left(\sqrt{h_v}\right)$

Where Q_{FO} = heat release rate necessary for flashover (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover
$Q_{FO} = 750\, A_v \left(\sqrt{h_v}\right)$

Q_{FO} = 2611.29 kW — Answer

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-184.

$Q_{FO} = 7.8\, A_T + 378\, A_v \left(\sqrt{h_v}\right)$

Where Q_{FO} = heat release rate necessary for flashover (kW)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover
$Q_{FO} = 7.8\, A_T + 378\, A_v \left(\sqrt{h_v}\right)$

Q_{FO} = 5617.57 kW — Answer

Summary of Result

Calculation Method	Flashover HRR (kW)
METHOD OF MQH	2739
METHOD OF BABRAUSKAS	2611
METHOD OF THOMAS	5618

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-14

Problem Statement

Consider a closed compartment in a facility (a pump room) 2.75 m wide x 2.75 m long x 3.7 m high (9.0 ft wide x 9.0 ft long x 12 ft high) (w_c x l_c x h_c). A fire starts with a constant power of 75 kW. Estimate the pressure increase attributable to the expansion of gases after 15 seconds.

Solution

Purpose:

(1) Estimate the pressure rise in the compartment at 15 seconds after ignition.

Assumptions:

(1) The energy release rate is constant.
(2) The mass rate of the fuel is neglected in the conversion of mass.
(3) The specific heat is constant with temperature.
(4) The hydrostatic pressure difference over the height of the compartment is negligible compared to the dynamic pressure.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 14_Compartment_Over_Pressure_Calculations.xls

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

- Compartment Width (w_c) = 9 ft
- Compartment Length (l_c) = 9 ft
- Compartment Height (h_c) = 12 ft
- Fire Heat Release Rate $(\dot{Q})$ = 75 kW
- Time After Ignition (t) = 15 sec

Results

Pressure Rise*	16.53 kPa (2.40 psi)

*spreadsheet calculations attached on next page

Spreadsheet Calculations

FDT[s]: 14_Compartment_Over_Pressure_Calculations.xls

CHAPTER 14. ESTIMATING PRESSURE RISE DUE TO A FIRE IN A CLOSED COMPARTMENT

Version 1805.0

The following calculations estimate the pressure rise in a compartment due to fire and combustion.
Parameters in YELLOW CELLS are Entered by the User.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entryin a cell(s).
The chapter in the NUREG guide should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	9.00	ft	2.74 m
Compartment Length (l_c)	9.00	ft	2.74 m
Compartment Height (h_c)	12.00	ft	3.66 m
Fire Heat Release Rate (Q)	75.00	kW	
Time after Ignition (t)	15.00	sec	
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K

Calculate

AMBIENT CONDITIONS

Initial Atmospheric Pressure (P_a)	14.70	psi	101.35 kPa
Specific Heat of Air at Constant Volume (c_v)	0.71	kJ/kg-K	
(Note: Values of c_v ranges from 0.71 to 0.85 kJ/kg-k)			
Ambient Air Density (ρ_a)	1.18	kg/m³	

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

METHOD OF KARLSSON AND QUINTIERE

Reference: *Karlsson and Quintiere, Enclosure Fire Dynamics, 1999, Page 192.*

$(P - P_a) / P_a = Q\,t / (V\,\rho_a\,c_v\,T_a)$

Where
- P = compartment pressure due to fire and combustion (kPa)
- P_a = initial atmospheric pressure (kPa)
- Q = heat release rate of the fire (kW)
- t = time after ignition (sec)
- V = compartment volume (m^3)
- ρ_a = ambient density (kg/m^3)
- c_v = specific heat of air at constant volume (kJ/kg-K)
- T_a = ambient air temperature (K)

Compartment Volume Calculation

$V = w_c \times l_c \times h_c$

Where
- V = volume of the compartment (m^3)
- w_c = compartment width (m)
- l_c = compartment length (m)
- h_c = compartment height (m)

V = 27.52 m^3 972 ft^3

Pressure Rise in Compartment

$(P - P_a) / P_a = Q\,t / (V\,\rho_a\,c_v\,T_a)$

$(P-P_a)/P_a =$ 0.163 atm

Multiplying by the atmospheric pressure (P_a) = 101 kPa

Gives a pressure difference = 16.53 kPa 2.40 psi Answer

This example shows that in a very short time the pressure in a closed compartment rises to quite large value.

Most buildings have leaks of some sort. The above example indicates that even though a fire compartment may be closed, the pressure is very rapid and would presumably lead to sufficient leaks to prevent further pressure rise from occurring. We will use this conclusion when dealing with pressure rises in enclosures with small leaks.

NOTE

The above calculations are based on principles developed in the Enclosure Fire Dynamics.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-15

Problem Statement

The licensee used UL Design No. 816 to protect a number of unrestrained beams. The licensee's quality assurance (QA) program verified that there is 6.35 cm (2½ in) thickness of fire protection insulation on all of the beams. The size of the tested beam was W12 x 26. Determine whether the 6.35 cm (2½ in) thickness of fire protection insulation is acceptable for a beam that is W8 x 13.

Solution

Purpose:

(1) Determine whether the 6.35 cm (2½ in.) thickness of fire protection insulation is acceptable for a W8 x 13 beam using the data for a W12 x 26 beam.

Assumptions:

(1) The heat transfer is one-dimensional.
(2) The analysis assumes that as the structural member heats up, structural properties change substantially.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 17.1_FR_Beams_Columns_Substitution_Correlation.xls (Click on *Beam*)

FDT^s Input Parameters:

Enter the following parameters in the spreadsheet (values only):

- Rated Design Thickness of Beam Insulation (T_2) = 2.5 in
- Select Beam with ***known*** rating for insulation thickness: select **W12 x 26**
- Select Beam with ***unknown*** rating for insulation thickness: select **W8 x 13**

Note: When beam size (e.g., W12 x 26) is selected from the combo box**,** its properties are automatically selected from the table ("*Data*" spreadsheet) and entered in the corresponding input yellow cells.

Results

Required Equivalent Thickness*	7.09 cm (2.79 in) not appropriate

*spreadsheet calculations attached on next page

From the substitution correlation, we obtain that 6.35 cm (2.5 in.) of fire protection insulation is not appropriate for W8 x 13 because the required thickness is more than 6.35 cm (2.5 in.).

A similar problem can be analyzed for a column, the calculations for columns are included in the same FDT^s (not shown).

Spreadsheet Calculations

FDT^s: 17.1_FR_Beams_Columns_Substitution_Correlation.xls (Beam)

CHAPTER 17. ESTIMATING THICKNESS OF FIRE PROTECTION SPRAY-APPLIED COATING FOR STRUCTURAL STEEL BEAMS (SUBSTITUTION CORRELATION)

Version 1805.0

For beams protected by spray-applied protections, following correlation enables substitution of one beam from another by varying the thickness of the fire protection insulation.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Beam Selected.
All subsequent output values are calculated by the spreadsheet, and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Rated Design Thickness of Beam Insulation (T_2)	2.5	in
Known Insulation Rating		
Weight of the Beam (W_2)	26	lb/ft
Heated Perimeter of Beam (D_2)	43.45	in
Unknown Insulation Rating		
Weight of the Beam (W_1)	13.00	lb/ft
Heated Perimeter of Beam (D_1)	27.52	in

SECTIONAL FACTORS FOR STEEL BEAMS

Select the Beam with known rating for insulation thickness	Select the Beam with unknown rating for insulation thickness
W12 x 26	W8 x 13
Subscript 2 (Rated Beam)	**Subscript 1 (Substitute Beam)**

Calculate

ESTIMATING THICKNESS OF FIRE PROTECTION INSULATION ON UNRATED BEAM

Reference: *UL Fire Resistance Directory, Volume 1, 1995, Page 10.*

$T_1 = ((W_2/D_2 + 0.6)\, T_2)/(W1/D_1 + 0.6)$

Where
- T_1 = calculated thickness of fire protection insulation on unrated beam (in)
- T_2 = design thickness of insulation on rated beam (in)
- W_1 = weight of beam with unknown insulation rating (lb/ft)
- W_2 = weight of design rated beam (lb/ft)
- D_1 = heated perimeter of unrated beam (in)
- D_2 = heated perimeter of the rated beam (in)

Required Equivalent Thickness of Fire Protection Insulation on Unrated Beam

$T_1 = ((W_2/D_2 + 0.6)\, T_2)/(W1/D1 + 0.6)$

T_1 = 2.79 in   Answer

Beams with a larger W/D ratio can always be substituted for the structural member listed with a specific fire resistive covering without changing the thickness of the covering.

NOTE

The above calculations are based on method developed in the UL Fire Resistance Directory, Volume 1, 1995. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

UNITED STATES NUCLEAR REGULATORY COMMISSION

Problem J-16

Problem Statement

During a routine fire protection inspection, an NRC inspector discovers a significant oil leak in a station air compressor in an access corridor in the fuel building. It is important to determine whether a fire involving a 76.0-liter (20.0-gallon) spill of lubricating oil from a compressor could damage the safety-related cable tray and electrical cabinet in the corridor. The compressor is on a pedestal approximately (1.0 ft) above floor level and has a 1.12 m^2 (12.0 ft^2) oil retention dike. The safety-related cable trays are located 2.5 m (8.0 ft) above the corridor floor with a horizontal distance of 1.2 m (4.0 ft) from the edge of the compressor's oil retention dike. The horizontal distance between the compressor oil dike and the electrical cabinet is 1.52 m (5.0 ft).

The access corridor has a floor area of 6.0 m wide x 4.6 m long (20 ft wide x 15 ft long) (w_c x l_c), ceiling height of 3.0 m (10.0 ft) (h_c), and a single unprotected vent opening (door) that is 1.2 m wide x 1.8 m high (4.0 ft wide x 6.0 ft high) (w_v x h_v). The corridor has no forced ventilation and it is constructed of 0.3048 m (1.0 ft) thick concrete. The corridor has a smoke and heat detection system and a wet pipe sprinkler system. The nearest sprinkler is rated at 74 °C (165 °F) with an RTI of 235 $(m\text{-}sec)^{1/2}$ and is located 2.98 m (9.8 ft) from the center of the dike. Determine whether there is a credible fire hazard to the safety-related cable trays and electrical cabinet. Evaluate the hazard of the fire scenario using the following parameters:

(a) pool fire heat release rate, $\dot{Q}$, flame height, z, and burning duration, t_b

(b) compartment hot gas layer temperature, T_g, as well as gas layer height z

(c) heat flux to the target (electrical cabinet) using the point source model, $\dot{q}''_{cabinet}$

(d) heat flux to the target (cable trays) using the solid-flame radiation model, $\dot{q}''_{cable}$

(e) centerline plume temperature, $T_{p(centerline)}$

(f) sprinkler activation time, $t_{activation}$

(g) HRR necessary to cause flashover, $\dot{Q}_{FO}$

Solution

Purpose:

(1) Determine if the given fire scenario could represent a hazard for the safety-related cable trays and electrical cabinet.

Solution Approach:

To analyze this fire scenario, we are going to use various concepts that have been presented individually in the NUREG. A logical approach for this type of problem is to analyze the heat source and then its effect over the safety-related targets and fire suppression systems. First, we are going to calculate the HRR, flame height, and the burning duration of the pool fire (see Chapter 3) in order to determine the intensity and geometrical characteristics of the fire. Then calculate the hot gas layer temperature and gas layer height (see Chapter 2). Then calculate the centerline plume temperature to obtain an estimate of the maximum temperature in the fire scenario (see Chapter 9). Then, we are going to calculate the radiative heat flux from the pool fire to the electrical cabinet and cable tray (see Chapter 5). After that, evaluate the activation time of the sprinkler system to determine if the system is able to respond to the actual developed fire (see Chapter 10). The last calculation is the required HRR for flashover (see Chapter 13). Once we get all these values, we have to use them to evaluate the hazard of the fire scenario.

Assumptions:

(1) There is instantaneous and complete involvement of the liquid in the pool fire.
(2) The pool fire is burning in the open.
(3) The pool is circular or nearly circular.
(4) The fire is located at the center of the corridor or away from the walls.
(5) All heat is released at a point
(6) Buoyant forces are more significant than momentum forces
(7) Radiation to the surroundings can be approximated as being isotropic or emanating from a point source (valid for point source radiation model only).
(8) Only convective heat transfer is considered for sprinkler activation.
(9) The ambient (or initial condition of the air) is at 25 °C (77 °F)
(10) The bottom of the oil retention dike is at ground level.
(11) The distance from the top of the fuel package (oil pool) to the ceiling is 10 ft, the pool height or oil layer thickness is negligible compared to ceiling height (about 0.22 ft).

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls
(b) 02.1_Temperature_NV.xls
(c) 09_Plume_Temperature_Calculations.xls
(d) & (e) 05.1_Heat_Flux_Calculations_Wind_Free.xls (select *Point Source* and *Solid Flame 2* for the target cabinet and cable tray heat flux analyses, respectively)
(f) 10_Detector_Activation_Time.xls (select *Sprinkler*)
(g) 13_Compartment_Flashover_Calculations.xls (select *Flashover-HRR* to calculate the HRR for flashover)

FDT^s Input Parameters:

Enter the following parameters in the spreadsheets (values only):

(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls
- Fuel spill volume (V) = 20 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 12 ft^2
- Select Fuel Type: select **Lube Oil** from the combo box

Note: When **Lube Oil** is selected**,** its properties are automatically selected from the table and entered in the corresponding input cells.

Results*

Heat Release Rate $\dot{Q}$ kW (Btu/sec)	Burning Duration t_b (min)	Pool Fire Flame Height H_f m (ft)	
		Method of Heskestad	Method of Thomas
1,131 (1,072)	22.0	2.7 (8.85)	2.95 (9.67)

*spreadsheet calculations attached at the end of the problem

(b) 02.1_Temperature_NV.xls

- Compartment Width (w_c) = 20 ft
- Compartment Length (l_c) = 15 ft
- Compartment Height (h_c) = 10 ft
- Vent Width (w_v) = 4 ft
- Vent Height (h_v) = 6 ft
- Top of Vent from Floor (V_T) = 6 ft
- Interior Lining Thickness (δ) = 12 in
- Heat Release Rate $(\dot{Q})$ = 1131 kW
- Select Material: select **Concrete** from the combo box

Note: When **Concrete** is selected**,** its properties are automatically selected from the table and entered in the corresponding input cells.

