## 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 | $\mathrm{FDT}^{\text {s }}$ |
| :---: | :---: | :---: |
| J-1 | Chapter 2. Predicting Hot Gas Layer Temperature and Smoke Layer Height in a Room Fire with Natural and Forced Ventilation <br> 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 <br> Method of Foote, Pagni, and Alvares (FPA) <br> Compartment with Thermally Thick/Thin Boundaries <br> Method of Deal and Beyler <br> 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 <br> Method of McCaffrey, Quintiere, and Harkleroad (MQH) Compartment with Thermally Thick/Thin Boundaries <br> Chapter 2. Method of Predicting Hot Gas Layer Temperature in Room Fire with Forced Ventilation <br> Method of Foote, Pagni, and Alvares (FPA) Compartment with Thermally Thick/Thin Boundaries <br> Method of Deal and Beyler Compartment with Thermally Thick/Thin Boundaries | 02.1_Temperature_NV.xls <br> 02.2_Temperature_FV.xls |
| J-4 | Chapter 3. Estimating Burning Characteristics of Liquid Pool Fire, Heat Release Rate, Burning Duration and Flame Height <br> 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 ${ }^{\text {s }}$ |
| :---: | :---: | :---: |
| 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 <br> Wall_Line_Flame_Height <br> Corner_Flame_Height <br> 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 <br> Method of Foote, Pagni, and Alvares (FPA) Compartment with Thermally Thick/Thin Boundaries <br> 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 <br> Solid Flame Radiation Model (Target Above Ground Level, with Wind) | ```05.2_Heat_Flux_Calculations_W ind_Free.xls (Solid Flame 2)``` |
| J-8 | Chapter 6. Estimating the Ignition Time of a Target Fuel Exposed to a Constant Radiative Heat Flux <br> 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_Calcul ations.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 | $\mathrm{FDT}^{\text {s }}$ |
| :---: | :---: | :---: |
| J-13 | Chapter 13. Predicting Compartment Flashover Compartment Post-Flashover Temperature. <br> Method of Law. <br> Minimum Heat Release Rate Required to Compartment Flashover. <br> Method of (1) McCaffrey, Quintiere, and Harkleroad (MQH), (2) Babrauskas, and (3) Thomas | 13_Compartment_Flashover_ Calculations.xls <br> (Post_Flashover_Temperature) <br> (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 <br> 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 <br> Wind-Free Condition <br> Point Source Radiation Model <br> (Target at Ground Level) <br> Solid Flame Radiation Model <br> (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_ <br> Calculations.xls <br> (Flashover-HRR) |

NUREG Chapter and Related Calculation Methods

| Problem | NUREG Chapter | FDT $^{\text {s }}$ |
| :--- | :--- | :--- |
| J-17 | Chapter 3. Estimating Burning Characteristics <br> of Liquid Pool Fire, Heat Release Rate, <br> Burning Duration, and Flame Height <br> Chapter 2. Predicting Hot Gas Layer Temperature <br> and Smoke Layer Height in a Room Fire with Natural <br> and Forced Ventilation <br> Method of McCaffrey, Quintiere, and Harkleroad (MQH) <br> Compartment with Thermally Thick/Thin Boundaries | 03_HRR_Flame_Height_Burning <br> Duration_Calculations.xls |
| J-18 | Chapter 3. Estimating Burning Characteristics <br> of Liquid Pool Fire, Heat Release Rate, <br> Burning Duration, and Flame Height <br> Chapter 8. Estimating Burning Duration <br> of Solid Combustibles | $02.1^{\text {Con_Temperature_NV.xls }}$ |

## Problem J-1

## Problem Statement

Consider a compartment 9.0 m wide $\times 9.0 \mathrm{~m}$ long x 3.7 m high ( 30 ft wide $\times 30 \mathrm{ft}$ long x 12 ft high ) $\left(w_{c} \times I_{c} \times h_{c}\right)$ with a door vent that is 0.92 m wide $\times 2.15 \mathrm{~m}$ high ( 3 ft wide $\times 7 \mathrm{ft}$ high $)\left(\mathrm{w}_{\mathrm{v}} \times \mathrm{h}_{\mathrm{v}}\right)$. The fire is constant with an HRR of $1,500 \mathrm{~kW}(1,422 \mathrm{Btu} / \mathrm{sec})$. Assume that the top of the vent is at $2.45 \mathrm{~m}(8 \mathrm{ft})$. 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 $\left(T_{g}\right)$ at $t=5 \mathrm{~min}$ after ignition.
(2) Determine the smoke layer height $(z)$ at $t=5 \mathrm{~min}$ after ignition.

Assumptions:
(1) Air properties (ambient) are at $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$.
(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 $\mathrm{FDT}^{\mathrm{s}}$ :
(a) 02.1_Temperature_NV.xls

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):

- Compartment Width $\left(\mathrm{w}_{\mathrm{c}}\right)=30 \mathrm{ft}$
- Compartment Length ( $\mathrm{I}_{\mathrm{c}}$ ) $=30 \mathrm{ft}$
- Compartment Height $\left(h_{c}\right)=12 \mathrm{ft}$
- Vent Width $\left(\mathrm{w}_{\mathrm{v}}\right)=3 \mathrm{ft}$
- Vent Height $\left(h_{v}\right)=7 \mathrm{ft}$
- Top of Vent from Floor $\left(\mathrm{V}_{\mathrm{T}}\right)=8 \mathrm{ft}$
- Interior Lining Thickness $(\delta)=1$ in
- Select Material: select Gypsum Board from the combo box
- Fire Heat Release Rate $(\dot{Q})=1,500 \mathrm{~kW}$
- Time after Ignition ( t ) $=5 \mathrm{~min}$

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 $\mathrm{t}=5$ minutes after ignition we obtain:

| Hot Gas Layer Temperature <br> $\mathrm{T}_{\mathrm{g}}{ }^{\circ} \mathrm{C}\left({ }^{\circ} \mathrm{F}\right)$ | Smoke Layer Height <br> $\mathrm{z} \mathrm{m}(\mathrm{ft})$ |
| :--- | :--- |
| $351(664)$ | $2.44(8.00)$ <br> smoke is exiting through the vent |

*spreadsheet calculations attached on next page

## Spreadsheet Calculations

FDTs': 02.1_Temperature_NV.xls

CH APTER 2. PREDICTIIIG HOT GAS LAYER TEMPERATURE AIID SMOKE
LAYER HEIGHT III A ROOMFIRE WITH HATURAL VEIITILATIOH
COMPARTME IIT WITH THERMALLY THICK/THIII BOUHDARIES
Version 18050
The obowig calcintors esthate the rot gas byer temperature and smoke tyer he git erchsire fre.
Parameters In YELLOWCELLS are Entered by the User.
ParameteriIn GREEN CELLS are Automatically selectedtom the DROP DOWN MENU tor the materlal selected.
Alls ibsequento ipit values are calculat dby the spreakleetand base don values specredit the lupit

The clapter in the NUREG stouthbe readbetire at atalys k made.

## IIIPUT PARAMETERS

COMPARTMEIIT IIIFORMATION

| EIIT IINFOR MATION |  |  |
| :---: | :---: | :---: |
| Compartne it Wtith $\mathrm{N}_{\text {c }}$ ) | 30.00 | 2144 m |
| Compartne it Leigth (1) | 30.00 | 2.144 m |
| Comparme it He git ( ) | 12.00 | 3.enta m |
| Ve itwkith (W) | 3.00 | 0.934 |
| Veithetit (i) | 7.00 | 2.134 m |
| Top of Vestrom Fbor ( $V$ ) | 8.00 | 2433 m |
| Interbr Lingioti Ekiess (9) | 1.00 | 0.0254 m |


| AMBIENT CONDTIOHS |  |
| :---: | :---: |
| AmbleıtAr Temperature ( $\mathrm{T}_{\text {\% }}$ ) | 77.00 |
| Specme Heator Alr en) | 1.00 |
| Ambleıtar Dessly, (P) | 1.18 |
| THER MAL PROPERTIES OFOOMPARTMENT EICCLOS IIIG SURFACES FOR |  |
| Interlor Lining Tremal lie rth of(c) | 0.18 |
| Interbr Linlig Themal Condictult/ (\%) | 0.00017 |
| Interlor LiningSpecife Heat (c) | 1.1 |
| Interlor Linin Densty ${ }^{(p)}$ | 960 |

Interbr Lisig Desty $(\bar{\rho}$ )
$960 . \mathrm{gm}^{2}$

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

| Mat tal |  | EWMA-10 |  | $\begin{aligned} & \mathrm{p} \\ & \lg / \mathrm{m}) \\ & \hline \end{aligned}$ | Select Material <br> GiDsum Eoard |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Alum intim pire) <br> Stel (0.5** Carbor) <br> Concret <br> Brlk <br> Glass, Plat <br> BribkCOncet Ebck <br> Gypsim Board <br> Pl/wood <br> Fber lus iktbi Board <br> Cipboard <br> AR ned COICRE <br> Plateriboard <br> Cakcinm Sllbat Boasl <br> Alum Ina Sllibat block <br> Glass Fber list atbor <br> Expanded Poyst/rene <br> User Specmed Vahe |  | 0.206 <br> 0.054 <br> 0.0016 <br> 0.0006 <br> 0.00076 <br> 0.00073 <br> 0.00017 <br> 0.00012 <br> 0.00053 <br> 0.00015 <br> 0.00026 <br> 0.00016 <br> 0.00013 <br> 0.00014 <br> 0.000037 <br> 0.000034 <br> Eit r Value | 0.895 0.455 0.75 0.8 0.8 0.84 1.1 2.5 1.25 1.25 0.96 0.84 1.12 1 0.8 1.5 Eit r Value | 2710 7850 2400 2500 2710 1900 960 540 240 800 500 950 700 260 60 20 Eıt r Valıe | Seroll to desired materlal then Click the selection |

Fire Heat Release Rate (0) $\quad 1500.00 \mathrm{kw}$

Calculate
METHOD OF McCAFFREY, QUIIITIERE, AIID HARKLEROAD (MOH)
Reverence: SFPE Hiwhtion of Five Piorection Englueerhg, 3 Elllon, 2002, Page 3-175.
$\left.\dot{\mu} T_{1}=6.85\left[0^{2} /\left(A^{(h)}\right)^{12}\right)\left(A h_{V}\right)\right]^{1 a}$
Where $\quad \Delta T_{3}=T_{B}-T_{a}=$ upper layer gas temperature rise abo ve ambient ( $K$ )
$0=$ heat release rate ofthe fire (kif)
$A=$ area of ventilation opening ( $\mathrm{m}^{2}$ )
$h_{v}=$ height of ventilation opening (m)
$h_{\text {. }}=$ convective heat transfer coefficient ( $\mathrm{k}_{\mathrm{h}}^{\left.\mathrm{h} \mathrm{hm}^{2}-\mathrm{K}\right) ~}$
$A=$ total area ofthe compartment enclosing surface boundaries exoluding area of went openings (m)
Area of Ventilation Opening Calculation

```
A = (w.)(h)
Where A}= = area of ventilation opening (m
w w
hv = vent height (m)
A = 1.95m
```

Thermal Penetration Time Calculation
$t_{1}=\quad(\rho c / k)(5 / 2)^{2}$
Where $\quad t_{p}=$ themal penetration time (sec)
$\rho=$ interior construction densit $v$ ( $\mathrm{k} / \mathrm{m} / \mathrm{m}$ )
$\mathrm{c}_{\mathrm{p}}=$ interior construction heat capacity ( $\mathrm{k} / \mathrm{kg}-\mathrm{K}$ )
$\mathrm{k}=$ interior construction themal conductivity (kiohm-K)
$\delta=$ interior construction thickness (m)
$t_{1}=\quad 1001.90$ sec
Heat Transfer Coefficient Calculation

| h. | w(kpot) | (k/6) | t |
| :---: | :---: | :---: | :---: |

Where $\quad h_{k}=$ heat transter coefficient $\left(\mathbf{k} 0 / \mathrm{m}^{2}-\mathrm{K}\right)$
$\mathrm{k} \rho \mathrm{c}=$ interior construction themal inertia $\left(\mathrm{k} 0 / \mathrm{N}_{\mathrm{m}} \mathrm{m}^{2}-\mathrm{K}\right)^{2}-\mathrm{sec}$
(a thermal property of material responsible forthe rate oftemperature rise)
$\mathrm{t}=$ time after ignition (sec)
See table below for results
Area of Compartmert Enclosing Surface Boundaries
$A=\quad\left[2\left(w_{0} \times 1\right)+2(h \times w)+2(h \times l e)\right] \cdot A$
Where $\quad A_{v}=$ total area ofthe compartment enclosing surface boundaries excluding area of vent openings ( $\mathrm{m}^{2}$ )
$w_{c}=$ compartment width (m)
$\mathrm{I}_{\mathrm{c}}=$ compartment lengh (m)
$h_{\text {: }}=$ compartment height ( m )
$A=$ area of ventilation opening ( m )
$\mathrm{A}=\quad 299.05 \mathrm{~m}$
Compartment Hat Gas Laver Temperature With Natural Ventilation
$\left.\dot{4} \mathrm{~T}_{\mathrm{s}}=6.85\left[\mathrm{Q}^{2} \mathrm{MA}(\mathrm{h}) \mathrm{H}^{\prime 2}\right)(\mathrm{Ah})\right]$
$\dot{\Delta} \mathrm{T}_{\mathrm{s}}=\quad \mathrm{T}_{8} \cdot \mathrm{~T}_{\mathrm{a}}$
$T_{19}=\quad \Delta T_{1}+T_{a}$

Result

| Time After Ignition (t) |  | $\begin{gathered} \mathrm{h}_{\mathrm{k}} \\ \text { awin }-19 \end{gathered}$ | $\overline{\Delta \mathbf{T}_{a}}$$(0)$ | $\begin{aligned} & \mathrm{T}_{0} \\ & 0 \\ & \hline \end{aligned}$ | $\begin{gathered} \mathrm{T}_{9} \\ \mathrm{C}) \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{T}_{\mathrm{a}} \\ \text { (F) }) \\ \hline \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (ta) | (sec) |  |  |  |  |  |
| 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=(63*Q t/3A)+(1/4
Wher zosmoke taver leggitm;
    Q = leatrelease rat ofthe Tre (NW)
    t= the atter kgitbi (sec)
    l= compartnestlegglt (m)
    Ac compartmestfbor are a (m)
    k = a constaitgles by k=0.076/p
    p}=1\mathrm{ ot gas ka/erde 1s It/ (kg/m)
    p, & glve: by P
    T}=1\mathrm{ lotgas myer emperatu R (%)
Compartment Area Calculation
A= (W) (1)
Where }\mp@subsup{\textrm{A}}{c}{}=\mathrm{ compartnettiborarea (mo)
    w
    l= compatme it eigtu(i)
A= }\quad83.61\textrm{m
Hot Ga: Laver Densit/ Calculation
P}= 353/
Calc ulation for Cons tant \(K\)
```

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

| Time <br> ( m n ) | ${\underset{(k g i m}{m})}_{\infty}$ | Conctant (k) <br> (kWWm-k | $\begin{gathered} \text { Smoke tayer helght } \\ \mathbf{z ~ g n )} \end{gathered}$ | $\begin{gathered} \text { Smoke tayer heloht } \\ z(10 \\ \hline \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 1.18 | 0.064 | 3.66 | 12.00 |
| 1 | 0.64 | 0.118 | 2.44 | 8.00 |
| 2 | 0.61 | 0.124 | 2.44 | 8.00 |
| 3 | 0.69 | 0.129 | 2.44 | 8.00 |
| 4 | 0.68 | 0.132 | 2.44 | 8.00 |
| 5 | 0.67 | 0.134 | 2.44 | 8.00 |
| 10 | 0.63 | 0.143 | 2.44 | 8.00 |
| 15 | 0.61 | 0.148 | 2.44 | 8.00 |
| 20 | 0.44 | 0.172 | 2.44 | 8.00 |
| 26 | 0.44 | 0.172 | 2.44 | 8.00 |
| 30 | 0.44 | 0.172 | 2.44 | 8.00 |
| 36 | 0.44 | 0.172 | 2.44 | 8.00 |
| 40 | 0.44 | 0.172 | 2.44 | 8.00 |
| 45 | 0.44 | 0.172 | 2.44 | 8.00 |
| 60 | 0.44 | 0.172 | 2.44 | 8.00 |
| 66 | 0.44 | 0.172 | 2.44 | 8.00 |
| 60 | 0.44 | 0.172 | 2.44 | 8.00 |

CAUTION: SMOKEIS EXITIMGOUT VEMT CAUTION: SMOKEIS EXITIMGOUT VEHT CA UTION: OMOKEIS EXITIMGOUT VEHT CAUTION: OMOKEIS EXITIMGOUT VEHT CAUTION: MMOKEIS EXITIMGOUT VEHT CAUTIOK: SMOKEIS EXITIMGOUT VERT CAUTION: OMOKEIS EXITIMGOUT VEHT CAUTIOK: SMOKEIS EXITIMGOUT VEHT CAUTION: GMOKEIS EXITIMGOUT VEHT CAUTIOR: OMOKEIS EXITIMGOUT VEHT CAUTION: BMOKEIS EXITIMGOUT VEHT CAUTION: SMOKEIS EXITIMGOUT VEHT CAUTION: SMOKEIS EXITIMGOUT VEHT CAUTION: MMOKEIS EXITIMGOUT VEHT CAUTIOR: SMOKEIS EXITIMGOUT VEN CAUTIOK: MMOKEIS EXITIMGOUT VENT


NOTE
The above calculalons are based on princliks de veloped in lie SFPE Haybock of fre prokelon Englineering, 3 Ellion, 2002
alaitalons are based on cerlah atsump bons and have inverenillmilatons. Tie re sult of sukh calcuablons may or may nollave rearonable predictere capab illes for a glven silualion, and shoub orty be inkerpre ked by an Imbrimed ure r.
 here it mo absokule guranke of the accurag of livese calculatont.
Any que sions, com ments, concerns, and sugges lons, or bo reporian error(s) In the sprealste el, please send an em al lo nis erregou.


## Problem J-2

## Problem Statement

Consider a compartment 12.0 m wide $\times 12.0 \mathrm{~m}$ long $\times 3.7 \mathrm{~m}$ high ( 40.0 ft wide $\times 40.0 \mathrm{ft}$ long $\times 12.0 \mathrm{ft}$ high) $\left(w_{c} \times I_{c} \times h_{c}\right)$ with a forced ventilation rate of $3.78 \mathrm{~m}^{3} / \mathrm{s}(8,000 \mathrm{cfm})$. Calculate the hot gas layer temperature in the compartment for a fire size $(\dot{Q})$ of $2,000 \mathrm{~kW}(1,896 \mathrm{Btu} / \mathrm{sec})$ 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 $\left(\mathrm{T}_{\mathrm{g}}\right)$ at $\mathrm{t}=5 \mathrm{~min}$ after ignition.

Assumptions:
(1) Air properties (ambient) are at $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$.
(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 $=1 \mathrm{~atm}$ ).

Spreadsheet (FDT ${ }^{s}$ ) Solution Procedure:
Use the following FDTs
(a) 02.2_Temperature_FV.xIs

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in both spreadsheets (values only):

- Compartment Width $\left(\mathrm{w}_{\mathrm{c}}\right)=40 \mathrm{ft}$
- Compartment Length ( $\mathrm{I}_{\mathrm{c}}$ ) $=40 \mathrm{ft}$
- Compartment Height $\left(\mathrm{h}_{\mathrm{c}}\right)=12 \mathrm{ft}$
- Interior Lining Thickness ( $\delta$ ) $=2$ in
- Select Material: select Gypsum Board from the combo box
- Compartment Ventilation Rate ( $\dot{\mathrm{m}}$ ) $=8,000 \mathrm{cfm}$
- Fire Heat Release Rate ( Q$)=2,000 \mathrm{~kW}$

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 $\mathrm{t}=5$ minutes after ignition we obtain:

| Hot Gas Layer Temperature* $\mathrm{T}_{\mathrm{g}}{ }^{\circ} \mathrm{C}\left({ }^{\circ} \mathrm{F}\right)$ |  |
| :--- | :--- |
| Method of Foot, Pagni, and <br> 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 layertemperature and smoke layer height in enclosure ire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Atomatically Selected from the DROP DOWN M ENU for the Material Selected.
Al subsequent output values are calculated bythe spreadsheet and based on value s specified in the input
parameters. This spreadstheet 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 Mofth ( $\mathrm{m}_{\mathrm{c}}$ ) | $4000 \pi$ | 12.19 m |
| Compartment Length (1) | $4000 \pi$ | 12.19 m |
| Compartment Height (h) | 1200 t | 3.65 m |
| Interior Lining Thickness (s) | 20011 | 0.0508 m |
| AMBIENT CONDITIONS |  |  |
| Ambient Air Temperature ( $\mathrm{T}_{3}$ ) | $7700{ }^{\circ}$ | $25.00^{\circ} \mathrm{C}$ |
|  |  | 296.50 K |
| Specific Heat of Air ( $\mathrm{c}_{p}$ ) | 100 kJkgh |  |
| Ambient Air Density ( $P$ ) | $1.18{ }^{\text {kgm }}$ |  |
| THERMAL PROPERTIE S OF COMPARTMENT ENCLOSING SURFACES |  |  |
| Interior Lining Thermal Inertia (kpo) |  |  |
| Interior Lining Thermal Conductivity (k) | 0.00017 kWm - |  |
| Interior Lining Specific Heat (c) | 1.1 kJkgH |  |
| Interior Lining Density ( $p$ ) | $960 \mathrm{kq4}$ |  |
| Note: Air densitywill automatically comect with Ambient Air Temperature ( $\mathrm{T}_{2}$ ) Input |  |  |

## THERMAL PROPERTIES FOR COMMOII IIITERIOR LIIIIIG MATERIALS

| Material | $\begin{aligned} & k \rho c \\ & \left(k \omega_{i} k \pi^{2} \cdot K\right)^{2} \cdot \sec \end{aligned}$ | $\begin{aligned} & \mathrm{k} \\ & \mathrm{k}(\mathrm{k} / \mathrm{j} / \mathrm{m}-\mathrm{K}) \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{c} \\ & (\mathrm{k} \cdot / \mathrm{kg} \cdot \mathrm{~K}) \end{aligned}$ | $\begin{aligned} & \mathrm{p} \\ & \left(\mathrm{~kg} \mathrm{~km}^{3}\right) \end{aligned}$ | Select Material <br> Gypsum Ecard |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Auminum (pure) | 500 | 0.206 | 0895 | 2710 | Scroll to desired material then |
| Steel (0.5\% Carbon) | 197 | 0.054 | 0.465 | 7850 | Click on selection |
| Conerete | 29 | 0.0016 | 0.75 | 2400 |  |
| Brick | 1.7 | 0.0008 | 08 | 2600 |  |
| Glass, Plate | 1.6 | 0.00076 | 08 | 2710 |  |
| Brick/Concrete Block | 12 | 0.00073 | 084 | 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 | 125 | 240 |  |
| Chipboard | 0.15 | 0.00015 | 125 | 800 |  |
| Aerated Concrete | 0.12 | 0.00026 | 0.96 | 500 |  |
| Plasterboard | 0.12 | 0.00016 | 084 | 950 |  |
| Calcium Silicate Boand | 0098 | 0.00013 | 1.12 | 700 |  |
| Aumina Silicate Block | 0036 | 0.00014 | 1 | 260 |  |
| Glass Fiber hsulation | 00018 | 0.000037 | 08 | 60 |  |
| Expanded Polystyrene | 0001 | 0.000034 | 15 | 20 |  |
| User Specified Value | Enter Value | Enter Value | Enter Value | Enter Value |  |


| COMPART MENT MASS VENTILATION FLOW RATE <br> Forced Ventilation Flow Rate (m) | 8000.00 cmn | 3.776 m mec 4.472 kg asec |
| :---: | :---: | :---: |
| FIRE SPECIFICATIONS |  |  |
| Fire Heat Release Rate ( $Q$ ) | 2000.00 kw |  |
|  | Calculate |  |

## METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reterice: SFPEHandlook of Fle Piotcton Engheering, $3^{\text {E }}$ Editbi, 2002, Page 3-177.
$\Delta T_{g} / T_{a}=0.63\left(Q / m_{p} T_{a}\right)^{0.72}\left(h_{4} A_{T} / m c_{p}\right)^{-0.35}$
Where $\quad \Delta T_{g}=T_{g}-T_{a}=$ upper layer gas temperature rise above ambient ( $k$ )
$\mathrm{T}_{\mathrm{s}}=$ ambient air temper ature ( $(\mathrm{K})$
$Q=$ heat release rate of the fire (kiof)
$m=$ compartment mass ventilation flow rate (kg/sec)
$\omega_{p}=$ specific heat of air (kJ/kg-K)
$\mathrm{k}_{\mathrm{k}}=$ convective heat transfer coefficient $\left(\mathrm{k} / \mathrm{m} / \mathrm{m}^{2}-\mathrm{K}\right)$
$A_{T}=$ total area of the compartment enclosingsurface boundaries ( $\mathrm{m}^{2}$ )
Thermal Peneration Time Calculation
$t_{p}=\quad\left(\rho \rho_{\mu} k\right)(5 / 2)^{2}$
Where $\quad \phi=$ thermal penetration time (sec)
$\rho=$ interior construction dersity $\left(\mathrm{kg}^{\prime} / \mathrm{m}^{3}\right)$
$\phi_{0}=$ interior construction heat cap acity ( $\mathrm{kJ} / \mathrm{kg}$. $)$
$k=$ interior construction thermal conductivity $(k) W / m$, $)$
$\delta=$ interior construction thickness (m)
$t_{p}=\quad 4007.58 \mathrm{sec}$
Hea Transer Coefficient Calculation
$h_{k}=\quad v(k \rho \cos )$ for $t<t_{p} \quad$ or $\quad(k \infty)$ for $t>t_{b}$

Where $\quad h_{k}=$ heat transfer coefficient $\left(\mathrm{koj} / \mathrm{m}^{2}-\right.$ 以)
$k \rho_{0}=$ interior construction thermal inertia $\left(\mathrm{k} \omega /\left(\mathrm{m}^{2}-k\right)^{2}-\mathrm{sec}\right.$
(a thermal property of material responsible for the rate of temperature is e)
$t=$ time after ignition (sec)
See table below for result
Area of Compart ment Endosing Surface Boundaries
$A_{T}=\quad 2\left(\omega_{c} \times l_{c}\right)+2\left(h_{c} \times n_{c}\right)+2\left(h_{c} \times l\right)$
Where $\quad A_{\pi}=$ total area of the compartment enclosingsurface boundaries ( $\mathrm{m}^{2}$ )
$\mathrm{m}_{\mathrm{c}}=$ compartment width (m)
$k=$ compartment length (m)
$h_{c}=$ compartment height (m)
$A_{v}=$ area of ventilation opening $\left(m^{2}\right)$
$A_{T}=$
$475.66 \mathrm{~m}^{2}$

Compartment Hot Gas Layer Temperature With Forced Ventilation

$\Delta T_{g}=\quad T_{g}-T_{a}$
$T_{g}=\quad \Delta T_{g}+T_{\mathrm{g}}$

## Results

| Time After ganition(t) |  | $\frac{h_{x^{2}}}{\left(k^{2} h^{2}-k\right)}$ | $\underline{\text { ¢ }} \mathrm{T}_{\mathrm{c}} / \mathrm{T}_{\text {a }}$ | $\begin{aligned} & {\mathbf{1} \mathrm{T}_{\mathrm{a}}}^{(\mathrm{K}} \end{aligned}$ | $\begin{aligned} & T_{a} \\ & (\mathbb{K}) \end{aligned}$ | $\begin{gathered} \mathrm{T}_{\mathrm{a}} \\ \left(\mathrm{Q}_{\mathrm{C}}\right) \end{gathered}$ | $\begin{gathered} \mathrm{T}_{\mathrm{o}} \\ \left({ }^{\left({ }^{2}\right)}\right. \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (min) | (sec) |  |  |  |  |  |  |
| 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 | 0.88 | 20182 | 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 | 080 | 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 | 27430 | 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

He at Transter Coemele lent Calculation

1.     - $\quad 0.4 \mathrm{~V} / \mathrm{pc} / \mathrm{t}$ tort t


a themal prope ityofmatilal responsbe to the rat of temperature ite)

l. -
$0.022 \mathrm{~kW} / \mathrm{m}^{2}-\mathrm{K}$
Area of Comparment Enclosing surtace Boundarle :
$\mathrm{A}_{1}=\quad 2(W \cdot \times \mathrm{l})+2(\mathrm{l} \times W)+2(\mathrm{l} \times \mathrm{D})$
$\mathrm{A}_{1}=\quad 475.66 \mathrm{~m}^{2}$
Compartment Hot Gas Laver Temperature Wth Forced Ventlation
$\Delta T_{0}=Q /\left(\mathrm{nc}_{\mathrm{p}}+\mathrm{H}_{1} \mathrm{~A}_{\mathrm{i}}\right)$

Where $\quad \Delta T_{0}=T_{0}-T_{-}=$ipper bipergas emperature rke abowe ambe it (r)
$\mathrm{T}_{\mathrm{i}}=$ ambleıtalr tempe ature (1)
$Q=$ leat e e ase rat of the $\mathrm{Tl} \mathrm{R}(\mathrm{WW})$
m = comparinestmass vertatbon figw at agiec)
$c_{p}=$ specrl leat ofal (kJ/ighry

$A_{1}=$ thalare a of the compartmert encosing surkse bouctarles (m)
Resulti

| Time Atter kginition (t) |  | $\begin{gathered} h_{k} \\ \text { aWin }+9 \end{gathered}$ | $\begin{gathered} \mathrm{\Delta T}_{9} \\ 10 \end{gathered}$ | $\begin{aligned} & \mathrm{T}_{9} \\ & 16 \end{aligned}$ | $\begin{aligned} & \mathrm{T}_{9} \\ & (\mathrm{C}) \end{aligned}$ | $\begin{gathered} \mathrm{T}_{9} \\ \left.{ }^{\circ} \mathrm{F}\right) \\ \hline \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (in) | (sec) |  |  |  |  |  |
| 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 |



## Summarvo fiesut:



## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Frotection Engineering. 3 Edition, 2002.
Calculations are based on certain assumptions and have irherent limitations. The results of such cabulations may or may not have reasonable predictive capabities for a given situation, and should onlybe interpreted by an informed user.
Athough each calculation in the spreadsheat has been verified with the results ofhand calcuation, there is no absolute guarartee of the acouracyof these calculations.
Anyquestions,corrments, concems, and suggestions, or to report an enror's) in the spreadsheet, please send an emai to nxignregov or mes3@regov.


## Problem J-3

## Problem Statement

Consider a compartment 4.6 m wide $\times 4.9 \mathrm{~m}$ long $\times 3.0 \mathrm{~m}$ high ( 15 ft wide $\times 16 \mathrm{ft}$ long $\times 10 \mathrm{ft}$ 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 $\times 0.6 \mathrm{~m}$ high ( 2 ft wide $\times 2 \mathrm{ft}$ high ) and one vent of 1.2 m wide $\times 2.1 \mathrm{~m}$ high ( 4 ft wide $\times 7 \mathrm{ft}$ high), all located on the same wall. The top of the highest vent is at $2.4 \mathrm{~m}(8 \mathrm{ft})$ 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 $\mathrm{T}_{\mathrm{g}}=218^{\circ} \mathrm{C}\left(\mathrm{T}_{\mathrm{g}}=425^{\circ} \mathrm{F}\right)$ 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 $0.236 \mathrm{~m}^{3} / \mathrm{s}(500 \mathrm{cfm})$ 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 $\left(\mathrm{T}_{\mathrm{g}}\right)$ at 10 min after ignition if the mechanical ventilation system is activated and the $H R R$ is equal to the $H R R$ 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 $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$.
(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 $=1 \mathrm{~atm}$ ).

Pre FDT ${ }^{\text {s }}$ Calculations:
Equivalent Vent
Since the $\mathrm{FDT}^{\mathrm{s}}$ 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 $w_{v}$ <br> $(\mathrm{ft})$ | Height $\mathrm{h}_{\mathrm{v}}$ <br> $(\mathrm{ft})$ | Are A <br> $\left(\mathrm{ft}^{2}\right)$ | MQH Factor $A_{\circ}$ <br> $\left(\mathrm{ft}^{5 / 2}\right)$ |  |
| 2 | 2 | 4 | 5.66 |  |
| $\mathbf{h}_{\mathrm{v}}$ |  |  |  |  |
| 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: $\mathrm{A}_{\circ} \sqrt{\mathbf{h}_{\mathrm{v}}}=85.4 \mathrm{ft}^{5 / 2}$

$$
36 \mathrm{ft}^{2} \sqrt{\mathrm{~h}_{\mathrm{v}}}=85.4 \mathrm{ft}^{5 / 2}
$$

$$
h_{v}=5.63 \mathrm{ft}=5.6 \mathrm{ft}
$$

Condition 2: $w_{v} \times h_{v}=36 \mathrm{ft}^{2}$

$$
\begin{aligned}
& \mathrm{w}_{\mathrm{v}} \times 5.63 \mathrm{ft}=36 \mathrm{ft}^{2} \\
& \mathrm{w}_{\mathrm{v}}=6.39 \mathrm{ft}=6.4 \mathrm{ft}
\end{aligned}
$$

Spreadsheet (FDT ${ }^{\text {s }}$ ) Solution Procedure:
Natural Ventilation Scenario
Use the following FDTs ${ }^{\text {s }}$
(a) 02.1_Temperature_NV.xls

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):

- Compartment Width $\left(\mathrm{w}_{\mathrm{c}}\right)=15 \mathrm{ft}$
- Compartment Length ( $\mathrm{I}_{\mathrm{c}}$ ) $=16 \mathrm{ft}$
- Compartment Height $\left(\mathrm{h}_{\mathrm{c}}\right)=10 \mathrm{ft}$
- Vent Width $\left(w_{v}\right)=6.4 \mathrm{ft}$
- Vent Height $\left(h_{v}\right)=5.6 \mathrm{ft}$
- Top of Vent from Floor $\left(\mathrm{V}_{\mathrm{T}}\right)=8 \mathrm{ft}$
- Interior Lining Thickness $(\delta)=6$ in
- Select Material: select Gypsum Board from the combo box
- Fire Heat Release Rate ( $\delta$ ) $=410$ 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 $218{ }^{\circ} \mathrm{C}\left(425{ }^{\circ} \mathrm{F}\right)$, we need to enter HRR values on the spreadsheet until get a temperature close to $218^{\circ} \mathrm{C}\left(425^{\circ} \mathrm{F}\right)$ at 10 min after ignition. This trial and error procedure is shown in the following table.

| Trial and error procedure to determine the HRR <br> Target: $T_{g}=425{ }^{\circ} \mathrm{F}$ for natural ventilation scenario |  |  |
| :--- | :--- | :--- |
| Trial | Heat Release Rate <br> $(\dot{Q})(\mathrm{kW})$ | Hot Gas Layer Temperature $\left(\mathrm{T}_{\mathrm{g}}\right)$ <br> at 10 min after Ignition $\left({ }^{\circ} \mathrm{C}\right)\left({ }^{\circ} \mathrm{F}\right)$ |
| 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 $t=10 \mathrm{~min}$

## 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 $218^{\circ} \mathrm{C}\left(425^{\circ} \mathrm{F}\right)$ 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 $\mathbf{4 0 0} \mathbf{~ k W}$ ( $\mathbf{3 7 9} \mathbf{~ B t u / s e c ) ~ m a y ~ g e n e r a t e ~ a ~ h o t ~ g a s ~ l a y e r ~ t e m p e r a t u r e ~}$ of $\mathbf{2 0 4 +}{ }^{\circ} \mathbf{C}\left(\mathbf{4 0 0} \mathbf{+}^{\circ} \mathrm{F}\right)$. Also, the smoke layer height at 10 minutes after ignition is approximately $\mathbf{z}$ $=0.39 \mathrm{~m}(1.27 \mathrm{ft})$, 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 $\left(V_{T}\right)$.

## Spreadsheet Calculations

FDTs : 02.1_Temperature_NV.xls (Temperature_NV Thermally Thick)
CH APTER 2. PREDICTIIIG HOT GAS LAYER TEMPERATURE AIID SMOKE
LAYER HEIGHT III A ROOMFIRE WITH HATURAL VEIITILATIOH
COMPARTME IT WITH THERMALLY THICK/THIII BOUHDARIE S
Version 18050

Parameteri In YELLOWCELLS are Entered by the User.
Parametersin GREEN CELLS are Automatically selectedton the DROP DOWN MENU tor the materlal selected.


The chapt it the NUREG stouthbe readbetre an analyk k madk.

## IIIPUT PARAMETERS

COMPARTMEITT IIFORMATION

| EIT IINFOR MATION |  |  |
| :---: | :---: | :---: |
| Comparme it Wtith $N_{\text {c }}$ ) | 15.00 | 4572 m |
| Compartme it Leigtu (1) | 16.00 | 4.8764 |
| Comparme it He gigt ( ) | 10.00 | 3046 |
| Ve it Wkith (W) | 6.40 | 1.951 m |
| Vest He tit (i) | 5.60 | 2.708 m |
| Top of Vestrom Fbor ( $V_{0}$ ) | 8.00 | 24331 m |
| Interbr LinhgTi Ekiess (9) | 6.00 | 0.1524 m |


| AMBIENT CONDTIOHS |  |
| :---: | :---: |
| AmbleıtA I Temperature ( $\mathrm{T}_{\text {) }}$ ) | 77.00 |
| Specme Heator Alr e.) | 1.00 |
| Amblertar Dessly (p) | 1.18 |
| THER MAL PROPERTIES OFOOMPA RTMENT EIICLOS IIGG SURFACES FOR |  |
| Interlor Lining Themal Condictitit on) | 0.00017 |
| Interlor Liningspecme Heat (c) | 1.1 |
| Interlor Lininq Dessty $(p)$ | 960 |

Interbr Ling Dest 19 )
1.1

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

| Mat Ital | $\begin{array}{\|l\|} \hline k \rho c \\ k N a n^{2}+y^{2}-\sec \end{array}$ |  | $\begin{aligned} & \mathrm{c} \\ & \mathrm{KJ} k \mathrm{CH} 6 \end{aligned}$ | $\operatorname{l}_{\lg / m)}$ | Select Material <br> GiDsun Eoard |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Alum intin pire) Stel (0.5** Carbon) Concret Brlk <br> Glass, Plat <br> BrakCOICRE B bck <br> Gypsim Board <br> Pl/wood <br> Fber lus Iktbi B oard <br> CIpboard <br> Ae ned Concet <br> Plateriboard <br> Calclum Sllbat Boasd <br> Alum Ina Sllbat Bbok <br> Glass F ber hst latbon <br> Expanded Poystrene <br> User Specmed Vahe | 500 197 2.9 1.7 1.6 1.2 0.18 0.16 0.16 0.15 0.12 0.12 0.056 0.036 0.0018 0.001 Eı tr Valse |  | 0.895 0.465 0.75 0.8 0.8 0.84 1.1 2.5 1.25 1.25 0.96 0.84 1.12 1 0.8 1.5 Eit r Value | 2710 7850 2400 2500 2710 1900 960 540 240 800 500 960 700 260 60 20 Eit r Value | Scroll to deslredmaterial then Click the selection |

Fire Heat Release Rate (0) 410.00 kw

Calculate
METHOD OF McCAFFREY, QUIITIERE, AlID HARKLEROAD (MOH)
Reverence: SFPE Hiwhtion of Five Piorection Engineerhg, 3 Ellion, 2002, Page 3-175.

Where $\quad \Delta T_{0}=T_{0} \cdot T_{n}=$ upper layer gas temperature ise above ambient ( $K$ )
0 = heat release rate of the fire (kin)
A = area of ventilation opening (mi)
hv = height of ventilation opening(m)
$h=$ convective heat transter coeeficient (kioulm -K )
$A=$ total area ofthe compartment enclosing surfice boundaries excluding area of vent openings (m)

| ead | Iation Opening Calculation |
| :---: | :---: |
| A = | (w) (h) |
| Where | A = area of ventilation opening (m) |
|  | $\omega_{\mathrm{V}}=$ vent width ( m ) |
|  | $\mathrm{h}_{\mathrm{v}}=$ vent height ( m ) |
| $\mathrm{A}=$ | $3.33 \mathrm{~m}^{2}$ |

Thermal Penetration Time Calculation

## $t_{\mathrm{p}}=\quad(\rho \subset / k)(5 / 2)^{2}$

Where $\quad t_{p}=$ themal penetration time (sec)
$\rho=$ interior construction densitv (kp/m)
$\mathrm{c}_{\mathrm{p}}=$ interior construction heat capacity ( $\mathrm{k} / \mathrm{ikg}-\mathrm{K}$ )
$\mathrm{k}=$ interior construction themal conductivity ( $\mathrm{k} / \mathrm{\omega} / \mathrm{m} \mathrm{m}-\mathrm{K}$ )
$\delta=$ interior construction thickness ( m )
$t_{1}=\quad 36068.24$ sec

Heat Transfer Coefficient Calculation
$h_{k}=\quad w(k) \quad$ for $t<t \quad$ or $\quad(k / \delta)$ fort $>t_{t}$

Where $\quad h_{k}=$ heat transter coefficient $\left(\mathbf{k} 0 / \mathrm{m}^{2}-\mathrm{K}\right)$
$\mathrm{k} \rho \mathrm{C}=$ interior construction themmal inertia $\left(\mathrm{k} / \mathrm{N} / \mathrm{m}^{2}-\mathrm{K}^{2}-\mathrm{sec}\right.$
(a thermal property of material responsible forthe rate oftemperature rise)
$\mathrm{t}=$ time after ignition (sec)
See table below for results
Area of Compartmert Enclosing Surface Boundaries
$A=\quad[2(w \times 1)+2(h \times w)+2(h \times l c)]-A$
Where $\quad A_{0}=$ total area ofthe compartment enclosing surface boundaries excluding area of vent openings ( $\mathrm{m}^{2}$ )
$w_{c}=$ compartment width (m)
$I_{c}=$ compartment length (m)
$h_{\text {: }}=$ compartment height ( m )
A = area of ventilation opening (m)
$\mathrm{A}=\quad 98.86 \mathrm{~m}$
Compartment Hat Gas Laver Temperature With Natural Ventilation
$\dot{4} \mathrm{~T}_{\mathrm{a}}=6.85\left[\mathrm{O}^{2}\right.$ (A(h)) (Ah)]
$\dot{\Delta T_{0}}=\quad \mathrm{T}_{\mathrm{g}} \cdot \mathrm{T}_{\mathrm{a}}$
$\mathrm{T}_{\mathrm{s}}=\quad \dot{\mathrm{A}} \mathrm{T}_{\mathrm{a}}+\mathrm{T}$

| Time After larition (t) |  | $h_{\text {s }}$ ( $\mathrm{k} \mathrm{NO}_{\mathrm{m}} \mathrm{m}^{-\mathrm{K}}$ - | $\begin{aligned} & \hline \boldsymbol{1} T_{s} \\ & (K) \\ & \hline(K) \end{aligned}$ | $\begin{gathered} \mathrm{T}_{\mathrm{s}} \\ (\mathrm{~K}) \\ \hline \end{gathered}$ | $\begin{gathered} \mathrm{T}_{\mathrm{g}} \\ \left({ }^{\circ} \mathrm{C}\right) \\ \hline \end{gathered}$ | $\begin{gathered} T_{s} \\ \left({ }^{(T)}\right) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (min) | (sec) |  |  |  |  |  |
| 0 | 0.00 | - | - | 298.00 | 25.00 | 77.00 |
| 1 | 60 | 0.05 | 131.88 | 429.88 | 15688 | 31439 |
| 2 | 120 | 0.04 | 148.03 | 446.03 | 173.03 | 343.46 |
| 3 | 180 | 0.03 | 15838 | 45638 | 18338 | 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 | 49157 | 218.57 | 425.43 |
| 15 | 900 | 0.01 | 207.11 | 505.11 | 232.11 | 449.79 |
| 20 | 1200 | 0.01 | 21728 | 51528 | 24228 | 468.10 |
| 25 | 1500 | 0.01 | 225.51 | 52351 | 25051 | 482.92 |
| 30 | 1800 | 0.01 | 232.47 | 530.47 | 25747 | 495.45 |
| 35 | 2100 | 0.01 | 23852 | 53652 | 26352 | 50634 |
| 40 | 2400 | 0.01 | 24389 | 541.89 | 26889 | 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 |

Hot Gas Layer Temper ature Natural Ventilation (MOH Method)


ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANAAND TANAKA