Results*

Time (min)	Hot Gas Layer Temperature T_g °C (°F)	Gas Layer Height z m (ft)
0	25 (77)	3.05 (10)
1	199 (389)	1.83 (6.0)
2	220 (428)	1.83 (6.0)
3	233 (452)	1.83 (6.0)
4	244 (471)	1.83 (6.0)
5	252 (486)	1.83 (6.0)
10	280 (536)	1.83 (6.0)
15	298 (568)	1.83 (6.0)
20	311 (592)	1.83 (6.0)

*spreadsheet calculations attached at the end of the problem

(c) 09_Plume_Temperature_Calculations.xls

- Heat Release Rate $(\dot{Q})$ = 1131 kW
- Distance from the Top of the Fuel to the Ceiling (z) = 9 ft
- Area of Combustible Fuel: 12 ft^2

Results*

Heat Release Rate $\dot{Q}$ (kW)	Plume Centerline Temperature $T_{p(centerline)}$ °C (°F)
1,131	473 (884)

*spreadsheet calculations attached at the end of the problem

(d) 05.1_Heat_Flux_Calculations_Wind_Free.xls

Point Source (heat flux to the electrical cabinet)

- Fuel Spill Area or Dike Area (A_{dike}) = 12 ft^2
- Distance between Fire and Target (L) = 5 ft
- Select Fuel Type: select **Lube Oil** from the combo box

(e) 05.1_Heat_Flux_Calculations_Wind_Free.xls

Solid Flame 2 (heat flux to the cable tray)

- Fuel Spill Area or Dike Area (A_{dike}) = 12 ft^2
- Distance between Fire and Target (L) = 4 ft
- Vertical Distance of Target from Ground ($H_1 = H_{f1}$) = 7 ft
- Select Fuel Type: select **Lube Oil** from the combo box

Note: When **Lube Oil** is selected**,** its properties are automatically selected from the table and entered in the corresponding input cells.

Results*

Radiation Model	Target	Radiant Heat Flux $\dot{q}''$ kW/m^2 (Btu/ft^2-sec)
Point Source	Electrical Cabinet	6.0 (0.53)
Solid Flame	Cable Tray	13.24 (1.17)

*spreadsheet calculations attached at the end of the problem

(f) 10_Detector_Activation_Time.xls

Sprinkler

- Heat Release Rate of the Fire $(\dot{Q})$ = 1,131 kW
- Distance from the Top of the Fuel Package to the Ceiling (H) = 9 ft
- Radial Distance from the Plume Centerline to the Sprinkler (r) = 9.8 ft
- Ambient Air Temperature (T_a) = 77 °F
- Select Type of Sprinkler = select **Standard response link** from the combo box
- Select Sprinkler Classification = select **Ordinary** from the combo box

Note: Standard response is selected because it corresponds with the given RTI value. Also, **Ordinary** classification has been selected because the rated value for the sprinklers in this problem (165 °F) is within the range of temperature ratings for ordinary sprinklers (135 °F–170 °F).

Results*

Sprinkler Type	Sprinkler Activation Time $t_{activation}$ (min.)
Standard response link	1.73

*spreadsheet calculations attached at the end of the problem

(g) 13_Compartment_Flashover_Calculations.xls
- Compartment Width (w_c) = 20 ft
- Compartment Length (l_c) = 15 ft
- Compartment Height (h_c) = 10 ft
- Vent Width (w_v) = 4 ft
- Vent Height (h_v) = 6 ft
- Interior Lining Thickness (δ) = 12 in
- Select Material: select **Concrete** from the combo box

Note: When **Concrete** is selected**,** its properties are automatically selected from the table and entered in the corresponding input cells.

Results*

HRR for Flashover $\dot{Q}_{FO}$ kW (Btu/sec)		
Method of MQH	Method of Babrauskas	Method of Thomas
836 (729)	2,261 (2,143)	2,064 (1,956)

*spreadsheet calculations attached at the end of the problem

Conclusions

According to the calculations the fire could represent a hazard to the safety-related targets (cable tray and electrical cabinets) due to the following results:

- From the pool fire analysis we obtain that the flame height is greater that the cable tray height. That means that the flame probably will impinge upon the cable trays since the pool is just at 4 ft from the cable tray (horizontal distance).
- The hot gas layer analysis estimates that the hot gas temperature will be over 500 °F and almost 600 °F at 10 minutes and one (1) minute, respectively. These temperature values are the critical temperatures for thermoplastic cables. Also the corridor will be almost filled with smoke at one minute after the ignition, which means that the cable tray and electrical cabinet will be rapidly exposed to the hot gas layer.
- Heat flux calculations show that the solid flame model predicts a radiant heat flux greater than the critical heat flux for IEEE-383 qualified and unqualified cables. Also, the heat flux to the electrical cabinet could represent a hazard for the integrity of the cabinet components.
- The HRR of the fire is very close to the HRR for flashover. Therefore, the whole corridor could flashover. The sprinkler should activate approximately at 2 minute after the fire development, during this time the fire should begin to be controlled. The burning time of the pool is significantly greater than the activation time of the sprinklers; thus, a complete and immediate extinguishment of the fire is not expected.

Spreadsheet Calculations

(a) FDT^s: 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

CHAPTER 3. ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE,
HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT
Version 1805.0

The following calculations estimate the heat release rate, burning duration, and flame height for liquid pool fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	20.00	gallons	0.0757 m^3
Fuel Spill Area or Dike Area (A_{dike})	12.00	ft^2	1.115 m^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg	
Fuel Density (ρ)	760	kg/m^3	
Empirical Constant ($k\beta$)	0.7	m^{-1}	
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K
Gravitational Acceleration (g)	9.81	m/sec^2	
Ambient Air Density (ρ_a)	1.18	kg/m^3	

Calculate

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Density ρ (kg/m^3)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	796	100
Ethanol	0.015	26,800	794	100
Butane	0.078	45,700	573	2.7
Benzene	0.085	40,100	874	2.7
Hexane	0.074	44,700	650	1.9
Heptane	0.101	44,600	675	1.1
Xylene	0.09	40,800	870	1.4
Acetone	0.041	25,800	791	1.9
Dioxane	0.018	26,200	1035	5.4
Diethy Ether	0.085	34,200	714	0.7
Benzine	0.048	44,700	740	3.6
Gasoline	0.055	43,700	740	2.1
Kerosine	0.039	43,200	820	3.5
Diesel	0.045	44,400	918	2.1
JP-4	0.051	43,500	760	3.6
JP-5	0.054	43,000	810	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	760	0.7
561 Silicon Transformer Fluid	0.005	28,100	960	100
Fuel Oil, Heavy	0.035	39,700	970	1.7
Crude Oil	0.0335	42,600	855	2.8
Lube Oil	0.039	46,000	760	0.7
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Select Fuel Type
Lube Oil
Scroll to desired fuel type
Click on selection

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-26.

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-25.

$Q = \dot{m}''\Delta H_{c,eff}(1 - e^{-k\beta D}) A_{dike}$

Where
- Q = pool fire heat release rate (kW)
- $\dot{m}''$ = mass burning rate of fuel per unit surface area (kg/m^2-sec)
- $\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
- $A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)
- $k\beta$ = empirical constant (m^{-1})
- D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

Where
- A_{dike} = surface area of pool fire (m^2)
- D = pool fire diamter (m)

$D = \sqrt{(4A_{dike}/\pi)}$

D = 1.191 m

Heat Release Rate Calculation

$Q = \dot{m}''\Delta H_{c,eff}(1 - e^{-k\beta D}) A_{dike}$

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

Q =	1131.38 kW	1072.34 Btu/sec	Answer

ESTIMATING POOL FIRE BURNING DURATION

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-197.

$t_b = 4V / \pi D^2 v$

Where
- t_b = burning duration of pool fire (sec)
- V = volume of liquid (m^3)
- D = pool diameter (m)
- v = regression rate (m/sec)

Calculation for Regression Rate

$v = \dot{m}''/\rho$

Where
- v = regression rate (m/sec)
- $\dot{m}''$ = mass burning rate of fuel (kg/m^2-sec)
- ρ = liquid fuel density (kg/m^3)

v = 0.000051 m/sec

Burning Duration Calculation

$t_b = 4V/\pi D^2 v$

t_b =	1323.37 sec	22.06 minutes	Answer

Note that a liquid pool fire with a given amount of fuel can burn for long periods of time over small area or for short periods of time over a large area.

ESTIMATING POOL FIRE FLAME HEIGHT
METHOD OF HESKESTAD

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 2-10.

$H_f = 0.235\, Q^{2/5} - 1.02\, D$

Where
- H_f = pool fire flame height (m)
- Q = pool fire heat release rate (kW)
- D = pool fire diameter (m)

Pool Fire Flame Height Calculation

$H_f = 0.235\, Q^{2/5} - 1.02\, D$

H_f =	2.70 m	8.85 ft	Answer

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-204.

$H_f = 42\ D\ (m''/\rho_a \surd(g\ D))^{0.61}$

Where H_f = pool fire flame height (m)
m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ρ_a = ambient air density (kg/m^3)
D = pool fire diameter (m)
g = gravitational acceleration (m/sec^2)

Pool Fire Flame Height Calculation

$H_f = 42\ D\ (m''/\rho_a \surd(g\ D))^{0.61}$

H_f =	2.95 m	9.67 ft	Answer

Flame Height Calculation - Summary of Results

Calculation Method	Flame Height (ft)
METHOD OF HESKESTAD	8.85
METHOD OF THOMAS	9.67

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	94.28	15880.43	3.60	4.08
2	0.19	0.49	188.56	7940.21	4.64	5.19
3	0.28	0.60	282.84	5293.48	5.38	5.97
4	0.37	0.69	377.13	3970.11	5.97	6.60
5	0.46	0.77	471.41	3176.09	6.47	7.13
6	0.56	0.84	565.69	2646.74	6.91	7.60
7	0.65	0.91	659.97	2268.63	7.30	8.02
8	0.74	0.97	754.25	1985.05	7.66	8.40
9	0.84	1.03	848.53	1764.49	7.99	8.75
10	0.93	1.09	942.82	1588.04	8.30	9.07
11	1.02	1.14	1037.10	1443.68	8.58	9.38
12	1.11	1.19	1131.38	1323.37	8.85	9.67
13	1.21	1.24	1225.66	1221.57	9.11	9.94
14	1.30	1.29	1319.94	1134.32	9.35	10.20
15	1.39	1.33	1414.22	1058.70	9.58	10.45
20	1.86	1.54	1885.63	794.02	10.60	11.55
25	2.32	1.72	2357.04	635.22	11.46	12.48
50	4.65	2.43	4714.08	317.61	14.58	15.87
75	6.97	2.98	7071.12	211.74	16.75	18.28
100	9.29	3.44	9428.17	158.80	18.47	20.20

Caution: The purpose of this random spill size chart is to aid the user in evaluating the hazard of random sized spills. Please note that the calculation does not take into account the viscosity or volatility of the liquid, or the absorptivity of the surface. The results generated for small volume spills over large areas should be used with extreme caution.

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

(b) FDT[s]: 02.1_Temperature_NV.xls

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN A ROOM FIRE WITH NATURAL VENTILATION COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

Version 1805.0

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Parameter	Value	Unit	Converted
Compartment Width (w_c)	20.00	ft	6.096 m
Compartment Length (l_c)	15.00	ft	4.572 m
Compartment Height (h_c)	10.00	ft	3.048 m
Vent Width (w_v)	4.00	ft	1.219 m
Vent Height (h_v)	6.00	ft	1.829 m
Top of Vent from Floor (V_T)	6.00	ft	1.829 m
Interior Lining Thickness (δ)	12.00	in	0.3048 m

AMBIENT CONDITIONS

Parameter	Value	Unit	Converted
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.18	kg/m³	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Parameter	Value	Unit
Interior Lining Thermal Inertia ($k\rho c$)	2.9	$(kW/m^2-K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.0016	kW/m-K
Interior Lining Specific Heat (c)	0.75	kJ/kg-K
Interior Lining Density (ρ)	2400	kg/m^3

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ $(kW/m^2-K)^2$-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Select Material

Concrete

Scroll to desired material then Click the selection

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002, Page 270.

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	1131.00	kW
	Calculate	

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-175.

$\Delta T_g = 6.85\,[Q^2/(A_v(h_v)^{1/2})(A_T h_k)]^{1/3}$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)

Q = heat release rate of the fire (kW)

A_v = area of ventilation opening (m^2)

h_v = height of ventilation opening (m)

h_k = convective heat transfer coefficient (kW/m^2-K)

A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$A_v = (w_v)(h_v)$

Where A_v = area of ventilation opening (m^2)

w_v = vent width (m)

h_v = vent height (m)

A_v = 2.23 m^2

Thermal Penetration Time Calculation

$t_p = (\rho c_p/k)(\delta/2)^2$

Where t_p = thermal penetration time (sec)

ρ = interior construction density (kg/m^3)

c_p = interior construction heat capacity (kJ/kg-K)

k = interior construction thermal conductivity (kW/m-K)

δ = interior construction thickness (m)

t_p = 26128.98 sec

Heat Transfer Coefficient Calculation

$h_k = \sqrt{(k\rho c/t)}$ for $t < t_p$ or (k/δ) for $t > t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec

(a thermal property of material responsible for the rate of temperature rise)

t = time after ignition (sec)

See table below for results

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)] - A_v$

Where A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

w_c = compartment width (m)

l_c = compartment length (m)

h_c = compartment height (m)

A_v = area of ventilation opening (m^2)

A_T = 118.54 m^2

Compartment Hot Gas Layer Temperature With Natural Ventilation

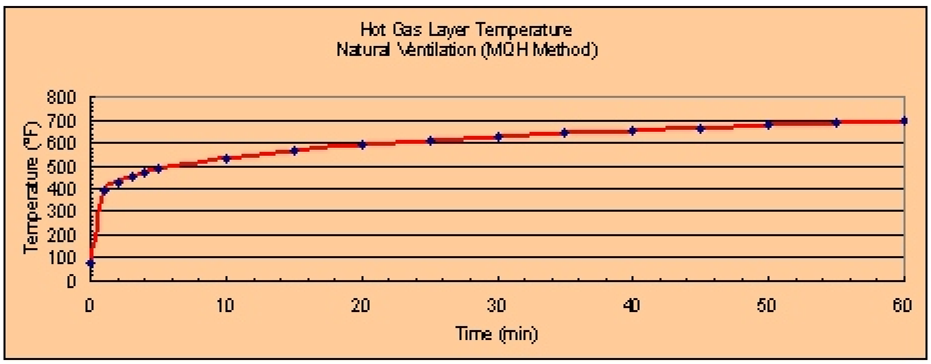
$\Delta T_g = 6.85\,[Q^2/(A_v(h_v)^{1/2})(A_T h_k)]^{1/3}$

$\Delta T_g = T_g - T_a$

$T_g = \Delta T_g + T_a$

Results

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0.00	-	-	298.00	25.00	77.00
1	60	0.22	173.60	471.60	198.60	389.48
2	120	0.16	194.86	492.86	219.86	427.75
3	180	0.13	208.49	506.49	233.49	452.27
4	240	0.11	218.73	516.73	243.73	470.71
5	300	0.10	227.01	525.01	252.01	485.62
10	600	0.07	254.81	552.81	279.81	535.66
15	900	0.06	272.63	570.63	297.63	567.73
20	1200	0.05	286.02	584.02	311.02	591.83
25	1500	0.04	296.86	594.86	321.86	611.34
30	1800	0.04	306.02	604.02	331.02	627.83
35	2100	0.04	313.98	611.98	338.98	642.16
40	2400	0.03	321.05	619.05	346.05	654.88
45	2700	0.03	327.41	625.41	352.41	666.34
50	3000	0.03	333.21	631.21	358.21	676.78
55	3300	0.03	338.55	636.55	363.55	686.38
60	3600	0.03	343.49	641.49	368.49	695.28



ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANA AND TANAKA

$z = ((2kQ^{1/3}t/3A_c) + (1/h_c^{(2/3)}))^{-3/2}$

Where z = smoke layer height (m)
Q = heat release rate of the fire (kW)
t = time after ignition (sec)
h_c = compartment height (m)
A_c = compartment floor area (m^2)
k = a constant given by $k = 0.076/\rho_g$
ρ_g = hot gas layer density (kg/m^3)
ρ_g is given by $\rho_g = 353/T_g$
T_g = hot gas layer temperature (K)

Compartment Area Calculation
$A_c = (w_c)(l_c)$
Where A_c = compartment floor area (m^2)
w_c = compartment width (m)
l_c = compartment length (m)

A_c = 27.87 m^2

Hot Gas Layer Density Calculation
$\rho_g = 353/T_g$

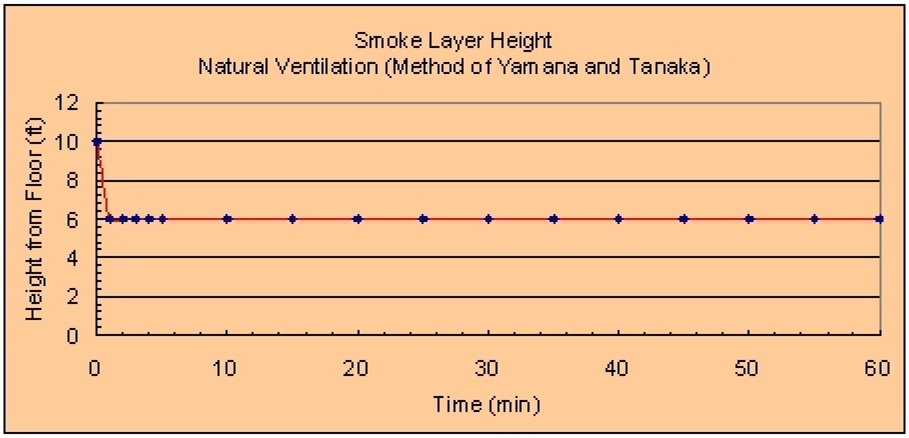
Calculation for Constant K
$k = 0.076/\rho_g$

Smoke Gas Layer Height With Natural Ventilation
$z = [(2kQ^{1/3}t/3A_c] + (1/h_c^{2/3})^{-3/2}$

Results

Caution! The smoke layer height is a conservative estimate and is only intended to provide an indication where the hot gas layer is located. Calculated smoke layer height below the vent height are not creditable since the calculation is not accounting for the smoke exiting the vent.

Time (min)	ρ_g (kg/m^3)	Constant (k) (kW/m-K)	Smoke Layer height z (m)	Smoke Layer height z (ft)	
0	1.18	0.064	3.05	10.00	
1	0.75	0.102	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
2	0.72	0.106	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
3	0.70	0.109	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
4	0.68	0.111	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
5	0.67	0.113	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
10	0.64	0.119	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
15	0.62	0.123	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
20	0.60	0.126	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
25	0.59	0.128	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
30	0.58	0.130	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
35	0.58	0.132	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
40	0.57	0.133	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
45	0.56	0.135	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
50	0.56	0.136	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
55	0.55	0.137	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
60	0.55	0.138	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT



NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov.

CHAPTER 9. ESTIMATING CENTERLINE TEMPERATURE OF A BUOYANT FIRE PLUME

Version 1805.0

The following calculations estimate the centerline plume temperature in a compartment fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Heat Release Rate of the Fire (Q)	1131.00	kW	
Elevation Above the Fire Source (z)	9.00	ft	2.74 m
Area of Combustible Fuel (A_c)	12.00	ft^2	1.11 m^2
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
	Calculate		298.00 K

AMBIENT CONDITIONS

Specific Heat of Air (c_p)	1.00	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3
Acceleration of Gravity (g)	9.81	m/sec^2
Convective Heat Release Fraction (χ_c)	0.70	

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

ESTIMATING PLUME CENTERLINE TEMPERATURE

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 2-6.

$$T_{p(centerline)} - T_a = 9.1\,(T_a/g\,c_p^2\,\rho_a^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$$

Where $T_{p(centerline)}$ = plume centerline temperature (°C)
Q_c = convective portion of the heat release rate (kW)
T_a = ambient air temperature (K)
g = acceleration of gravity (m/sec^2)
c_p = specific heat of air (kJ/kg-K)
ρ_a = ambient air density (kg/m^3)
z = distance from the top of the fuel package to the ceiling (m)
z_0 = hypothetical virtual origin of the fire (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c\, Q$

Where Q_c = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χ_c = convective heat release fraction

Q_c = 791.7 kW

Fire Diameter Calculation

$A_c = \pi D^2/4$

Where A_c = area of combustible fuel (m^2)
D = fire diameter (m)

$D = \sqrt{(4\,A_c/\pi)}$

D = 1.19 m

Hypothetical Virtual Origin Calculation

$z_0/D = -1.02 + 0.083\,(Q^{2/5})/D$

Where z_0 = virtual origin of the fire (m)

Q = heat release rate of fire (kW)

D = fire diameter (m)

z_0/D = 0.14

z_0= 0.17 m

Centerline Plume Temperature Calculation

$T_{p(centerline)} - T_a = 9.1\,(T_a/g\,c_p^2\,\rho_a^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$

$T_{p(centerline)} - T_a$= 448.21

$T_{p(centerline)}$ = 746.21 K

$T_{p(centerline)}$ =	473.21 °C	883.79 °F	**Answer**

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.

Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.

Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

(d) FDT^s: 05.1_Heat_Flux_Calculations_Wind_Free.xls (Point Source)

CHAPTER 5. ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITION POINT SOURCE RADIATION MODEL

Version 1805.0

The following calculations estimate the radiative heat flux from a pool fire to a target fuel.
The purpose of this calculation is to estimate the radiation transmitted from a burning fuel array to a target fuel positioned some distance from the fire at ground level to determine if secondary ignitions are likely with no wind.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg	
Empirical Constant ($k\beta$)	0.7	m^{-1}	
Heat Release Rate (Q)	1131.38	kW	
Fuel Area or Dike Area (A_{dike})	12.00	ft^2	1.11 m^2
Distance between Fire and Target (L)	5.00	ft	1.524 m
Radiative Fraction (χ_r)	0.30		

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here ? [ ] kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-26.

Select Fuel Type: Lube Oil

Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-272.*

POINT SOURCE RADIATION MODEL

$q'' = Q \chi_r / 4 \pi R^2$

Where q'' = incident radiative heat flux on the target (kW/m²)

Q = pool fire heat release rate (kW)

χ_r = radiative fraction

R = distance from center of the pool fire to edge of the target (m)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{4A_{dike}/\pi}$

Where A_{dike} = surface area of pool fire (m²)

D = pool fire diamter (m)

D = 1.19 m

Heat Release Rate Calculation

$Q = m'' \Delta H_{c,eff} (1 - e^{-k\beta D}) A_f$

Where Q = pool fire heat release rate (kW)

m'' = mass burning rate of fuel per unit surface area (kg/m²-sec)

ΔH_c = effective heat of combustion of fuel (kJ/kg)

A_f = surface area of pool fire (area involved in vaporization) (m²)

$k\beta$ = empirical constant (m⁻¹)

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 1131.38 kW

Distance from Center of the Fire to Edge of the Target Calculation

$R = L + D/2$

Where R = distance from center of the pool fire to edge of the target (m)

L = distance between pool fire and target (m)

D = pool fire diameter (m)

R = 2.12 m

Radiative Heat Flux Calculation

$q'' = Q \chi_r / 4 \pi R^2$

q'' =	6.01 kW/m²	0.53 Btu/ft²-sec	Answer

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

(e) FDT[s]: 05.1_Heat_Flux_Calculations_Wind_Free.xls (Solid Flame 2)

CHAPTER 5. ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL ABOVE GROUND LEVEL UNDER WIND-FREE CONDITION SOLID FLAME RADIATION MODEL

Version 1805.0

The following calculations estimate the radiative heat flux from pool fire to a target fuel.
The purpose of this calculation is to estimate the radiation transmitted from a burning fuel array to a target fuel positioned some distance from the fire above ground level to determine if secondary ignitions are likely with no wind.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Mass Burning Rate of Fuel ($\dot{m}''$)	0.039	kg/m²-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg	
Empirical Constant ($k\beta$)	0.7	m⁻¹	
Heat Release Rate ($\dot{Q}$)	1131.38	kW	
Fuel Area or Dike Area (A_{dike})	12.00	ft²	1.11 m²
Distance between Fire and Target (L)	4.00	ft	1.2192 m
Vertical Distance of Target from Ground ($H_t = H_{f1}$)	7.00	ft	2.1336 m

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here ? [ ] kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m²-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m⁻¹)
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-26.

Select Fuel Type

Lube Oil

Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-276*.

SOLID FLAME RADIATION MODEL

$q'' = EF_{1\to 2}$

Where
- q'' = incident radiative heat flux on the target (kW/m^2)
- E = emissive power of the pool fire flame (kW/m^2)
- $F_{1\to 2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

$D = \sqrt{(4A_{dike}/\pi)}$

Where
- A_{dike} = surface area of pool fire (m^2)
- D = pool fire diamter (m)

D = 1.19 m

Emissive Power Calculation

$E = 58\ (10^{-0.00823\ D})$

Where
- E = emissive power of the pool fire flame (kW/m^2)
- D = diameter of the pool fire (m)

E = 56.71 (kW/m^2)

View Factor Calculation

$F_{1\to 2,V1} = 1/(\pi S)\tan^{-1}(h_1/(S^2-1)^{1/2}) - (h_1/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2} + A_1h_1/\pi S(A_1^2-1)^{1/2}\tan^{-1}((A_1+1)(S-1)/(A_1-1)(S+1))^{1/2}$

$F_{1\to 2,V2} = 1/(\pi S)\tan^{-1}(h_2/(S^2-1)^{1/2}) - (h_2/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2} + A_2h_2/\pi S(A_2^2-1)^{1/2}\tan^{-1}((A_2+1)(S-1)/(A_2-1)(S+1))^{1/2}$

$A_1 = (h_1^2+S^2+1)/2S$

$A_2 = (h_2^2+S^2+1)/2S$

$B = (1+S^2)/2S$

$S = 2R/D$

$h_1 = 2H_{f1}/D$

$h_2 = 2H_{f2}/D$

$F_{1\to 2,V} = F_{1\to 2,V1} + F_{1\to 2,V2}$

Where
- $F_{1\to 2,V}$ = total vertical view factor
- R = distance from center of the pool fire to edge of the target (m)
- H_f = height of the pool fire flame (m)
- D = pool fire diameter (m)

Distance from Center of the Pool Fire to Edge of the Target Calculation

$R = L + D/2$

Where
- R = distance from center of the pool fire to edge of the target (m)
- L = distance between pool fire and target (m)
- D = pool fire diameter (m)

R = L+D/2 = 1.815 m

Heat Release Rate Calculation

$Q = m''\Delta H_{c,eff}(1 - e^{-k\beta D})A_{dike}$

Where
- Q = pool fire heat release rate (kW)
- m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
- ΔH_c = effective heat of combustion of fuel (kJ/kg)
- A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
- $k\beta$ = empirical constant (m^{-1})
- D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 1131.38 kW

Pool Fire Flame Height Calculation

$H_f = 0.235\ Q^{2/5} - 1.02\ D$

Where

H_f = flame height (m)

Q = heat release rate of fire (kW)

D = fire diameter (m)

H_f = 2.698 m

$S = 2R/D$ =		3.047						
$h_1 = 2H_{f1}/D$ =		3.582						
$h_2 = 2H_{f2}/D$ =	$2(H_f - H_{f1})/D$ =	0.947						
$A_1 = (h_1^2 + S^2 + 1)/2S$ =		3.793						
$A_2 = (h_2^2 + S^2 + 1)/2S$ =		1.835						
$B = (1 + S^2)/2S$ =		1.687						
			F_{V1}	F_{V2}	F_{V3}	F_{V4}		$F_{1\to2,V1}$
$F_{1\to2,V1}$ =		0.153		0.093	0.231	0.388	0.750	0.153
$F_{1\to2,V2}$ =		0.081	F_{V1}	F_{V2}	F_{V3}	F_{V4}		$F_{1\to2,V2}$
$F_{1\to2,V} = F_{1\to2,V1} + F_{1\to2,V2}$ =		0.234		0.033	0.061	0.118	0.919	0.081

Radiative Heat Flux Calculation

$q'' = EF_{1\to2}$

q'' =	13.24 kW/m^2	1.17 Btu/ft^2-sec	Answer

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.

Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.

Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

(f) FDT^s: 10_Detector_Activation_Time.xls (Sprinkler)

CHAPTER 10. ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.0

The following calculations estimate sprinkler activation time.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Sprinkler Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1131.00	kW	
Sprinkler Response Time Index (RTI)	130	(m-sec)$^{1/2}$	
Activation Temperature of the Sprinkler ($T_{activation}$)	165	°F	73.89 °C
Height of Ceiling above Top of Fuel (H)	9.00	ft	2.74 m
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	9.80	ft	2.99 m
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K
Convective Heat Release Rate Fraction (χ_c)	0.70		

r/H = 1.09

Calculate

GENERIC SPRINKLER RESPONSE TIME INDEX (RTI)*

Common Sprinkler Type	Generic Response Time Index (RTI) (m-sec)$^{1/2}$
Standard response bulb	235
Standard response link	130
Quick response bulb	42
Quick response link	34
User Specified Value	Enter Value

Select Type of Sprinkler

Standard response link

Scroll to desired sprinkler type then Click on selection

Reference: Madrzykowski, D., "Evaluation of Sprinkler Activation Prediction Methods" ASIAFLAM95, International Conference on Fire Science and Engineering, 1[st] Proceeding, March 15-16, 1995, Kowloon, Hong Kong, pp. 211-218.

*Note: The actual RTI should be used when the value is available.

GENERIC SPRINKLER TEMPERATURE RATING ($T_{activation}$)*

Temperature Classification	Range of Temperature Ratings (°F)	Generic Temperature Ratings (°F)
Ordinary	135 to 170	165
Intermediate	175 to 225	212
High	250 to 300	275
Extra high	325 to 375	350
Very extra high	400 to 475	450
Ultra high	500 to 575	550
Ultra high	650	550
User Specified Value	--	Enter Value

Select Sprinkler Classification

Ordinary

Scroll to desired sprinkler class then Click on selection

Reference: Automatic Sprinkler Systems Handbook, 6[th] Edition, National Fire Protection Association, Quincy, Massachusetts, 1994, Page 67.

*Note: The actual temperature rating should be used when the value is available.

ESTIMATING SPRINKLER RESPONSE TIME

Reference: NFPA Fire Protection Handbook, 19[th] Edition, 2003, Page 3-140.

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\,(\ln(T_{jet} - T_a)/(T_{jet} - T_{activation}))$

Where
- $t_{activation}$ = sprinkler activation response time (sec)
- RTI = sprinkler response time index (m-sec)$^{1/2}$
- u_{jet} = ceiling jet velocity (m/sec)
- T_{jet} = ceiling jet temperature (°C)
- T_a = ambient air temperature (°C)
- $T_{activation}$ = activation temperature of sprinkler (°C)

Ceiling Jet Temperature Calculation

$T_{jet} - T_a = 16.9\,(Q_c)^{2/3}/H^{5/3}$ for r/H = 0.18

$T_{jet} - T_a = 5.38\,(Q_c/r)^{2/3}/H$ for r/H > 0.18

Where
- T_{jet} = ceiling jet temperature (°C)
- T_a = ambient air temperature (°C)
- Q_c = convective portion of the heat release rate (kW)
- H = height of ceiling above top of fuel (m)
- r = radial distance from the plume centerline to the sprinkler (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c\, Q$

Where Q_c = convective portion of the heat release rate (kW)

Q = heat release rate of the fire (kW)

χ_c = convective heat release rate fraction

Q_c = 791.7 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.09 r/H > 0.15

$T_{jet} - T_a$ = {5.38 (Qc/r)^2/3}/H

$T_{jet} - T_a$ = 80.92

T_{jet} = 105.92 (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\,(Q/H)^{1/3}$ for r/H = 0.15

$u_{jet} = (0.195\, Q^{1/3}\, H^{1/2})/r^{5/6}$ for r/H > 0.15

Where u_{jet} = ceiling jet velocity (m/sec)

Q = heat release rate of the fire (kW)

H = height of ceiling above top of fuel (m)

r = radial distance from the plume centerline to the sprinkler (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.09 r/H > 0.15

u_{jet} = (0.195 Q^1/3 H^1/2)/r^5/6

u_{jet} = 1.352 m/sec

Sprinkler Activation Time Calculation

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\,(\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation}$ = 103.61 sec

The sprinkler will respond in approximately	1.73 minutes	Answer

NOTE: If $t_{activation}$ = "NUM" Sprinkler does not activate

NOTE

The above calculations are based on principles developed in the NFPA Fire Protection Handbook 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

UNITED STATES NUCLEAR REGULATORY COMMISSION

(g) FDT^s: 13_Compartment_Flashover_Calculations.xls (Flashover-HRR)

CHAPTER 13. PREDICTING COMPARTMENT FLASHOVER HEAT RELEASE RATE
Version 1805.0

The following calculations estimate the minimum heat release rate required to compartment flashover.

Parameters in YELLOW CELLS are Entered by the User.

Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft	6.096 m
Compartment Length (l_c)	15.00	ft	4.57 m
Compartment Height (h_c)	10.00	ft	3.048 m
Vent Width (w_v)	4.00	ft	1.219 m
Vent Height (h_v)	6.00	ft	1.83 m
Interior Lining Thickness (δ)	12.00	in	0.3048 m
Interior Lining Thermal Conductivity (k)	0.0016	kW/m-K	

Calculate

THERMAL PROPERTIES DATA

Material	Thermal Conductivity k (kW/m-K)
Aluminum (pure)	0.206
Steel (0.5% Carbon)	0.054
Concrete	0.0016
Brick	0.0008
Glass, Plate	0.00076
Brick/Concrete Block	0.00073
Gypsum Board	0.00017
Plywood	0.00012
Fiber Insulation Board	0.00053
Chipboard	0.00015
Aerated Concrete	0.00026
Plasterboard	0.00016
Calcium Silicate Board	0.00013
Alumina Silicate Block	0.00014
Glass Fiber Insulation	0.000037
Expanded Polystyrene	0.000034
User Specified Value	Enter Value

Select Material: Concrete

Scroll to desired material then Click on selection

Reference: Klote, J., J. Milke, *Principles of Smoke Management*, 2002, Page 270.

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.*

$Q_{FO} = 610\,\sqrt{(h_k\,A_T\,A_v\,\sqrt{h_v})}$

Where
- Q_{FO} = heat release rate necessary for flashover (kW)
- h_k = effective heat transfer coefficient (kW/m^2-K)
- A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
- A_v = area of ventilation opening (m^2)
- h_v = height of ventilation opening (m)

Heat Transfer Coefficient Calculation

$h_k = k/\delta$ — Assuming that compartment has been heated thoroughly before flashover, i.e., $t > t_p$

Where
- h_k = effective heat transfer coefficient (kW/m^2-K)
- k = interior lining thermal conductivity (kW/m-K)
- δ = interior lining thickness (m)

h_k = 0.005 kW/m^2-K

Area of Ventilation Opening Calculation

$A_V = (w_V)(h_V)$

Where	A_V = area of ventilation opening (m^2)
	w_V = vent width (m)
	h_V = vent height (m)
A_V =	2.23 m^2

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)] - A_V$

Where	A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
	w_c = compartment width (m)
	l_c = compartment length (m)
	h_c = compartment height (m)
	A_V = area of ventilation opening (m^2)
A_T =	118.54 m^2

Minimum Heat Release Rate for Flashover

$Q_{FO} = 610 \sqrt{(h_k A_T A_V \sqrt{h_V})}$

Q_{FO} = 835.57 kW **Answer**

METHOD OF BABRAUSKAS

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-184.

$Q_{FO} = 750 A_V \sqrt{h_V}$

Where	Q_{FO} = heat release rate necessary for flashover (kW)
	A_V = area of ventilation opening (m^2)
	h_V = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover

$Q_{FO} = 750 A_V \sqrt{h_V}$

Q_{FO} = 2261.44 kW **Answer**

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-184.

$Q_{FO} = 7.8 A_T + 378 A_V \sqrt{h_V}$

Where	Q_{FO} = heat release rate necessary for flashover (kW)
	A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
	A_V = area of ventilation opening (m^2)
	h_V = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover

$Q_{FO} = 7.8 A_T + 378 A_V \sqrt{h_V}$

Q_{FO} = 2064.41 kW **Answer**

Summary of Result:

Calculation Method	Flashover HRR (kW)
METHOD OF MQH	836
METHOD OF BABRAUSKAS	2261
METHOD OF THOMAS	2064

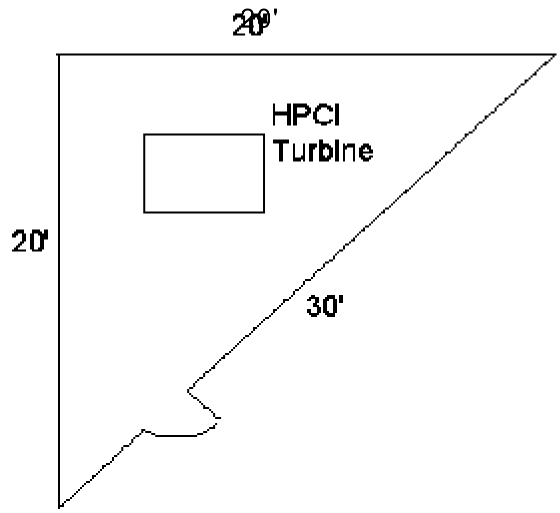
NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Problem J-17

Problem Statement

Consider a triangular corner compartment (as shown in the figure) in a boiling water reactor (BWR). The compartment is 4.6 m (15.0 ft) high with 0.3048 m (12.0 in) thick concrete walls, floor, and ceiling and with a door that is 2.15 m (7.0 ft) wide x 3.0 m (10.0 ft) high (w_v x h_v).



Problem 17: Pool Fire Scenario in a Triangular compartment

A fire scenario arises from a spill of lube oil from the high-pressure coolant injection (HPCI) turbine. Assume that 113.5 liters (30.0 gallons) of lube oil spills in a 1.12 m^2 (12.0 ft^2) oil retention dike. The lube oil spreads and reaches steady burning almost instantly. Two unprotected safety-related cable trays are located 3.0 m (10.0 ft) above the HPCI turbine. Determine whether there is a credible fire hazard to the unprotected safety-related cable trays.

Evaluate the hazard of the fire scenario using the following parameters:

(a) pool fire HRR, $\dot{Q}$, flame height, z, and burning duration, t_b

(b) compartment hot gas layer temperature, T_g, as well as gas layer height z

Solution

Purpose:

(1) Determine if the given fire scenario could represent a hazard for the safety-related cable trays.

Solution Approach:

The solution of this problem is very similar to the previous problem, but in this case we do not have or we are not considering any heat radiation and fire suppression system. First, we are going to calculate the heat release rate, flame height, and the burning duration of the pool fire (see Chapter 3) in order to determine the fire source characteristics. Notice that although the compartment is triangular, we are not going to consider a corner fire. It is reasonable to assume that the HPCI turbine is at a large distance away from the walls. Also, we will determine the hot gas layer temperature and the gas layer height (see Chapter 2).

Once we get all these values, we have to use them to estimate the hazard of the fire scenario.

Assumptions:

(1) There is instantaneous and complete involvement of the liquid in the pool fire.
(2) The pool fire is burning in the open.
(3) The pool is circular or nearly circular.
(4) The fire is located away from the walls.
(5) The ambient (or initial condition of the air) is at 25 °C (77 °F)
(6) The bottom of the oil retention dike is at ground level.
(7) The distance from the top of the fuel package (oil pool) to the ceiling is 15 ft, the pool height or oil layer thickness is negligible compared with the height of the ceiling.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls
(b) 02.1_Temperature_NV.xls

FDT^s Input Parameters:

Enter the following parameters in the spreadsheets (values only):

(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

- Fuel spill volume (V) = 30 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 12 ft^2
- Select Fuel Type: select Lube Oil from the combo box

Note: When Lube Oil is selected, its properties are automatically selected from the table and entered in the corresponding input cells.

Results*

Heat Release Rate $\dot{Q}$ kW (Btu/sec)	Burning Duration (t_b) (min)	Pool Fire Flame Height H_f m (ft)	
1,131 (1,072)	33 min	Method of Heskestad	Method of Thomas
		2.7 (8.9)	3.0 (9.7)

*spreadsheet calculations attached at the end of the problem

(b) 02.1_Temperature_NV.xls

Equivalent Compartment:

The FDT^s for hot gas layer temperature and flame height are designed for a quadrilateral compartment. Since the compartment is triangular, we have to calculate an equivalent square compartment in order to use the FDT^s.

- ❑ Triangular Compartment Surface Area:
  SA= (½ x (base) x (width)) + ($A_{wall \#1}$ + $A_{wall \#2}$ + $A_{wall \#3}$)
  SA= (½ x 20 x 20) + ((20 x 15) + (30 x 15) + (20 x 15)) = 1450 ft^2
- ❑ Equivalent Rectangular Compartment with Same Height:
  SA= Area Floor + Area Ceiling + Area Walls
  SA= (L x W) + (L x W) + 2(L x 15) + 2(W x 15)
  since equivalent L = W
  SA= (L^2) + (L^2) + 4(L x 15)
  1450 = $2L^2$ + 60L => L = 15.8 ft = W

Input Parameters:

- Compartment Width (w_c) = 15.8 ft
- Compartment Length (l_c) = 15.8 ft
- Compartment Height (h_c) = 15 ft
- Vent Width (w_v) = 7 ft
- Vent Height (h_v) = 10 ft
- Top of Vent from Floor (V_T) = 10 ft
- Interior Lining Thickness (δ) = 12 in
- Select Material: select **Concrete** from the combo box
- Fire Heat Release Rate $(\dot{Q})$ = 1,131 kW

Note: When **Concrete** is selected, its thermal properties are automatically selected from the table and entered in the corresponding input cells.

Results*

Time (min)	**Hot Gas Layer Temperature T_g °C (°F)**	**Gas Layer Height z m (ft)**
0	25 (77)	4.57 (15)
1	134 (273)	3.05 (10) venting
2	147 (297)	3.05 (10) venting
3	156 (312)	3.05 (10) venting
4	162 (324)	3.05 (10) venting
5	167 (333)	3.05 (10) venting
10	185 (364)	3.05 (10) venting
15	196 (385)	3.05 (10) venting
20	204 (400)	3.05 (10) venting

*spreadsheet calculations attached at the end of the problem

Conclusions

We can note that the fire power (HRR) and the pool fire flame height values are similar to the previous problem. The reason for this similarity is because the correlations to determine the HRR and flame height are based on the type of fuel and the dike area (or dike diameter), and in this problem we are dealing with a pool fire similar to problem 16. The amount of combustible in the pool (volume) will determine the duration of the pool fire, that is, the burning time. Thus, we obtained a different burning time value because we have more fuel volume.