```
Wher z=smoke ta/erleglit (m)
    - leatrelease raterthe ME (kW)
    t-the atter ky tbu (gec)
    A. - compartnettelght (m)
    Ac - compartmestrbor area (in)
    k=aconstargle lbyk=0.076/p
    P- Iot gas ha/ercte is Ity (kg/m)
    p & q|ver by p = 353/T
    T
Compartment area Calculation
A- (W) (1)
Where Ac = compartmeittborarea(m)
    w
    L=compatme it eigti (i)
A = }\quad22.30\textrm{m
Hot Ga: Laver Densit/ Calculation
p- 353/T
Calculation for Cons tant K
k= 0.076/p
Smoke Ga : Laver Helght Wh Hatural Ventlation
z= [l2kQ t/3A]+(1/k )
```

Result Castion! The smoke layer height is a conservative estima and is only intended to provide an indication where the hot gas layer is located. Calculated smoke layer height belowthe vent height are not credit able since the calculation is nd accounting for the smoke exiting the vent.

| $\begin{aligned} & \operatorname{Tin} \theta \\ & \tan ) \end{aligned}$ | $\begin{gathered} \text { Po } \\ (\mathrm{kg} \mathrm{~m}) \end{gathered}$ | $\begin{gathered} \text { Cons tant (k) } \\ \text { awan-19 } \end{gathered}$ | Smoke Laver halght $Z$ (in) | Smoke Laverhelght z (ty |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 1.18 | 0.064 | 3.05 | 10.00 |
| 1 | 0.82 | 0.093 | 2.44 | 8.00 |
| 2 | 0.79 | 0.096 | 2.44 | 8.00 |
| 3 | 0.77 | 0.098 | 2.44 | 8.00 |
| 4 | 0.76 | 0.100 | 2.44 | 8.00 |
| 5 | 0.75 | 0.101 | 2.44 | 8.00 |
| 10 | 0.72 | 0.106 | 2.44 | 8.00 |
| 15 | 0.70 | 0.109 | 2.44 | 8.00 |
| 20 | 0.69 | 0.111 | 2.44 | 8.00 |
| 25 | 0.67 | 0.113 | 2.44 | 8.00 |
| 30 | 0.67 | 0.114 | 2.44 | 8.00 |
| 35 | 0.66 | 0.116 | 2.44 | 8.00 |
| 40 | 0.65 | 0.117 | 2.44 | 8.00 |
| 45 | 0.65 | 0.118 | 2.44 | 8.00 |
| 50 | 0.64 | 0.119 | 2.44 | 8.00 |
| 55 | 0.64 | 0.120 | 2.44 | 8.00 |
| 60 | 0.63 | 0.120 | 2.44 | 8.00 |

CAUTION: SMOKE IS EXTIHG OUT VENT CAUTIOH: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIIGG OUT VENT CAUTION: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIIG OUT VENT CAUTIOH: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIIG OUT VENT CAUTIOH: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIIGG OUTVENT CAUTION: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTTHG OUT VENT CAUTION: SMOKE IS EXTTHG OUT VEIT CAUTION: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIHG OUT VENT


## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering. 3 Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or maynot have reasonable predictive cap abilities for a given situation, and should only be interpreted by an informed user.
Athough each calculation in the spreadsheet has been veried with the results of hand calculation, there is no absolute guarantee of the acouracy ofthese calculations.
Anyquestions, comments, concems, and suggestions, or to report an erron'(s) in the spreadsheet, please send an email to nxi@rieg gov.


## Spreadsheet (FDT ${ }^{\text {s }}$ ) Solution Procedure:

## Forced Ventilation Scenario

Use the following FDTs
(a) 02.2_Temperature_FV.xls

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in both spreadsheets (values only):

- Compartment Width $\left(\mathrm{w}_{\mathrm{c}}\right)=15 \mathrm{ft}$
- Compartment Length ( $\mathrm{I}_{\mathrm{c}}$ ) $=16 \mathrm{ft}$
- Compartment Height ( $\mathrm{h}_{\mathrm{c}}$ ) $=10 \mathrm{ft}$
- Interior Lining Thickness ( $\delta$ ) $=6$ in
- Material: select Gypsum Board from the combo box
- Compartment Ventilation Rate ( $\dot{\mathrm{m}}$ ) $=500 \mathrm{cfm}$
- Fire Heat Release Rate ( $\dot{\mathrm{Q}})=410 \mathrm{~kW}$

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 $\mathrm{t}=10$ minutes after ignition we obtain:

| Hot Gas Layer Temperature* $\mathrm{T}_{\mathrm{g}}{ }^{\circ} \mathrm{C}\left({ }^{\circ} \mathrm{F}\right)$ |  |
| :--- | :--- |
| Method of Foot, Pagni, and <br> 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 ${ }^{\text {s }}$ : 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 layertemperature and smoke layer height in enclosure ire. Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Atomatically Selected from the DROP DOWN M ENU for the Material Selected.
Al subsequent output values are calculated bythe spreadsheet and based on values specified in the input
parameters. This spreadstheet 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 Mofth ( $\mathrm{w}_{\mathrm{c}}$ ) |  |  | 1500 t | 4.57 m |
| Compartment Length (1) |  |  | 1600 t | 4.88 m |
| Compartment Height (h) |  |  | 1000 t | 3.55 m |
| Interior Lining Thickness (s) |  |  | 60011 | 0.1524 m |
| A MBIENT CONDITIONS |  |  |  |  |
| Ambient Air Temperature ( $\mathrm{T}_{3}$ ) |  |  | $7700{ }^{\circ} \mathrm{F}$ | $25.00^{\circ} \mathrm{C}$ |
|  |  |  | 100 kJkgH |  |
| Ambient Air Density ( $P_{1}$ ) |  |  | $1.18 \mathrm{kgtm}^{2}$ |  |
| THERMAL PROPERTIE S OF COMPARTMENT ENCLOSING SURFACES |  |  |  |  |
| Interior Lining Thermal Inertia (kpo) |  |  | $0.18 \mathrm{mNAm}^{2}-1 \mathrm{sec}^{2} \mathrm{sec}$ |  |
|  |  |  | 0.00017 kWm + |  |
|  |  |  | 1.1 kJkgh |  |
| Interior Lining Specific Heat (c)Interior Lining Density ( $p$ ) |  |  | 960 katm |  |
| Note: Air density will automatically cormect with Ambient Air Temperature ( $T_{i}$ ) Input |  |  |  |  |
| THERMAL PROPERTIES FOR COMMOII IIITERIOR LIIIIIG MATERIALS |  |  |  |  |
| Material | kfo |  | $\bigcirc$ | Select Material |
|  | $\left(\mathrm{KOH} \mathrm{m}^{2}-K\right)^{2}-\mathrm{sec}$ | (kedolim-K) | (kullkg-K) (kg $\mathrm{mm}^{3}$ ) | Scroll to desired material then |
| Steel ( $0.5 \%$ Carbon) <br> Concrete | 500 | 0.206 | 0.895 2710 |  |
|  | 197 | 0.054 | 0.465 7850 | Click on selection |
|  | 29 | 0.0016 | 0.75 2400 |  |
| Brick | 1.7 | 0.0008 | 0832600 |  |
| Glass, Plate | 1.6 | 0.00076 | 08 2710 |  |
| Brick/Concrete Block | 12 | 0.00073 | 0.84 1900 |  |
| Gypsum Board | 0.18 | 0.00017 | 1.1 960 |  |
| Plywood | 0.16 | 0.00012 | $25 \quad 540$ |  |
| Fiber Insulation Board | 0.16 | 0.00053 | 125 240 |  |
| Chipboard | 0.15 | 0.00015 | 125 800 |  |
| Aerated Concrete | 0.12 | 0.00026 | 0.96 500 |  |
| Plastertoand | 0.12 | 0.00016 | 084 |  |
| Calcium Silicate Board | 0098 | 0.00013 | 1.12 700 |  |
| Aumina Silicate Block | 0036 | 0.00014 | $1{ }^{1}$ |  |
| Glass Fiber hsulation | 00018 | 0.000037 | 0.8 60 |  |
| Expanded Polystyrene | 0001 | 0.000034 | $15 \quad 20$ |  |
| User Specified Value | Enter Value | Enter Value | Enter Value Enter Value |  |



## Results

| Time difter lanition (t) |  | $\frac{h_{x_{2}}}{\left(\omega_{0} N^{2}-k\right)}$ | $\underline{\mathbf{H}} \mathrm{T}_{\mathrm{c}} / \mathrm{T}_{\text {a }}$ | $\begin{aligned} & {\mathbf{1} \mathrm{T}_{\mathrm{a}}}^{(\mathrm{K}} \end{aligned}$ | $\begin{aligned} & T_{\mathrm{o}} \\ & (\mathrm{~K}) \end{aligned}$ | $\begin{gathered} \mathrm{T}_{\mathrm{a}} \\ \left(\mathrm{Q}_{\mathrm{C}}\right) \end{gathered}$ | $\begin{gathered} \mathrm{T}_{\mathrm{o}} \\ \left({ }^{\mathrm{a} F}\right) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (min) | (sec) |  |  |  |  |  |  |
| 0 | 0 | - | $\cdot$ | - | 298.00 | 25.00 | 77.00 |
| 1 | 60 | 0.05 | 0.57 | 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 | 24503 | 543.03 | 270.03 | 518.06 |
| 4 | 240 | 0.03 | 0.87 | 25805 | 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 | 30433 | 602.33 | 329.33 | 624.79 |
| 15 | 900 | 0.01 | 1.10 | 32737 | 625.37 | 352.37 | 666.26 |
| 20 | 1200 | 0.01 | 1.16 | 344.77 | 642.77 | 369.77 | 697.58 |
| 25 | 1500 | 0.01 | 120 | 358.90 | 656.90 | 383.90 | 723.01 |
| 30 | 1800 | 0.01 | 124 | 370.87 | 668.87 | 395.87 | 744.57 |
| 35 | 2100 | 0.01 | 128 | 38130 | 679.30 | 406.30 | 763.35 |
| 40 | 2400 | 0.01 | 131 | 390.58 | 688.58 | 415.58 | 780.04 |
| 45 | 2700 | 0.01 | 134 | 398.95 | 696.95 | 423.95 | 795.11 |
| 50 | 3000 | 0.01 | 136 | 406.59 | 704.59 | 431.59 | 808.86 |
| 55 | 3300 | 0.01 | 139 | 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

Heat Transter Coetriclent Calculation
h. - $\quad 0.4 \mathrm{v}(\mathrm{APC} / \mathrm{t})$ 加 $\mathrm{t}<\mathrm{t}$

Where $\quad \mathrm{b}$ - leat tanst roce tite it aWin ${ }^{2}$-ly

(a the malpoperty ormat inalesporsble tor the rate of tmperature ike)
$\bar{j}=\mathrm{t}$ blicess of litibrlilig (in)

1. $\quad 0.022 \mathrm{~kW} \mathrm{~mm}^{-\mathrm{K}}$

Area of Compartment Enclosing surface Boundarie:
$A_{i}=\quad 2\left(W_{c} \times 1\right)+2(1 \times w)+2(1 \times 1)$
$A_{i}=\quad 102.19 \mathrm{~m}^{2}$
Compartment Hot Ga: Layer Tem perature Wh Forced ventliation
$\Delta T_{2}=Q /\left(\operatorname{tnc}_{c_{p}}+\mathbf{H}_{1} A_{1}\right)$

Where


$Q=$ leat e pase ate oftle fre (kW)
$\mathrm{m}=$ compartnes tmass ve ithtor tow rate (kgisec)
$c_{p}=$ specric be atotali ( JJ/g-ry

1.     - convectue reattans tr coe make it *Win ${ }^{2}-19$
$A_{1}=$ tetalarea orthe compartme ite ichosig surtace boudarks (in)

## Results

| Tim $\theta$ After Ignition ( $t$ ) |  | $\begin{gathered} \mathrm{h}_{\mathrm{k}} \\ \text { gWWin }-15 \end{gathered}$ | $\begin{gathered} \hline \mathrm{AT}_{9} \\ \mathbf{C O} \end{gathered}$ | $\begin{aligned} & \hline \mathrm{T}_{9} \\ & \mathrm{CO} \\ & \hline \end{aligned}$ | $\begin{gathered} \hline \mathrm{T}_{\mathrm{e}} \\ \mathrm{Cl} \end{gathered}$ | $\begin{gathered} \mathrm{T}_{\mathrm{a}} \\ (\mathrm{~F}) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (f) (i) | (sec) |  |  |  |  |  |
| 0 | - | - | - | 298.00 | 25.00 | 77.00 |
| 1 | 60 | 0.02 | 162.80 | 450.80 | 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 | 1345.30 |
| 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 Fotection Engineering. 3 Edition, 2002.
Caculations are based on certain assumptions and have irherent limitations. The results of such calculations may or may not have reasonable predictive capabilties for a given situation, and should onlybe interpreted by an informed user.
Athough each calculation in the spreadsteat has been verified with the results of hand calculation, there is no absolute guarartee of the acouracyof these calculaions.
Anyquestions,corrments, concems, and suggestions, or to report an enror's) in the spreadsheet, please send an emai to nxi@nre.gov or mxs3(igre.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 $0.55-\mathrm{m}^{2}\left(6.0-\mathrm{ft}^{2}\right)$ 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 $\times 6.0 \mathrm{~m}$ long $\times 3.7 \mathrm{~m}$ high ( 20.0 ft wide $\times 20.0 \mathrm{ft}$ long $\times 12.0 \mathrm{ft}$ ). Two cable trays are located above the pool fire at heights of $2.15 \mathrm{~m}(7.0 \mathrm{ft})$ and $3.0 \mathrm{~m}(10.0 \mathrm{ft})$, 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 $\left(\mathrm{H}_{\mathrm{f}}\right)$.
(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 ${ }^{\text {s }}$ ) Solution Procedure:
Use the following FDTs
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):

- Fuel spill volume (V) = 10 gallons
- Fuel Spill Area or Dike Area $\left(\mathrm{A}_{\text {dike }}\right)=6.0 \mathrm{ft}^{2}$
- 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* <br> $\dot{\text { Q }} \mathrm{kW}$ (Btu/sec) | Burning <br> Duration* <br> $t_{b}(\mathrm{~min})$ | Pool Fire Flame Height* $\mathrm{H}_{\mathrm{f}} \mathrm{m}$ (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': 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
Verston 1805.0



Alabsequen capulvalues a calaisked by the spreativel and baed on wakes spedted in te mpul
arame ks. Thit sprealitieetis prokeced and seare basok emors de ba mong entry ha al(s).
tie ctop lein te MURE日 shand be real betre anandyats is make.

## INPUIT PARAMETERS



| 1000 |
| ---: |
| 6000 |
| 0039 |
| 43000 |
| 820 |
| 3.5 |
| 77.00 |

асату $\mathrm{m}^{2}$
ases $\mathrm{m}^{2}$
Flel कill Areacr Dke Area (A).
hans Runtry Rate off (el(mi)
F(el Denaly ( $\rho$ )
Bnprical Constarl (a)

Grast bit and Agcter alon(\$
981 manc $^{\prime}$
$1.18 \mathrm{kain}^{3}$
Nor: Ar endty will alonalat
HEFAMAL PROPERTIES DATA
BURHIHG RAT EDAT A RORLIRUIDHYDROCARBOH FUEL $\% ~$

| Fuas | naxs Buring Rale $\mathrm{m}^{\prime \prime}\left(\mathrm{kgm}^{-25 e C}\right.$ | $\begin{aligned} & \text { Healof comburlan } \\ & \left.2 \mathrm{H}_{\mathrm{A}}=\boldsymbol{9 N} / \mathrm{Ng}\right) \end{aligned}$ | Denaly b kg gm ) | Emplicad cavt lan kp(m) | 3eleot Fuel Type |
| :---: | :---: | :---: | :---: | :---: | :---: |
| lise taral | 0.017 | 20,000 | 796 | 100 | Soroll to dectred wel type |
| Eiarcl | 0.015 | 25,800 | 794 | 100 | Cliok on celeotion |
| Qulare | 0.108 | 45,700 | 373 | 2.7 |  |
| Bercere | 0.585 | 40,150 | 87. | 2.7 |  |
| Hexare | 0.8 T 4 | +4,700 | 350 | 1.9 |  |
| Hep lare | 0.101 | 44,600 | 575 | 1.1 |  |
| > dere | 0.09 | 40,800 | 870 | 1.4 |  |
| Acelore | 0.041 | 25,800 | 791 | 1.9 |  |
| Dloware | 0.018 | 25,200 | 1036 | 5.4 |  |
| Diely Elw | 0.085 | 34,200 | 714 | 0.7 |  |
| Bentre | 0.048 | +4,700 | 740 | 3.5 |  |
| Garcire | 0.065 | 43,700 | 740 |  |  |
| leroatre | 0.039 | 43,200 | 320 | 3.5 |  |
| Dksel | 0.045 | +4,400 | 918 | 2.1 |  |
| JP-4 | 0.051 | 43,500 | 760 | 3.5 |  |
| JP-5 | 0.054 | 43,000 | 810 | 1.5 |  |
| Tlandiomer Oll, Hydrocaton | 0.859 | 46,000 | 760 | 0.7 |  |
| 31 aldon Trarctormer flas | 0.05 | 28,150 | 960 | 100 |  |
| Fued ol, Heary | 0.385 | 39,700 | 970 | 1.7 |  |
| Cruse oll lue ol |  | $\begin{aligned} & 42,900 \\ & 45,500 \end{aligned}$ |  |  |  |
| libe OI User Gedred vake | $\begin{aligned} & 0.389 \\ & \text { Erver value } \end{aligned}$ | +6,000 Entr Vathe | $\begin{aligned} & 760 \\ & \text { Ever value } \end{aligned}$ | 0.7 Eler VJuk |  |

## ESTIMATING POOL FIRE HEAT RELEASE RATE

Retreice: SFPE Hanctook of Flie Po Ecton Engheering , $3^{3}$ Eatbl 2002 , Page 3-25

$$
Q=\pi r^{1} \Delta H_{c a t}\left(1-e^{-w i}\right) A_{t h a}
$$

Where $\quad Q=$ pool fire heat release rate (kot)
$m^{\prime \prime}=$ mass burning rate of fuel per unit surface area $\left(\mathrm{kg} / \mathrm{m}^{2} \cdot \mathrm{sec}\right)$
$\Delta \mathrm{H}_{\mathrm{caf}}=$ effective heat of combustion of fuel ( $\mathrm{kJ} / \mathrm{kg}$ )
$A=A n=$ surface area of pool fire (area involved in vaporization) ( $\mathrm{m}^{2}$ )
$\mathrm{k} \beta=$ empirical constant ( m )
$\mathrm{D}=$ diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)
Pod Fire Diameter Calculation
$\mathrm{A}_{\mathrm{yk} \mathrm{e}}=\quad \pi \mathrm{D}^{2} / 4$
Where $\quad A_{t h n}=$ surface area of pool fire $\left(m^{2}\right)$
$D=$ pool fire diamter (m)
$D=v(4 A \cdot d \pi)$
$D=0.842 m$
Hea Release Rate Calculation
Clanks with elatvellathast polit, the tanstomeroll, require
 bcated reathig acheve kython)

| Q = | 889.91 kW | 843.48 Btulsec | Answer |
| :---: | :---: | :---: | :---: |

## ESTIMATING POOL FIRE BURNING DURATION

Retrence: SFP EHanchook of Fle Pio Ecton Engheering , $2^{4}$ Editu1, 1996, Page 3-197.
$\mathrm{t}=4 \mathrm{~V} / \pi 0^{2} \mathrm{v}$
Where $\quad t=$ burning duration of pool fire (sec)
$V=$ volume of liquid ( m )
$\mathrm{D}=$ pool diameter ( m )
$\mathrm{v}=$ regression rate (m/sec)

Calculation for Regression Rate
$\mathrm{v}=\quad \quad \mathrm{m}^{11} / \rho$
Wh here $\quad v=$ regression rate (mvec)
$\mathrm{m}^{\prime \prime}=$ mass burning rate of fuel ( $\mathrm{k} \mathrm{g}^{\prime} \mathrm{m}^{2}-\mathrm{sec}$ )
$\rho=$ liquid fuel dersitv $\left(\mathrm{k} \mathrm{g}^{\prime} \mathrm{m}^{3}\right)$
$v=\quad 0.000048 \quad$ misec
Burning Duration Calculation
$t=4 v \pi 0^{2} v$

| $=$ | 1427.85 sec | 23.90 minutes |
| :--- | :--- | :--- |
| Answer |  |  |

 stortperbds of the cuer a karge area.

## ESTIMATING POOL FIRE FLAME HEIGHT

## METHOD OF HESKESTAD

Retereice : SFPE Handbook of Flie Pio Acton Engheering , $2^{n}$ Edith1, 1985, Page 2-10.
$\mathrm{H}=0.235 \mathrm{Q}^{20}-1.02 \mathrm{D}$
Where $\quad H_{t}=$ poolfire flame height ( m )
Q = pool fire heat rele ase rate (kN')
$D=$ pool fire diameter (m)
Pod Fire Flame Height Caloulation
$\mathrm{H}_{\mathrm{t}}=0.235 \mathrm{Q}-1.02 \mathrm{D}$
$\mathrm{H}_{\mathrm{t}}=2.70 \mathrm{~m} \quad 8.84 \mathrm{ft}$

METHOD OF THOMAS

$\mathrm{H}=42 \mathrm{D}\left(\mathrm{n}^{*} / \rho_{\mathrm{F}} \mathrm{V} \text { g D) }\right)^{064}$
Wher $\quad H=$ pool tire tame he git (in)

$\rho_{n}=$ ambe italidessty $(\mathrm{g} / \mathrm{m})$
D = poolfre diameter (in)
$q=q$ quitatoralasce entor (ingec)
Pool Rre Rame Helght Calculation



Flame Helaht Calculation - sum mary of Resulti

| Calculation Method | Hame Halght (ft) |
| :--- | :---: |
| METHODOF HESKESTAD | 8.84 |
| METHODOF THOMAS | 7.60 |

ESTIMATING POOL FIRE RESULTS FOR RANDOMSIZE SPILLS USING INPUT PARAMETERS

| Area (ft') | Area ( $\mathrm{m}^{2}$ ) | Clameter (m) | Q(kW) | $\mathrm{t}_{\mathrm{a}}(\mathrm{sec})$ | $\mathrm{H}_{\text {c }}(\mathrm{tt})(\mathrm{Heske}$ stad) | $\mathrm{H}_{\text {c }}(\mathrm{tt})\left(\right.$ Thoma ${ }^{\text {a }}$ ) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 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 | 0.45 | 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 Protedion 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.


## Problem J-5

## Problem Statement

Consider a compartment with cable trays at $4.60 \mathrm{~m}(15 \mathrm{ft})$ 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 $1.4 \mathrm{~m}^{2}$ ( $15 \mathrm{ft}^{2}$ ), 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 $\mathrm{FDT}^{\text {s }}$ :
(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_Flā̄e_Height for line fire analysis

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in all spreadsheets (values only):

- Fuel spill volume $(V)=2$ gallons
- Fuel Spill Area or Dike Area $\left(\mathrm{A}_{\text {dike }}\right)=15 \mathrm{ft}^{2}$
- 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* <br> $\mathrm{H}_{\mathrm{f}} \mathrm{m}(\mathrm{ft})$ |
| :--- | :--- |
| 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 ${ }^{\text {s }}$ : 04_Flame_Height_Calculations.xls (Wall_Flame _Height)

## CHAPTER 4. ESTIMATING WALL FIRE FLAME HEIGHT

## Version 18050

The tollow ing cakikaths estin ate the wall fre thame be kgt
Parameters In YELLOWCELL S are Entered by the User.
Parameters In GREEN CELLS are Automatically selected trom the DROP DOWN MENU for the Fuel selected.
AI subseque it ouputvalues are calculated by the spreack leetad basedor valies specmed in the input
parametrs. Tis speadsleet $k$ protecedandsecre to avoklerrors die to wrongeitry li a cell(s).
The chaper it the NUREG stonklbe ead be tore at analys $t$ made.

## INPUT PARAMETERS

Freispill Volume ( $($ )
FieISpill Area or Dve Area ( $A_{\text {s }}$ )
Mass Bunlig Rate of Fiel in")
Etrectlve Heat of Combistbi offiel ( $\left.\Delta \mathrm{H}_{\mathrm{cut}}\right)$
Emprralconstant (d. F )

| 2.00 | ga bos | 0.0076 m |
| :---: | :---: | :---: |
| 15.90 | t | $1394 \mathrm{~m}^{2}$ |
| 0.039 | $\mathrm{kgm}^{2}$-6ec |  |
| 46000 | $\mathrm{kJ} / \mathrm{kg}$ |  |
| 0.7 |  |  |

Calculate

THERMÁL PROPERTIESFOR
BURHING RATE DATA FOR LIQUID HYDROCAREON FUELS

| Fiel | Mass EInlig Rat $\mathrm{m}^{*}$ (kg/m²-sec) | Heator com bistos $\Delta \mathrm{H}_{\text {ciat }}$ ( kJ kg ) | EnplitalConstat $k \beta\left(\mathrm{~m}^{-1}\right)$ | Select Fuel Type Lube Cil |
| :---: | :---: | :---: | :---: | :---: |
| Methat | 0.017 | 20,000 | 100 | Seral to de slred tuel type then |
| Ethatol | 0.015 | 26,800 | 100 | Click on selecton |
| B itare | 0.978 | 45,700 | 2.7 |  |
| Bevze re | 0.085 | 40,100 | 2.7 |  |
| Hexare | 0.074 | 44,700 | 1.9 |  |
| Heptae | 0.101 | 44,600 | 1.1 |  |
| xylere | 0.09 | 40,800 | 1.4 |  |
| Ace ble | 0.041 | 25,800 | 1.9 |  |
| Dibxare | 0.018 | 26,200 | 5.4 |  |
| Detry Etrer | 0.085 | 34,200 | 0.7 |  |
| belze ne | 0.048 | 44,700 | 3.6 |  |
| Gasolite | 0.055 | 43,700 | 2.1 |  |
| Kerose ne | 0.039 | 43,200 | 3.5 |  |
| Dresel | 0.045 | 44,400 | 2.1 |  |
| JP-4 | 0.051 | 43,500 | 3.6 |  |
| JP-5 | 0.054 | 43,000 | 1.6 |  |
| Trasstmmer Oll, Hydrocalbon | 0.039 | 46,000 | 0.7 |  |
| 561 Silleon Trasstmmer Fhid | 0.005 | 28,100 | 100 |  |
| Fieloll, Heavy | 0.035 | 39,700 | 1.7 |  |
| Cricle Oll | 0.034 | 42,600 | 2.8 |  |
| Libe OI | 0.039 | $46,000$ | 0.7 |  |
| User Spectit d Valte | Eiter Valse | Eitr Valie | Eıtr Valıe |  |



## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire
Protection Engineering. $3^{\text {nd }}$ Edition, 2002, and NF PAFre Frotection Handbook, 19 Edition, 2000.
Calculations are based on centain assumptions and have inherent imitations. The results of such calculations mayor maynd have reasonable predictive capabilities or a given stuation, and stould conlybe interpreted byan informed user.
Athough each calculation in the spreadshet has been verived with the resuts of hand calculation. there is no absolute guarantee of the acouracy ofthese calculations.
Any questions, corrments, concems, and suggestions, or to report an ermer's) in the spreadsheet,
please send an email to nxi@ne govormxs3 @enregov.


FDT ${ }^{\text {s }}$ : 04_Flame_Height_Calculations.xls (Corner_Flame _Height)

## CHAPTER 4. ESTIMATING CORNER FIRE FLAME HEIGHT

## Version 1805.0

The ollow ing calcutatons estm ate the coner tre thame he kit
Parameters in YELLOWCELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically selected tom the DROP DOWN mENU for the Fuel selected.


The craptitithe NUREG stotkl be read be fore at atalsk t made.
INPUT PARAMETERS

| Fielspllvonme (V) | 2.00 | galbes: | $0.5076 \mathrm{~m}^{\text {2 }}$ |
| :---: | :---: | :---: | :---: |
| Fielspllarea or Dke Area ( $A_{\text {dwa }}$ ) | 15.00 | $\pi$ | $1.394 \mathrm{~m}^{2}$ |
| Mass Bunlig Rat of Fiel (nn) | 0.039 | $\mathrm{kqm}^{2}-\mathrm{sec}$ |  |
| Etectue Heatorcan bistor of Fiel ( $\Delta \mathrm{H}_{\text {cat }}$ ) | 46000 | kJkg |  |
| Emplicalconstant ( $\beta$ ) | 0.7 | m |  |

Calculate
THERMAL PROPERTIES FOR

| Fiel | Mass bining Rate m* $\mathrm{kg}^{\mathrm{m}} \mathrm{m}^{2}$-sec) | He at or Combus tor <br>  | $\begin{aligned} & \text { EmprkalConstat } \\ & k \beta\left(\mathrm{~m}^{-1}\right) \\ & \hline \end{aligned}$ | Select Fuel Type <br> Lube Cll |
| :---: | :---: | :---: | :---: | :---: |
| metranol | 0.017 | 20,000 | 100 | Seroll to de slred fuel type then |
| Etratol | 0.015 | 25,800 | 100 | Click on selection |
| Brave | 0.078 | 45,700 | 2.7 |  |
| berzere | 0.085 | 40,100 | 2.7 |  |
| Hexare | 0.074 | 44,700 | 1.9 |  |
| Heptare | 0.101 | 44,600 | 1.1 |  |
| xyere | 0.09 | 40,800 | 1.4 |  |
| Acetore | 0.041 | 25,800 | 1.9 |  |
| Draxate | 0.018 | 25.200 | 5.4 |  |
| Detry Ether | 0.085 | 34,200 | 0.7 |  |
| berzere | 0.048 | 44,700 | 3.5 |  |
| G aolle | 0.055 | 43,700 | 2.1 |  |
| Kerosere | 0.039 | 43,200 | 3.5 |  |
| Desel | 0.045 | 44,400 | 2.1 |  |
| JP-4 | 0.051 | 43,500 | 3.5 |  |
| JP-5 | 0.054 | 43,000 | 1.5 |  |
| Trastomeroll, Hydrocatbot | 0.039 | 45,000 | 0.7 |  |
| 561 Sllbol Trastomerfinkd | 0.005 | 28,100 | 100 |  |
| Freloll, Heavy | 0.035 | 39,700 | 1.7 |  |
| Cride ol | 0.034 | 12,500 | 2.8 |  |
| Labe oll | 0.039 | 45,000 | 0.7 |  |
| User ispecmed dalue | Eiter Value | Eitivalue | Eiter Vane |  |

## Hea Release Rate Calculation