As problem 16, we have a high intensity fire with a flame height that probably will impinge upon the cable trays. Also, the hot gas layer temperature analysis predicts that the temperature of the gases will reach the failure temperature for thermoplastic cables ($T \cong 425$ °F) approximately at 2 minutes after ignition and the compartment will be full with smoke at this time too. If there is no intervention of any suppression system during the 33 minutes of flame exposure, there is no doubt that there is a credible hazard for the safety related cables.

Spreadsheets Calculations

(a) FDT^s: 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

CHAPTER 3. ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE, HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT

Version 1805.0

The following calculations estimate the heat release rate, burning duration, and flame height for liquid pool fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	30.00	gallons	0.1136 m^3
Fuel Spill Area or Dike Area (A_{dike})	12.00	ft^2	1.115 m^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg	
Fuel Density (ρ)	760	kg/m^3	
Empirical Constant (kβ)	0.7	m^{-1}	
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K
Gravitational Acceleration (g)	9.81	m/sec^2	
Ambient Air Density (ρ_a)	1.18	kg/m^3	

Calculate

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Density ρ (kg/m^3)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	796	100
Ethanol	0.015	26,800	794	100
Butane	0.078	45,700	573	2.7
Benzene	0.085	40,100	874	2.7
Hexane	0.074	44,700	650	1.9
Heptane	0.101	44,600	675	1.1
Xylene	0.09	40,800	870	1.4
Acetone	0.041	25,800	791	1.9
Dioxane	0.018	26,200	1035	5.4
Diethy Ether	0.085	34,200	714	0.7
Benzine	0.048	44,700	740	3.6
Gasoline	0.055	43,700	740	2.1
Kerosine	0.039	43,200	820	3.5
Diesel	0.045	44,400	918	2.1
JP-4	0.051	43,500	760	3.6
JP-5	0.054	43,000	810	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	760	0.7
561 Silicon Transformer Fluid	0.005	28,100	960	100
Fuel Oil, Heavy	0.035	39,700	970	1.7
Crude Oil	0.0335	42,600	855	2.8
Lube Oil	0.039	46,000	760	0.7
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-26.

Select Fuel Type

Lube Oil

Scroll to desired fuel type
Click on selection

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: *SFPE Handbook of Fire Protection Engineering*, 3[rd] Edition, 2002, Page 3-25.

$Q = \dot{m}''\Delta H_{c,eff}\,(1 - e^{-k\beta D})\,A_{dike}$

Where Q = pool fire heat release rate (kW)

$\dot{m}''$ = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

$k\beta$ = empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

Where A_{dike} = surface area of pool fire (m^2)

D = pool fire diamter (m)

$D = \sqrt{(4A_{dike}/\pi)}$

D = 1.191 m

Heat Release Rate Calculation

$Q = \dot{m}''\Delta H_{c,eff}\,(1 - e^{-k\beta D})\,A_{dike}$

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

Q =	1131.38 kW	1072.34 Btu/sec	Answer

ESTIMATING POOL FIRE BURNING DURATION

Reference: *SFPE Handbook of Fire Protection Engineering*, 2[nd] Edition, 1995, Page 3-197.

$t_b = 4V / \pi D^2 v$

Where t_b = burning duration of pool fire (sec)

V = volume of liquid (m^3)

D = pool diameter (m)

v = regression rate (m/sec)

Calculation for Regression Rate

$v = \dot{m}''/\rho$

Where v = regression rate (m/sec)

$\dot{m}''$ = mass burning rate of fuel (kg/m^2-sec)

ρ = liquid fuel density (kg/m^3)

v = 0.000051 m/sec

Burning Duration Calculation

$t_b = 4V/\pi D^2 v$

t_b =	1985.05 sec	33.08 minutes	Answer

Note that a liquid pool fire with a given amount of fuel can burn for long periods of time over small area or for short periods of time over a large area.

ESTIMATING POOL FIRE FLAME HEIGHT
METHOD OF HESKESTAD

Reference: *SFPE Handbook of Fire Protection Engineering*, 2[nd] Edition, 1995, Page 2-10.

$H_f = 0.235\,Q^{2/5} - 1.02\,D$

Where H_f = pool fire flame height (m)

Q = pool fire heat release rate (kW)

D = pool fire diameter (m)

Pool Fire Flame Height Calculation

$H_f = 0.235\,Q^{2/5} - 1.02\,D$

H_f =	2.70 m	8.85 ft	Answer

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-204.

$H_f = 42\ D\ (\dot{m}''/\rho_a \sqrt{g\ D})^{0.61}$

Where H_f = pool fire flame height (m)

$\dot{m}''$ = mass burning rate of fuel per unit surface area (kg/m^2-sec)

ρ_a = ambient air density (kg/m^3)

D = pool fire diameter (m)

g = gravitational acceleration (m/sec^2)

Pool Fire Flame Height Calculation

$H_f = 42\ D\ (\dot{m}''/\rho_a \sqrt{g\ D})^{0.61}$

H_f =	2.95 m	9.67 ft	Answer

Flame Height Calculation - Summary of Results

Calculation Method	Flame Height (ft)
METHOD OF HESKESTAD	8.85
METHOD OF THOMAS	9.67

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	94.28	23820.64	3.60	4.08
2	0.19	0.49	188.56	11910.32	4.64	5.19
3	0.28	0.60	282.84	7940.21	5.38	5.97
4	0.37	0.69	377.13	5955.16	5.97	6.60
5	0.46	0.77	471.41	4764.13	6.47	7.13
6	0.56	0.84	565.69	3970.11	6.91	7.60
7	0.65	0.91	659.97	3402.95	7.30	8.02
8	0.74	0.97	754.25	2977.58	7.66	8.40
9	0.84	1.03	848.53	2646.74	7.99	8.75
10	0.93	1.09	942.82	2382.06	8.30	9.07
11	1.02	1.14	1037.10	2165.51	8.58	9.38
12	1.11	1.19	1131.38	1985.05	8.85	9.67
13	1.21	1.24	1225.66	1832.36	9.11	9.94
14	1.30	1.29	1319.94	1701.47	9.35	10.20
15	1.39	1.33	1414.22	1588.04	9.58	10.45
20	1.86	1.54	1885.63	1191.03	10.60	11.55
25	2.32	1.72	2357.04	952.83	11.46	12.48
50	4.65	2.43	4714.08	476.41	14.58	15.87
75	6.97	2.98	7071.12	317.61	16.75	18.28
100	9.29	3.44	9428.17	238.21	18.47	20.20

Caution: The purpose of this random spill size chart is to aid the user in evaluating the hazard of random sized spills. Please note that the calculation does not take into account the viscosity or volatility of the liquid, or the absorptivity of the surface. The results generated for small volume spills over large areas should be used with extreme caution.

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995.

Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.

Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.

Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

(b) FDT^{s}: 02.1_Temperature_NV.xls

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN A ROOM FIRE WITH NATURAL VENTILATION COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

Version 1805.0

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Parameter	Value	Unit	Converted
Compartment Width (w_c)	15.80	ft	4.81584 m
Compartment Length (l_c)	15.80	ft	4.81584 m
Compartment Height (h_c)	15.00	ft	4.572 m
Vent Width (w_v)	7.00	ft	2.134 m
Vent Height (h_v)	10.00	ft	3.048 m
Top of Vent from Floor (V_T)	10.00	ft	3.048 m
Interior Lining Thickness (δ)	12.00	in	0.3048 m

AMBIENT CONDITIONS

Parameter	Value	Unit	Converted
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_a)	1.18	kg/m^3	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Parameter	Value	Unit
Interior Lining Thermal Inertia ($k\rho c$)	2.9	(kW/m^2-K)^2-sec
Interior Lining Thermal Conductivity (k)	0.0016	kW/m-K
Interior Lining Specific Heat (c)	0.75	kJ/kg-K
Interior Lining Density (ρ)	2400	kg/m^3

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ (kW/m^2-K)^2-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: Klote, J., J. Milke, Principles of Smoke Management, 2002, Page 270.

Select Material
Concrete
Scroll to desired material then
Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) | 1131.00 kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, Page 3-175.

$\Delta T_g = 6.85\ [Q^2/(A_v(h_v)^{1/2})(A_T h_k)]^{1/3}$

Where $\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)

Q = heat release rate of the fire (kW)

A_v = area of ventilation opening (m^2)

h_v = height of ventilation opening (m)

h_k = convective heat transfer coefficient (kW/m^2-K)

A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$A_v = (w_v)(h_v)$

Where A_v = area of ventilation opening (m^2)

w_v = vent width (m)

h_v = vent height (m)

A_v = 6.50 m^2

Thermal Penetration Time Calculation

$t_p = (\rho c_p/k)(\delta/2)^2$

Where t_p = thermal penetration time (sec)

ρ = interior construction density (kg/m^3)

c_p = interior construction heat capacity (kJ/kg-K)

k = interior construction thermal conductivity (kW/m-K)

δ = interior construction thickness (m)

t_p = 26128.98 sec

Heat Transfer Coefficient Calculation

$h_k = \sqrt{(k\rho c/t)}$ for $t < t_p$ or (k/δ) for $t > t_p$

Where h_k = heat transfer coefficient (kW/m^2-K)

$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec

(a thermal property of material responsible for the rate of temperature rise)

t = time after ignition (sec)

See table below for results

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)] - A_v$

Where A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

w_c = compartment width (m)

l_c = compartment length (m)

h_c = compartment height (m)

A_v = area of ventilation opening (m^2)

A_T = 127.95 m^2

Compartment Hot Gas Layer Temperature With Natural Ventilation

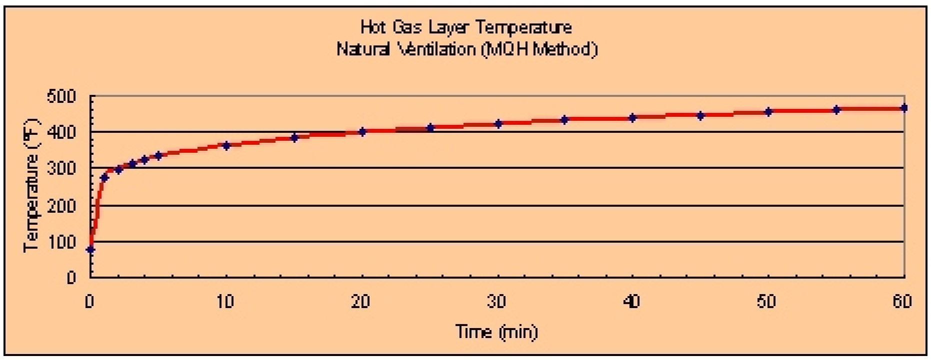
$\Delta T_g = 6.85\ [Q^2/(A_v(h_v)^{1/2})(A_T h_k)]^{1/3}$

$\Delta T_g = T_g - T_a$

$T_g = \Delta T_g + T_a$

Results

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0.00	-	-	298.00	25.00	77.00
1	60	0.22	108.78	406.78	133.78	272.81
2	120	0.16	122.11	420.11	147.11	296.79
3	180	0.13	130.64	428.64	155.64	312.16
4	240	0.11	137.06	435.06	162.06	323.70
5	300	0.10	142.25	440.25	167.25	333.05
10	600	0.07	159.67	457.67	184.67	364.41
15	900	0.06	170.84	468.84	195.84	384.50
20	1200	0.05	179.23	477.23	204.23	399.61
25	1500	0.04	186.02	484.02	211.02	411.83
30	1800	0.04	191.76	489.76	216.76	422.16
35	2100	0.04	196.75	494.75	221.75	431.14
40	2400	0.03	201.17	499.17	226.17	439.11
45	2700	0.03	205.16	503.16	230.16	446.29
50	3000	0.03	208.80	506.80	233.80	452.83
55	3300	0.03	212.14	510.14	237.14	458.85
60	3600	0.03	215.24	513.24	240.24	464.43



ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANA AND TANAKA

$z = ((2kQ^{1/3}t/3A_c) + (1/h_c^{2/3}))^{-3/2}$

Where
- z = smoke layer height (m)
- Q = heat release rate of the fire (kW)
- t = time after ignition (sec)
- h_c = compartment height (m)
- A_c = compartment floor area (m^2)
- k = a constant given by $k = 0.076/\rho_g$
- ρ_g = hot gas layer density (kg/m^3)
- ρ_g is given by $\rho_g = 353/T_g$
- T_g = hot gas layer temperature (K)

Compartment Area Calculation

$A_c = (w_c)(l_c)$

Where
- A_c = compartment floor area (m^2)
- w_c = compartment width (m)
- l_c = compartment length (m)

$A_c =$ 23.19 m^2

Hot Gas Layer Density Calculation

$\rho_g = 353/T_g$

Calculation for Constant K

$k = 0.076/\rho_g$

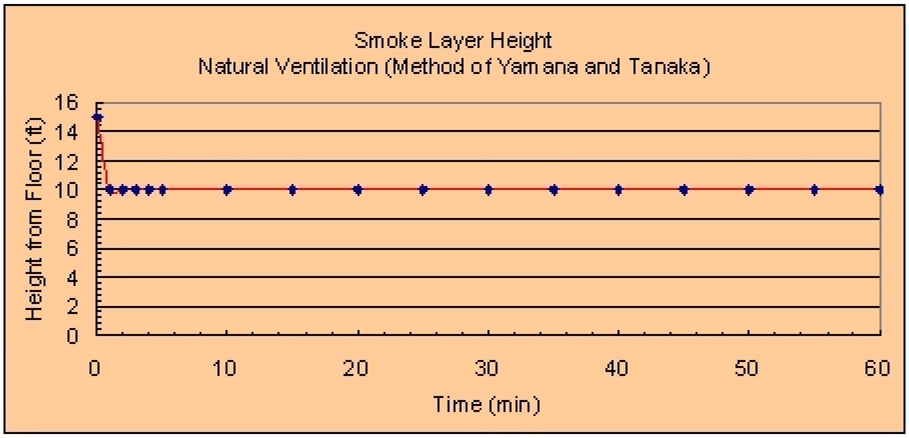
Smoke Gas Layer Height With Natural Ventilation

$z = [(2kQ^{1/3}t/3A_c) + (1/h_c^{2/3})]^{-3/2}$

Results

Caution! The smoke layer height is a conservative estimate and is only intended to provide an indication where the hot gas layer is located. Calculated smoke layer height below the vent height are not creditable since the calculation is not accounting for the smoke exiting the vent.

Time (min)	ρ_g (kg/m^3)	Constant (k) (kW/m-K)	Smoke Layer height z (m)	Smoke Layer height z (ft)	
0	1.18	0.064	4.57	15.00	
1	0.87	0.088	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
2	0.84	0.090	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
3	0.82	0.092	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
4	0.81	0.094	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
5	0.80	0.095	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
10	0.77	0.099	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
15	0.75	0.101	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
20	0.74	0.103	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
25	0.73	0.104	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
30	0.72	0.105	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
35	0.71	0.107	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
40	0.71	0.107	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
45	0.70	0.108	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
50	0.70	0.109	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
55	0.69	0.110	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT
60	0.69	0.110	3.05	10.00	CAUTION: SMOKE IS EXITING OUT VENT



NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov.

UNITED STATES NUCLEAR REGULATORY COMMISSION

Problem J-18

Problem Statement

The operators of Bywater NPP are planning their summer company picnic. A fire scenario arises from a pile of instant-lighting charcoal briquets. Ten 3.62-kg (8.0-lb) bags of these briquets have been stored on the floor of a corridor in the NPP. Assume that a strong ignition source is present and ignites the charcoal briquets. Compute the heat release rate, $\dot{Q}$, flame height, H_f, and burning duration, t_b, of pile of charcoal briquets, assuming that the area of the charcoal pile is 0.28 m^2 (3 ft^2).

Additional Information

Charcoal briquets are a combustible material and become more combustible when soaked with lighter fluid (an accelerant) during the manufacturing process (Ref. 1). The lighter fluid is usually kerosene or a petroleum distillate (Refs. 2 and 3). No direct burning rate data are available for instant-lighting charcoal briquets. A breakdown of the combustion data for plain charcoal and kerosine (Ref. 4) is provided below. Average values can be used as a composition when specific burning rate data are not available. The density of charcoal is approximately 400 kg/m^3.

Combustion Properties of Charcoal and Kerosine		
Combustible Material	Heat of Combustion H_c (kJ/kg)	Mass Loss Rate $\dot{m}''$ (kg/m^2-sec)
Charcoal	31,400	0.01082*
Kerosine	43,300	0.039
Average	**37,350**	**0.02491**
* Mass loss rate of charcoal is not available in the literature, mass loss rate of plain plywood can be used, since charcoal is a derivative of wood.		

References

1. Roblee, C.L., "Hazards of Charcoal Briquets," *Fire and Arson Investigator*, Volume 33, No. 3, March 1993.
2. Lincoln, S., "Case in Review: Charcoal Lighter Fluid Used as an Arson Accelerant," *Fire and Arson Investigator*, Volume 41, No. 1, September 1991.
3. Wiltshire, L.L., and R.S. Alger, "Carbon Monoxide Production in Charcoal Briquete Fires," NOLTR 71-104, Project MAT-03L-00/ZRO11-01-01, Naval Ordnance Laboratory, Silver Spring, Maryland, July 7, 1971.
4. SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995.

Solution

Purpose:

(1) Determine the heat release rate, $\dot{Q}$ flame height, H_f, and burning duration, t_b, of the pile of charcoal briquets for the given fire scenario.

Solution Approach:

To calculate the HRR and flame height, we are going to use the pool fire approach. These calculations are just fuel type and area dependent; therefore, we are going to model the area of the charcoal pile as the area of a dike and use the average values of heat of combustion, mass loss rate and density (values are given in the problem statement). The burning duration of the pile can be calculated with the learned concepts in Chapter 8 of NUREG.

Assumptions:

(1) There is instantaneous and complete involvement of the charcoal pile.
(2) The charcoal pile is burning in the open.
(3) The charcoal pile area is circular or nearly circular.
(4) The fire is located away from the walls.
(5) The ambient (or initial condition of the air) is at 25 °C (77 °F)
(6) Combustion is incomplete and takes place entirely within the confines of the compartment.

Spreadsheet (FDT^s) Solution Procedure:

Use the following FDT^s:

(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls
(b) 08_Burning_Duration_Solid.xls

FDT^s Input Parameters:

Enter the following parameters in the spreadsheets (values only):

(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

- Fuel spill volume (V) = 0 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 3 ft^2
- Mass Burning Rate of Fuel $(\dot{m}'')$ = 0.02491 kg/m^2-sec
- Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$) = 37,350 kJ/kg
- Fuel Density (ρ) = 400 kg/m^3
- Empirical constant = 100 (since unknown)

Note: For this calculation, use any value of spill volume because the burning time based on the pool fire calculation is not applicable. We are just going to accept the HRR and flame height values as reasonable estimates. Mass burning rate, heat of combustion, and density values are from the given properties in the problem statement. Select User-Specified Value and enter the values in the proper areas.

Results*

Heat Release Rate $\dot{Q}$ kW (Btu/sec)	Pool Fire Flame Height H_f m (ft)	
	Method of Heskestad	Method of Thomas
259 (246)	1.56 (5.13)	1.38 (4.54)

*spreadsheet calculations attached at the end of the problem

(b) 08_Burning_Duration_Solid.xls

HRR per Unit Floor Area:

The HRR per unit of area is defined as $\dot{Q}'' = \Delta H_{c,eff}\dot{m}''$. Therefore, from the given properties in the problem statement we have:

$\dot{Q}'' = \Delta H_{c,eff}\dot{m}''$ = 37,350 kJ/kg (0.02491 kg/m^2-sec) = 930 kW/m^2

Input Parameters:

- Mass of Solid Fuel (m_{solid}) = 80 lb
- Exposed Fuel Surface Area (A_{fuel})= 3 ft^2
- HRR per Unit Floor Area $(\dot{Q}'')$ = 930 kW/m^2
- Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$) = 37,350 kJ/kg

Note: Select User-Specified Value and enter the inputs.

Results*

Material	Burning Duration t_{solid} (min.)
Charcoal briquets	87

*spreadsheet calculations attached at the end of the problem

Spreadsheet Calculations

(a) FDT[s]: 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

CHAPTER 3. ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE,
HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT

Version 1805.0

The following calculations estimate the heat release rate, burning duration, and flame height for liquid pool fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Fuel Spill Volume (V)	0.00	gallons	0.0000 m^3
Fuel Spill Area or Dike Area (A_{dike})	3.00	ft^2	0.279 m^2
Mass Burning Rate of Fuel (m")	0.02491	kg/m^2-sec	
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	37350	kJ/kg	
Fuel Density (ρ)	400	kg/m^3	
Empirical Constant (kβ)	100	m^{-1}	
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
			298.00 K
Gravitational Acceleration (g)	9.81	m/sec^2	
Ambient Air Density (ρ_a)	1.18	kg/m^3	

Calculate

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Density ρ (kg/m^3)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	796	100
Ethanol	0.015	26,800	794	100
Butane	0.078	45,700	573	2.7
Benzene	0.085	40,100	874	2.7
Hexane	0.074	44,700	650	1.9
Heptane	0.101	44,600	675	1.1
Xylene	0.09	40,800	870	1.4
Acetone	0.041	25,800	791	1.9
Dioxane	0.018	26,200	1035	5.4
Diethy Ether	0.085	34,200	714	0.7
Benzine	0.048	44,700	740	3.6
Gasoline	0.055	43,700	740	2.1
Kerosine	0.039	43,200	820	3.5
Diesel	0.045	44,400	918	2.1
JP-4	0.051	43,500	760	3.6
JP-5	0.054	43,000	810	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	760	0.7
561 Silicon Transformer Fluid	0.005	28,100	960	100
Fuel Oil, Heavy	0.035	39,700	970	1.7
Crude Oil	0.0335	42,600	855	2.8
Lube Oil	0.039	46,000	760	0.7
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-26.

Select Fuel Type
User Specified Value
Scroll to desired fuel type
Click on selection

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: *SFPE Handbook of Fire Protection Engineering*, 3[rd] Edition, 2002, Page 3-26.

$Q = \dot{m}''\Delta H_{c,eff}(1 - e^{-k\beta D})A_{dike}$

Where Q = pool fire heat release rate (kW)

$\dot{m}''$ = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

$k\beta$ = empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$

Where A_{dike} = surface area of pool fire (m^2)

D = pool fire diameter (m)

$D = \sqrt{(4A_{dike}/\pi)}$

D = 0.596 m

Heat Release Rate Calculation

$Q = \dot{m}''\Delta H_{c,eff}(1-e^{-k\beta D})A_{dike}$

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

Q =	259.31 kW	245.78 Btu/sec	Answer

ESTIMATING POOL FIRE BURNING DURATION

Reference: *SFPE Handbook of Fire Protection Engineering*, 2[nd] Edition, 1995, Page 3-197.

$t_b = 4V / \pi D^2 v$

Where t_b = burning duration of pool fire (sec)

V = volume of liquid (m^3)

D = pool diameter (m)

v = regression rate (m/sec)

Calculation for Regression Rate

$v = \dot{m}''/\rho$

Where v = regression rate (m/sec)

$\dot{m}''$ = mass burning rate of fuel (kg/m^2-sec)

ρ = liquid fuel density (kg/m^3)

v = 0.000062 m/sec

Burning Duration Calculation

$t_b = 4V/\pi D^2 v$

t_b =	0.00 sec	0.00 minutes	Answer

Note that a liquid pool fire with a given amount of fuel can burn for long periods of time over small area or for short periods of time over a large area.

ESTIMATING POOL FIRE FLAME HEIGHT

METHOD OF HESKESTAD

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 2-10.

$H_f = 0.235\, Q^{2/5} - 1.02\, D$

Where
- H_f = pool fire flame height (m)
- Q = pool fire heat release rate (kW)
- D = pool fire diameter (m)

Pool Fire Flame Height Calculation

$H_f = 0.235\, Q^{2/5} - 1.02\, D$

H_f =	1.56 m	5.13 ft	Answer

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering*, 2nd Edition, 1995, Page 3-204.

$H_f = 42\, D\, (m''/\rho_a \sqrt{(g\, D)})^{0.61}$

Where
- H_f = pool fire flame height (m)
- m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
- ρ_a = ambient air density (kg/m^3)
- D = pool fire diameter (m)
- g = gravitational acceleration (m/sec^2)

Pool Fire Flame Height Calculation

$H_f = 42\, D\, (m''/\rho_a \sqrt{(g\, D)})^{0.61}$

H_f =	1.38 m	4.54 ft	Answer

Flame Height Calculation - Summary of Results

Calculation Method	Flame Height (ft)
METHOD OF HESKESTAD	5.13
METHOD OF THOMAS	4.54

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	86.44	0.00	3.44	3.10
2	0.19	0.49	172.87	0.00	4.43	3.95
3	0.28	0.60	259.31	0.00	5.13	4.54
4	0.37	0.69	345.74	0.00	5.69	5.02
5	0.46	0.77	432.18	0.00	6.16	5.43
6	0.56	0.84	518.62	0.00	6.58	5.78
7	0.65	0.91	605.05	0.00	6.95	6.10
8	0.74	0.97	691.49	0.00	7.29	6.39
9	0.84	1.03	777.92	0.00	7.60	6.65
10	0.93	1.09	864.36	0.00	7.89	6.90
11	1.02	1.14	950.80	0.00	8.16	7.14
12	1.11	1.19	1037.23	0.00	8.41	7.35
13	1.21	1.24	1123.67	0.00	8.65	7.56
14	1.30	1.29	1210.10	0.00	8.88	7.76
15	1.39	1.33	1296.54	0.00	9.10	7.95
20	1.86	1.54	1728.72	0.00	10.06	8.78
25	2.32	1.72	2160.90	0.00	10.88	9.49
50	4.65	2.43	4321.80	0.00	13.81	12.08
75	6.97	2.98	6482.69	0.00	15.84	13.90
100	9.29	3.44	8643.59	0.00	17.45	15.37

Caution: The purpose of this random spill size chart is to aid the user in evaluating the hazard of random sized spills. Please note that the calculation doe not take into account the viscosity or volatility of the liquid, or the absorptivity of the surface. The results generated for small volume spills over large areas should be used with extreme caution.

NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

(b) FDT^s: 08_Burning_Duration_Solid.xls

CHAPTER 8. ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.0

The following calculations provides an approximation of the burning duration of solid combustibles based on free burning rate with a given surface area.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Mass of Solid Fuel (m_{solid})	80.00	lb	36.29	kg
Exposed Floor Area (Length x Width) of Fuel (A_{fuel})	3.00	ft²	0.28	m²
Heat Release Rate per Unit Floor Area (Q")	930	kW/m²		
Effective Heat of Combustion ($\Delta H_{c,eff}$)	37350	kJ/kg		

Calculate

THERMAL PROPERTIES OF SOLID COMBUSTIBLE MATERIALS

Materials	HRR per Unit Floor Area (L x W) Q" (kW/m²)	Heat of Combustion ΔH_c (kJ/kg)
PE/PVC	589	24000
XPE/FRXPE	475	28300
XPE/Neoprene	354	10300
PE, Nylon/PVC, Nylon	231	9200
Teflon	98	3200
Douglas fir plywood	221	17600
Fire retardant treated plywood	81	13500
Particle Board, 19 mm thick	1900	17500
Nylon 6/6	1313	32000
Polymethylmethacrylate (PMMA)	665	26000
Polypropylene (PP)	1509	43200
Polystyrene (PS)	1101	42000
Polyethylene (PE)	1408	46500
Polycarbonate	420	24400
Polyurethane	710	45000
Polyvinyl Chloride (PVC) Flexible	237	15700
Styrene-butadiene Copolymers (SBR)	163	44000
Ethylene Propylene Dien Rubber (EPDM)	956	28800
Empty Cartons 15 ft high	1700	12700
Wood pallets, stacked 1.5 ft high	1420	14000
Wood pallets, stacked 5 ft high	3970	14000
Wood pallets, stacked 10 ft high	6800	14000
User Specified Value	Enter Value	Enter Value

Select Material

User Specified Value

Scroll to desired material then Click on selection

References: "Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters," EPRI Research Project 1165-1, NP-1200, Part 1.
Karlsson and Quintiere, Enclosure Fire Dynamics, Chapter 3, Energy Release Rate,"
CRC Press, 1999.
Johnson, D. G., "Combustion Properties of Plastics," Journal of Applied Fire Science, Volume 4, No. 3, 1994-95, pp. 185-201.
Hirschler, M. M., "Heat Release from Plastic Materials," Heat Release in Fires, Babrauskas and Grayson, Editors, Elsevier Applied Science, 1992.