```
            Retere nce: SFPE Hancbook of Fle PNecton Englneerigg, 3"t Edton, 2002, Page 3-25.
```

$$
Q=m^{n \prime} H \operatorname{cem}\left(1-e^{-\varphi v}\right) A_{1}
$$

Where $\quad Q=$ pool fire heat release rate (kiol)

$$
m^{\prime \prime}=\text { mass burning rate of fuel per unit surface are } a\left(\mathrm{~kg}^{\prime} / \mathrm{m}^{2}-\mathrm{sec}\right)
$$

$\Delta \mathrm{H}_{\mathrm{cen}}=$ effective heat of combustion of fuel ( $\mathrm{kJ} / \mathrm{kg}$ )
$A_{r}=A_{d k e}=$ surface area of pool fire (area imvolved in vaporization) (m)
$k \beta=$ empirical constant $\left(\mathrm{m}^{-1}\right)$
$D=$ diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m) (Liquids with relatively high flash point, like trars former oil require localized heating to achieve ignition)
Pool Fire Diameter Calculation
$A_{\text {dke }}=\pi D^{2} / 4$
$D=v\left(4 A_{d k} / \pi\right)$
$\begin{array}{ll}\text { Where } & A_{d v e}=\text { surface area of pool fire }\left(\mathrm{m}^{2}\right) \\ & D=\text { pool fire diamter }(\mathrm{m}) \\ D= & 1.332\end{array}$
Heat Release Rate Caloulation
$Q=m " \lambda H_{c e m}\left(1-e^{+i+D}\right)$ Adke
$Q=\quad 151602 \mathrm{kO}$
1436.91 Btu/sec

ESTIMATING CORNER FIRE FLAME HEIGHT
Retere ice: Hesem/and Tokungge, "Nocelng of Turbulen tDithslan Flames and Fire Plumes tor the Analyals of Fire Growth,"

$\mathrm{H}_{\text {ramen }}=0.075 \mathrm{Q}^{\mathrm{si}}$
Where $\quad Q=$ heat release rate of the fire (kion)
$\mathrm{H}_{\text {taxien }}=0.075 \mathrm{Q}^{x 3}$

| $\mathrm{H}_{\text {roormen }}=$ | 6.07 m |
| :--- | :--- |
| Answer |  |

## NOTE

The above calculations are bas ed on principles developed in the SF PE Handbook of Fire Protection Engineering. $3^{\text {rd }}$ Edition, 2002 and Hesemi and Tokunage, 1983.
C alculations are based on certain ass umptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation. and should onty 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, pleasesend an email to $n \times i\left(\begin{array}{l}\text { nre.gov or } m \times s 3 @ n r o g o v . ~\end{array}\right.$


FDT ${ }^{\text {s }}$ : 04_Flame_Height_Calculations.xls (Wall_Line_Flame _Height)

## 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 bythe User.
Parametersin GREEN CELLS are Rutomatically Selected from the DROP DOWN M ENU for the Fuel Selected.
Al subsequent outut values are calculated bythe spreadsheet and based on values specified in the input
parameters. This spreadstheet is protected and secure to a void 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) | 200 | galbıs | $0.0076 \mathrm{~m}^{2}$ |
| :---: | :---: | :---: | :---: |
| Fuel Spill Area or Dike Area ( $A_{\text {din }}$ ) | 1500 | It | $1.394 \mathrm{~m}^{2}$ |
| Mass Buming Pate of Fuel (m') | 0039 | $\mathrm{kg} / \mathrm{m}^{2}+\mathrm{ec}$ |  |
| Effective Heat of Combustion of Fuel ( $4 \mathrm{H}_{\text {cut }}$ ) | 46000 | kJ.kg |  |
| Errpirical Constant (kß) | 0.7 | $\mathrm{m}^{-1}$ |  |

Calculate
THERMAL PROPERTIES FOR

| Fuel | Mass Buming Fate $\mathrm{m}=\left(\mathrm{kg} / \mathrm{m}^{2}-\mathrm{sec}\right)$ | Heat of Combustion i $\mathrm{H}_{\text {cant }}$ ( $\mathrm{k} . / \mathrm{kg}$ ) | Empirical Constant $\mathrm{k} \beta\left(\mathrm{m}^{-1}\right)$ | Select Fued Type <br> Lube Cll |
| :---: | :---: | :---: | :---: | :---: |
| Methanol | 0017 | 20000 | 100 | Scroll to desired fuel type then |
| Ethanol | 0015 | 26800 | 100 | Click on selection |
| Butane | 0078 | 45,700 | 2.7 |  |
| Benzene | 0085 | 40.100 | 2.7 |  |
| Hexane | 0074 | 44,700 | 1.9 |  |
| Heptane | 0.101 | 44,600 | 1.1 |  |
| x ylene | 009 | 40800 | 1.4 |  |
| Acetone | 0041 | 25800 | 1.9 |  |
| Dioxane | 0018 | 26,200 | 5.4 |  |
| Diethy Eher | 0085 | 34,200 | 0.7 |  |
| Benzene | 0048 | 44,700 | 3.6 |  |
| Gasoline | 0055 | 43,700 | 2.1 |  |
| Kerosene | 0039 | 43,200 | 3.5 |  |
| Diesel | 0045 | 44,400 | 2.1 |  |
| JP-4 | 0051 | 43500 | 3.6 |  |
| JP-5 | 0054 | 43000 | 1.5 |  |
| Transtormer Oil, Hydrocarbon | 0039 | 46000 | 0.7 |  |
| 561 Silicon Transformer Fuid | 0005 | 28.100 | 100 |  |
| Fuel Oil, Heavy | 0035 | 39,700 | 1.7 |  |
| Crude Oil | 0034 | 42,600 | 28 |  |
| Lube Oil | 0039 | 46000 | 0.7 |  |
| User Specited Value | Enter Value | Enter Value | Enter Value |  |

## Heat Release Rate Calculation


$Q=m m^{*} \Delta H_{\text {cat }}\left(1-e^{* \phi}\right) A_{c}$
Where $\quad Q$-pooltie teat releate ate (kW)

$\Delta \mathrm{H}_{\mathrm{g}}=$ ettectre leat of combistbi oftrel (kJ kg)
$A_{1}=A_{\text {dw }}=s$ intace area of pool tire erea involed in vaporteaton) $\left(n^{2}\right)$
$k \beta=$ empircalconstant $\left(\mathrm{m}^{-}\right)$
 Lkikls with re katue wink thas polit ike tanstomer oll requ lre bcallued leatig to acheve kgithor)
Pool Rre Diameter Calculaton
$A_{\text {diel }}=\pi D^{2} / 4$
$D=V\left(4 A_{\text {dus }} / n\right)$
Where $\quad A_{\text {dsen }}=$ surtace areaot pool itre $\left(\mathrm{m}^{2}\right)$
D = pooltire damer (n)
$D=\quad 1.332$
m

He at Release Rate Calculation


| Q - | 1516.02 kW | 1436.91 Bt isec |
| :---: | :---: | :---: |
| Heat Release Rate Per UnIt Length of Flre Calculation |  |  |

$Q^{\prime}=Q / L$
Where $\quad Q^{\prime}=$ leat elease rat perintiengtu (kW/m)
$Q=$ Tle leat release at of the tire (W)
$\mathrm{L}=\mathrm{k} \mathbf{1} \mathrm{g} \mathrm{g} \mathrm{h}$ of the fire source (m)

Rre source Length Calculation
$\mathrm{L} \times \mathrm{W}=\mathrm{A}_{\mathrm{san}}$

| $\mathrm{L} \times \mathrm{W}=$ | $1.394 \mathrm{~m}^{2}$ |
| :--- | ---: |
| $\mathrm{~L}=$ | 1.180 m |
|  |  |
| $Q^{\prime}=Q / \mathrm{L}$ |  |
| $Q^{\prime}=$ | $1284.23 \mathrm{~kW} / \mathrm{m}$ |

ESTIMATING LINE WALL FIRE FLAME HEIGHT
Peierence:NPPAF/e Practionihivtiook, $9^{n}$ Eation 2003 Page 3-134
$\mathrm{H}_{\text {swal } \operatorname{lng}}=0.017 \mathrm{Q}^{.2 a}$
Where $\quad H_{\text {(ual mon }}=$ wall fire thame le gitt (in)

$\mathrm{H}_{\text {inadimel }}=0.017 \mathrm{Q}^{\prime}$


## NOTE

The above calculatons are based on pricples deve loped 1 the SFPE Handbook of Fire
 Catilatbis are based on certal assimptbis and lave intere it im lations. The res itt of
 shonkivbe tepreedby an in med isem.
Athongl each calcilatbi In the spreack leet ias bee iverifledwith the pasite of land cat ilation. there $k$ absolite grarante of the accu koy of these calcu lations.
Anyquestbis, comment, concens, andsiggestons, orb reportan errors) the spreadsteet, please se ud an emall $u x$ uenrgov ormxs3eurcgov.


## Problem J-6

## Problem Statement

Consider a compartment that is 15.2 m wide $\times 12.20 \mathrm{~m}$ long $\times 3.70 \mathrm{~m}$ height ( 50 ft wide $\times 40 \mathrm{ft}$ long $x 12 \mathrm{ft}$ height) with two forced ventilation rates: $2.4 \mathrm{~m}^{3} / \mathrm{s}$ and $2.8 \mathrm{~m}^{3} / \mathrm{s}(5,000 \mathrm{cfm}$ and $6,000 \mathrm{cfm})$. If a fire scenario arises with a fire power of $1,500 \mathrm{~kW}(1,422 \mathrm{Btu} / \mathrm{sec})$, find the average hot gas layer temperature for gypsum board (boundary material) that is $1 / 2,5 / 8,3 / 4,1,11 / 2$, 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 $6,000 \mathrm{cfm}$ ) at 15 minutes after ignition.

Assumptions:
(1) Air properties (ambient) are at $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$.
(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 $=1 \mathrm{~atm}$ ).

Spreadsheet (FDT ${ }^{\text {s }}$ ) Solution Procedure:
Use the following $\mathrm{FDT}^{s}$ :
(a) 02.2_Temperature_FV.xls

## FDT ${ }^{\text {s }}$ Input Parameters:

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

- Compartment Width $\left(\mathrm{w}_{\mathrm{c}}\right)=50 \mathrm{ft}$
- Compartment Length ( $\mathrm{I}_{\mathrm{c}}$ ) $=40 \mathrm{ft}$
- Compartment Height $\left(\mathrm{h}_{\mathrm{c}}\right)=12 \mathrm{ft}$
- Interior Lining Thickness $=0.5$ in
- Select Material: select Gypsum Board from the combo box
- Compartment ventilation rate ( $\dot{\mathrm{m}}$ ) $=5,000 \mathrm{cfm}$ and $6,000 \mathrm{cfm}$
- Fire Heat Release Rate ( $\dot{\mathrm{Q}}$ ) $=1,500 \mathrm{~kW}$

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 I․ (cfm) | Trial | Material Thickness (in) | Hot Gas Layer Temperature $\mathrm{T}_{\mathrm{g}}\left[^{\circ} \mathrm{C}\left({ }^{\circ} \mathrm{F}\right)\right]$ |  |
| :---: | :---: | :---: | :---: | :---: |
|  |  |  | 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 $5,000 \mathrm{cfm}$ scenario are similar.

FDT $^{\text {s: }}$ : 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 layertemperature and smoke layer height in enclosure ire. Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are A tomatically Selected from the DROP DOWN MENU for the Material Selected.
Al subsequent output values are calculated bythe spreadsheet and based on values specified in the input parameters. This spreadsteet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG stould be read before an analysis is made.
INPUT PARAMETERS


| COMPART MENT MASS VENTILAT ION FLOW RATE <br> Forced Ventilation Flow Rate (m) | 6000.00 cmn <br> FIRE SPECIFICATIONS <br> Fire Heat Release Rate (Q) |
| :--- | :---: |

## METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reterice: SFPEHandlook of Fle Piotcton Engheering, $3^{\text {E }}$ Editbi, 2002, Page 3-177.
$\Delta T_{g} / T_{a}=0.63\left(Q / m_{0} \varphi_{p} T_{a}\right)^{0.72}\left(h_{4} A_{T} / m c_{p}\right)^{-0.35}$
Where $\quad \Delta T_{g}=T_{g}-T_{a}=$ upper layer gas temperature rise above ambient ( $k$ )
$\mathrm{T}_{\mathrm{s}}=$ ambient air temper ature ( $(\mathrm{K})$
$Q=$ heat release rate of the fire (kiof)
$\mathrm{m}=$ compartment mass ventilation flow rate ( $\mathrm{kg} / \mathrm{sec}$ )
$\omega_{p}=$ specific heat of air (kJ/kg-K)
$\mathrm{k}_{\mathrm{k}}=$ convective heat transfer coefficient $\left(\mathrm{k} / \mathrm{m} / \mathrm{m}^{2}-\mathrm{K}\right)$
$A_{T}=$ total area of the compartment enclosingsurface boundaries ( $\mathrm{m}^{2}$ )
Thermal Peneration Time Calculation
$t_{p}=\quad\left(\rho \rho_{p k}\right)(\delta / 2)^{2}$
Where $\quad \phi=$ thermal penetration time (sec)
$\rho=$ interior corstruction dersity $\left(\mathrm{kg} / \mathrm{m}^{3}\right)$
$\phi_{0}=$ interior construction heat cap acity ( $\mathrm{kJ} / \mathrm{kg}$. $)$
$k=$ interior construction thermal conductivity $(k) W / m$, $)$
$\delta=$ interior construction thickness (m)
$t_{p}=\quad 2254.26 \mathrm{sec}$
Hea Transer Coefficient Calculation
$h_{k}=\quad v(k \rho$ cit $)$ for $t<t_{p} \quad$ or $\quad(k / 5)$ for $t>t_{b}$

Where $\quad h_{k}=$ heat transfer coefficient $\left(\mathrm{koj} / \mathrm{m}^{2}-\right.$ 以)
$k \rho_{0}=$ interior construction thermal inertia $\left(\mathrm{k} \omega /\left(\mathrm{m}^{2}-k\right)^{2}-\mathrm{sec}\right.$
(a thermal property of material responsible for the rate of temperature is e)
$t=$ time after ignition (sec)
See table below for result
Area of Compart ment Endosing Surface Boundaries
$A_{T}=\quad 2\left(\omega_{c} \times l_{c}\right)+2\left(h_{c} \times n_{c}\right)+2\left(h_{c} \times l\right)$
Where $\quad A_{T}=$ total area of the compartment enclosingsurface boundaries ( $\mathrm{m}^{2}$ )
$\mathrm{m}_{\mathrm{c}}=$ compartment width (m)
$k=$ compartment length (m)
$h_{c}=$ compartment height (m)
$A_{v}=$ area of ventilation opening $\left(m^{2}\right)$
$A_{T}=$
$572.28 \mathrm{~m}^{2}$

Compartment Hot Gas Layer Temperature With Forced Ventilation

$\Delta T_{g}=\quad T_{g}-T_{a}$
$T_{g}=\quad \Delta T_{g}+T_{\mathrm{g}}$

## Results

| Time After ganition (t) |  | $\begin{gathered} h_{x_{2}} \\ \left(k_{0} \omega^{2}-k\right) \end{gathered}$ |  | $\begin{aligned} & \mathbf{i} \mathrm{T}_{\mathrm{a}} \\ & (\mathrm{~K}) \end{aligned}$ | $\begin{aligned} & T_{\mathrm{o}} \\ & (\mathrm{~K}) \end{aligned}$ | $\begin{gathered} \mathrm{T}_{\mathrm{a}} \\ (\mathrm{C}) \end{gathered}$ | $\begin{gathered} \mathrm{T}_{\mathrm{a}} \\ \left({ }^{\mathrm{a}}\right) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (min) | (sec) |  |  |  |  |  |  |
| 0 | 0 | - | - | - | 298.00 | 25.00 | 77.00 |
| 1 | 60 | 0.05 | 038 | 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 | 14436 | 442.36 | 169.36 | 336.84 |
| 5 | 300 | 0.02 | 0.50 | 15027 | 448.27 | 175.27 | 347.49 |
| 10 | 600 | 0.02 | 0.57 | 17024 | 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 | 21330 | 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 A1 | 575.41 | 302.41 | 576.34 |
| 50 | 3000 | 0.00 | 0.93 | 277 A1 | 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

Heat Transter Coetriclent Calculation
h. - $\quad 0.4 \mathrm{v}(\mathrm{APC} / \mathrm{t})$ 加 $\mathrm{t}<\mathrm{t}$

Where $\quad \mathrm{b}$ - leat tanst roce tite it aWin ${ }^{2}$-ly
$\mathrm{kPC}=$ Iiteribr constrictor the mallier tha $k W \mathrm{ma}^{2}-\kappa^{2}-\mathrm{sec}$
(athe malpopert ofmat inale sporsble to the rate or temperature ike)
0 - tubliess of litibrlilig (in)
$\mathrm{t}-\quad 0.022 \mathrm{~kW} \mathrm{~mm}^{-\mathrm{K}}$

Area of Compartment Enclosing surface Boundarie:
$\mathrm{A}_{\mathrm{r}}=\quad 2\left(\mathrm{~W}_{\sim} \times \mathrm{D}\right)+2\left(\mathrm{c} \times \mathrm{w}_{\mathrm{c}}\right)+2(\mathrm{c} \times \mathrm{l})$
$\mathrm{A}_{\mathrm{I}}=\quad 572.28 \mathrm{~m}^{2}$
Compartment Hot Ga: Layer Tem perature Wh Forced ventliation
$\Delta T_{\mathrm{e}}=\mathrm{Q} /\left(\mathrm{dn} \mathrm{C}_{\mathrm{p}}+\mathrm{H}_{1} \mathrm{~A}_{1}\right)$

Where


$Q=$ leat e pase ate oftle fre (kW)
$\mathrm{m}=$ compartnes tmass ve ithtor tow rate (ggisec)
$c_{p}=$ specric be atotali ( JJ/g-ry

1.     - convectue reattans tr coe make it *Win ${ }^{2}-19$
$A_{1}=$ tetarea orthe compartme ite ichosig surtace boudarks (in)

## Results

| Tim $\theta$ After Ignition ( $t$ ) |  | $\begin{gathered} \mathrm{h}_{\mathrm{k}} \\ \text { gWWin }-15 \end{gathered}$ | $\begin{gathered} \hline \mathrm{AT}_{9} \\ \mathbf{C O} \end{gathered}$ | $\begin{aligned} & \hline \mathrm{T}_{9} \\ & \mathrm{CO} \\ & \hline \end{aligned}$ | $\begin{gathered} \hline \mathrm{T}_{\mathrm{e}} \\ \mathrm{Cl} \end{gathered}$ | $\begin{gathered} \mathrm{T}_{\mathrm{a}} \\ (\mathrm{~F}) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (ma) | (sec) |  |  |  |  |  |
| 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 | 455.38 | 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 | 515.45 |
| 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 |



## Summarvo fiesut:



## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Frotection Engineering. 3 Edition, 2002.
Calculations are based on certain assumptions and have irherent limitations. The results of such cabulations may or may not have reasonable predictive capabities for a given situation, and should onlybe interpreted by an informed user.
Athough each calculation in the spreadsteat has been verified with the results ofhand calcuation, there is no absolute guarartee of the acouracyof these calculations.
Anyquestions,corrments, concems, and suggestions, or to report an enror's) in the spreadsheet, please send an emai to nxignregov or mes3@regov.


## Problem J-7

## Problem Statement

Consider a compartment with an open vent that allows the air entrance at $3.60 \mathrm{~m} / \mathrm{s}$ ( $700 \mathrm{ft} / \mathrm{min}$ ). Assume that heptane from a tank spills on the concrete floor forming a $1.86 \mathrm{~m}^{2}\left(20 \mathrm{ft}^{2}\right)$ pool. The edge to edge distance from the pool fire to a certain target is about $9.0 \mathrm{~m}(30 \mathrm{ft})$. 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 FDTs:
(a) 05.2_Heat_Flux_Calculations_Wind.xls (select Solid Flame 2)

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):

- Fuel Spill Area or Dike Area $\left(\mathrm{A}_{\text {dike }}\right)=20 \mathrm{ft}^{2}$
- Distance between Fire and Target (L) = 30 ft
- Vertical Distance of Target from Ground Level $\left(\mathrm{H}_{1}=\mathrm{H}_{\mathrm{f} 1}\right)=10 \mathrm{ft}$
- Wind Speed or Velocity $\left(u_{w}\right)=700 \mathrm{ft} / \mathrm{min}$
- 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* <br> $\dot{\mathrm{q}}^{\prime \prime}$ <br> $\mathrm{kW} / \mathrm{m}^{2}\left(\mathrm{Btu} / \mathrm{ft}^{2}-\mathrm{sec}\right)$ |
| :--- | :--- |
| Solid Flame | $4.06(0.36)$ |

*spreadsheet calculations attached on next page

## Spreadsheet Calculations

FDTs : 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 WND (TILTED FLAME)

## SOLID FLAME RADIATION MODEL

## Version 1805.0




Param eters In YEL LOW CELLS are Enteredby the User.
Parameters In GREENCELLS are Automatcally selected tom the DROP DOWN MENU for the Ruel selected.
Allsibsequentorpitvalues are calculatedby the speadsheetand based or vanes specired it the lupit

The chapter the NUREG shott be reall betre at aralys t made.

## INPUT PARAMETERS

| Hass bining Rat of Fiel (tn) | $0.101 \mathrm{~m} / \mathrm{m}^{2}-\mathrm{sec}$ |  |
| :---: | :---: | :---: |
|  | $44600 \mathrm{kN} / \mathrm{kg}$ |  |
| Empricalcosstatap) | $1.1 \mathrm{~m}^{-1}$ |  |
| FielArea or Dke Area ( $A_{\text {dsu }}$ ) | $20.00{ }^{\text {n }}$ | $1.85 \mathrm{~m}^{2}$ |
| Distance between $F$ re and Tagjet(L) | $30.00{ }^{11}$ | 9.144 m |
| Verttal Dt tace of Target tom G roud Leve I ( $\mathrm{H}_{-}=\mathrm{H}_{3}$ ) | 10.00 n | 3.048 m |
| Whad Speed or Ve betty ( ${ }_{\text {w }}$ ) | 700 mmh | $3.35 \mathrm{~m} / \mathrm{sec}$ |
| AmbeitA ir Tempenatire ( $\mathrm{T}_{4}$ ) | 77.00 "F | $25000^{\circ} \mathrm{C}$ |
|  |  | 29850 K |
| G raulatl ial Aocele ration (g) | $9.81 \mathrm{~m} / \mathrm{sec}$ |  |
| Ambeitair Deistep ( $\rho_{\text {a }}$ ) | $1.18 \mathrm{kgm}^{3}$ |  |
|  | Calculate |  |
|  |  |  |

THERMAL PROPERTIE S LO TA
BURNING RATE DATA FOR FUELS

| Fiel | Mass buning Rat $\mathrm{m}^{*}$ ( $9 \mathrm{~g} \mathrm{~m}^{2}-\mathrm{sec}$ ) | He atot Can bistbı $\Delta \mathrm{H}_{\mathrm{c}}$ an ( kJ kg ) | Emplical Coustat $\mathrm{k} \beta\left(\mathrm{m}^{-1}\right)$ | Select Fuel Type |
| :---: | :---: | :---: | :---: | :---: |
| Methatol | 0.017 | 20,000 | 100 | Seroll to deslred tueltype then |
| Etual | 0.015 | 26,800 | 100 | Click on selection |
| 6 ttate | 0.078 | 45,700 | 2.7 |  |
| Berzere | 0.085 | 40,100 | 2.7 |  |
| Hexate | 0.074 | 44,700 | 1.9 |  |
| Heptare | 0.101 | 44,500 | 1.1 |  |
| Xylere | 0.09 | 40,800 | 1.4 |  |
| Ace bre | 0.041 | 25,800 | 1.9 |  |
| Droxare | 0.018 | 26,200 | 5.4 |  |
| Ditur Etier | 0.085 | 34,200 | 0.7 |  |
| berzlie | 0.048 | 44,700 | 3.6 |  |
| Gasolite | 0.055 | 43,700 | 2.1 |  |
| Keroslie | 0.039 | 43,200 | 3.5 |  |
| Desel | 0.045 | 44,400 | 2.1 |  |
| JP-4 | 0.051 | 43,500 | 3.5 |  |
| JP-5 | 0.054 | 43,000 | 1.5 |  |
| Trastomer 01. Hydocatbor | 0.039 | 46,000 | 0.7 |  |
| 561 Sillso Transtomer Fhkl | 0.005 | $28,100$ | 100 |  |
| fieloll, Heary | 0.035 | 39,700 | 1.7 |  |
| Cricle OII | 0.0335 | 42,600 | 2.8 |  |
| Libe Oll | 0.039 | 46,000 | 0.7 |  |
| Dosglas Fr Pl/wood | 0.01082 | 10,900 | 100 |  |
| User Specrled Vahe | Eiter Valie | Eiter Valie | Eitr Valie |  |

## ES TIMATIMG RADIATIVE HEAT FLUX TO A TA RGET FUEL II PRES EIICE OF WIID

SOLID FLAMERACI ATIO M MODEL IM PRESEM CEOF WIMD
$\mathrm{q}^{*}=$ 日
Where $\quad \mathbf{q}^{*}$ - Inddent ratalte heal tix on te lagel $\mathbf{k W} \mathrm{Wm}^{3}$ )
E- embstre power of te pod te tame gWMm) F $=$ view tocter be theen brgeland te tome inpresence of wird

Fool Rie ClameterCaloulation
$A_{-2}=\pi D^{1 / 4}$
$D=v+A_{2} s$
Where $\quad A_{-2}=$ sutire area ofpool te (mi)
D = pool Ire dian ker (m)
D =
Pool Fre Radius ccalculation

| $\mathrm{r}=$ | $\mathrm{D} / 2$ |  |
| :--- | :--- | :--- |
| $\mathrm{r}=$ | 0.77 m |  |

Rame Enledve Rower Caloulaton
E. 58 ( 10 :

Where E-embitue power of the pod te tome GWM)
0 = dame er or the poor te (in)
E$66.33 \mathrm{~g} \cdot\left(\mathrm{~m}^{2}\right)$

Vbw Fandor Caloulation in Recence of Wha

| "10N0 |  |
| :---: | :---: |
| ${ }_{5} \mathrm{~F}_{100 \mathrm{Na}}=$ |  |
| A. | $a^{3}+(b+1)^{-2 a}(b+1)$ atre |
| $A_{2}=$ | $a^{3}+$ + ${ }^{2}+b^{2}-2 a_{0}(b+1)$ aire |
| B. $=$ |  |
| $B_{1}=$ |  |
| C - | $1+\left(b^{3}-1\right) c \alpha^{\prime} \theta$ |
| a $=$ | $2 \mathrm{H} \cdot \mathrm{r}=2 \mathrm{H}$ /r |
| a. | $2 \mathrm{H}_{3} \mathrm{r}=2 \mathrm{H}_{4}-\mathrm{H}_{2} \mathrm{\lambda} \mathrm{r}$ |
| b $=$ | Ris |
|  |  |
| Where |  |
|  | $\mathrm{R}=$ dstance fom center of te pool te b edje of the trge l(mi) |
|  | $\mathrm{H}_{2}=$ heighl ofle pool te tane (m) |
|  | $\mathrm{r}=$ pool fre raike (m) |
|  | $\theta=$ tame Ill or aryk ofdeleclon(ralary) |



Fame Tiltor Angle of Deicoton Caloulation
$\operatorname{cose}=1$
cose $=1$ (vin $\quad$ or $\mathrm{u}^{+}=1$
Snce $\mathrm{u}^{\prime}=1$

-     - ACO S(1/(u'y 0.5$)=$
$\left.A=a^{2}+(b+)^{2}-2 a+d+1\right) \sin \theta=$
$\left.A=a+(b+1)^{2}-2 a d+1\right) \sin \theta=$
$\left.B=a+(b-1)^{2}-2 a d-1\right)+t h A=$
$\left.B_{2}=a^{2}+(b-1)^{2}-2 a d-1\right)=\operatorname{ch}=$
$c=1+\Phi^{2}-t \cos ^{2} \theta=$
$a=2 H_{r} \pi=2 H i r=$
a- $2 \mathrm{H}_{\mathrm{C}} \mathrm{H}=2\left(\mathrm{H}-\mathrm{H}_{\mathrm{C}} \mathrm{O} \mathrm{H}=\right.$
$b=R i r=$

| 0.985 Rad | 55.42 degree |
| :--- | ---: |
| 0.985 Rad | 56.42 degree |
| 0 Rad | 0.00 degree |
| 72.30 |  |
| 97.71 |  |
| 47.16 |  |
| 63.98 |  |
| 61.61 |  |
| 7.93 |  |
| 6.36 |  |
| 12.89 |  |


| $\mathrm{F}_{1 \times 2 \mathrm{VH}}$ | 0.04306 |
| :---: | :---: |
| F | 0.02899 |
|  | 0.07204 |


| $\mathrm{F}_{\mathrm{v}}$ |  |  |
| :---: | :---: | :---: |
|  | 0.697 | 1.023 |
| $\mathrm{F}_{\mathrm{n}}$ |  |  |
|  | 0.351 | 1.022 |



Radlative Heat Rur Caloulation in Fre cenee of Wind
$\mathbf{q}^{*}=\mathrm{EF}$
$\begin{array}{ll}q^{\prime \prime}= & 4.06 \mathrm{kWim}\end{array}$
0.36 Etu/ft'-coo

An ewar

## мOT E

The aboue caldalans are based on primelples developed in the SFPE Haxdbock of f re Prokecton Exdinering, 3 Ellon 2002.
Calculalons are based an ceribinastump bont and have wherewilimitalons. Tie resilt of such
calcutalans may or may nol tave rearonsble prediblue capabil bes for a given siluilon, and shoubl calcualans may or may nollase reatond
onty be inkerprekd by an mbrmed urer. tere is no absolule guaranke of the acuracy of tese calalalons.
Tere is no absockle gusanke of the saciracy of these calalalons.
Any questons, comments, concems, and suggestons, or breporian erion(s) in the spreatiteel, Ary questons, comments, concems, and suggestons, or
pleare send an emall io nuiepryog or mxi3e itcgov.


## Problem J-8

## Problem Statement

Consider a compartment that has been insulated with $1.27 \mathrm{~cm}(1 / 2 \mathrm{in})$ of gypsum board, wallboard (S142M). If a pool fire scenario arises with a heat flux of $75 \mathrm{~kW} / \mathrm{m}^{2}$, 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 $\mathrm{FDT}^{\mathrm{s}}$ :
(a) 06_Ignition_Time_Calculations.xls (select Ignition_Time _Calculations1)

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):
-Exposure or External Radiative Heat Flux to Target Fuel $\left(\dot{\mathrm{q}}_{e}{ }_{e}\right)=75 \mathrm{~kW} / \mathrm{m}^{2}$
-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* <br> $\mathrm{t}_{\mathrm{ig}}(\mathrm{min})$ |
| :--- | :--- |
| 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 ${ }^{\text {s }}$ : 06_Ignition_Time_Calculations.xls (Ignition_Time _Calculations1)

CHAPTER 6. ESTIMATING THE IGNITION TIME OF ATARGET FUEL EXPOSEDTO A
CONSTANT RADIATVE HEAT FLUX
version 1805.0

exkmal rallalve tealiure
Parametera in YELICNCELI 9 are Bitered by the U cer.
Farametera in GREX CE 13 are Autmathoally soleoted tom the DROP DONK MENU tortio Material opleoted.
Alsubsequent cupul values are calataled by te spreatiteel and tased on values epectied in te trpulpaane lers.



INPUT PARAMETERS
MATERIAL FLAME SPREAD PROPERTIES
Makital hrivion Temper akre (T)
Makital Tiemal terta (hpo
Makertal Critical Heal Flue ior brition $\left(q^{\text {a }}\right.$,
Flame Spreal Parame ker b
Eqporre or Ex prod Rasable Heal fluk ín $^{*}$ )
Amblent Ar Temperakre (T)
Heal tiantior coetidery al brillond


FLAME SPREAD PROPERTIES OF COMMON MATERIALS

| Aakeras: | briflon Temperakre $T$ (C) | Thermal herlatpc <br>  | Critcal Healf kix tor brilon $\mathrm{q}^{*}$ (chay kWim) | Flame Spreat Parameler b (c) | Select Material |
| :---: | :---: | :---: | :---: | :---: | :---: |
| PIMSA Polycar 1 ( 1.59 mm ) | 278 | 0.73 | 9 | 0.04 | Scroll to dedred n |
| Hardboard (6.35mm) | 298 | 1.87 | 10 | 0.03 | Click on coleoton |
| Capel/Arcyio | 300 | 0.42 | 10 | 0.06 |  |
| Flber maxilon Board | 350 | 0.45 | 14 | 0.07 |  |
| Hardboard (3.175mm) | 365 | 0.88 | 14 | 0.05 |  |
| PIMAA Type G (1.27 an) | 378 | 1.02 | 15 | 0.05 |  |
| Asphall ctilug | 378 | 0.7 | 15 | 0.06 |  |
| Dounlar fre Parlck Boad ( $1 . Z \mathrm{~cm}$ ) | 385 | 0.94 | 16 | 0.05 |  |
| Plywood Plin (1.27 an) | 350 | 0.54 | 16 | 0.07 |  |
| Plywood Plah (0.635 an) | 350 | 0.46 | 16 | 0.07 |  |
| Foam Flextle ( 2.54 cm ) | 350 | 0.32 | 16 | 0.09 |  |
| GRP (2.24mm) | 350 | 0.32 | 16 | 0.09 |  |
| Hardboard (Glors Paing ( 3.4 mm ) | 400 | 1.22 | 17 | 0.05 |  |
| Hardboard wircceluliose Painb | 400 | 0.79 | 17 | 0.05 |  |
| $G R P(1.1+\mathrm{mm})$ | +60 | 0.72 0.93 | 17 18 | 0.06 |  |
| Parlie Boud (1.2 cm Slod) capel (Mytonvbol Elery) | +12 | 0.93 0.68 | 18 18 | 0.05 |  |
| Gypam Board, Walbord (31423.5) | +12 | 0.57 | 18 | 0.97 |  |
| Capele 2(Vool Unteskd) | 435 | 0.25 | 20 | 0.11 |  |
| Foam Rbld ( $2.5+\mathrm{cm}$ ) | 435 | 0.03 | 30 | 0.32 |  |
| Flberglars Sinule | 445 | 0.5 | 21 | 0.08 |  |
| Pobltoyarxale ( 5.58 cm ) | 445 | 0.022 | 21 | 0.35 |  |
| capel\# 2(Vool Teaked) capel: 1 (Wool, Slod) | 4 | 0.24 | 22 | 0.12 |  |
| Ar | 506 | 0.24 | 28 | 0.13 |  |
| Gypram Board F R (127 cmi | 510 | 0.4 | 28 | 0.1 |  |
| Pobcaronste ( 1.52 mm ) | 588 | 1.16 | 30 | 0.95 |  |
| Gypram Eoard (Canmorv ( 1.27 mm ) | 565 | 0.45 | 35 | 0.11 |  |
| Plywod FR (1.27 an) <br> Pofy brene ( 5.58 cm ) | 630 | 0.76 | $4+$ 46 | 0.1 0.14 |  |
| User Jectied Vakn | Biler Vaske | Erer Vake | Erer Vatue | Entr vake |  |



## Problem J-9

## Problem Statement

A 75.0-liter (20-gallon) trash bag exposure fire source is located $3.0 \mathrm{~m}(10.0 \mathrm{ft})$ beneath a horizontal cable tray. Assume that the trash fire ignites an area of approximately $1.0 \mathrm{~m}^{2}\left(11.0 \mathrm{ft}^{2}\right)$ of the cable tray, and the cables in the tray are IEEE-383-qualified XPE/FRXPE cables. Compute the full-scale $\operatorname{HRR},\left(\dot{Q}_{6}\right)$ of the XPE/FRXPE cable insulation. The bench scale HRR $\left(\dot{Q}_{\mathrm{b}}\right)$ of the XPE/FRXPE is $475 \mathrm{~kW} / \mathrm{m}^{2}$.

## 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 FDTs:
(a) 07_Cable_HRR_Calculations.xIs

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):
-Exposure Cable Tray Burning Area $\left(A_{f}\right)=11 \mathrm{ft}^{2}$
-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 <br> HRR $\dot{\mathrm{Q}}_{\mathrm{fs}}$ <br> $\mathrm{kW}(\mathrm{Btu} / \mathrm{sec})$ |
| :--- | :--- |
| XPE/FRXPE | $218(207)$ |

*spreadsheet calculations attached on next page.

## Spreadsheet Calculations

FDT ${ }^{\text {s }}$ : 07_Cable_HRR_Calculations.xls

CHAPTER 7. ESTIMATING THE FULL-SC ALE HEAT RELEASE RATE OF A CABLE TRAY FIRE
Version 1805.0
The follow h calcikatbis estmate the til-scak cable tray leat rekase rat.
Param $\theta$ ters In YEL LOW CELLS are Entered by the User.
Parameteri In GREEN CELLS are Automatically selected from the DROP DOWM MENU tor the Cable selected.
Allsubsequertorpitvalses are cabilated by the spreadsleet and based on valies specmed the liput

The chapter $\boldsymbol{t}$ the NUREG $s$ hot th be read betore al anays $t \mathrm{k}$ made.

## INPUT PARAMETERS

Cable Betcl-Scat HRR $Q_{b}$ )
Exposed Fbor Area (le igth $\times W$ ktth) of $B$ ining Cable Tray (A)


Calculate
HEAT RELEASE RATE DATA. FOR CQ BLE TRAY FIRE

| Cable Type | Berct-Scat HRR per Uit Fbor Area ( $\mathrm{L} \times \mathrm{W}$ ) <br>  | Select Cable Type <br> XPERXPE <br> scroll to detirea cadie type then Click on selection |
| :---: | :---: | :---: |
| kI PE <br> PEPVC <br> XPE/FRXPE <br> PEPVC <br> PEPVC <br> XPE/Ne opre Ie <br> PE, PPRCI.S.PE <br> PEPVVC <br> XPE/Ne opre le <br> PE, PP CIIS.PE <br> PE, PPACI.S.PE <br> FRXPE/CIS.PE <br> $P$ E, Nybi/PVC, Nybi <br> PE, Nybı/PVC, Nybı <br> XPECIS.PE <br> Slloore, ghas brakl, asbests <br> XPEAPE <br> PE, PPRCI.S.PE <br> Slloole, quass brakl <br> Te for <br> Use i Specired Valie | 1071 589 475 395 359 354 345 312 302 299 271 258 231 218 204 182 178 177 128 98 Eite r Valte |  |



## E STIMATIIIG FULL-SCALE CABLE TRAY HEAT RELEASE RATE


$\mathrm{Q}_{15}=0.45 \mathrm{Q} \mathrm{A}$
Where $\quad Q_{i=}=$ cable tray full-scale HRR (kid)
$\mathrm{Q}_{\mathrm{a}}=$ cable traybench-scale $\mathrm{HRR}\left(\mathrm{k}^{0} 0\right)$
$A=$ exposed 1 oor area (length $x$ with) of buming cable tray $\left(m^{2}\right)$
Heat Release Rate Calculation
$\mathrm{Q}_{\mathrm{s}}=0.45 \mathrm{D} \mathrm{A}$

| $\mathrm{Q}_{\mathrm{a}}=$ | 218.44 kW | 207.04 Btulsec | Answer |
| :--- | :--- | :--- | :--- |

## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering. $3^{\text {nl }}$ Edition, 2002.
Calculations are based on certain assumptions and has inherent lirritations. The results of such calculations may or maynot have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Athough each calculation in the spreadsheet has been veriied with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Anyquestions, comments, concems, and suggestions, or to report an erron(s) in the spreadsheet, please send an email to nxi@nregov or mxs3@nregov.


## Problem J-10

## Problem Statement

Estimate the maximum plume temperature ( $\mathrm{T}_{\mathrm{p} \text { (centerine }}$ ) at the ceiling of a $6.0-\mathrm{m}(20.0-\mathrm{ft})$ high compartment above a $1,420 \mathrm{~kW}$ fire involving a $11 / 2 \mathrm{ft}$ high stack of wood pallets in a $0.92 \mathrm{~m}^{2}$ $\left(10.0 \mathrm{ft}^{2}\right)$ pallet area. Assume that the ambient temperature is $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$.

## 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 ${ }^{\text {s }}$ ) Solution Procedure:
Use the following FDTs:
(a) 09_Plume_Temperature_Calculations.xls

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):
-Heat Release Rate ( $\dot{\mathrm{Q}}$ ) $=1,420 \mathrm{~kW}$
-Distance from the Top of the Fuel to the Ceiling ( $z$ ) = 20 ft
-Area of Combustible Fuel $=10 \mathrm{ft}^{2}$

## Results

| Heat Release Rate <br> $\dot{\mathrm{Q}}$ (kW) | Plume Centerline <br> Temperature <br> $\mathrm{T}_{\text {p (centerline) }}$ <br> ${ }^{\circ} \mathrm{C}\left({ }^{\circ} \mathrm{F}\right)$ |
| :---: | :--- |
| 1,420 | $164(328)$ |

*spreadsheet calculations attached on next page.

## Spreadsheet Calculations

FDTs ${ }^{\text {s }}$ 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 ONLYIN 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



$$
\begin{array}{r}
6.10 \mathrm{~m} \\
0.93 \mathrm{~m}^{2} \\
25.00 \mathrm{c} \\
296.00 \mathrm{~K}
\end{array}
$$

Specific Heat of Air $\left(\rho_{p}\right) \quad 1.00 \mathrm{~kJ} / \mathrm{kg}-\mathrm{K}$
Ambient Air Dersity ( Pa )
$1.18 \mathrm{~kg} / \mathrm{m}$

Comective Heat Release Fraction ( ${ }^{3} \mathrm{c}$ )
9.81 mvsec
0.70

Note: Air dersity will automatically correct with Ambient Air Temperature ( $T_{2}$ ) Input
PLUME CENTERLINE TEMPERATURE

$\mathrm{T}_{\mathrm{p} \text { (cenkitre) }}-\mathrm{T}_{\mathrm{a}}=9.1\left(\mathrm{~T}_{\mathrm{s} / \mathrm{g}}{\rho_{p}}^{2} \rho_{0}\right)^{1 / s} \mathrm{Q}_{\mathrm{c}}{ }^{\mu l s}\left(\mathrm{z} \cdot \mathrm{z}_{0}\right)^{-2 / s}$
Wh'here $\quad T_{p(a n t r i n e)}=$ plume centerline temperature ( ${ }^{\circ} \mathrm{C}$ )
$Q_{c}=$ comvective portion of the heat release rate (kid)
$\mathrm{Ta}_{a}=$ ambient air temper ature ( K )
$\mathrm{g}=$ acceleration of gravity (m/sec)
$\mathrm{cp}=$ specific he at of air (kJ*g-K)
$=$ ambient air dersity $(\mathrm{kg} / \mathrm{m})$
$z=$ distance from the top of the fuel package to the ceiling (m)
$z_{0}=$ hypotheticalvirtual origin of the fire (m)

Convective Hea Release Rate Calculation
$Q_{c}=\jmath_{c} \subset Q$
$Q=$ heat release rate of the fire (kiof)
$\mathrm{Z}_{\mathrm{c}}=$ convective heat release fraction
$Q_{C}=\quad 994 \mathrm{kjol}$

Fire Calculation
$A_{c}=\pi D^{2} / 4$
Where $\quad A c=$ area of combustible fuel $\left(\mathrm{m}^{2}\right)$
$D=v\left(4 A^{\prime} / \pi\right)$
$D=\quad 1.09$
m

Hypothetical Virtual Origin Calculation
$\mathrm{ZOND}=-1.02+0.083\left(\mathrm{Q}^{25}\right) \mathrm{D}$
Where $\quad \begin{aligned} z_{0} & =\text { virtual origin of the fire }(\mathrm{m}) \\ Q & =\text { heat release rate of fire }(\mathrm{KM}) \\ \mathrm{D} & =\text { fire diameter }(\mathrm{m})\end{aligned}$
$\mathrm{zaD}=$
$Z_{0}=$
0.37
0.40 m

## Certerline Plume Temperature Calculation

$\mathrm{T}_{\mathrm{p} \text { (cenkilles) }} \mathrm{T}_{\mathrm{a}}=9.1\left(\mathrm{Talg} \mathrm{Cp}_{\mathrm{p}}^{2} \rho_{\mathrm{a}}^{2}\right)^{1 / 3} \mathrm{Qc}^{2 / 3}(\mathrm{Z}-\mathrm{Zo}){ }^{-5 / 3}$
$T_{p(\text { cenkerlire })}-T_{a}=139.22$
$T_{p(\text { cenkellbe })}=\quad 437.22 \mathrm{~K}$


## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering. $3^{\text {mi }}$ Edition, 2002. Caloulations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predidive 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 acouracy of these calculations.
Any questions, comments, concems, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nre.gov or mxs3@nrc.gov.


## Problem J-11

## Problem Statement

A fire with $\dot{Q}=3,000 \mathrm{~kW}$ occurs in a makeup pump room protected with sprinkler protection. The sprinklers are rated at $74^{\circ} \mathrm{C}\left(165^{\circ} \mathrm{F}\right)$ [standard response bulb with RTI 235 (m-sec) ${ }^{1 / 2}$ and located $3.0 \mathrm{~m}(10.0 \mathrm{ft})$ 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 $70^{\circ} \mathrm{F}$

Spreadsheet (FDT ${ }^{\text {s }}$ ) Solution Procedure:
Use the following $\mathrm{FDT}^{\mathrm{s}}$ :
(a) 10_Detector_Activation_Time.xls (select Sprinkler)

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):

- Heat Release Rate of the Fire $(\dot{Q})=3,000 \mathrm{~kW}$
- Distance from the Top of the Fuel Package to the Ceiling $(\mathrm{H})=18 \mathrm{ft}$
- Radial Distance from the Plume Centerline to the Sprinkler (r) $=10 \mathrm{ft}$
- Ambient Air Temperature $\left(T_{a}\right)=70^{\circ} \mathrm{F}$
- 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 ( $165{ }^{\circ} \mathrm{F}$ ) is within the range of temperature ratings for ordinary sprinklers ( $135^{\circ} \mathrm{F}-170^{\circ} \mathrm{F}$ ).
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* <br> $\mathrm{t}_{\text {activation (min.) }}$ |
| :---: | :---: |
| Standard <br> response bulb | 2.47 |

*spreadsheet calculations attached on next page.

## Spreadsheet Calculations

FDT': 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 Ertered by the User.
Parameters in GREEN CELLS are Rutomatically Selected fromthe DROP DOWN MENU for the Sprirkler Selected.
Al subsequent output values are calculated bythe spreadsteet and based on values specified in the input
parameters. This spreadsseet is protected and secure to awoid e mors due to a wrong entry in a cell(s)
The chapter in the NUREG should be read before an analysis is made.

## INPUT PARAMETERS



ESTIMATING SPRINKLER RESPONSE TIME
Reference: NFPA Five Protection Henobook, 19 Eolition, 2003, Page 3-140.

Where $\quad t_{\text {sctuat }}=$ sprinkler activation response time (sec)
$\mathrm{RTI}=$ sprinkler response time index $(\mathrm{m}-\mathrm{sec})^{1 / 2}$
$\mathrm{u}_{\mathrm{k} t}=$ ceiling jet velocity ( $\mathrm{m} / \mathrm{sec}$ )
$\mathrm{T}_{\text {let }}=$ ceiling jet temperature ( ${ }^{\circ} \mathrm{C}$ )
$\mathrm{T}_{\mathrm{a}}=$ ambient air temperature ( ${ }^{\circ} \mathrm{C}$ )
$\mathrm{T}_{\text {actuatsa }}=$ activation temperature of sprinkler ( ${ }^{\circ} \mathrm{C}$ )

## Ceiling Jet Temperature Calculation

$\mathrm{T}_{\text {let }}-\mathrm{T}_{\mathrm{a}}=16.9\left(\mathrm{Q}_{2}\right)^{23} / \mathrm{h}^{5 / 3}$
for $\mathrm{r}^{\prime} \mathrm{H}=0.18$
$\mathrm{T}_{\text {let }}-\mathrm{T}_{\mathrm{a}}=5.38\left(\mathrm{Q}_{\mathrm{d}} \mathrm{r}\right)^{2 / 3} / \mathrm{H}$
for $\mathrm{r}^{\prime} \mathrm{H}=0.18$
Where $\quad \mathrm{T}_{\text {let }}=$ ceiling jet temperature ( ${ }^{\circ} \mathrm{C}$ )
$\mathrm{T}_{\mathrm{a}}=$ ambient air temperature ( ${ }^{\circ} \mathrm{C}$ )
$Q_{\mathrm{c}}=$ corvective portion of the heat release rate ( $\mathrm{K} M$ )
$\mathrm{H}=$ height of ceiling above top of fuel ( m )
$r=$ radial distance from the plume centerline to the sprinkler $(m)$

## Convective Heat Release Rate Calculation

$Q_{c}=x_{c} Q$
Where $\quad Q_{c}=$ convective portion of the heat release rate ( $\mathrm{K} M$ )
$Q=$ heat release rate of the fire $(\mathrm{KN})$
$x_{c}=$ corvective heat release rate fraction
$Q_{\mathrm{c}}=$
2100 kN
Radial Distance to Ceiling Height Ratio Calculation
ri'H =
$0.56 \mathrm{riH}=0.15$
$T_{\text {let }}-T_{a}=\left\{5.38(Q \mathrm{c} / \mathrm{f})^{\wedge} 2 / 23\right\} / \mathrm{H}$
$\mathrm{T}_{\text {let }}-\mathrm{T}_{\mathrm{a}}=\quad 76.49$
$\mathrm{T}_{\text {jet }}=\quad 101.49\left({ }^{\circ} \mathrm{C}\right)$

## Ceiling Jet Velocity Calculation

$\mathrm{L}_{\mathrm{et}}=0.96(\mathrm{O} / \mathrm{H})^{1 / 3}$
for $\mathrm{r}^{\prime} \mathrm{H}=0.15$
Let $^{2}=\left(0.195 \mathrm{Q}^{1 / 3} \mathrm{H}^{1 / 2}\right) \mathrm{r}^{5 / 6} \quad$ for $r^{\prime} / \mathrm{H}=0.15$
Where $\quad u_{k t}=$ ceiling jet velocity ( $\mathrm{m} / \mathrm{sec}$ )
$Q=$ heat release rate of the fire $(\mathrm{KN})$
$\mathrm{H}=$ height of ceiling above top of fuel (m)
$r=$ radial distance from the plume centerline to the sprinkler ( m )

Radial Distanceto Ceiling Height Ratio Calculation
r/ $/ \mathrm{H}=$ $0.56 \mathrm{r} / \mathrm{H}>0.15$

| $u_{e l}=$ | $\left(0.195 \mathrm{Q}^{M} / 3 \mathrm{H}^{M} / 2\right) / \mathrm{r}^{\wedge} 5 / 6$ |  |
| :--- | :--- | ---: |
| $u_{\mathrm{el}}=$ | 2.602 | $\mathrm{~m} / \mathrm{sec}$ |

Sprinker Activation Time Calculation

$t_{\text {aotuaton }}=\quad 148.47 \mathrm{sec}$
The sprinker will respond in approximately
NOTE: If $\mathbf{t}_{\text {ac } 1 \text { vation }}=$ "NUM" Sprinkler does not activate

## NOIE

The above calculations are bas ed on principles developed in the NFPA Fire Protection H andbook $19^{\text {h }}$ Edition, 2003. Calculations are based on certain ass umptions 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 result of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerrs, and suggestions, or to report an error(s) in the spreadsheet, please send an email to $n \times i\left(\begin{array}{l}\text { neregov or } m \times s 3 \text { (@nregov. }\end{array}\right.$


## Problem J-12

## Problem Statement

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


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 $\mathrm{FDT}^{\mathrm{s}}$ :
(a) 10_Detector_Activation_Time.xls (select FTHDetectors)

## FDT ${ }^{\text {s }}$ Input Parameters:

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

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

Note: When $\mathbf{T}_{\text {activation }}$ 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 <br> $\mathrm{t}_{\text {activation }}(\mathrm{min})$. |
| :---: | :---: |
| Fixed <br> Temperature | 3.03 |

*spreadsheet calculations attached on next page.

## Spreadsheet Calculations

FDT ${ }^{\text {s }}$ : 10_Detector_Activation_Time.xls (FTHDetectors)

## CHAPTER 12 ESTIMATING HEAT DETECTOR RESPONSE TIME

Version 1805.0

Parameters in YELLOWCELLS are Entered by the User.
Parameter: in GREEN CELLS are Automatically selected from the DROP DOWN MENU for the Detector selected.
AIsubseque stortutvalies are caks kated by the spreadsheetand based on valses spectred in the lipit

The chapt in the NUREG s to akl be read be fore at analys $k \mathrm{k}$ made.
INPUT PARAMETERS

| He at Re ease Rat of the Flre (C) Staty Ste) | 1000.00 | WN |  |
| :---: | :---: | :---: | :---: |
|  | 10.00 | 11 | 305 m |
| Actrator Tempenature of the Flued Temperatie Heat Detector ( $T_{\text {atmam) }}$ | 128 | - | $5333{ }^{\circ} \mathrm{C}$ |
| Detector Response Tme Index (RTb | 306.00 | an-sec ${ }^{\text {a }}$ |  |
| He titor Celliggabove Top of Fiel(H) | 12.00 | 11 | 366 m |
| Amble it Ar Temperature ( $\mathrm{T}_{4}$ ) | 77.00 | /F | $2500{ }^{\circ}$ |
| Convectle Heat Release F actbi (2) | 0.70 |  |  |
| $\mathrm{r} / \mathrm{H}=00.83$ | Calculate |  |  |

INP UT DATA FOR ESTIMA TING HEAT DETECTOR RE SPONSE TIME

| Mctivation Temperature $T_{2}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| ff $\mathrm{T}=128 \mathrm{~F}$ | $\begin{aligned} & \text { UL LEEdSpactg } \\ & \text { i(t) } \end{aligned}$ | Response The Index RTI (n-sec) | $\begin{aligned} & \text { ActratbI } \\ & \text { Tempenatu re (CF) } \end{aligned}$ | Select Detector Spacing |
|  | 10 | 490 | 128 | Seroll to de slred spacing then Click on selection |
|  | 15 | 306 | 128 |  |
|  | 20 | 325 | 128 |  |
|  | 25 | 152 | 128 |  |
|  | 30 | 116 | 128 |  |
|  | 40 | 87 | 128 |  |
|  | 50 | 72 | 128 |  |
|  | $170$ <br> User Specmed Valte | 4 <br> Eitr Value | $128$ <br> EIEr Value |  |
|  |  |  |  |  |
| $C \mathrm{~T}=135 \mathrm{~F}$ | $\begin{aligned} & \text { UL LEt dSpactg } \\ & \text { ( (t) } \end{aligned}$ | Response The lidex RTI (n-sec) | Actuatb: <br> Tempe atare (F) | Select Detector Spacing |
|  | 10 | 404 | 135 |  |
|  | 15 | 233 | 135 | Scroll to de are dipacing then Click on selection |
|  | 20 | 165 | 135 |  |
|  | 25 | 123 | 135 |  |
|  | 30 | 96 | 135 |  |
|  | 40 | 70 | 135 |  |
|  |  | $54$ | 135 |  |
|  | $70$ | $20$ | $135$ |  |
|  | User Specmed Value | Eitrvalue |  |  |
| $\mathrm{C}_{\mathrm{T}}=145 \mathrm{~F}$ |  |  |  | Select Detector Spacing <br> Seroll to de alre d apacing then Click on selection |
|  | UL LE EdSpacig I (t) | Response Tine lidex RTI (n-sec) | Actraty <br> Tempentare ( 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 ispecmed dalue | Eitivalue |  |  |


| C $\mathrm{T}=160 \mathrm{~F}$ | $\begin{aligned} & \text { UL Listed Spacing } \\ & \text { I(ft) } \end{aligned}$ | $\begin{aligned} & \text { Response Time Index } \\ & \text { RTI(m-sec) } \end{aligned}$ | Activation Temperature (F) | Select Detector Spacing |
| :---: | :---: | :---: | :---: | :---: |
|  | $\begin{aligned} & 10 \\ & 15 \end{aligned}$ | $\begin{aligned} & 239 \\ & 135 \end{aligned}$ | $\begin{aligned} & 160 \\ & 160 \end{aligned}$ | Scroll to de sired spacing then Click on selection |
|  | 20 | 86 | 160 |  |
|  | 25 | 59 | 160 |  |
|  | 30 | 44 | 160 |  |
|  | $40$ | $22$ | $160$ |  |
|  | User Speciied Value | Enter V/alue |  |  |
| $\mathrm{C}=170 \mathrm{~F}$ | UL Listed Spacing $\mathrm{r}(\mathrm{tt})$ | $\begin{aligned} & \text { Response Time Index } \\ & \text { RTI (m-sec) } \\ & \hline \end{aligned}$ | Activation <br> Temperature (F) | Select Detector Spacing |
|  | 10 | 196 | 170 |  |
|  | 15 | 109 | 170 | Scroll to de sired spacing then Click on selection |
|  | $\begin{aligned} & 20 \\ & 25 \end{aligned}$ | 64 | 170 |  |
|  | $\begin{aligned} & 25 \\ & 30 \end{aligned}$ |  |  |  |
|  | User Speciied Value | Enter V/alue | Enter Value |  |
| $C \mathrm{~T}=196 \mathrm{~F}$ | UL Listed Spacing | Response Time Index | Activation | Select Detector Spacing |
|  | let | RTI (m-sec) | Temperature (\%) |  |
|  | 10 | 119 | 196 |  |
|  | 15 | 55 | 196 | Soroll to de sired spacing then |
|  | 20 | 21 | 196 |  |
|  | User Specired Value | Enter V/alue | Enter Value | Click on selection |

## E STIMATIIIG FIXED TEMPERATURE HEAT DETECTOR RESPOHSE TIME

## Reference: NFPA Fire Procection hisncbioov, to Ection 2003, Page 3-140


Where $\quad t_{\text {aswan }}=$ detectoractivation time (sec)
RTI = detector response time index (m-sec)
$u_{p t}=$ ceiling jet velocity (msec)
$\mathrm{T}_{\text {ad }}=$ ceiling jet temperature ( ${ }^{\circ} \mathrm{C}$ )
$\mathrm{T}_{3}=$ ambient air temperature ( ${ }^{\circ} \mathrm{C}$ )
$\mathrm{T}_{\text {admatan }}=$ activation temperature of detector ( ${ }^{(C)}$
Ceiling Jet Temperature Calculation


```
Tmi
Where }\quad\mp@subsup{T}{id}{}=\mathrm{ ceiling jet temperature ('C)
Ta}=\mathrm{ ambient air temperature ('C)
O}=\mathrm{ convective portion ofthe heat release rate (kif)
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
\(\mathrm{O}_{\mathrm{c}}=\mathrm{x}=\mathrm{D}\)
Where \(\quad \mathrm{Q}_{\mathrm{c}}\)-convective heat release rate (W0')
\(0=\) heat release rate of the ire (kNo)
\(x_{c}=\) convective heat release fraction
\(0_{c}=\)
700 koj
```

Radal Distance to Ceiling Height Ratio Calculation
r/H =
$0.83 \mathrm{r} / \mathrm{H}>0.15$

| $>0.15$ | 55.16 | $<0.15$ | 153.45 |
| :--- | :--- | :--- | :--- |

$\mathrm{T}_{p+1} \cdot \mathrm{~T}_{a}=538\left(\left(0 \mathrm{c} / \mathrm{r}^{2} 2 / 3\right)^{\prime} \mathrm{H}\right.$
$\mathrm{T}_{\mathrm{pa}} \cdot \mathrm{T}_{\mathrm{a}}=\quad 55.16$
$\mathrm{T}_{p 1}=\quad 80.16\left({ }^{\circ} \mathrm{C}\right)$
Ceiling Jet Velocity Calculation

| $\mathrm{U}_{\text {a }}=0.96(0 / \mathrm{H})$ |  | for $\mathrm{r} / \mathrm{H}=0.15$ |
| :---: | :---: | :---: |
| $u_{i d}=\left(0.1950^{10} \mathrm{H}^{12}\right)^{50}$ |  | for $\mathrm{r} / \mathrm{H}>0.15$ |
| Where | $\mathrm{u}_{p+1}=$ ceilin |  |
|  | $\begin{aligned} & \mathrm{O}=\text { heat } \mathrm{re} \\ & \mathrm{H}=\text { height } \\ & \mathrm{r}=\text { radial di } \end{aligned}$ | the detector |


| Radal Distance to Ceiling Height Ratio Calculation |  |  |
| :---: | :---: | :---: |
|  |  |  |
| $\mathrm{U}_{0}=\quad\left(0.195 \mathrm{Q}^{\wedge} 1 / 3 \mathrm{H}^{\mathrm{n}} 1 / 2\right) \mathrm{t}^{\prime \prime}(5 / 6)$ |  |  |
| $\mathrm{u}_{1 \mu}=1.473$ misec |  |  |
| Detector Activation Time Calcuation |  |  |
|  |  |  |
| $t_{\text {actuvion }}=181.72 \mathrm{sec}$ |  |  |
| The detector will respond in approximately | 3.03 minutes | Answer |

## HOTE: If $\mathrm{t}_{\text {antiation }}=$ 'IIUM" Detector does not activate

## NOTE

The above calculations are based on principles developed in the NF PAFire Protection Handbook 19 Edition, 2003. Calculations are based on cettain 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 intormed user.
Athough each calculation in the spreadsheet has been verived with the results of hand calculation. there is no absolute guarantee of the accuracy of these calculations.
Anyquestions, comments, concems, and suggestions, orto report an error(s) in the spreadsheet, please send an email to nxi@nro govormxs3@nre gov.


## Problem J-13

## Problem Statement

Calculate the HRR necessary for flashover $\left(\dot{Q}_{\mathrm{FO}}\right)$ and the post-flashover temperature in a long access corridor that is 30.5 m long $\times 5.5 \mathrm{~m}$ wide $\times 3.0 \mathrm{~m}$ high ( 100.0 ft long $\times 18.0 \mathrm{ft}$ wide $\times 10.0 \mathrm{ft}$ high), with an opening that is $0.91 \mathrm{~m}(3.0 \mathrm{ft})$ wide $\times 2.5 \mathrm{~m}(8.0 \mathrm{ft})$ 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 (FDTs ${ }^{s}$ ) Solution Procedure:
Use the following $\mathrm{FDT}^{\mathrm{s}}$ :
(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 ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in both spreadsheets (values only):

- Compartment Width $\left(w_{c}\right)=18 \mathrm{ft}$
- Compartment Length $\left(\mathrm{I}_{\mathrm{c}}\right)=100 \mathrm{ft}$
- Compartment Height $\left(\mathrm{h}_{\mathrm{c}}\right)=10 \mathrm{ft}$
- Vent Width $\left(w_{v}\right)=3 \mathrm{ft}$
- Vent Height $\left(\mathrm{h}_{\mathrm{v}}\right)=8 \mathrm{ft}$
- Interior Lining Thickness $(\delta)=6$ 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 <br> Temperature <br> $\mathrm{T}_{\text {PFO(max) }}$ <br> ${ }^{\circ} \mathrm{C}\left({ }^{\circ} \mathrm{F}\right)$ | Flashover HRR <br> $\dot{\mathrm{Q}}_{\mathrm{Fo}} \mathrm{kW}(\mathrm{Btu} / \mathrm{sec})$ |  |  |
| :--- | :--- | :--- | :--- |
| Method of Law | Method of MQH | Method of Babrauskas | Method of Thomas |
| $478(892)$ | $2,739(2,596)$ | $2,611(2,475)$ | $5,618(5,325)$ |

[^0]
## Spreadsheet Calculations

FDTs: 13_Compartment_Flashover_Calculations.xls (Post_Flashover_Temperature)

## CHAPTER 13. PREDICTING COMPARTMENT POST-FLASHOVER

 TEMPERATUREVersion 1805.0
The following calculations estimate the compartment post-flashovertemperature.
Parameters in YELLOW CELLS are Ertered by the User.
Al subsequent output values are calculated by the spreadsheet and based on values specified in the inp ut
parameters. This spreadsheet is protected and secure to awoid emors 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


## PREDICTIIIG COMPARTMEIIT POST-FLASHOVER TEMPERATURE METHOD OF MARGARETLAW

Retere na: SFPE Hinchook of Five Protection Engineeriga, $3^{\text {nd }}$ Edtion, 2002, Page 3-15.
$\mathrm{T}_{\text {Pro (max })}=6000\left(1-\mathrm{e}^{-1}\right) /(\mathrm{MD})$
Where $\quad T_{\text {Wro imax }}=$ maxirmum compartment post-flashover temperature ( ${ }^{\circ} \mathrm{C}$ )
$\boldsymbol{\Omega}=$ ventilation factor

Where $\quad \boldsymbol{\lambda}=(A-A) / A$ (vh $)$
$A=$ total area of the compartment enclosing surface boundaries excluding area of vent openings (m)
$A=$ area of ventilation opening ( $m^{2}$ )
$h_{v}=$ height of ventilation opening (m)
Area of Vertilation Opening Calcuation
$\mathrm{A}=(\mathrm{w})(\mathrm{h})$
Where $\quad A=$ area of ventilation opening $\left(\mathrm{m}^{2}\right)$
$w_{v}=$ vent width (m)
$h_{\mathrm{v}}=$ vent height (m)
$A=223 \quad \mathrm{~m}^{2}$
Area of Compartmert Enclosing Surface Boundaries

Where $\quad A=$ total area of the compartment enclosing surface boundaries excluding area of vent openings (m)
$\omega_{c}=$ compartment width (m)
$I_{\text {e }}=$ compartment length (m)
$h_{\text {e }}=$ compartment height (m)
A = area of ventilation opening (m)
$A=\quad 551.47 \quad \mathrm{~m}$

Ventilation Factor Calculation
$\mathrm{A}=(\mathrm{A}-\mathrm{A}) / \mathrm{A}(\mathrm{wh})$
Where $\quad \boldsymbol{A}=$ ventilation factor
$A=$ total area ofthe compartment enclosing surface boundaries excluding area of vent openings ( $\mathrm{m}^{2}$ )
$A=$ area of ventilation opening (m)
$h_{\mathrm{v}}=$ vent height ( m )
ค $=$
157.75 m

Compartment Post-Flashover Temperature Calculation
$T_{\text {PFO (max }}=6000\left(1-e^{-10}\right) /(\mathrm{MD})$


## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, $3^{\text {mi }}$ 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 acouracy of these calculations.
Any questions, comments, concerns, and suggestions, or to report an error(s) in the spreadsheets, please send an em ail to $n x i(\ldots r c . g o v$ or $m x s 3$ (@nrc.gov.


FDT ${ }^{\text {s }}$ : 13_Compartment_Flashover_Calculations.xls (Flashover-HRR)

## CHAPTER 13. PREDICTING COMPARTMENT FLASHOVER HEAT RELEASE RATE

Version 1805.0

Parameter: In YELLOWCELLS are Entered by the User.
Parameteri In GREEN CELLS are Automatically selectedtrom the DROP DOWN MENU tor the Materlal selected.

parametrs. Tits speads leett protected and secure to avokl errors die to a wroigeity in ace lis).
The chapte it the NUREG shond be e ad be tore at analys t made.

## INPUT PARAMETERS

COMPAR TIMENT IIIFORMATION
Compartnest Wkath (W)
Compartment Le igth (1)
Compartneıt Helgit(a)
Ve it $W$ kith ( $W$ )

| 100.00 n | 30.48 m |
| :---: | :---: |
| $18.00{ }^{11}$ | 5.49 m |
| $10.00{ }^{17}$ | 3.048 m |
| $3.00{ }^{11}$ | 0.914 m |
| $8.00{ }^{11}$ | 2.44 m |
| 6.00 ln | 0.1524 m |
| 0.0016 k |  |

IterbrLilig Tink ress ()
$0.0016 \mathrm{kWm} \mathrm{m}-\mathrm{k}$
0.1524 m

THERMAL PROPERTIES DATA

| Materlal | $\begin{aligned} & \text { Themalcordictult } \\ & k \text { s. W/m-k } \end{aligned}$ | Select Material |
| :---: | :---: | :---: |
| Altim In inf ple | 0.205 | Scroll to de siredmatrial then Click on selection |
| stee $1(0.5 \%$ Cabol) Concret | 0.054 0.0016 |  |
| Brba | 0.0008 |  |
| Glass Plat | 0.00076 |  |
| Brat Concrete block | 0.00073 |  |
| Gypsim Boak | 0.00017 |  |
| Pl/wood | 0.00012 |  |
| Fter ins tation board | 0.00053 |  |
| Clpboard | 0.00015 |  |
| Ae ratd concret | 0.00026 |  |
| Plast bocard | 0.00016 |  |
| Cathm Sllwate board | 0.00013 |  |
| Altm It a Sllcat Ebck | 0.00014 |  |
| Glass Fber lus tatyor | 0.000037 |  |
| Experided Polystyrere | 0.000034 |  |
| Use r Spectred Valte | Eitivale |  |

## PREDICTIIG FLASHO VER HEAT RELEASE RATE METHOD OF McCAFFREY, QUIIITIERE, AIID HARKLEROAD (MOH) <br> Retrence: SFPE hinctiook of Five Pucrection Engineerhg, $3^{\text {na }}$ Edtion, 2002, Page 3-104.