BURNING DURATION OF SOLID COMBUSTIBLES

Reference: *Buchanan, A.H., "Structural Design for Fire Safety," 2001, Page 38.*

The burning duration of a solid fuel can be calculated if the total energy contained in the fuel and HRR are known.

The burning duration is given by:

$Q = E / t_{solid}$

or

$t_{solid} = (E) / (Q'' A_{Fuel})$

Where t_{solid} = burning duration of solid combustible (sec)
$E = m_{Fuel} \Delta H_C$ = total energy contained in the fuel (kJ)
Q = heat releare rate of fire (kW)
Q" = heat release rate per unit floor area of fuel (kW/m^2)
A_{Fuel} = exposed floor area (length x width) of fuel (m^2)

$t_{solid} = (m_{Fuel} \Delta H_C) / (Q'' A_{Fuel})$

Where m_{Fuel} = mass of solid fuel (kg)
ΔH_C = fuel effective heat of combustion (kJ/kg)

$t_{solid} = (m_{solid} \Delta H_C) / (Q'' A_{solid})$

t_{solid} =	5228.92 sec	87.15 minutes	Answer

NOTE

The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001.
Calculations are based on certain assumptions and have inherent limitations.
The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nrc.gov or mxs3@nrc.gov.

Additional Problems

1. Consider a pool fire caused by a 38.0 liters (10 gallons) spill of flammable liquid (kerosine oil) in a 0.55-m^2 (6.0-ft^2) dike area in a compartment with a concrete floor. The kerosine oil is ignited and spreads rapidly over the surface, reaching steady burning almost instantly. Compute the HRR, burning duration, and flame height of the pool fire. The dimensions of the compartment are 6.0 m wide x 6.0 m long x 3.7 m high (20.0 ft wide x 20.0 ft long x 12.0 ft high). Two cable trays are located above the pool fire at heights of 2.15 m (7.0 ft) and 3.0 m (10.0 ft), respectively. Determine whether flame will impinge upon the cable trays. Assume instantaneous, complete involvement of the liquid pool with no fire growth and no intervention by the plant fire department or automatic suppression systems.

2. Assume that heptane from a tank spills on a concrete floor forming a 113.0 m^2 (1261.0 ft^2) pool, the distance from the center of the pool fire to the target edge is 30.0 m (98.0 ft). Calculate the radiative heat flux of the flame at ground level with no wind using—
   (a) Point Source Model
   (c) Solid Flame Radiation Model

3. A trash fire with an HRR $(\dot{Q})$ of 1,500 kW occurs in an NPP backup power battery room protected with the fixed temperature heat detectors with an RTI of 165 $(m\text{-}sec)^{1/2}$. Calculate the activation time for the detectors, using listed spacing of 3.05 m (20.0 ft) with a ceiling height of 4.60 m (15 ft). Assume that the detectors have an activation temperature of 57 °C (135 °F) and the ambient temperature is 25 °C (77 °F).

4. A fire scenario arises from the failure of a 4,160V switchgear in a cable spreading room. A stack of safety-related cable (IEEE-383 non-qualified PE/PVC) is located 4.6 m (15.0 ft) horizontally from the 4,160V breaker. Assume that the breaker fire produces a maximum flame heat flux 50 kW/m^2 and the surface of the cable trays initially at 25 °C (77 °F). Calculate the ignition time (t_{ig}) of IEEE-383 non-qualified PE/PVC cables.

5. A pool fire scenario arises from a rupture in an oil-filled transformer. This event allows the fuel contents of the transformer to spill along a wall with an area of 1.4 m^2 (15 ft^2). A safety-related cable tray is located 5.5 m (18 ft) above the pool fire. Calculate the wall flame height ($H_{f(wall)}$) of the fire, and determine whether flame will impinge upon the cable tray.

6. A fire scenario arises from a rupture in the housing of an auxiliary lube oil pump. This event allows the fuel contents of the pump to spill along a wall with an area of 0.75 m^2 (8.0 ft^2). A cable tray is located 3.0 m (10.0 ft) above the fire. Calculate the flame height of the line fire ($H_{f(wall\ line)}$), and determine whether the flame will impinge upon the cable tray.

7. A fire scenario arises from a rupture in an oil-filled transformer in a facility. This event allows the fuel contents of the transformer to spill along the corners of walls with an area of 0.55 m^2 (6.0 ft^2). A cable tray is located 5.5 m (18 ft) above the fire. Calculate the corner fire flame height ($H_{f(corner)}$), and determine whether flame will impinge upon the cable tray.

8. Consider a compartment that is 9.0 m wide x 9.0 m long x 3.7 m high (30.0 ft wide x 30.0 ft long x 12.0 ft high) (w_c x l_c x h_c) with a door vent that is 0.91 m (3.0 ft) wide x 2.15 m (7.0 ft) high (w_v x h_v). The fire is constant with an HRR $(\dot{Q})$ of 1,500 kW. Compute the hot gas temperature (T_g) in the compartment as well as smoke layer height (z) at 5 minutes after ignition, assuming that the compartment boundaries are made of 2.54 cm (1.0 in) thick gypsum board.

9. Consider a compartment that is 12.2 m wide x 12.2 m long x 3.0 m high (40.0 ft wide x 40.0 ft long x 10.0 ft high) (w_c x l_c x h_c) with a door vent that is (4.0 ft) wide x (8.0 ft) high (w_v x h_v). The fire is constant with an HRR$(\dot{Q})$ of 2,000 kW. Compute the hot gas temperature (T_g) in the compartment as well as smoke layer height (z) at 3 minutes after ignition, assuming that the compartment boundaries are made of 0.3048 (12.0 in) thick concrete.

10. Consider a compartment that is 15.25 m wide x 12.2 m long x 3.7 m high (50.0 ft wide x 40.0 ft long x 12.0 ft high) (w_c x l_c x h_c) with a forced ventilation rate of 1,500 cfm. Calculate the hot gas layer temperature (T_g) in the compartment for a fire size $(\dot{Q})$ of 1,800 kW at 5 minutes after ignition, assuming that the compartment boundaries are made of 2.54 cm (1.0 in) thick gypsum board.

11. Consider a compartment that is 13.7 m wide x 15.25 m long x 3.35 m high (45.0 ft wide x 50.0 ft long x 11.0 ft high) (w_c x l_c x h_c) with a forced ventilation rate of 1,800 cfm. Calculate the hot gas layer temperature (T_g) in the compartment for a fire size $(\dot{Q})$ of 2,200 kW at 8 minutes after ignition, assuming compartment boundaries are made of 0.245 m (10.0 in) thick concrete.

12. Consider a pool fire caused by a 30.30liters (8.0 gallons) spill of flammable liquid (lube oil) in 0.38 m^2 (4.0 ft^2) dike area in a compartment with a finished concrete floor. The lube oil is ignited and spreads rapidly over the surface reaching steady burning almost instantly. Compute the HRR, burning duration, and flame height of the pool fire. The dimensions of the compartment are 4.9 m wide x 3.7 m long x 3.0 m high (16.0 ft wide x 12.0 ft long x 10.0 ft high). Two cable trays are located above the pool fire at heights of 1.8 m (6.0 ft) and 2.5 m (8.0 ft), respectively. Determine whether flame will impinge upon the cable trays. Assume instantaneous, complete involvement of the liquid pool with no fire growth and no intervention by the plant fire department or automatic suppression systems.

13. A 75.7-liter (20.0-gallon) trash bag (transient) exposure fire source is located 2.5 m (8.0 ft) beneath a horizontal cable tray. Assumed that the trash fire ignites an area of approximately 0.92 m^2 (10.0 ft^2) of the cable tray, and the cables in the tray are ld PE. Compute the full-scale HRR of ld PE cable insulation. The bench-scale HRR $(\dot{Q}''_{bs})$ of the ld PE type cable material is 1,071 kW/m^2.

14. Assume that heptane from a tank spills on a concrete floor, forming a 0.92 m^2 (10.0 ft^2) pool and exposing a safety-related electrical cabinet in a corridor. The distance from the center of the pool fire to the target (cabinet) edge is 3.7 m (12.0 ft). Calculate the radiative heat flux of the flame to the electrical cabinet with no wind using—
    (a) Point Source Model
    (b) Solid Flame Radiation Model

15. Estimate the maximum plume temperature ($T_{p(centerline)}$) at the ceiling of a 4.6-m (15.0-ft) high room above a 1,500-kW fire involving a 1½-ft high stack of wood pallets in a 0.92-m^2 (10.0-ft^2) pallet area. Assume that the ambient temperature is 25 °C (77 °F).

16. A fire with $\dot{Q}$ = 3,000 kW occurs in a makeup pump room protected with a wet pipe sprinkler system. Fire sprinklers are rated at 74 °C (165 °F) [standard response bulb with RTI 235 $(m\text{-}sec)^{½}$] and are located 3.0 m (10.0 ft) on the center. The compartment ceiling is 5.5 m (18.0 ft) high. Determine whether the sprinklers would activate, and if so how long it would take for them to activate.

17. A fire scenario may arise from failure of a vital 480V AC breaker in a switchgear room. A stack of safety-related cable (IEEE-383 non-qualified PE/PVC) is located 3.0 m (10.0 ft) horizontally from the 480V AC breaker. Assumed that the vital breaker fire produces a maximum flame heat flux of 30 kW/m^2 and the surface of the cable trays is initially at 25 °C (77 °F). Calculate the ignition time (t_{ig}) of IEEE-383 non-qualified PE/PVC cables.

18. A pool fire scenario arises from a rupture in an oil-filled transformer containing (5 gallons) lube oil. This event allows the fuel contents of the transformer to spill along a wall with an area of 1.4 m^2 (15.0 ft^2). A safety-related cable tray is located 4.6 m (15.0 ft) above the pool fire. Calculate the wall flame height of the fire, and determine whether flame will impinge upon the cable tray.

19. A fire scenario arises from a rupture in the housing of a makeup pump containing 30.3 liters (8 gallons) lube oil. This event allows the fuel contents of the pump to spill along a wall with an area of 0.75 m^2 (8.0 ft^2). A cable tray is located 3.7 m (12.0 ft) above the fire. Calculate the flame height of the line fire, and determine whether flame will impinge upon the cable tray.

20. A fire scenario arises from a rupture in an oil-filled transformer in a facility containing (6 gallons) lube oil. This event allows the fuel contents of the transformer to spill along the corners of the walls with an area of 0.55 m^2 (6 ft^2). A cable tray is located 4.3 m (14.0 ft) above the fire. Calculate the corner fire flame height, and determine whether flame will impinge on the cable tray.

21. Calculate the HRR necessary for flashover $(\dot{Q}_{FO})$ in a compartment that is 5.5 m wide x 6.0 m long x 3.7 m high (18.0 ft wide x 20.0 ft long x 12.0 ft high) (w_c x l_c x h_c), with an opening that is 0.60 m (2.0 ft) wide x 1.83 m (6.0 ft) high (w_v x h_v). Assume that the boundary material is concrete and the door is open.

22. Calculate the HRR necessary for flashover $(\dot{Q}_{FO})$ in a cable spreading room (CSR) that is 15.3 m wide x 24.4 m long x 6.0 m high (50.0 ft wide x 80.0 ft long x 20.0 ft high) (w_c x l_c x h_c) with a door opening 1.2 m (4.0 ft) wide x 3.0 m (10.0 ft) high (w_v x h_v). The compartment boundaries are made of concrete and the door is open.

23. Consider a compartment in a facility pump room that is 3.0 m wide x 2.7 m long x 2.5 m high (10.0 ft wide x 9.0 ft long x 8.0 ft high) (w_c x l_c x h_c). A fire starts with a constant effect of 75 kW. Estimate the pressure increase attributable to the expansion of hot fire gases after 15 seconds, assuming that the door is closed.

24. The licensee used UL Design No. 816 to protect a number of unrestrained beams. The licensee's quality assurance (QA) program verified that there is 6.35 cm (2½ in) thickness of fire protection insulation on all of the beams. The size of the tested beam was W12 x 26. Determine whether the 6.35 cm (2½ in) thickness of fire protection insulation is acceptable for a beam that is W8 x 13.

25. A hydrogen line leaks 1 lb. of hydrogen in a turbine building. What is the worst case pressure increase, blast wave, and TNT equivalent.

26. A compartment that is 15.25 m wide x 15.25 m long x 3.7 m high (50 ft wide x 50 ft long x 12 ft high) has a hydrogen leak. What is the volume of gas needed for a deflagration.

INDEX

Note: This is a brief index to quickly assist the user of this document.
For a more thorough search, use the Search feature on the electronic .pdf version.