```
Qro=610 wh. A A (wh))
Where }\quad\mp@subsup{Q}{FO}{\prime}=\mathrm{ heat release rate necessary for lashover (W0/)
h
Av = total area of the compartment enclosing suriace boundaries excluding area of vent openings (m)
A = area of ventilation opening (m)
hv = height of ventilation opening (m)
```

Heat Transfer Coefficiert Calculation
$h_{k}=k^{6} \quad$ Assumingthat compartment has been heated thoroughly beforeflashover, i.e., $t>t_{p}$.
Where $\quad h_{k}=$ effective heat transtercoeficient $\left(\mathrm{k} / \mathrm{f} / \mathrm{m}^{2}-\mathrm{K}\right)$
$k=$ interior lining themal conductivitv( $\mathrm{KN} / \mathrm{m} \mathrm{m}-\mathrm{K})$
$\delta=$ interior lining thickness ( m )
$h_{\mathrm{L}}=\quad 0.010 \mathrm{kij} \mathrm{mm}^{2}-\mathrm{K}$
Area of Ventilation Opening Calculation
$A=\left(m_{v}\right)\left(h_{v}\right)$
Where $\quad A=$ area of ventilation opening (m)
$\mathrm{w}_{\mathrm{v}}=$ vent width (m)
$h_{v}=$ vent height ( $m$ )
$A=2.23 \quad \mathrm{~m}^{2}$
Area of Compartment Enclosing Surface Boundaries
$A=[2(m \times 1)+2(h \times w)+2(h \times 1)] \cdot A$
Where $\quad A=$ total area of the compartment enclosing surface boundaries excluding area of vent openings ( $\mathrm{m}^{2}$ )
$w_{c}=$ compartment width (m)
$I_{c}=$ comp artment length (m)
$h_{\text {: }}=$ compartment height ( m )
$\mathrm{A}=$ area of ventilation opening ( $\mathrm{m}^{2}$ )
$\mathrm{A}=\quad 551.47 \mathrm{~m}$
Minimum Heat Release Ratefor Flashover

Qro $=2738.77 \mathrm{~kW}$ Answer

## METHOD OF BABRAUSKAS

Reterence: SFPE hivcibook of Rle Piotection Engilneerhg, $3^{\text {nd }}$ Ell lon, 2002, Paye 3-184.
$\mathbf{Q}_{\mathrm{Fo}}=750 \mathrm{~A}(\mathrm{wh})$
Where $\quad \mathbf{Q}_{\text {Fo }}=$ heat release rate necessary for lashover (k00)
$A=$ area of ventilation opening $\left(\mathrm{m}^{2}\right)$
$h_{v}=$ height of ventilation opening (m)
Minimum Heat Release Rate for Flashover
$\mathrm{O}_{\mathrm{FO}}=750 \mathrm{~A}(\mathrm{wh})$
$Q_{\text {ro }}=2261129 \mathrm{k} \mathrm{W}^{\prime}$ Answer

## METHOD OF THOMAS

Reterence: SFPE Ainction of Five Piotection Engineerhg, $3^{\text {din }}$ Ellion, 2002, Poge 3-184.
$\mathbf{Q}_{F c}=7.8 \mathrm{~A}_{\mathrm{t}}+378 \mathrm{~A}_{/}\left(\mathrm{wh}_{\mathrm{v}}\right)$
Where $\mathbf{Q}_{\text {Fo }}=$ heat release rate necessary for iashover (kof)
$A=$ total area of the comp artment enclosing surface boundaries exoluding area of vent openings ( $\mathrm{m}^{2}$ )
$A=$ area of ventilation opening $\left(\mathrm{m}^{2}\right)$
$h_{v}=$ height of ventilation opening (m)
Minimum Heat Release Ratefor Flashover
$\mathrm{Q}_{\mathrm{Fo}}=7.8 \mathrm{~A}_{\mathrm{t}}+378 \mathrm{~A}_{v}$ (vh $)$
$Q_{\text {ro }}=\quad 561757 \mathrm{kw}$ Answer

## Summarv of Result

| Calculation Method | Aashover HRR [kw] |
| :--- | ---: |
| METHOD OF MQH | 2739 |
| METHOD OF BABRA USKAS | 2611 |
| METHOD OF THOMAS | 5618 |

## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, ${ }^{-14}$ 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 onlybe interpreted by an intomed user.
Athough each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy ofthese calculations. Any questions, comments, concems, and suggestions, or to report an erron(s) in the spreadsheets, please send an email to nxi@riogovormxs3@nre gov.


## Problem J-14

## Problem Statement

Consider a closed compartment in a facility (a pump room) 2.75 m wide $\times 2.75 \mathrm{~m}$ long $\times 3.7 \mathrm{~m}$ high ( 9.0 ft wide $\times 9.0 \mathrm{ft}$ long $\times 12 \mathrm{ft}$ high) $\left(\mathrm{w}_{\mathrm{c}} \times \mathrm{I}_{\mathrm{c}} \times \mathrm{h}_{\mathrm{c}}\right)$. 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 $\mathrm{FDT}^{\text {s }}$ :
(a) 14_Compartment_Over_Pressure_Calculations.xls

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):

- Compartment Width $\left(\mathrm{w}_{\mathrm{c}}\right)=9 \mathrm{ft}$
- Compartment Length $\left(I_{c}\right)=9 \mathrm{ft}$
- Compartment Height $\left(\mathrm{h}_{\mathrm{c}}\right)=12 \mathrm{ft}$
- Fire Heat Release Rate $(\dot{\mathrm{Q}})=75 \mathrm{~kW}$
- Time After Ignition ( t ) $=15 \mathrm{sec}$

Results
$\square$
Pressure Rise* $\quad 16.53 \mathrm{kPa}(2.40 \mathrm{psi})$
*spreadsheet calculations attached on next page

## Spreadsheet Calculations

FDT': 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 ire and combustion.
Parameters in YELLOW CELLS are Entered by the User.
Al subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsteet is protected and secure to avoid errors due to a wrong entryin a cell(s).
The chapter in the NUREG guide stould be read before an analysis is made.

## INPUT PARAMETERS



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

Most buildings have leaks of some sort. The above example indicates that even though a fire compartm ent 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 condusion when dealing with pressure rises in enclosures with stn all leaks.

## HOTE

The above calculations are based on principles developed in the Enclosure Fire Dynam ics. Calculations are based on certain assumptions and have inherent lim itations. 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 $n x(\ldots n r c . g o v$ or $m \times s 3(\ldots n r c . g o v$.


## 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 $6.35 \mathrm{~cm}(21 / 2$ in) thickness of fire protection insulation on all of the beams. The size of the tested beam was $\mathrm{W} 12 \times 26$. Determine whether the $6.35 \mathrm{~cm}(21 / 2 \mathrm{in})$ thickness of fire protection insulation is acceptable for a beam that is W8 $\times 13$.

## Solution

Purpose:
(1) Determine whether the $6.35 \mathrm{~cm}(21 / 2$ in.) thickness of fire protection insulation is acceptable for a W $8 \times 13$ beam using the data for a W $12 \times 26$ 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 ${ }^{\text {s }}$ ) Solution Procedure:
Use the following FDT ${ }^{\text {s }}$
(a) 17.1_FR_Beams_Columns_Substitution_Correlation.xls (Click on Beam)

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheet (values only):

- Rated Design Thickness of Beam Insulation ( $\mathrm{T}_{2}$ ) $=2.5$ in
- Select Beam with known rating for insulation thickness: select W12 x $\mathbf{2 6}$
- Select Beam with unknown rating for insulation thickness: select W8 $\mathbf{x} 13$

Note: When beam size (e.g., W12 $\times 26$ ) 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 <br> Thickness* | $7.09 \mathrm{~cm}(2.79 \mathrm{in})$ <br> 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 $\mathrm{W} 8 \times 13$ 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 ${ }^{\mathrm{s}}$ (not shown).

## Spreadsheet Calculations

FDTs: 17.1_FR_Beams_Columns_Substitution_Correlation.xls (Beam)

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

 Version 1805.0For bears protected byspray applied protections, following corr elation enables substitution of one
beam from another by varying the thickness of the fire protection insulation.
Parameters in YELLCW CELLS are Entered by the User.
Parameters in GREEN CELLSare Automaically Selectedfromthe 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 worong entyy 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 ( $\mathrm{T}_{2}$ ) | 2.5 in |
| :---: | :---: |
| Known naylation Rating |  |
| Wheight of the Beam (Ni) | $26 \mathrm{lb} / \mathrm{t}$ |
| Heated Perimeter of Beam (D2) | 43.45 in |
| Unknown neylation Rating |  |
| Wreight of the Beam (0f) | $13.00 \mathrm{lb} / \mathrm{t}$ |
| Heated Perimeter of Beam (D) | 27.52 in |

SECTIONAL FACTORS FOR STEEL BEAMS

| Select the Beam with known rating for insulation thickness <br> W $12 \times 26$ |  | Select the Beam with unknown rating for insulation thickness $W 8 \times 13$ |
| :---: | :---: | :---: |
| Subscript 2 (Rated Beam) | Calculate | Subscript 1 (Substitute Beam) |

# ESTIMATING THICKNESS OF FIRE PROTECTION INSULATION ON UNRATED BEAM 

Peterence: U Fle Reslstace Diectovy, whme 1,7905 , Page 19.
$\left.\mathrm{T}_{1}=\left(\mathrm{KN}^{\prime} / \mathrm{D}_{2}+0.6\right) \mathrm{T}_{2}\right)\left(0 / 1 / \mathrm{D}_{1}+0.6\right)$
Where $\quad T_{1}=$ calculated thickness of fire protection insulation on unrated beam (in)
$T_{2}=$ design thickness of irsulation on rated beam (in)
'Wf', = weight of beam with urk nown irsulation rating (lb/ft)
$\mathrm{WH}_{2}=$ weight of design rated beam (lb/ff)
$D_{1}=$ 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
$\left.\mathrm{T}_{1}=\left(\mathrm{KOH} / \mathrm{D}_{2}+0.6\right) \mathrm{T}_{2}\right)(\mathrm{NO} 1 / \mathrm{D} 1+0.6)$
$\mathrm{T}_{1}=\quad 2.79 \mathrm{in}$ Answer
Beame with alarger WiD raio 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.
Athough 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, concerrs, and suggestions, or to report an erron's) in the spreadsheet, please send an email to nxi@nre.gow or m凶s 3 (inro.gow.


## 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 $1.12 \mathrm{~m}^{2}\left(12.0 \mathrm{ft}^{2}\right)$ oil retention dike. The safety-related cable trays are located $2.5 \mathrm{~m}(8.0 \mathrm{ft})$ above the corridor floor with a horizontal distance of $1.2 \mathrm{~m}(4.0 \mathrm{ft})$ from the edge of the compressor's oil retention dike. The horizontal distance between the compressor oil dike and the electrical cabinet is $1.52 \mathrm{~m}(5.0 \mathrm{ft})$.

The access corridor has a floor area of 6.0 m wide $\times 4.6 \mathrm{~m}$ long ( 20 ft wide $\times 15 \mathrm{ft}$ long $)\left(\mathrm{w}_{\mathrm{c}} \times \mathrm{I}_{\mathrm{c}}\right)$, ceiling height of $3.0 \mathrm{~m}(10.0 \mathrm{ft})\left(\mathrm{h}_{\mathrm{c}}\right)$, and a single unprotected vent opening (door) that is 1.2 m wide $x 1.8 \mathrm{~m}$ high ( 4.0 ft wide $\times 6.0 \mathrm{ft}$ high) $\left(\mathrm{w}_{\mathrm{v}} \times \mathrm{h}_{\mathrm{v}}\right)$. The corridor has no forced ventilation and it is constructed of $0.3048 \mathrm{~m}(1.0 \mathrm{ft})$ thick concrete. The corridor has a smoke and heat detection system and a wet pipe sprinkler system. The nearest sprinkler is rated at $74^{\circ} \mathrm{C}\left(165{ }^{\circ} \mathrm{F}\right)$ with an RTI of $235(\mathrm{~m}-\mathrm{sec})^{1 / 2}$ and is located $2.98 \mathrm{~m}(9.8 \mathrm{ft})$ 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, $\mathrm{T}_{\mathrm{g}}$, as well as gas layer height z
(c) heat flux to the target (electrical cabinet) using the point source model, $\mathrm{q}^{\pi}$
(d) heat flux to the target (cable trays) using the solid-flame radiation model, $\dot{q}^{\prime \prime}$
(e) centerline plume temperature, $\mathrm{T}_{\mathrm{p} \text { (centerline) }}$
(f) sprinkler activation time, $t_{\text {activation }}$
(g) HRR necessary to cause flashover, $\dot{\mathrm{Q}}_{\mathrm{Fo}}$

## 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 $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$
(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 ${ }^{\text {s }}$ ) Solution Procedure:
Use the following FDTs:
(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 ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheets (values only):
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

- Fuel spill volume $(\mathrm{V})=20$ gallons
- Fuel Spill Area or Dike Area $\left(\mathrm{A}_{\text {dike }}\right)=12 \mathrm{ft}^{2}$
- 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 <br> $\dot{Q} \mathrm{~kW}(\mathrm{Btu} / \mathrm{sec})$ | Burning Duration <br> $\mathrm{t}_{\mathrm{b}}(\mathrm{min})$ | Pool Fire Flame Height <br> $\mathrm{H}_{\mathrm{f}} \mathrm{m}(\mathrm{ft})$ |  |
| :--- | :--- | :--- | :--- |
|  | Method of <br> Heskestad | Method of <br> 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 $\left(\mathrm{w}_{\mathrm{c}}\right)=20 \mathrm{ft}$
- Compartment Length $\left(\mathrm{I}_{\mathrm{c}}\right)=15 \mathrm{ft}$
- Compartment Height $\left(\mathrm{h}_{\mathrm{c}}\right)=10 \mathrm{ft}$
- Vent Width $\left(w_{v}\right)=4 \mathrm{ft}$
- Vent Height $\left(\mathrm{h}_{\mathrm{v}}\right)=6 \mathrm{ft}$
- Top of Vent from Floor $\left(\mathrm{V}_{\mathrm{T}}\right)=6 \mathrm{ft}$
- Interior Lining Thickness $(\delta)=12$ in
- Heat Release Rate $(\dot{\mathrm{Q}})=1131 \mathrm{~kW}$
- 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 <br> $(\min )$ | Hot Gas Layer <br> Temperature <br> $\mathrm{T}_{\mathrm{g} ~}{ }^{\circ} \mathrm{C}\left({ }^{\circ} \mathrm{F}\right)$ | Gas Layer Height <br> 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 $(\dot{\mathrm{Q}})=1131 \mathrm{~kW}$
- Distance from the Top of the Fuel to the Ceiling $(z)=9 \mathrm{ft}$
- Area of Combustible Fuel: $12 \mathrm{ft}^{2}$


## Results*

| Heat Release <br> Rate $\dot{\mathrm{Q}}(\mathrm{kW})$ | Plume Centerline Temperature <br> $\mathrm{T}_{\mathrm{p}(\text { centerline })}{ }^{\circ} \mathrm{C}\left({ }^{\circ} \mathrm{F}\right)$ |
| :---: | :---: |
| 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 $\left(\mathrm{A}_{\text {dike }}\right)=12 \mathrm{ft}^{2}$
- 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 $\left(\mathrm{A}_{\text {dike }}\right)=12 \mathrm{ft}^{2}$
- Distance between Fire and Target (L) $=4 \mathrm{ft}$
- Vertical Distance of Target from Ground $\left(\mathrm{H}_{1}=\mathrm{H}_{\mathrm{f} 1}\right)=7 \mathrm{ft}$
- 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 <br> $\dot{q}^{\prime \prime} \mathrm{kW} / \mathrm{m}^{2}\left(\mathrm{Btu} / \mathrm{ft}^{2}-\mathrm{sec}\right)$ |
| :--- | :--- | :--- |
| 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 $(\dot{Q})=1,131 \mathrm{~kW}$
- Distance from the Top of the Fuel Package to the Ceiling (H) $=9 \mathrm{ft}$
- Radial Distance from the Plume Centerline to the Sprinkler (r)=9.8 ft
- Ambient Air Temperature $\left(\mathrm{T}_{\mathrm{a}}\right)=77^{\circ} \mathrm{F}$
- 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 $\left(165^{\circ} \mathrm{F}\right)$ is within the range of temperature ratings for ordinary sprinklers $\left(135^{\circ} \mathrm{F}-170^{\circ} \mathrm{F}\right)$.

## Results*

| Sprinkler Type | Sprinkler Activation Time <br> $\mathrm{t}_{\text {activation }}(\mathrm{min})$. |
| :--- | :--- |
| Standard response link | 1.73 |

[^1](g) 13_Compartment_Flashover_Calculations.xls

- Compartment Width $\left(\mathrm{w}_{\mathrm{c}}\right)=20 \mathrm{ft}$
- Compartment Length ( $\mathrm{I}_{\mathrm{c}}$ ) $=15 \mathrm{ft}$
- Compartment Height $\left(h_{c}\right)=10 \mathrm{ft}$
- Vent Width $\left(\mathrm{w}_{\mathrm{v}}\right)=4 \mathrm{ft}$
- Vent Height $\left(\mathrm{h}_{\mathrm{v}}\right)=6 \mathrm{ft}$
- Interior Lining Thickness ( $\delta$ ) = 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 <br> $\dot{\mathrm{Q}}_{\mathrm{FO}} \mathrm{kW}($ 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 $500^{\circ} \mathrm{F}$ and almost $600{ }^{\circ} \mathrm{F}$ 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) $\mathrm{FDT}^{\text {s }}$ : 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







## INPIT PARAMEIERS



| 2000 |
| ---: |
| 1200 |
| 0039 |
| 40000 |
| 760 |
| 0.7 |
| 77.00 |

Flel क्pll Areacr Dke Area(A._)
hass Rurriry Rake off (el(mi)
Flel Deratty ( $\rho$ )
Bnprical Constarl (k)
imbleniAr Temperakre ( $T$ )
981 macc
$1.18 \mathrm{ka}^{2}$
mbleniAr Deraly (i)

THERMAL PROPERTIES DATA
BURHIMG RAT EDAT AFORIIQUIDHYDROCARBOK FUEL \&

| Fun | Daxs Buring Rale $\mathrm{m}^{*} \mathrm{kgm}^{-5 \mathrm{sec}} \mathrm{C}$ | Healor comburlan <br> $\left.2 \mathrm{H}_{\sim}=\mathrm{dN} / \mathrm{ing}\right)$ | $\begin{aligned} & \text { Denaly } \\ & \text { p } \mathbf{k g m} \text { ? } \end{aligned}$ | Emplitica cavt lant kp(m) | Seleot Fuel Type |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Iis liand | 0.017 | 20,000 | 796 | 100 | Soroll to de cred wel type |
| Evaral | 0.015 | 25,300 | 794 | 100 | Calok on coleotion |
| Qulsre | 0.108 | +5,700 | 713 | 2.7 |  |
| Bermere | 0.885 | 40,500 | 874 | 2.7 |  |
| Hexare | 0.57 4 | +4,700 | 550 | 1.9 |  |
| Hep lare | 0.121 | +4,600 | 575 | 1.1 |  |
| xplere | 0.09 | 40,800 | 370 | 1.4 |  |
| Acelore | 0.041 | 25,800 | 791 | 1.9 |  |
| Dloxare | 0.018 | 25,200 | 1036 | 5.4 |  |
| Diely Elw | 0.885 | 34,200 | 714 | 0.7 |  |
| Bentre | 0.048 | +4,700 | 740 | 3.5 |  |
| Garcire | 0.065 | +3,700 | 740 | 2.1 |  |
| Veroatre | 0.039 | 43,200 | 320 | 3.5 |  |
| Dksel | 0.045 | +4,40 | 918 | 2.1 |  |
| JP-4 | 0.561 | 43,500 | 760 | 3.5 |  |
| JP-5 | 0.554 | 43,000 | 810 | 1.5 |  |
| Tlantormer Oil, Hydrocarion | 0.539 | 46,000 | 760 | 0.7 |  |
| \$61 Illon Trarctormer flal | 0.05 | 28,100 | 960 | 100 |  |
| Fiut ol, Heary | 0.185 | 39,700 | 970 | 1.7 |  |
|  |  | +2,900 |  |  |  |
| lube ol | 0.039 | 46,000 | 760 |  |  |
| User Peedted Vake | Ever Valu | Enter Voske | Eter Vauk | Ever Vatue |  |

## ESTIMATING POOL FIRE HEAT RELEASE RATE

Retresce: SFPE Hanchook of Fle Plotecton Engheening, 3 Edtbi, 2002, Page 3-25.
$\mathrm{Q}=\mathrm{m}^{\prime \prime} d \mathrm{H}_{\mathrm{car}}\left(1-\mathrm{e}^{-N i \mathrm{D}}\right) \mathrm{A}_{\mathrm{tha}}$
Where $\quad \mathrm{Q}=$ pool fire heat rele ase rate (kid)
$m^{\prime \prime}=$ mass burning rate of fuel per unit surface area ( $k q^{\prime} m^{2}-s e c$ )
$\Delta \mathrm{H}_{\text {cat }}=$ effective heat of combustion of fuel ( $\mathrm{kJ} / \mathrm{g}$ )
$A=A_{t k n}=$ surface area of pool fire (area invohed in vaporization) ( $m^{2}$ )
$k \beta=$ empirical corstant ( $m$ )
$D=$ diameter of pool fire (diameter inwohed in vaporization, circular poolis assumed) (m)
Pod Fire Diameter Calculation
$A_{\mathrm{j}, \mathrm{e}}=\quad \quad \mathrm{TD}^{2} / 4$
Where $\quad A_{t h n}=$ surface area of pool fire $\left(\mathrm{m}^{2}\right)$
$D=$ pool fire diamter (m)
$D=0(4 A n)$
$D=1.191 \mathrm{~m}$
Heat Release Rate Calculation (Lkyk with riatuevitu that polit, lke trastomer oll, require


| $Q=$ | 1131.38 kW |
| :--- | :--- |

ESTIMATING POOL FIRE BURNING DURATION
Retresce: SFP E Hancbook of Fie Piotecton Engheering, $2^{\text {nd }}$ Editu 1, 1965, Page 3-197.
$t=4 v / \pi D^{2} v$
Where $\quad t=$ burning duration of pool fire (sec)
$v=$ volume of liquid $(m)$
$D=$ pool diameter (m)
$\mathrm{v}=$ reqression rate (msec)

Calculation for Regression Rate
$v=\quad \quad \mathrm{m}^{\prime \prime} / \mathrm{l} /$
Where $\quad v=$ regression rate (misec)
$m^{\prime \prime}$ - mass burning rate of fuel ( $\mathrm{k}_{\mathrm{\prime}} \mathrm{~m}^{2}$-sec)
$\rho=$ liquid fuel dersitv $\left(k \not q^{\prime} m^{\prime}\right)$
$\mathrm{v}=\quad 0.000051 \quad$ misec
Burning Duration Calculation
$t=4 v / \pi D^{2} v$

| $t=$ | 1323.37 sec | 22.06 minutes |
| :--- | :--- | :--- |

Not that a llyuk pool tre with a glves amont ofthel can bun tor bigperbds of the cuer small an a or tor stortperbck of the overa large area.

## ESTIMATING POOL FIRE FLAME HEIGHT

## METHOD OF HESKESTAD


$\mathrm{H}=0.235 \mathrm{Q}^{20} \cdot 1.02 \mathrm{D}$
Where $\quad H_{t}=$ poolfire flame height ( m )
$Q=$ pool fire heat rele ase rate (kN')
D = pool fire diameter (m)
Pod Fire Flame Height Calculation
$\mathrm{H}_{1}=0.235 \mathrm{Q}-1.02 \mathrm{D}$

| $\mathrm{H}_{+}=$ | 2.70 m | 8.85 ft | Answer |
| :---: | :---: | :---: | :---: |

METHOD OF THOMAS
Rềrerce: SFPEhivctiook of Fie Porection Exiteenty, $2^{\text {¹ }}$ Eillon, 1995, Page 3-204.
$\left.\mathrm{H}_{1}=42 \mathrm{D}\left(\mathrm{n}^{2} / \rho_{a}, V \mathrm{~g} \mathrm{D}\right)\right)^{\mu \mathrm{n}}$
Where $\quad H_{l}=$ pooltre thme le ight (in)
$\mathrm{m}^{*}=\mathrm{m}$ assbinlig ate of the Iperintsumace area $\mathrm{kg} \mathrm{m}^{2}$-sec)
$\mathrm{P}_{\mathrm{a}}=$ ambleıt alr de usty (kg/m)
D = pool fire dametrin)

Pool Rre Fame Helght Calculation
$\mathrm{H}_{1}=42 \mathrm{D}\left(\mathrm{n}^{*} / \boldsymbol{\rho}_{a} \vee(\mathrm{~g} \mathrm{D})\right)^{40}$

| $\mathrm{H}_{\mathrm{t}}=$ | 2.95 m | 9.67 t |
| :--- | :--- | :--- |


\section*{Flame Heiaht Calculation - Summaru of Riesults <br> | Calculation Me thod | Ram $\theta$ Helght ( ft$)$ |
| :--- | :---: |
| METHOD OF HESKESTAD | 8.85 |
| METHOD OF THOMAS | 9.67 |}

ESTIMATING POOL FIRE RESULTSFOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

| Area ( tt ) | Area (m ${ }^{2}$ ) | Clameter (m) | Q(kW) | t. ( 10 C ) | $\mathrm{H}_{2}(\mathrm{tt})$ (He skestad) | $\mathrm{H}_{\text {( }}$ (tt)(Thom as ) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 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 | 11.45 | 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 |






## NOTE

The above catuatb is are base dor prichles deve byed it the SFP E Han dook of Fif Protedbi Eigreertig. 2 d Edtbor, 1995.
 ofsicl calculatons may or may uot iave reasonable predictue capabiltes tora ghe 1 sthatti, andshonklonl/be tepredby an intmed ise I.
Althogh each catiatbi in the spreak heet has bee ivemed with the res it of hand

Any questons, commeit, concens, and suggesthes, or to report an enor(s) In the spreack heets, pleae se dal emallo $\mathbf{x}$ @urgovormxs3@u egov.

(b) FDT $^{\text {s. }}$ : 02.1_Temperature_NV.xls

CH APTER 2. PREDICTIIIG HOT GAS LAYER TEMPERATURE AIID SMOKE
LAYER HEIGHT III A ROOMFIRE WITH IIATURAL VEIITILATIOH
COMPARTME IT WITH THERMALLY THICK/THIII BOUHDARIES
Version 18050
The tobowig calcu bubus estunate the lot gas byer emperature and smoke byer he git enchsire fre.
Parameters in YELLOWCELLS are Entered by the User.
Parametrain GREEN CELLS are Automatically selectedtom the DROP DOWN MENU to the materlal selected.

panmeter. Tik spreads heet t prot ced andsecure to avokle ros die to a wrongenty in a cellis).

IIIPUT PARAMETERS
COMPARTMENTT IIIFORMATION

| Compartme it Wtith (N) | 20.00 | 1.093 |
| :---: | :---: | :---: |
| Comparme it Leigto (1) | 15.00 | 4572 m |
| Compartme it He kgit (1) | 10.00 | 104 c m |
| Vestwith ( $W$ ) | 4.00 | 129 m |
| Ve it He tit (i) | 6.00 | 1.aza m |
| Top of Veuttom Fbor ( $V$ ) | 6.00 | 1.823 m |
| Interbr Ling Ti Ekiess (9) | 12.00 | 0.30404 |

AmbIENIT COHDTTOHS
AmbleıtAr Temperature $(T) \quad 77.00$

| Specinc Heatot Alr $\epsilon_{2}$ ) |  |
| :--- | ---: |
| AmbleıtAr Dessity $(\hat{\rho})$ | 1.00 |
|  | $1.18 \mathrm{~kg} / \mathrm{m}-$ |

THERMAL PROPERTIES OFOOMPARTMENT EICLOS IIGG SURFACES FOR Interbor Ling Tiemal lie rita dapc) Interlor Ling ThemalCondicthity (o) Interbr Ling inspecifc Heat (c) Interbr Linig Deisiv (p)

| 2.9 | WWim $\mathrm{m}^{3}+\mathrm{c}^{2}-\sec$ |
| :---: | :---: |
| 0.0016 | Wim-k |
| 0.75 | . Wha-K |
| 2400 | . $\mathrm{mm}^{2}$ |

0.75 . $\mathrm{ha}-k$

MATERIALS
EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

| Itat tal | $\begin{array}{\|l\|} \hline k \rho c \\ k W h m^{2}+\sec \end{array}$ | knom-6 | $\begin{aligned} & \mathrm{c} \\ & \mathrm{~kJ} k \mathrm{CH} \mathrm{C}) \end{aligned}$ | $\begin{aligned} & p \\ & (g / m) \\ & \hline \end{aligned}$ | Select Material <br> Consrete |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Alum limp $p$ re) <br> Stel (0.5** Carbon) <br> Concret <br> Brlsk <br> Gass, Plat <br> BrkkConcre Ebck <br> Gypsim Board <br> Pl/wood <br> Fber In sulatbi Board <br> Cilpoard <br> Af ated Concret <br> Platerboard <br> Caklom Silbat Boas <br> Alum Ina Silleat block <br> Glass Fber list atbon <br> Expanded Poyst/rene <br> User Specifled Vahe | 500 197 2.9 1.7 1.6 1.2 0.18 0.16 0.16 0.15 0.12 0.12 0.096 0.036 0.0018 0.001 Ei tr Valse | $\begin{aligned} & 0.206 \\ & 0.054 \\ & 0.0016 \\ & 0.0006 \\ & 0.00076 \\ & 0.00073 \\ & 0.00017 \\ & 0.00012 \\ & 0 . .00053 \\ & 0.00015 \\ & 0.00026 \\ & 0.00016 \\ & 0.00013 \\ & 0.00014 \\ & 0 . .000037 \\ & 0.000034 \\ & \text { Eit r valıe } \\ & \hline \end{aligned}$ | 0.895 0.455 0.75 0.8 0.8 0.84 1.1 2.5 1.25 1.25 0.96 0.84 1.12 1 0.8 1.5 Eitr Valte | 2710 7850 2400 2500 2710 1900 960 540 240 800 500 960 700 250 60 20 Elt r Valie | Scroll to deslred materlal then Click the selection |

Fire Heat Release Rate (0) $\quad 1131.00 \mathrm{~kW}$

Calculate

## METHOD OF McCAFFREY, QUIITIERE, AlID HARKLEROAD (MQH)

Reierence: SFPE Hinctiook of Fire Piorection Engineering, 3 Eillon, 2002, Poje 3-175.
$\dot{\mu} T_{1}=6.85\left[0^{2} /\left(A\left(h_{v}\right)\right)\left(A h^{12}\right)\right]^{1 a}$
Where $\quad \Delta T_{3}=T_{B}-T_{a}=$ upper layer gas temperature rise abo ve ambient ( $K$ )
$0=$ heat release rate ofthe fire (kif)
$A=$ area of ventilation opening ( $m^{2}$ )
$h_{v}=$ height of ventilation opening (m)
$h_{\text {. }}=$ convective heat transfer coefficient ( $\mathrm{k}_{\mathrm{h}}^{\left.\mathrm{h} \mathrm{hm}^{2}-\mathrm{K}\right) ~}$
$A_{u}=$ total area ofthe compartment enclosing surface boundaries exoluding area of vent openings (m)
Area of Ventilation Opening Calculation

```
A = (w.)(h)
Where A = area of ventilation opening (m)
wv}=\mathrm{ vent width (m)
hv}=\mathrm{ vent height (m)
A = 2.23m
```

Thermal Penetration Time Calculation
$t_{1}=\quad(\rho c / k)(5 / 2)^{2}$
Where $\quad t_{p}=$ themal penetration time (sec)
$\rho=$ interior construction densit $v$ ( $\mathrm{k} / \mathrm{m} / \mathrm{m}$ )
$\mathrm{c}_{\mathrm{p}}=$ interior construction heat capacity ( $\mathrm{k} / \mathrm{kg}-\mathrm{K}$ )
$\mathrm{k}=$ interior construction themal conductivity ( $\mathrm{k} / \mathrm{\omega} / \mathrm{m} \mathrm{m}-\mathrm{K}$ )
$\delta=$ interior construction thickness ( m )
$t_{t}=\quad 26128.98 \mathrm{sec}$
Heat Transfer Coefficient Calculation
$h_{k}=\quad v(k$ pot $) \quad$ for $t<t \quad$ or $\quad(k / s)$ fort $>t_{t}$
Where $\quad h_{k}=$ heat transter coefficient $\left(\mathbf{k} 0 / \mathrm{m}^{2}-\mathrm{K}\right)$
$\mathrm{k} \rho \mathrm{C}=$ interior construction themal inertia $\left(\mathrm{k} / 0 / \mathrm{m}^{2}-\mathrm{K}^{2}-\mathrm{sec}\right.$
(a thermal property of material responsible forthe rate oftemperature rise)
$\mathrm{t}=$ time after ignition (sec)
See table below for results
Area of Compartmert Enclosing Surface Boundaries
$A=\quad[2(w \times 1)+2(h \times w)+2(h \times 1 c)] \cdot A$
Where $\quad A_{v}=$ total area ofthe compartment enclosing surface boundaries excluding area of vent openings $\left(\mathrm{m}^{2}\right)$
$w_{c}=$ compartment width (m)
$I_{=}=$compartment length (m)
$h_{\text {: }}=$ compartment height ( m )
A = area of ventilation opening (m)
$\mathrm{A}_{\mathrm{s}}=\quad 118.54 \mathrm{~m}$
Compartment Hat Gas Laver Temperature With Natural Ventilation
$\left.\dot{4} \mathrm{~T}_{8}=6.85\left[\mathrm{Q}^{2} \mathrm{M}(\mathrm{A}(\mathrm{h}))^{\prime 2}\right)(\mathrm{A} h)\right]$
$\dot{\Delta T_{0}}=\quad \mathrm{T}_{\mathrm{g}} \cdot \mathrm{T}_{\mathrm{a}}$
$T_{8}=\quad \Delta T_{3}+T_{a}$

## Resultit

| Time After Ignition (t) |  | $\begin{gathered} \mathrm{h}_{\mathrm{k}} \\ \text { gWin }-19 \end{gathered}$ | $\begin{gathered} \hline \mathbf{A T}_{\mathbf{a}} \\ \mathbf{0 6} \\ \hline \end{gathered}$ | $\begin{aligned} & \mathrm{T}_{0} \\ & 0 \\ & \hline \end{aligned}$ | $\begin{gathered} \mathrm{T}_{a} \\ \mathrm{C}) \\ \hline \end{gathered}$ | To (F) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (m) | (sec) |  |  |  |  |  |
| 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 | 345.05 | 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=(3,0 t/3A) + (1/k m)
Wher z=smoke kyerlulght (m)
    Q - heatrelease rat ofthe tre (NW)
    t-the attergutbu (gec)
    1. - compartneitheght (m)
    Ac-compartmestrbor area (m)
    k=a constatgle nbyk=0.076/p
    pol}=1\mathrm{ lot gas ka/erde nsity (kg/m)
    Pa E glver by P = 353/T
    T
Compartment Area Calculation
A= (W) (1)
Where Ac=compartnesttborarea(m)
    w}=\mathrm{ =omparme it wktt (m)
    L= compartme it Eigtu(i)
A= }\quad27.87\textrm{m
HotGa: Laver Denalti Calculation
p= 353/T
Calculation for Constant K
k= 0.076/p
Smoke Ga : Laver Helght Wht Hatural Ventlation
z= [l2kQ t/3A]+(1/L
```

Reiult Caution! The smoke layer height is a conservative estime and is only intended to provide an indication where the hot gas layer is located. Calculated smoke layer height belowthe vent height are not oredit able since the calculation is nd accounting for the smoke exiting the vent.

| $\begin{aligned} & \operatorname{Tim} \theta \\ & \operatorname{tn} \mathrm{n}) \end{aligned}$ | $\underset{(\mathrm{Pg},}{\mathrm{P},}$ | $\begin{gathered} \hline \text { Cons tant(k) } \\ \text { (NWin-19 } \\ \hline \end{gathered}$ | Smoke Layer helght $z$ (in) | Smoke Layerhelght z fit |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 1.18 | 0.064 | 3.05 | 10.00 |
| 1 | 0.75 | 0.102 | 1.83 | 6.00 |
| 2 | 0.72 | 0.106 | 1.83 | 6.00 |
| 3 | 0.70 | 0.109 | 1.83 | 6.00 |
| 4 | 0.68 | 0.111 | 1.83 | 6.00 |
| 5 | 0.67 | 0.113 | 1.83 | 6.00 |
| 10 | 0.64 | 0.119 | 1.83 | 6.00 |
| 15 | 0.62 | 0.123 | 1.83 | 6.00 |
| 20 | 0.60 | 0.126 | 1.83 | 6.00 |
| 25 | 0.59 | 0.128 | 1.83 | 6.00 |
| 30 | 0.58 | 0.130 | 1.83 | 6.00 |
| 35 | 0.58 | 0.132 | 1.83 | 6.00 |
| 40 | 0.57 | 0.133 | 1.83 | 6.00 |
| 45 | 0.56 | 0.135 | 1.83 | 6.00 |
| 50 | 0.56 | 0.136 | 1.83 | 6.00 |
| 55 | 0.55 | 0.137 | 1.83 | 6.00 |
| 60 | 0.55 | 0.138 | 1.83 | 6.00 |

CAUTIOH: SMOKE IS EXTING OUT VENT CAUTION: SMOKE IS EXTIIGG OUT VENT CAUTION: SMOKE IS EXITIHG OUT VENT CAUTION: SMOKE IS EXTTHG OUT VENT CAUTION: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIHG OUT VENT CAUTIOH: SMOKE IS EXTTHG OUT VENT CAUTION: SMOKE IS EXTIIG OUT VENT CAUTOH: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIHG OUT VENT CAUTIOH: SMOKE IS EXTIHG OUT VENT CAUTION: SMOKE IS EXTIIG OUT VENT CAUTIOH: SMOKE IS EXITIMG OUT VENT CAUTION: SMOKE IS EXTIHG OUT VENT


## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering. 3 Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or maynot have reasonable predictive cap abilities for a given situation, and should only be interpreted by an informed user.
Athough each calculation in the spreadsheet has been veried with the results of hand calculation, there is no absolute guarantee of the acouracy ofthese calculations.
Anyquestions, comments, concems, and suggestions, or to report an erron'(s) in the spreadsheet, please send an email to nxieyre gov.