A

Abbreviations, G-1–G-11
Analogy of hydraulic and electric systems, B-11–B-12

B

Battery rooms hydrogen gas generation, 16-1–16-12
  explosive concentration, 16-1
  Fire Protection Code requirements, 16-7
  flammability limit, 16-2
  hydrogen and other gases concentration calculations, 16-2–16-9
  ignition of hydrogen, 16-1–16-6
  lower explosive limit, 16-1
  prevention and control of combustion, 16-5–16-7
  ventilation, 16-5, 16-10
Beam pockets, 2-23, 12-10
Burner, 3-9
  gas, 3-9, 3-14, 17-1
Burning duration, 3-7
  liquid pool fire, 3-8, 3-18
  solid combustible, 8-1–8-3
Burning rate, 3-1, 3-3, 3-4, 3-6, F-10

C

Cable, A-1
  damage threshold, 2-20, A-15–A-19
  cable fire (Browns Ferry), A-1
  cable material, 7-6, A-2, A-7, A-8
    thermoplastic, A-7
    thermosetting, A-8
  configuration and construction classification, A-2
  description, A-2
  function, 7-1, 7-2, A-3
  insulation of, 1-6, 1-8, A-2–A-4
  types of electrical, 2-20
Cable tray, 7-1–7-6, B-40
  fire hazard, 7-1
  burning mode, 7-2
  factors of behavior in a fire, 7-2
  scenarios, 7-2
  type combustion reactions, 7-3
Calorimetry, oxygen consumption, F-12
  See also Heat Release Rate; Flammability
  Apparatus 3-3, F-12
Ceiling jet, *See* Compartment fire
Char–forming products, 2-17
Combustibles, 1-6 *See also* Fire hazard
  fixed, 1-6–1-8, 2-19, 5-2
  heat release rate, 2-19–2-21, 8-1–8-3
  liquids
    classification, B-17
    definition, B-17
    flashpoint, B-19
    storage, B-20–22
  transient, 1-6–1-8, 2-19, 3-3, 5-2
Combustion, 1-4, 1-5, 2-16, 6-3, F-15
Compartment fires
  stages of, 2-1–2-6
    fire-plume/ceiling jet, 3-12, 4-1
    flashover, 13-1–13-9
  ventilation, 2-4
  pressure rise, 14-1–14-4
Conduction, *See* Heat transfer
Conductivity, *See* Thermal conductivity
Convection, *See also* Ventilation and Heat transfer
  forced, 2-23, 2-24
  natural, 2-23
Corner fire, *See also* Flame;
  height entrainment coefficient, 4-4
Critical temperature, 5-2, 7-5, 17-5–17-10
Critical heat flux (CHF), 2-20, 5-2, 6-5–6-7, 6-12, 6-13

D

Decay stage, 2-17
Defense-in-Depth (DID)
  objectives, 1-2
Deflagration, *See* Explosions
Density, 2-10, F-21
Detontation, *See* Explosions

E

Electronics, thermal effect on, 2-22
Emissivity, 5-2–5-7, C-6, F-22
Energy,
  radiant, 3-8, 5-2
  electromagnetic, 5-1, F-47
Enclosure fire, *See* Compartment fire
Explosions, 15-1–15-15
  characterization, 15-2, 15-3
  confine and unconfined explosions, 15-4
  definitions, 15-1, 15-2
  effects on components, 15-3
  effects on humans, 15-11
  energy release and effects, 15-5–15-11
  hazard associated with deflagration, 15-3
  flammable mixture, 15-3
  fuel vapor backdraft explosion, 15-4
  limits, boundaries and range, 15-4
  pressure increase due to explosion, 15-1
  pressure increase estimation, 15-13
  smoke explosion, 15-4

F

Fan, 2-4, 2-5
Fire classifications, B-13, B-14
  extinguishing mechanism, B-16
Fire computational models, B-78–B-88
Fire dynamics
  definition, 1-1
  Fire Dynamics Tools (FDTs), 1-1
  process of fire development, 1-4–1-6
Fire events in nuclear power plants, H-1–H-33

Fire extinguishing agents, B-16
  carbon dioxide system, B-46–B-52
  dry chemical, B-55–B-57
  foam extinguisher, B-58–B-64
  halon, B-41–B-46
Fire growth, B-1–B-10
  flame and heat growth, C-5
Fire hazard, 1-1–1-9, 2-19
  classification, B-14
  common fires, 1-5
  Fire Hazard Analysis (FHA), 1-3, 5-2
  fire load, 1-6, F-26
  fire location, 1-9
  practice problems and solution, J-1–J-134
  quantitative fire hazard analysis, I-1–I-17
  sources, 1-4
Fire plumes, *See also* Compartment fire and Flame
  buoyant axisymetric, 3-16, 4-1, 9-3
  characteristics, 9-3
  definition, 2-3, 9-1, F-45
  regimes, 3-13, 9-3
  centerline temperature, 9-4–9-7
  virtual origin, 9-5
  ceiling jet formation importance, 9-7
Fire protection, 1-1
  inspection findings, 1-3
  Nuclear Regulatory Commission (NRC) documents, D-1–D-44
  National Fire Protection Association codes, E-1–E-13
  program objectives, 1-1
  risk-informed, performance-based design basis, 1-9, F-49
Fire resistance, F-10
  construction type, B-36–B-38
  definition, C-6, F-10
  fire barriers endurance ratings, C-9–C-11
  test and standards, C-12–C-18
  ratings, B-8–B-11
Fire scenario, 2-19, F-28
Flame, 3-10
  categories, 3-10–3-12
  spread rates of flammable/combustible, 3-6, 6-10–6-11
  height, 3-8, 3-16
    liquid pool fire, 3-17
    wall fire, 4-1–4-3
    line fire, 4-1–4-3
    corner fire, 4-1, 4-4
  hydrogen, 3-8
  oxygen-acetylene, 3-12
  pulsing behavior, 3-12, 3-16
  regimes, 3-13, 4-1
  spread rates of flammable/combustible liquid, 3-6
  temperature, 3-16–3-18, 5-2
    adiabatic, 3-19, 3-20
Flammable gases
  classification, B-28
  deflagration-to-detonation transition (DDT), B-30
  explosive limits, B-30
  explosion prevention methods, B-30, B-31
  flammable limits, B-28
  hydrogen, B-33, B-34
Flammable liquids, B-17
  classification, B-17
  definition, F-31
  flashpoints, B-17
  storage, B-20, B-21
Flashover, 13-1–13-9
  definitions, 13-3, F-32
  experimental observations, 13-4
  flashover prediction in compartments, 13-1–13-6
  incipient period, 13-1
  methods to predict HRR compartment flashover, 13-5, 13-6
  methods to predict temperature compartment flashover, 13-7
  physical characteristic, 13-3
  stages, 13-3
Fuel, 3-1 *See also* Combustible & hazard materials
  chemistry, 3-7
  hydrocarbons, 3-3
  limited fires, 2-4
  liquid fuels, 1-8, 6-2
  loading, 3-1
  solid fuels, 6-1, 6-2
    thermal properties, 8-2
Fuel ignition, 6-1–6-13
  by radiative heat flux, 6-12, 6-13
  ignition time, 6-1, 6-4, 6-7, 6-8, 6-10, 15-10
  ignition temperature, 6-10, 6-11, 15-10
  flash point, 6-1
  piloted ignition, 6-1
  auto-ignition, 6-1
  heat flux sources, 6-4
  thermal response parameter (TRP), 6-5, 6-6

G

Gases, 2-14
  combustion toxic effluents, B-78
  hot, 2-14, 3-16
  layer, 2-8, 2-25
  plume of hot, 3-16
  temperature, 2-8, 2-13
  self ignite, 2-6

H

Heat capacity, 2-10, F-35
Heat detectors, 12-1–12-10
  response time index, 12-6 –12-8
  operational temperature limits, 12-1–12-2
  heat detector types, 12-2–12-5
  activation temperature calculation, 12-5
Heat of combustion, 2-20, 3-3–3-6, F-35

Heat release rate (HRR), 2-16–2-25
cable trays, 7-3, 7-4
curves, 2-18
data tables, 2-20–2-22
liquid pool fire, 3-1–3-4
bench-scale, 6-6, 7-3, 7-4
flammability apparatus, 6-5
Heat resistance of target fuel, C-4
Heat sources, C-2
heat intensity, C-2, C-3
heat flux, C-2, C-3
heat quantity, C-2
duration, C-2, C-3
incident heat, C-3
Heat transfer, 5-1
coefficient, 2-9–2-13
radiative (radiation), 3-17, 4-2, 5-2
convection, 5-1
conduction, 5-1
Horizontal fire, *See* Pool fire

I

Ignition threshold, 2-22, A-11–A-14
Incident heat flux, 2-10, 5-2, C-3, F-67
Inspection findings, 1-3

J

Jacketing materials, *See* Cable

L

Line fire, 4-2 *See also* Flame; height
geometry, 4-2, 4-3
entrainment coefficient, 4-2

M

Mass loss rate, 2-4, 3-3, 3-5, F-41
Metal combustion properties, B-29–B-31
extinguishing agents, B-31
melting, boiling and ignition temperature, B-30

N

Noncombustible ceiling, 4-4
Nuclear power plants,
fire hazard analysis, 1-3

O

Oxygen consumption, 3-3, 6-5, F-12

P

Performance-based, *See* Fire protection
Point source, *See* Radiation models
Pool Fires, 3-1–3-8, 3-14, 5-4
burning duration, 3-8
burning modes, 3-4
circular, 3-18
nuclear power plants (NPP), 3-4, 3-5
non-circular, 3-18, 5-4
Post-fire safe shutdown, 7-1
Post-flashover vented fire, *See* Compartment fire
Pre-flashover vented fire, *See* Compartment fire
Pyrolysis, 6-3, 7-3–7-5, F-46

Q

Quasi-steady balance, 2-8, 2-23

R

Radiation, 5-2 *See also* Heat transfer
spherical source, 5-3
Radiation models, 5-1
configuration factor, 5-2
point source, 5-2–5-5
solid flame, 5-4–5-17
Risk informed, *See* Fire protection

S

Scenario, *See* Fire scenario
Smoke detector, 11-1–11-11
alarm condition, 11-6
performance, 11-1–11-3
response parameter, 11-8
response time, 11-1
type of smoke detectors, 11-3–11-6
Smoke layer, 2-14–2-16
cool gas layer, 2-14
filling, 2-12–2-15
height estimation, 2-13, 2-17, 2-23
hot gas layer, 2-13, 2-14, 2-23
interface position, 2-15
visibility through smoke, 18-1–18-5
Smoldering, 6-3, F-55
Solid flames, *See* Radiation model
Sprinkler, 2-22, 3-16, 10-1–10-12
heat transfer characteristics, 10-3
installation configuration, 10-2
main function, 10-3
operating principles, 10-3
plume interaction, 10-13
response time, 10-1
types of automatic sprinklers, 10-1–10-3
sprinkler dynamics, 10-4
operational temperature, 10-5–10-8

Spills, 3-18
liquid fuel, 3-5, 4-1, 5-3
fuel volume of, 3-18, 4-5
fuel area, 3-18, 4-5
Structural building components, 17-1
building fire resistance rating, 17-3, 17-4
fire walls and fire barriers, 17-7–17-8
Structural steel, 17-1
beam, 17-16, 17-17
column, 17-1
failure criteria, 17-6
fire resistance calculation, 17-12–17-16
fire resistance classification, 17-1
fire resistance coatings, 17-9–17-12
protection methods, 17-4, 17-5, 17-13,
scenarios, 17-3, 17-4
temperature limits, 17-6
unloaded columns criteria, 17-4
unprotected steel columns, 17-2–17-12
numerical methods for temperature increase, 17-20–17-23

T

Tail stage, 2-17
Thermal capacity, 2-10, 2-11, F-35
Thermal conductivity, 2-10, 2-11, F-64
Thermal feedback, 2-1, 2-24, 13-6
Thermal Inertia, 2-10, 2-11, F-64
Thermal insulators, 2-10, 6-5
Thermal penetration time, 2-10, F-65
Thermal radiation, 5-1–5-16
field of flames, 5-3
hazard, 5-3
Thermoplastic, *See* Cable
Thermosetting, *See* Cable
Turbulent diffusion flame, 3-14, 4-5

V

Ventilation, 2-4
forced ventilation, 2-4, 2-5, 2-12, 2-13, 2-24
limited or controlled, 2-4
make up air, 2-4
natural ventilation, 2-8–2-12, 2-15, 2-24
Vulnerability
Fire-Induced Vulnerability Evaluation Method (FIVE), 2-19, 5-2

NRC FORM 335
(2-89)
NRCM 1102,
3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See instructions on the reverse)

1. REPORT NUMBER
(Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, if any.)

NUREG-1805

2. TITLE AND SUBTITLE

Fire Dynamics Tools (FDTs):
Quantitative Fire Hazard Analysis Methods
for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program

Final Report

3. DATE REPORT PUBLISHED

MONTH	YEAR
December	2004

4. FIN OR GRANT NUMBER

5. AUTHOR(S)

Naeem Iqbal, Mark Henry Salley

6. TYPE OF REPORT

Technical

7. PERIOD COVERED *(Inclusive Dates)*

8. PERFORMING ORGANIZATION - NAME AND ADDRESS *(If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)*

Division of Systems Safety and Analysis
Office of Nuclear Reactor Regulation
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

9. SPONSORING ORGANIZATION - NAME AND ADDRESS *(If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)*

Same as 8, above

10. SUPPLEMENTARY NOTES
Sunil Weerakkody, NRC Project Manager and Fire Protection Section Chief

11. ABSTRACT *(200 words or less)*

The U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Reactor Regulation (NRR), Division of Systems Safety and Analysis (DSSA), Plant Systems Branch (SPLB), Fire Protection Engineering and Special Projects Section has developed quantitative methods, known as “Fire Dynamics Tools (FDTs),” to assist regional fire protection inspectors in performing fire hazard analysis (FHA). These methods have been implemented in spreadsheets and taught at the NRC’s quarterly regional inspector workshops. FDTs were developed using state-of-the-art fire dynamics equations and correlations that were preprogrammed and locked into Microsoft Excel® spreadsheets. These FDTs will enable the inspector to perform quick, easy, first-order calculations for the potential fire scenarios using today’s state-of-the-art principles of fire dynamics. Each FDTs spreadsheet also contains a list of the physical and thermal properties of the materials commonly encountered in nuclear power plants. This NUREG addresses the technical bases for FDTs, which were derived from the principles developed primarily in the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, National Fire Protection Association (NFPA) Fire Protection Handbook, and other fire science literature. The subject matter of this NUREG covers many aspects of fire dynamics and contains descriptions of the most important fire processes. A significant number of examples, reference tables, illustrations, and conceptual drawings are presented in this NUREG to expand the inspector’s appreciation in visualizing and retaining the material and understanding calculation methods.

12. KEY WORDS/DESCRIPTORS *(List words or phrases that will assist researchers in locating the report.)*

Fire Dynamics
Hazard Analysis
Inspection
Significance Determination Process
Risk-Informed Evaluation

13. AVAILABILITY STATEMENT
unlimited

14. SECURITY CLASSIFICATION
(This Page)
unclassified
(This Report)
unclassified

15. NUMBER OF PAGES

16. PRICE

The NRC's mission is to regulate the Nation's civilian use of byproduct, source, and special nuclear materials to ensure adequate protection of public health and safety, to promote the common defense and security, and to protect the environment.