(c) $\mathrm{FDT}^{\text {s }}$ : 09_Plume_Temperature_Calculations.xls

## CHAPTER 9. ESTIMATING CENTERLINE TEMPERATURE OF A BUOYANT FIRE PLUME

## Version 1805.0

The following calculations estimate the center line plume temperature in a compartment fire. Parameters should be specified ONLYIN 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 anahysis is made.
INPUT PARAMETERS


## AMBIENT CONDITIONS

Specific Heat of Air ( $\mathrm{c}_{\mathrm{p}}$ ) $1.00 \mathrm{~kJ} / \mathrm{ig} \cdot \mathrm{K}$

Ambient Air Dersity ( P a)
$18 \mathrm{k} / \mathrm{m}$
Acceleration of Gravity (g)
$981 \mathrm{~m} / \mathrm{sec}^{2}$
Comvective Heat Release Fraction (3c)
0.70

Note: Air dersity will automatically correct with Ambient Air Temperature ( $\mathrm{T}_{2}$ ) Input
ESTIMATING PLUME CENTERLINE TEMPERATURE
Reterice:SFPE Hancbook of Fre Proecton Engneering $3^{n}$ Edton, 2002, Page 2-6.

Wh here $\quad T_{p}\left(\begin{array}{c}\text { ntime }\end{array}=\right.$ plume center line temper ature $\left({ }^{\circ} \mathrm{C}\right.$ )
$Q_{c}=$ comvective portion of the heat release rate (kifi)
$\mathrm{Ta}_{\mathrm{a}}=$ ambient air temperature ( K )
$\mathrm{g}=$ acceleration of gravity (m/sec)
$\mathrm{c}_{\mathrm{p}}=$ specific he at of air (kJ*g-K)
$\rho_{\mathrm{a}}=$ ambient air dersity $\left(\mathrm{kg}^{\prime} \mathrm{m}^{3}\right)$
$z=$ distance from the top of the fuel package to the ceiling (m)
$z_{0}=$ hypotheticalvirtual origin of the fire (m)

Convective Hea Release Rate Calculation
$Q_{c}=\eta c Q$
Where $\quad Q_{c}=$ comective portion of the he at release rate (kifi)
$Q=$ heat release rate of the fire (kiol)
$\chi_{c}=$ convective heat release fraction
$\mathrm{Q}_{\mathrm{c}}=\quad 791.7 \mathrm{k} \mathrm{kJ}^{\prime}$

Fire Diameter Calculation
$A_{c}=\pi D^{2} / 4$
Where $\quad A c=$ area of combustible fuel $\left(\mathrm{m}^{2}\right)$
$D=$ fire diameter (m)
$\left.D=v^{( } 4 A_{d} \cdot \pi\right)$
$D=1.19 \quad m$

```
Hypothetical Virtual Origin Calculation
\(z_{0} N=-1.02+0.083\left(0^{25}\right) / D\)
Where \(\quad z_{0}=\) virtual origin of the fire (m)
    \(Q=\) heat release rate of fire (kiof)
    D = fire diameter (m)
\(\mathrm{z}_{0} \mathrm{~V} D=\quad 0.14\)
\(\mathrm{zo}=\quad 0.17 \mathrm{~m}\)
Centerline Plume Temperaure Calculaion
\(\mathrm{T}_{\mathrm{p}(\text { cenkitre })}-\mathrm{T}_{\mathrm{a}}=9.1\left(\mathrm{~T}_{\mathrm{s}} / \mathrm{g} \mathrm{cp}_{\mathrm{p}}^{2} \mathrm{~Pa}_{\mathrm{a}}^{2}\right)^{1 / 3} \mathrm{Q}_{\mathrm{c}}^{2 / 3}\left(\mathrm{z}-\mathrm{z}_{0}\right)^{-93}\)
Tp(cenkitre) - \(\mathrm{Ta}_{a}=448.21\)
\(\mathrm{T}_{\mathrm{p} \text { (Cenkilire) }}=\quad 746.21 \mathrm{~K}\)
```

| $\mathrm{T}_{\mathrm{p} \text { (conterine) }}=$ | $473.21^{\circ} \mathrm{C}$ | $883.79^{\circ} \mathrm{F}$ | nswer |
| :---: | :---: | :---: | :---: |

## NOTE

The above calculations are based on principles developed in the SF PE Handbook of Fire Protection Engineering, $3^{\text {rd }}$ Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The res ults of such calculations may or may not have reasonable predictive capabilities for a givensituation, and should only be interpreted by an informed user.
Athough each calculation in the spreadsheet has been verified with the res ults of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
Any questions, comments, concerrs, and suggestions, or to report an erron(s) in the spreadsheet, please send an email to $n \times i(\oint n r e g o v$ or $m \times s 3$ (\%nre.gov.

(d) FDT $^{\text {s }}$ : 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 calcuationsestimate the radiative heat fux from a pool fire to a targe fuel.
The purpose of this calculation is to estimate the radiation transmitted from a burning fuel arrayto a target
fuel positioned some distance fom the ire at ground level to determine if secondary ignitions are likely with no wind. Parameters in YELLOW CELLS are Ertered bythe User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWNM ENU forthe Fuel Selected.
Al subsequent output values are calculated by the spreadstheet and based on values speciied 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

Wass Buming Fate of Fuel (m')
Effective Heat of Combustion of Fuel ( $\mathrm{H} \mathrm{H} \Rightarrow$ )
Etpinical Constant (h.
Heat Release Rate (0)
Fuel Area or Dke Area (Avin)
Distance between Fire and Target ( L )
Padiative Fraction ( 6 )
OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE
select "User specitied value" trom Ruel Type Menu and Enter Your HRR here?

$1.11 \mathrm{~m}^{2}$
1.524 m

## Calculate

THERMAL PROPERTIES DATA

| Fuel | Mass Buming Rate m" ( $\mathrm{kg}_{\left.\mathrm{g} / \mathrm{m}^{2}-\mathrm{sec}\right)}$ | Heat of Combustion i H .al ( $\mathrm{k} . \mathrm{lkg}$ ) | ETpincal Constant $14\left(\mathrm{~m}^{-1}\right)$ | Select Fuel Type <br> Lute oil |
| :---: | :---: | :---: | :---: | :---: |
| Methanol | 0017 | 20,000 | 100 | Scroll to desired fuel type then |
| Ehanol | 0015 | 26,800 | 100 | Click on selection |
| Butane | 0078 | 45,700 | 2.7 |  |
| Benzene | 0085 | 40,100 | 2.7 |  |
| Hexane | 0074 | 44,700 | 1.9 |  |
| Heptane | 0.101 | 44,600 | 1.1 |  |
| Xylene | 009 | 40,800 | 1.4 |  |
| Acetone | 0041 | 25,800 | 1.9 |  |
| Dioxane | 0018 | 26,200 | 5.4 |  |
| Diethy Eher | 0085 | 34,200 | 0.7 |  |
| Benzine | 0048 | 44,700 | 3.6 |  |
| Gasoline | 0055 | 43,700 | 2.1 |  |
| Kerosine | 0039 | 43,200 | 3.5 |  |
| Diesel | 0045 | 44,400 | 2.1 |  |
| JP-4 | 0051 | 43,500 | 3.8 |  |
| JP-5 | 0054 | 43,000 | 1.6 |  |
| Transtormer Oil, Hydrocarton | 0039 | 46,000 | 0.7 |  |
| 561 Silicon Transtommer Fluid | 0005 | 28,100 | 100 |  |
| Fuel 0i, Heavy | 0035 | 39,700 | 1.7 |  |
| Crude Ol | 00335 | 42,600 | 28 |  |
| Lube Oil | 0039 | 46,000 | 0.7 |  |
| Douglas Fir Prywood | 001082 | 10,900 | $100$ |  |
| User Specified Value | Enter Value | Enter Value | Eter Value |  |

## ESTIMATIIIG RADIATIVE HE AT FLUX TO A TARGE T FUEL

Reverence: SFPE hivchook of File Protection Englneerhg, 3 Billon, 2002, Page 3-272.
POINT SOURCE RADIATION MODEL
$\mathrm{q}^{\prime \prime}=0 \mathrm{n} / 4 \times \mathrm{R}^{2}$
Where
$q^{\prime \prime}=$ incident radiative heat fux on the target $\left(\mathrm{NOH}^{2} \mathrm{~m}^{2}\right)$
$\mathrm{Q}=$ pool fre heat release rate $(\mathrm{NOH})$
$\mathrm{K}_{\text {I }}=$ radiative fraction
$\mathrm{R}=$ distance from center of the pool fire to edge ofthe target (m)


## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering. $3^{\text {nd }}$ 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 tor a given situation, and should only be interprated by an informed user.
Athough each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the acouracy of these calculations.
Anyquestions, comments, concems, and suggestions, orto report an error(s) in the spreadsteet,
please send an email to nxi@nre.gov or mxs3@rc.gov.

(e) FDT $^{\text {s }}$ : 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 WND-FREE CONDITION SOLID FLAME RADIATION MODEL
Version 1805.0



Parameters In YELLOWCELL sare Entered by the User.
Parameters In GREEN CELLS are Aubmatically selected trom the DROP DOWN MENU tor the Ruel selected.


The chaptit the NUREG stombe read betore at atal/at $t$ made.

## INPUT PARAMETERS

## Mass binlig Rat offiel (in)

Ettectlve Heator Combstor of tel ( $\left.\Delta \mathrm{H}_{\text {cen }}\right)$

Heat Re lease Rate $(2)$
FielArea or Dke Ara (Aac)
Dktance betweer Fire and Tanget (L)
Verteal DEtance of Targe trion Grond ( $\mathrm{H}=\mathrm{H}_{n}$ )

| 0.039 m | mambec |
| :---: | :---: |
| 46000 k |  |
| 0.7 m |  |
| 1131.38 m |  |
| $12.00{ }^{17}$ | $1.11{ }^{\mathrm{m}}$ |
| $4.00{ }^{11}$ | 1.2192 m |
| 7.00 11 | 2.1335 m |

OPTIONAL CALCULATION FOR GVEN HEAT RELEASE RATE
sel eot "U cer ipeoli ed value" from Fuel Type Menu and Enter Your HRR here?


THERMAL PROPERTIES DATA

| Ftel | Mass Eming Rat $\mathrm{m}^{\prime}$ (ghtitec) | He at of Combstistor <br> $\Delta H_{\text {cen }}$ \& Jkg | Emplitalconstat kf (m) | Select Fual Type |
| :---: | :---: | :---: | :---: | :---: |
| methanol | 0.017 | 20,000 | 100 | Seroll to desired fuel type then |
| Etranol | 0.015 | 26,800 | 100 | Click on selection |
| E tare | 0.078 | 45,700 | 2.7 |  |
| berze re | 0.085 | 40,100 | 2.7 |  |
| Hexare | 0.074 | 4,700 | 1.9 |  |
| Heptare | 0.101 | 44,500 | 1.1 |  |
| cylere | 0.09 | 40,800 | 1.4 |  |
| Ace tre | 0.041 | 25,800 | 1.9 |  |
| Droxate | 0.018 | 26,200 | 5.4 |  |
| Detay Etre I | 0.085 | 34,200 | 0.7 |  |
| Berzue | 0.048 | 44,700 | 3.6 |  |
| Gacolle | 0.055 | 43,700 | 2.1 |  |
| Keros lie | 0.039 | 43,200 | 3.5 |  |
| Desel | 0.045 | 4,400 | 2.1 |  |
| JP-4 | 0.051 | 43,500 | 3.6 |  |
| JP-5 | 0.054 | 43,000 | 1.6 |  |
| Tanstmmeroll Hydrocator | 0.039 | 46,000 | 0.7 |  |
| 561 Sillor Trastomer flakd | 0.005 | 28,100 | 100 |  |
| Freloll, Heavy | 0.035 | 39,700 | 1.7 |  |
| crick oll | 0.0335 | 42,600 | 2.8 |  |
| Libe oll | 0.039 | 46,000 | 0.7 |  |
| Dotglas Fir P ¢wood | 0.01082 | 10,900 | 100 |  |
| User Specmed vane | Eiter Value | Eitivalue | Eitr Value |  |



ESTIMATIII G RADIATIVE HEAT FLUX TO A TARGE T FUEL
Ret rice: SFPE Handiook of Flie Po tcton Engheerhg, 3 Edtbi, 2000, Page 3-276.
SOLID FLAME RADIATION MODEL
$\mathrm{q}^{\prime \prime}=\mathrm{EF}$,
Where $\quad q^{\prime \prime}=$ incident radiative heat $\mathbf{l u x}$ on the tanget ( $\mathrm{k}_{\mathrm{N} / \mathrm{m}^{2} \text { ) }}$
$E=$ emissive power of the pool ire flame ( $\mathrm{k} / \mathrm{H}_{\mathrm{m}} \mathrm{m}^{2}$ )
$F_{1 \rightarrow 2}=$ view factor betweentarget and the flame

Pool Fire Diameter Calculation
$A_{t h e}=x D^{2} / 4$
$D=v\left(4 A_{b} / \pi\right)$
Where $\quad A_{t h a n}=$ surface area of pool fire $\left(\mathrm{m}^{2}\right)$
$\mathrm{D}=$
$\mathrm{D}=$ pool fire diamter ( m )

Emissive Power Calculation
$E=58$ ( 10 )
Where $\quad E=$ emissive power of the pool ire flame ( $\mathrm{k} / \mathrm{h} / \mathrm{m}^{2}$ )
$\mathrm{D}=$ diameter of the pool fire (m)

Vew Factor Calculation
$F_{1 \rightarrow 2 \mathrm{~V})}=$
$F_{1 \rightarrow 2 V 2}=$
$A=$
$A_{2}=\quad\left(h_{2}^{2}+S^{2}+1\right) 2 \mathrm{~S}$
$\mathrm{B}=\quad\left(1+\mathrm{S}^{2}\right) / 2 \mathrm{~S}$
$\mathrm{S}=\quad 2 \mathrm{R} / \mathrm{D}$
$h_{1}=\quad 2 \mathrm{H}_{1} \mathrm{D}$
$h_{2}=$
$2 \mathrm{H}_{2} \cdot \mathrm{D}$
$\mathrm{F}_{1 \rightarrow 2 \mathrm{x}}=$
F: $\sim_{2 v 1}+F_{\sim 2 v 2}$

Where
F $\quad=$ total verical view factor
$R=$ distance fom center ofthe pool fire to edge of the tanget (m)
$\mathrm{H}_{4}=$ height ofthe pool fire flame (m)
$\mathrm{D}=$ pool fire diameter $(\mathrm{m})$
Distance from Center of the Pod Fire to Edge of the Target Calculation
$\mathrm{R}=\mathrm{L}+\mathrm{D} / 2$
Where $\quad R=$ distance $\boldsymbol{r}$ om centerofthe pool fire to edge of thetarget ( $m$ )
$L=$ distance between pool fire and target ( $m$ )
$\mathrm{D}=$ pool fire diameter (m)
$\mathrm{R}=\mathrm{L}+\mathrm{D} / 2=$ 1.815 m

Heat Release Rate Calculation
$0=m " \dot{L} H_{c a t}\left(1-e^{-k i d}\right) A_{\text {bk }}$
Where
$0=$ pool ire heat release rate (kifi) $m^{\prime \prime}=$ mass buming rate of fuel per unit surface area ( $\mathrm{kg}^{\prime} / \mathrm{m}^{2} \cdot \mathrm{sec}$ )
i $\mathrm{H}_{\mathrm{c}}=$ effective heat of combustion of fuel ( kJ Jg )
$\mathrm{A}_{\mathrm{tbn}}=$ surface area of pool fire (area involved in vaporization) ( $\mathrm{m}^{2}$ )
$\mathrm{k} \beta=$ empinical constant $\left(\mathrm{m}^{-1}\right)$
$\mathrm{D}=$ diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)
$0=$
$1131.38 \mathrm{k} \mathrm{kN}^{\prime}$

| Fool Fire Rame Height Calculation $\mathrm{H}=0.235 \mathrm{a}^{20}-102 \mathrm{D}$ |  |  |  |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Where | $\mathrm{H}=$ flame height ( m ) |  |  |  |  |  |  |
|  | Q = heat release rate of fre (kfi) |  |  |  |  |  |  |
|  | $\mathrm{D}=$ fire diameter ( m ) |  |  |  |  |  |  |
| $\mathrm{H}=$ | 2.698 m |  |  |  |  |  |  |
| $\mathrm{S}=2 \mathrm{R} / \mathrm{D}=$ | 3.047 |  |  |  |  |  |  |
| $h=2 \mathrm{H} / \mathrm{D}=$ | 3.582 |  |  |  |  |  |  |
| $\mathrm{h}_{2}=2 \mathrm{H} / 2 \mathrm{D}=$ | $2(\mathrm{H}-\mathrm{H}) \mathrm{l} \mathrm{C}=$ | 0.947 |  |  |  |  |  |
| $\mathrm{A}=\left(\mathrm{h}^{2}+\mathrm{S}^{2}+1\right) 2 \mathrm{~S}=$ |  | 3.793 |  |  |  |  |  |
| $\mathrm{A}_{2}=\left(\mathrm{h}^{2}+\mathrm{S}^{2}+1\right) 2 \mathrm{~S}=$ |  | 1.835 |  |  |  |  |  |
| $\mathrm{B}=\left(1+\mathrm{S}^{2}\right) 2 \mathrm{~s}=$ |  | 1.687 |  |  |  |  |  |
|  |  | $\mathrm{F}_{1}$ | F |  |  | $\mathrm{F}_{\text {v }}$ | $\mathrm{F}_{1-\mathrm{s}, \mathrm{V}}$ |
| $\mathrm{F} \sim 2 \mathrm{v}=$ | 0.153 |  |  | 0.231 | 0.388 | 0.750 | 0.163 |
| $\mathrm{F} \sim_{2 \mathrm{~V} 2}=$ | 0.081 | $\mathrm{F}_{1}$ | F |  |  | $\mathrm{F}_{7}$ | $\mathrm{F}_{1 \times 8, \mathrm{v} 2}$ |
| $\mathbf{F} \sim_{2 v}=\mathbf{F} \sim_{2 v 1}+\mathbf{F} \sim_{2 v 2}=$ | 0.234 |  |  | 0.051 | 0.118 | 0.919 | 0.081 |

## Radative Heat Flux Calcuiation

$\mathrm{q}^{\prime \prime}=\mathrm{EF}{ }_{2}$
$\mathrm{q}^{\prime \prime}=\quad 13.24{\mathrm{~kW} \mathrm{~mm}^{2}}$

## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Frotection Engineering. $3^{\text {nd }}$ Edition, 2002.
Calculations are based on centain assumptions and have inherentlimitations. The resuts of such calculations mayor may not have reasonable predictive capabilities for a given situation, and should orly be interpreted by an informed user.
Athough each calculation in the spreadshee has been verited with the resuls of hand calculation. there is no absolute guarantee of the acouracyofthese calculations.
Any questions, comments, concems, and suggestions, or to report an erron(s) in the spreadsheet,
please send an email to nxi@nre govor mxs3 @rogov.

（f） $\mathrm{FDT}^{\text {s．}}$ ：10＿Detector＿Activation＿Time．xls（Sprinkler）

## CHAPTER 10．ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.0
The following calculaions estimate sprinlder activation time
Parameters in YELLOW CELLS are Etered by the User
Parameters in GREEN CELLS are Mutomatically Selected from the DROP DOWN MENU forthe Sprirkler Selected．
Al subsequent output values are calculated bythe spreadsheet and based on values specited in the input
parameters．This spreadsheet is protected and secure to avoid emors due to a wrong entry in a cell（s）．
The chapter in the NUREG should be read betore an analysis is made．

## INPUT PARAMETERS



GENERIC SPRINKLER RESP ONSE TIME INDEX（RTI）＊

| Common Sprinlder Type | Generic Response | Select Type of Sprirkler |
| :---: | :---: | :---: |
|  | Time hdex（RTI）（m－sec）${ }^{1 / 2}$ | standardre aponse liriv 习 |
| Standard resporse bulb | 235 | Scroll to desired sprirkler type then Click onselection |
| Standad resporse lirk | 130 |  |
| Quick response bulb | 42 |  |
| Quick response link | 34 |  |
| User Soecified Value | Erter Value |  |


Mand 地机 095 ，toution Hongkong pp．217210
＊Nate：The actusl RTI shouldbe used whenthe ualue is auailable．


| Temperature Classification | Fange of Temperaure Patings（＇F） | Generic Temperature Ratings（\％） | $\left.\right\|^{\text {Select Sprinkler Classification }}$ |
| :---: | :---: | :---: | :---: |
| Ordinary | 135 to 170 | 165 | Scroll to desired sprirkler class |
| Irtermediate | 175 to 225 | 212 | then Click onselection |
| High | 250 to 300 | 275 |  |
| Etra tigh | 325 to 375 | 350 |  |
| Veryextra high | 400 to 475 | 450 |  |
| Utra tigh | 500 to 575 | 550 |  |
| Ultra high | 650 | 550 |  |
| User Specified Value | － | Enter Value |  |
|  |  |  |  |
| Ascocition Ouncy，Masanchasetts wou，Pase o7． |  |  |  |
| ＊Nate：The actual temperature rating should be used whenthe value is ausilable． |  |  |  |

ESTIMATING SPRINKLER RESPONSE TIME


Where $\quad t_{\text {twatan }}=$ sprinider activation response time（sec）
RTI＝sprirkler response time index（m－sec）${ }^{1 / 2}$
$u_{\mu=1}=$ ceifing jet vebcity（misec）
$\mathrm{T}_{1 \mu}=$ ceiling je temperature（ ${ }^{\circ}$ ）
$\mathrm{T}_{3}=$ ambient airtemperature（＂C）
$\mathrm{T}_{\text {ancatan }}=$ activation temperature of sprinkler（ ${ }^{\circ} \mathrm{C}$ ）
Ceiling Jet Temperature Calculation
$\mathrm{T}_{\mu}-\mathrm{T}_{A}=169(0) \quad$（ $\mathrm{H}^{2} \quad$ for $\mathrm{r} / \mathrm{H}=0.18$

Where $T_{t / 2}=$ ceiling jat temperature（ ${ }^{( }$）
$\mathrm{T}_{3}=$ ambient airtemperature（ ${ }^{\circ}$ ）
$\mathrm{Q}=$ comective portion of the heat release rate（N00）
$\mathrm{H}=$ height of ceiling tove top of iuel（m） $r=$ radial distance from the plume centerine to the sprirkler（m）

Convective Hear Release Rate Calculation
$\mathrm{Q}_{\mathrm{c}}=\boldsymbol{J}_{\mathrm{D}} \mathrm{Q}$
Where $Q$ = comvective portion of the he at release rate (kiof)
$Q=$ heat release rate of the fire (kifi)
$\boldsymbol{z}=$ comvective heat releaserate fraction
$\mathrm{Q}_{\mathrm{C}}=$
791.7 kN

Radial Distance to Ceiling Height Ratio Caloustion $\mathrm{r}^{\prime} \mathrm{H}=\quad 1.09 \mathrm{r} / \mathrm{H}>0.15$
$\mathrm{T}_{\mathrm{a}} \cdot \mathrm{T}_{\mathrm{a}}=\left\{538(\mathrm{Qct})^{\prime} 2 / 3\right\} / \mathrm{H}$
$\mathrm{T}_{i d} \cdot \mathrm{~T}_{\mathrm{a}}=\quad 80.92$
$\mathrm{T}_{\mathrm{id}}=\quad 105.92\left({ }^{\circ} \mathrm{C}\right)$
Ceiling Jet Velocity Calculation
$\mathrm{u}_{d}=0.96(\mathrm{Q} / \mathrm{H}) \quad$ for $\mathrm{r} / \mathrm{H}=0.15$
$u_{d}=\left(0.195 Q^{13} H^{1 / 2} \mathrm{r}^{5 A} \quad\right.$ for $\mathrm{r} / \mathrm{H}>0.15$
Where $\quad u_{d}=$ ceiling jet velocity (mvec)
$Q=$ heat release rate of the fire (kil)
$\mathrm{H}=$ height of ceiling above top of fuel (m)
$\mathrm{r}=$ radial distance from the plume centerline to the sprinkler (m)
Radial Distance to Ceiling Height Ratio Calcuision
$\mathrm{r} / \mathrm{H}=$
$109 \mathrm{r} / \mathrm{H}>0.15$
$u_{d=}=\left(0.195 Q^{M} / 3 H^{M} / 2\right) r^{\prime} 5 / 6$
$u_{a}=1.352 \quad \mathrm{msec}$

Sprinkler Activation Time Calculation

$t_{\text {activation }}=103.61 \mathrm{sec}$
The sprinker will respond in approximately
HOTE: If $\mathrm{t}_{\text {actvaton }}=$ "IIUM" Sprinkler does not activate

## NOTE

The above calculations are based on principles developed in the NFPA Fire Protection Handbook $19^{16}$ 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 guar antee of the accuracy of these calculations.
Any questions, comment, concerrs, and suggestions, or to report an erron(s) in the spreadsheet, ple ase send an email to rxi@nre.gov or mes3(\%nrc.gov.

(g) $\mathrm{FDT}^{\text {s. }}$ : 13_Compartment_Flashover_Calculations.xls (Flashover-HRR)

CHAPTER 13. PREDICTING COMPARTMENT FLASHOVER HEAT RELEASE RATE
Version 1805.0
The followig carcilatons es that the minmm leat re e ase rat requ lred to compartme it fas hover.
Param $\theta$ ters In YELLOWCELLS are Entered by the User.
Param $\theta$ ters In GREEN CELLS are Automatically selected trom the DROP DOWN MENU for the Materlal selected.

parametrs. Tits speadsleett protected and secure tovoklerrors die to awrigetby it ace lis).
The clapte if the NUREG shonkibe read be fore at analist $t$ made.

## INPUT PARAMETERS

COMPAR TMEIT IIIFORMATION


THERMAL PROPERTIES DATA


## PREDICTING FLASHOVER HEAT RELEASE RATE

METHOD DF MCCAFFREY, QUINTIERE, AND HARKLERDAD (MQH)

$Q_{\text {Fo }}=610 v\left(A_{k} A_{1} A_{V}(V)\right)$
Wher $\quad Q_{\text {Fo }}=$ leat release rate vecessary tor thas toler ( WW )

$A_{r}$ - total are a ofthe compartmenterclosingsintace boundarles exclidig area of ve it ope ings (fn ${ }^{2}$ )

$l_{v}=$ legit of ve stlatbi ope iligg (n)
He at Transter Coeticlent Calculation
$\mathbf{h}_{\mathrm{k}}=\mathrm{k} / \mathrm{o} \quad$ Assum ing that compartm ent has $b e \theta$ heated thoroughly betore tiashover, l.e., $t>t_{>}$

$k=$ Interlor ining the mal condicthit/ $6 \mathrm{WW} / \mathrm{m}-\mathrm{F})$


$$
\mathbf{b}_{\mathrm{k}}=\quad 0.005 \mathrm{~kW} \mathrm{An}+
$$

Area of ventilation Opening Calculation
$A_{v}=(W)(1)$


Minlm um Heat Release Rate for Fla shover
$Q_{\mathrm{FO}}=610 \mathrm{v}\left(\mathbf{h}_{\mathrm{k}} \mathrm{A}_{\mathrm{I}} \mathrm{A}_{\mathrm{V}}\right.$ ( L D$)$
$Q_{\text {ro }}=835.57 \mathrm{~kW} \quad$ Answer

METHDD DF BABRAUSKAS

$Q_{F O}=750 \mathrm{~A}, ~(\mathrm{~L})$
Where $\quad Q$ - leatre lease rat lecessary tor thashover (kW)
$A_{v}=$ are a of ve 1 tiator opening (m)
$l_{v}=$ le git ofvertiator opeilig (in)
Minlm um Heat Release Rate for Fla shover
$Q_{\text {Fo }}=750 \mathrm{~A}_{\mathrm{v}}(\mathrm{vi})$
$Q_{\text {ro }}=2261.44 \mathrm{~kW}$ Answer
METHOD DF THOMAS
Reterenc: SFFE Hivibiool of Fire Pidection Englneetry, 3 Eillon, 2002, P sje 3-184.
$Q_{\mathrm{FO}}=7.8 \mathrm{~A}_{1}+378 \mathrm{~A}_{\mathrm{V}}(\mathrm{V} \mathrm{l})$
Where $\quad Q$ Folleatre lease rate lecessary tor thashowe $\quad$ ( $W$ )

$A_{v}=$ are a of ve ithation opeing $\left(\mathrm{m}^{2}\right)$
$\mathbf{h}_{\mathrm{v}}=$ le igit ofveitlation opeilig (m)
Minnim um Heat Release Rate for Fla shover
$Q_{\text {Fo }}=7.8 A_{1}+378 A_{V}\left(v \mathbf{l}_{v}\right)$


## Summarv of Result:

| Calculation Method | Hanthover HikR (kW) |
| :--- | ---: |
| METHODOF MQH | 836 |
| METHODOF BABRAUSKAS | 2261 |
| METHODOF THOMAS | 2064 |

## NOTE

The above calculatons are based on piltocples developed it the SFPE Handbook of Fire Potectbi Eigheerigg, $3^{\text {nd }}$ Edtbi, 2002.




cakitatbu, there a 10 absolite graraitee of the accuracy of these calcu bitbus.
Any questons, comments, concens, andsugestons, or to reportan errorg) the
spreadsheets, please serdat emallo ixerrogov ormxs3eurgou.


## Problem J-17

## Problem Statement

Consider a triangular corner compartment (as shown in the figure) in a boiling water reactor (BWR). The compartment is $4.6 \mathrm{~m}(15.0 \mathrm{ft})$ high with 0.3048 m ( 12.0 in ) thick concrete walls, floor, and ceiling and with a door that is $2.15 \mathrm{~m}(7.0 \mathrm{ft})$ wide $\times 3.0 \mathrm{~m}(10.0 \mathrm{ft})$ high $\left(\mathrm{w}_{\mathrm{v}} \times \mathrm{h}_{\mathrm{v}}\right)$.


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 $1.12 \mathrm{~m}^{2}\left(12.0 \mathrm{ft}^{2}\right)$ oil retention dike. The lube oil spreads and reaches steady burning almost instantly. Two unprotected safety-related cable trays are located $3.0 \mathrm{~m}(10.0 \mathrm{ft})$ 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, $\mathrm{T}_{\mathrm{g}}$, 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 $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$
(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 $^{\text {s }}$ ) Solution Procedure:
Use the following FDTs:
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls
(b) 02.1_Temperature_NV.xls

FDT ${ }^{\text {s }}$ 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 ( $\mathrm{A}_{\text {dike }}$ ) $=12 \mathrm{ft}^{2}$
- 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 <br> $\dot{Q} \quad \mathrm{~kW}(\mathrm{Btu} / \mathrm{sec})$ | Burning <br> Duration <br> $\left(\mathrm{t}_{\mathrm{b}}\right)(\mathrm{min})$ | Pool Fire Flame Height <br> $\mathrm{H}_{\mathrm{f}} \mathrm{m}(\mathrm{ft})$ |  |
| :--- | :--- | :--- | :--- |
| $1,131(1,072)$ | 33 min | Method of <br> Heskestad | Method of <br> 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 $\mathrm{FDT}^{\mathrm{s}}$ 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 $\mathrm{FDT}^{\mathrm{s}}$.
$\square$ Triangular Compartment Surface Area:

$$
\begin{aligned}
& S A=(1 / 2 \times(\text { base }) \times(\text { width }))+\left(A_{\text {wall\#1 }}+A_{\text {wall } \# 2}+A_{\text {wall\#3 }}\right) \\
& S A=(1 / 2 \times 20 \times 20)+((20 \times 15)+(30 \times 15)+(20 \times 15))=1450 \mathrm{ft}^{2}
\end{aligned}
$$

$\square$ Equivalent Rectangular Compartment with Same Height:
SA = Area Floor + Area Ceiling + Area Walls
$S A=(L \times W)+(L \times W)+2(L \times 15)+2(W \times 15)$
since equivalent $L=W$
$S A=\left(L^{2}\right)+\left(L^{2}\right)+4(L \times 15)$
$1450=2 L^{2}+60 \mathrm{~L} \quad \Rightarrow \quad L=15.8 \mathrm{ft}=W$
Input Parameters:

- Compartment Width $\left(w_{c}\right)=15.8 \mathrm{ft}$
- Compartment Length $\left(I_{c}\right)=15.8 \mathrm{ft}$
- Compartment Height $\left(\mathrm{h}_{\mathrm{c}}\right)=15 \mathrm{ft}$
- Vent Width ( $\mathrm{w}_{\mathrm{v}}$ ) $=7 \mathrm{ft}$
- Vent Height $\left(\mathrm{h}_{\mathrm{v}}\right)=10 \mathrm{ft}$
- Top of Vent from Floor $\left(\mathrm{V}_{\mathrm{T}}\right)=10 \mathrm{ft}$
- Interior Lining Thickness $(\delta)=12$ in
- Select Material: select Concrete from the combo box
- Fire Heat Release Rate ( $\dot{\mathrm{Q}})=1,131 \mathrm{~kW}$

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 <br> $\mathbf{T}_{\mathbf{g}}{ }^{\circ} \mathbf{C}\left({ }^{\circ} \mathbf{F}\right)$ | Gas Layer Height <br> $\mathbf{z ~ m}(\mathbf{f t})$ |
| :--- | :--- | :--- |
| 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 ( $\mathrm{T} \cong 425^{\circ} \mathrm{F}$ ) 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) $\mathrm{FDT}^{\text {s }}$ : 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
Verston 1805.0



Al subsequenl adpulvalues ae calaisked by the sprestivel and baed on wakes spedted in te trpul
parame kes. Thit sprealsteelts prokeck and seare basoll emors de ba wrong enty ha al(\$).
tie ctap erin te MURES shatid be real before ananslyats is make.

## INPUT PARAMEIERS

| Flel cill vdume (V) | 3000 |
| :---: | :---: |
| Flel ¢pll Areacr Dke Area (A, | 1200 |
| Hars Rurnty Rak off (el (mm) | 0039 |
|  | 46000 |
| $F(\underline{e l}$ Dendy ( $\varphi$ ) | 760 |
| Biplical Contisy 6 (b) | 0.7 |
| AmbleniAr Temperakre (T) | 77.00 |
| Grast tistand Agxeter alon(9) Ambienlar Dendy (9) | 981 1.18 |
|  |  |

THEFAMAL PROPERTIES DATA

| Fun | Dax: Buring Rak <br>  | Healor comburlan <br>  | $\begin{aligned} & \text { Dervily } \\ & \text { p kgim? } \end{aligned}$ | Enplicas Cavt lant k.p(m) | Seleot Fuel Type |
| :---: | :---: | :---: | :---: | :---: | :---: |
| IVe trand | 0.017 | 20,000 | 796 | 100 | 3oroll to dectred wel type |
| Evaral | 0.015 | 25,300 | 794 | 100 | Cllok on coleotion |
| Bulare | 0.078 | +5,700 | 513 | 2.7 |  |
| Bercere | 0.585 | 40,150 | 874 | 2.7 |  |
| Hexare | 0.85 | +4,700 | 350 | 1.9 |  |
| Heplore | 0.191 | +4,900 | 575 | 1.1 |  |
| >plere | 0.99 | 40,800 | 870 | 1.4 1.9 |  |
| Acelone | 0.041 | 25,800 | 791 | 1.9 |  |
| Dlowane | 0.018 | 25,200 | 1036 |  |  |
| Dely Elw Bencte | 0.885 | 34, 3 , 200 | 714 | 0.7 3.6 |  |
| Berdite Garclive | 0.048 | +4,700 43,700 | 740 $7+9$ | 3.5 2.1 3.5 |  |
| Gataline leroalre | 0.065 0.159 | +3,700 | 740 820 | 2.1 3.5 |  |
| Dlesel | 0.045 | +4,60 | 918 | 2.1 |  |
| JP-4 | 0.551 | +3,500 | 760 | 3.5 |  |
| JP-5 | 0.554 | +3,000 | 810 | 1.6 |  |
| Trandibmer Oll, Hydrocation | 0.089 | 45,000 | 760 | 0.7 |  |
| \$81 allonTrarctorme Fkis | 0.005 | 28,100 | 990 | 100 |  |
| Fux O1, Hesry | 0.035 | 39,700 | 970 | 1.7 |  |
| Cruse oll | 0.0335 | +2,900 | 855 | 28 |  |
| lube oll | 0.139 | 46,000 | 760 |  |  |
| User Coedted vokr | Eler Value | Entr Valke | Erer Value | Erier Vilue |  |

## ESTIMATING POOL FIRE HEAT RELEASE RATE

Retresce: SFPE Hanchook of Fle Piotecton Engheening, 3 Edtbi, 2002 , Page 3-25
$\mathrm{Q}=\mathrm{m}^{\prime \prime} d \mathrm{H}_{\mathrm{car}}\left(1-\mathrm{e}^{-N i \mathrm{D}}\right) \mathrm{A}_{\mathrm{tha}}$
Where $\quad \mathrm{Q}=$ pool fire heat rele ase rate (kid)
$m^{\prime \prime}=$ mass burning rate of fuel per unit surface area ( $k q^{\prime} m^{2}-s e c$ )
$\Delta \mathrm{H}_{\text {cat }}=$ effective heat of combustion of fuel ( $\mathrm{kJ} / \mathrm{g}$ )
$A=A_{t k n}=$ surface area of pool fire (area invohed in vaporization) ( $m^{2}$ )
$k \beta=$ empirical corstant ( $m$ )
$D=$ diameter of pool fire (diameter inwohed in vaporization, circular poolis assumed) (m)
Pod Fire Diameter Calculation
$A_{\mathrm{j}, \mathrm{e}}=\quad \quad \mathrm{TD}^{2} / 4$
Where $\quad A_{t h n}=$ surface area of pool fire $\left(\mathrm{m}^{2}\right)$
$D=$ pool fire diamter (m)
$D=0(4 A n)$
$D=1.191 \mathrm{~m}$
Heat Release Rate Calculation (Lkuks with ekatvel/ ith tash polit, like tanstomer oll, require


| $Q=$ | 1131.38 kW |
| :--- | :--- |

ESTIMATING POOL FIRE BURNING DURATION
Retresce: SFP E Hancbook of Fie Piotecton Engheering, $2^{\text {nd }}$ Editu 1, 1965, Page 3-197.
$t=4 v / \pi D^{2} v$
Where $\quad t=$ burning duration of pool fire (sec)
$v=$ volume of liquid $(m)$
$D=$ pool diameter (m)
$\mathrm{v}=$ reqression rate (msec)

Calculation for Regression Rate
$v=\quad \quad \mathrm{m}^{\prime \prime} / \mathrm{l} /$
Where $\quad v=$ regression rate (misec)
$m^{\prime \prime}$ - mass burning rate of fuel ( $\mathrm{k}_{\mathrm{\prime}} \mathrm{~m}^{2}$-sec)
$\rho=$ liquid fuel dersitv $\left(k \not q^{\prime} m^{\prime}\right)$
$\mathrm{v}=\quad 0.000051 \quad$ misec
Burning Duration Calculation
$t=4 v / \pi D^{2} v$

| $\boldsymbol{t}=$ | 1385.05 sec | 33.08 minutes | Ans Mer |
| :--- | :--- | :--- | :--- |

Not that a llyuk pool tre with a glves amont ofthel can bun tor bigperbds of the cuer small an a or tor s tortperbds of the over a tage area.

## ESTIMATING POOL FIRE FLAME HEIGHT

## METHOD OF HESKESTAD


$\mathrm{H}=0.235 \mathrm{Q}^{20} \cdot 1.02 \mathrm{D}$
Where $\quad H_{t}=$ poolfire flame height ( m )
$Q=$ pool fire heat rele ase rate (kN')
D = pool fire diameter (m)
Pod Fire Flame Height Calculation
$\mathrm{H}_{1}=0.235 \mathrm{Q}-1.02 \mathrm{D}$

| $\mathrm{H}_{+}=$ | 2.70 m | 8.85 ft | Answer |
| :---: | :---: | :---: | :---: |

METHOD OF THOMAS

$\left.\mathrm{H}_{1}=42 \mathrm{D}\left(\mathrm{n}^{2} / \rho_{a}, V \mathrm{~g} \mathrm{D}\right)\right)^{\mu \mathrm{n}}$
Where $\quad H_{l}=$ pooltre thme le ight (in)
$\mathrm{m}^{*}=\mathrm{m}$ assbinlig ate of the Iperintsumace area $\mathrm{kg} \mathrm{m}^{2}$-sec)
$\mathrm{P}_{\mathrm{a}}=$ ambleıt alr de usty (kg/m)
D = pool fire dametrin)

Pool Rre Fame Helght Calculation
$\mathrm{H}_{1}=42 \mathrm{D}\left(\mathrm{n}^{*} / \boldsymbol{\rho}_{a} \vee(\mathrm{~g} \mathrm{D})\right)^{40}$

| $\mathrm{H}_{\mathrm{t}}=$ | 2.95 m | 9.67 t |
| :--- | :--- | :--- |


\section*{Flame Heioht Calculation - Summary of Results <br> | Calculation Me thod | Ram $\theta$ Helght ( ft$)$ |
| :--- | :---: |
| METHOD OF HESKESTAD | 8.85 |
| METHOD OF THOMAS | 9.67 |}

ESTIMATING POOL FIRE RESULTSFOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

| Area ( tt ) | Area (m ${ }^{2}$ ) | Camater (m) | Q(kW) | t. ( 10 C ) | $\mathrm{H}_{2}(\mathrm{tt})$ (He skestad) | $\mathrm{H}_{\text {( }}$ (tt)(Thom as ) |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 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 | 11.45 | 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 |






## NOTE

The above catulatb is are base dor prichles deve byed it the SFP E Han dook of Fif Protedbi Eigreertig. 2 d Edtbor, 1995.
 ofsicl calculatons may or may uot iave reasonable predictue capabiltes tora ghe 1 sthatti, andshonklonl/be tepredby an intmed ise I.
Althogh each catiatbi in the spreak heet has bee ivemed with the res it of hand

Any questons, commeit, concens, and suggesthes, or to report an enor(s) In the spreack heets, pleae se dal emallo $\mathbf{x}$ @urgovormxs3@u egov.

(b) FDT $^{\text {s. }}$ : 02.1_Temperature_NV.xls

CH APTER 2. PREDICTIIIG HOT GAS LAYER TEMPERATURE AIID SMOKE LAYER HEIGHT III A ROOMFIRE WITH HATURAL VEIITILATIOH COMPARTME IIT WITH THERMALLY THICK/THIII BOUHDARIES
Version 18050

Parameters In YELLOWCELLS are Entered by the User.
Parametrain GREEN CELLS are Automatically selectedtom the DROP DOWN MENU to the 情terlal selected.
Alls ibsequentorpit values are cakikedby the spreakheetad basedon values specredin the hpit

The clapt in the NUREG stouthbe readbetor at analys t made.

## IIIPUT PARAMETERS

COMPARTMENTT IIIFORMATION

| Compatme it Wtith or ) | 15.80 | 4a 5 539 m |
| :---: | :---: | :---: |
| Compartme it Leigto (1) | 15.80 |  |
| Compartme it He kigt (i) | 15.00 | 4.572 m |
| Ve stwkith (w) | 7.00 | 2134 m |
| Veathe git (a) | 10.00 | 104 |
| Top of Vestrom Fbor (V) | 10.00 | 1044 m |
| Interlor Lining Ti Ekiess (\%) | 12.00 | 1.3044 |



EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

| Mat tal | $\begin{aligned} & \mathrm{k} \rho \mathrm{c} \\ & \mathrm{~kW} N \mathrm{~m}+\mathrm{m}^{2}-\mathrm{sec} \end{aligned}$ | kntare | $\begin{aligned} & \mathrm{c} \\ & \mathrm{~kJ} / \mathrm{c}-\mathrm{H}) \end{aligned}$ | $\begin{aligned} & \mathrm{p} \\ & \operatorname{sg} / \mathrm{m}) \\ & \hline \end{aligned}$ | Select Material Coneret |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Alum limp pire) <br> Stel (0.5** Carbol) <br> Concret <br> Brlk <br> Glacs, Plat <br> BrickCOncet Ebck <br> Gypsim Board <br> Pl/wood <br> F ber lis Iktbi B oard <br> Clpboard <br> Ae ned Concret <br> Plasterboard <br> Caklim Silleat Boakl <br> Alum Ina Slltat block <br> Glas F ber lisi laton <br> Expanded Poyst/rese <br> User Specmed Vahe | 500 197 2.9 1.7 1.6 1.2 0.18 0.16 0.16 0.15 0.12 0.12 0.096 0.035 0.0018 0.001 Eıtr Valse | $\begin{aligned} & 0.206 \\ & 0.054 \\ & 0.0016 \\ & 0.0006 \\ & 0.00076 \\ & 0.00073 \\ & 0.00017 \\ & 0.00012 \\ & 0.00053 \\ & 0.00015 \\ & 0.00026 \\ & 0.00016 \\ & 0.00013 \\ & 0.00014 \\ & 0.000037 \\ & 0.000034 \\ & \text { Eit r value } \end{aligned}$ | 0.895 0.465 0.75 0.8 0.8 0.84 1.1 2.5 1.25 1.25 0.96 0.84 1.12 1 0.8 1.5 Eit r Value | 2710 7850 2400 2500 2710 1900 960 540 240 800 500 960 700 260 60 20 Eit r Value | Scroll to dealred materlal then Click the selection |

Fire Heat Release Rate ( 0 ) $\quad \square 1131.00 \mathrm{~kW}$

## Calculate

## METHOD OF McCAFFREY, QUIITIERE, AlID HARKLEROAD (MQH)


$\dot{\mu} T_{1}=6.85\left[0^{2} /\left(A\left(h_{v}\right)\right)\left(A h^{12}\right)\right]^{1 a}$
Where $\quad \Delta T_{3}=T_{B}-T_{a}=$ upper layer gas temperature rise abo ve ambient ( $K$ )
$0=$ heat release rate ofthe fire (kif)
$A=$ area of ventilation opening ( $\mathrm{m}^{2}$ )
$h_{v}=$ height of ventilation opening (m)
$h_{\text {. }}=$ convective heat transfer coefficient ( $\mathrm{kh}_{\mathrm{h}}^{\left.\mathrm{h} \mathrm{m}^{2}-\mathrm{K}\right) ~}$
$A_{u}=$ total area of the compartment enclosing surface boundaries exoluding area of vent openings ( $\mathrm{m}^{2}$ )
Area of Ventilation Opening Calculation

```
A = (w.)(h)
Where A = area of ventilation opening (m)
wv}=\mathrm{ vent width (m)
hv = vent height (m)
A = 6.50m
```

Thermal Penetration Time Calculation
$t_{p}=\quad(\rho \subset / k)(5 / 2)^{2}$
Where $\quad t_{p}=$ themal penetration time (sec)
$\rho=$ interior construction densitv (kom)
$\mathrm{c}_{\mathrm{p}}=$ interior construction heat capacity ( $\mathrm{k} / \mathrm{kg}-\mathrm{K}$ )
$k=$ interior construction themal conductivity (kiohm-K)
$\delta=$ interior construction thickness (m)
$t_{1}=\quad 26128.98 \mathrm{sec}$
Heat Transfer Coefficient Calculation
$h_{k}=\quad v(k$ pot $) \quad$ for $t<t \quad$ or $\quad(k / s)$ fort $>t_{t}$
Where $\quad h_{k}=$ heat transter coefficient $\left(\mathbf{k} 0 / \mathrm{m}^{2}-\mathrm{K}\right)$
$\mathrm{k} \rho \mathrm{c}=$ interior construction themal inertia $\left(\mathrm{k} 0 / \mathrm{om}^{2}-\mathrm{K}\right)^{2}-\mathrm{sec}$
(a thermal property of material responsible forthe rate oftemperature rise)
$\mathrm{t}=$ time after ignition (sec)
See table below for results
Area of Compartmert Enclosing Surface Boundaries
$A=\quad[2(w \times 1)+2(h \times w)+2(h \times 1 c)] \cdot A$
Where $\quad A_{v}=$ total area ofthe compartment enclosing surface boundaries excluding area of vent openings ( $\mathrm{m}^{2}$ )
$w_{c}=$ compartment width (m)
$I_{i}=$ compartment length (m)
$h_{\text {: }}=$ compartment height ( m )
A = area of ventilation opening (m)
$\mathrm{A}_{\mathrm{s}}=\quad 127.95 \mathrm{~m}$
Compartment Hat Gas Laver Temperature With Natural Ventilation
$\left.\dot{4} \mathrm{~T}_{8}=6.85\left[\mathrm{Q}^{2} \mathrm{M}(\mathrm{A}(\mathrm{h}))^{\prime 2}\right)(\mathrm{A} h)\right]$
$\dot{\Delta} \mathrm{T}_{\mathrm{s}}=\quad \mathrm{T}_{8} \cdot \mathrm{~T}_{\mathrm{a}}$
$T_{19}=\quad \Delta T_{1}+T_{a}$

## Reiulti

| Time After Ignlion (t) |  | $\begin{gathered} \mathrm{h}_{\mathrm{k}} \\ \text { gWinn }-15 \end{gathered}$ | $\begin{aligned} & \hline \mathrm{AT}_{a} \\ & \mathbf{1 O} \\ & \hline \end{aligned}$ | $\begin{aligned} & \mathrm{T}_{0} \\ & \mathrm{O} \\ & \hline \end{aligned}$ | $\begin{gathered} \mathrm{T}_{a} \\ (\mathrm{C}) \end{gathered}$ | $\begin{gathered} \mathrm{T}_{0} \\ (\mathrm{~F}) \end{gathered}$ |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| (ta) | (8ec) |  |  |  |  |  |
| 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 | 458.84 | 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 | 454.43 |



ESTIMATING SMOKE LAYER HEIGHT

## METHOD OF YAMANAAND TANAKA

```
z=({3,0 t3A)+(1/4)
Wher z-smcke taver leglit(m)
    - leatrelease rat orthe ME (NW)
    t-the altr kutbu (sec)
    1. - compartne itrelgit(fm)
    A}=\mathrm{ comparmestrbor area (in)
    k=aconstatgle nbyk=0.076/p
```



```
    p, & glver by P
    T}=10tgas byer Emperatre(f
Compartment area Calculation
A= (W) (1)
Where Acompartmeittbor are a (mo)
    wc}=\mathrm{ compartme it wktth (m)
    L - comparme it Eigtu(n)
A= }\quad23.19\textrm{m
HotGa: Laver Densit/ Calculation
p= 353/T
Calculation for Constant K
k=
Smoke Ga L Laver Helght Wh Ha⿱ural ventlation
z= [[2kQ t/3A]+(1/k
```

Ranultu Caution! The smoke layer height is a conservati ve estima and is only intended to provide an indication where the hot gaslayer is located. Caloulated smoke layer height below the vent height are not credit able since the calculation is not accounting for the smoke exiting the vent.

| $\begin{aligned} & \operatorname{Tm} \theta \\ & \operatorname{tm} \mathrm{l}) \end{aligned}$ |  | Constant (k) <br> 6W:An-K | Smoke Layer leight $z$ (in) | Smoke Lay er helght 20 |
| :---: | :---: | :---: | :---: | :---: |
| 0 | 1.18 | 0.064 | 4.57 | 15.00 |
| 1 | 0.87 | 0.088 | 3.05 | 10.00 |
| 2 | 0.84 | 0.090 | 3.05 | 10.00 |
| 3 | 0.82 | 0.092 | 3.05 | 10.00 |
| 4 | 0.81 | 0.094 | 3.05 | 10.00 |
| 5 | 0.80 | 0.095 | 3.05 | 10.00 |
| 10 | 0.77 | 0.099 | 3.05 | 10.00 |
| 15 | 0.75 | 0.101 | 3.05 | 10.00 |
| 20 | 0.74 | 0.103 | 3.05 | 10.00 |
| 25 | 0.73 | 0.104 | 3.05 | 10.00 |
| 30 | 0.72 | 0.105 | 3.05 | 10.00 |
| 35 | 0.71 | 0.107 | 3.05 | 10.00 |
| 40 | 0.71 | 0.107 | 3.05 | 10.00 |
| 45 | 0.70 | 0.108 | 3.05 | 10.00 |
| 50 | 0.70 | 0.109 | 3.05 | 10.00 |
| 55 | 0.69 | 0.110 | 3.05 | 10.00 |
| 60 | 0.69 | 0.110 | 3.05 | 10.00 |

CAUTIOH: SMOKE IS EXITING OUT VENT CAUTION: SMOKE IS EXTIIIG OUT VEIIT CAUTION: SMOKE IS EXITIMG OUT VENT CAUTION: SMOKE IS EXTIIGG OUT VENT CAUTION: SMOKE IS EXITIMG OUT VENT CAUTION: SMOKE IS EXITIIG OUT VENT CAUTION: SMOKE IS EXITIMG OUT VENT CAUTION: SMOKE IS EXTIIGG OUT VENT CAUTION: SMOKE IS EXITIMG OUT VENT CAUTION: SMOKE IS EXTIMG OUT VENT CAUTION: S MOKE IS EXTIIIG OUT VENT
CAUTIOH: S MOKE IS EXTIIG OUT VENT CAUTION: SMOKE IS EXTIMG OUT VENT CAUTIOH: SMOKE IS EXTIMG OUT VENT CAUTION: SMOKE IS EXTIIIG OUT VENT
CAUTION: SMOKE IS EXIIIG OUT VENT


## NOTE

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering. 3 Edition, 2002.
Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or maynot have reasonable predictive cap abilities for a given situation, and should only be interpreted by an informed user.
Athough each calculation in the spreadsheet has been verited with the results of hand calculation, there is no absolute guarantee of the acouracy ofthese calculations.
Anyquestions, comments, concems, and suggestions, or to report an erron'(s) in the spreadsheet, please send an email to nxi@rieg gov.


## 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 $3.62-\mathrm{kg}(8.0-\mathrm{lb})$ 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, $\dot{\mathrm{Q}}$, flame height, $\mathrm{H}_{\mathrm{f}}$, and burning duration, $\mathrm{t}_{\mathrm{b}}$, of pile of charcoal briquets, assuming that the area of the charcoal pile is $0.28 \mathrm{~m}^{2}\left(3 \mathrm{ft}^{2}\right)$.

## 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 $400 \mathrm{~kg} / \mathrm{m}^{3}$.

| Combustion Properties of Charcoal and Kerosine |  |  |
| :--- | :--- | :--- |
| Combustible Material | Heat of Combustion <br> $\Delta \mathrm{H}_{\mathrm{c}}(\mathrm{kJ} / \mathrm{kg})$ | Mass Loss Rate <br> $\dot{\mathrm{m}}^{\prime \prime} \quad\left(\mathrm{kg} / \mathrm{m}^{2}-\mathrm{sec}\right)$ |
| Charcoal | 31,400 | $0.01082^{*}$ |
| Kerosine | 43,300 | 0.039 |
| Average | 37,350 | $\mathbf{0 . 0 2 4 9 1}$ |
| * Mass loss rate of charcoal is not available in the literature, mass loss rate of <br> 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, $2^{\text {nd }}$ Edition, 1995.

## Solution

Purpose:
(1) Determine the heat release rate, $\dot{\mathrm{Q}}$, flame height, $\mathrm{H}_{f}$, and burning duration, $\mathrm{t}_{\mathrm{b}}$, 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 $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$
(6) Combustion is incomplete and takes place entirely within the confines of the compartment.

## Spreadsheet (FDT ${ }^{s}$ ) Solution Procedure:

Use the following $\mathrm{FDT}^{\text {s }}$
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls
(b) 08_Burning_Duration_Solid.xls

FDT ${ }^{\text {s }}$ Input Parameters:
Enter the following parameters in the spreadsheets (values only):
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations.xls

- Fuel spill volume $(\mathrm{V})=0$ gallons
- Fuel Spill Area or Dike Area $\left(A_{\text {dike }}\right)=3 \mathrm{ft}^{2}$
- Mass Burning Rate of Fuel $\left(\dot{m}^{\prime \prime}\right)=0.02491 \mathrm{~kg} / \mathrm{m}^{2}-\mathrm{sec}$
- Effective Heat of Combustion of Fuel $\left(\Delta \mathrm{H}_{\mathrm{c}, \text { eff }}\right)=37,350 \mathrm{~kJ} / \mathrm{kg}$
- Fuel Density ( $\rho$ ) = $400 \mathrm{~kg} / \mathrm{m}^{3}$
- 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 <br> $\dot{Q} \mathrm{~kW}$ (Btu/sec) | Pool Fire Flame Height <br> $\mathrm{H}_{\mathrm{f}} \mathrm{m}(\mathrm{ft})$ |  |
| :---: | :---: | :---: |
|  | Method of <br> Heskestad | Method of <br> Thomas |
|  | $1.56(5.13)$ | $1.38(4.54)$ |

*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 $\dot{\mathrm{Q}}$ " $=\Delta \mathrm{H}_{\text {ceff }} \dot{\mathrm{m}}^{\prime \prime}$. Therefore, from the given properties in the problem statement we have:

$$
\dot{\mathrm{Q}}^{\prime \prime}=\Delta \mathrm{H}_{\mathrm{c}, \mathrm{ff}} \dot{\mathrm{~m}}^{\prime \prime}=37,350 \mathrm{~kJ} / \mathrm{kg}\left(0.02491 \mathrm{~kg} / \mathrm{m}^{2}-\mathrm{sec}\right)=930 \mathrm{~kW} / \mathrm{m}^{2}
$$

Input Parameters:

- Mass of Solid Fuel $\left(m_{\text {solid }}\right)=80 \mathrm{lb}$
- Exposed Fuel Surface Area $\left(\mathrm{A}_{\text {fuel }}\right)=3 \mathrm{ft}^{2}$
- HRR per Unit Floor Area $\left(\dot{Q}^{\prime \prime}\right)=930 \mathrm{~kW} / \mathrm{m}^{2}$
- Effective Heat of Combustion of Fuel $\left(\Delta \mathrm{H}_{\mathrm{c}, \text { eff }}\right)=37,350 \mathrm{~kJ} / \mathrm{kg}$

Note: Select User-Specified Value and enter the inputs.

## Results*

| Material | Burning Duration <br> $\mathrm{t}_{\text {solid }}$ <br> $(\mathrm{min})$. |
| :--- | :--- |
| Charcoal briquets | 87 |

*spreadsheet calculations attached at the end of the problem

## Spreadsheet Calculations

(a) $\mathrm{FDT}^{\text {s }}$ : 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
Verston 1805.0



Al subsequenl adpulvalues ae calaisked by the sprestivel and baed on wakes spedted in te trpul



## INPUT PARAMEIERS

|  | 0.00 |
| :---: | :---: |
| Flel Pill Areacr Dke frea (A, $)$ | 300 |
| Hans Rurnty Rake off (el (mi) | 0.02491 |
|  | 37350 |
| Flel Dendy ( $\varphi$ ) | 400 |
| Biphical Contiar (k) | 100 |
| AmbleniAr Temperakre (T) | 77.00 |
| Grast tistand Agxeter alon(9) Ambienlar Dendy (9) | 981 1.18 |
|  | ulat |

THEFAMAL PROPERTIES DATA

| Fux | Daxs Buring Rale $\mathrm{m}^{6}\left(\mathrm{~kg} \mathrm{~m}^{\prime}-\mathrm{sec}\right)$ | Healor comburlan $\left.2 \mathrm{H}_{\mathrm{H}} \quad \mathrm{aN} / \mathrm{kg}\right)$ | Dervily <br> 0. kg gm ) | Enplicad Cant lanl kp(m) | Seleot Fuel Type |
| :---: | :---: | :---: | :---: | :---: | :---: |
| Re trand | 0.017 | 20,000 | 796 | 100 | oroll to dectred wel type |
| Evarcl | 0.015 | 25,800 | 794 | 100 | Calok on celection |
| Qulare | 0.78 | +5,700 | 513 | 2.7 |  |
| Bercere | 0.585 | 40,150 | 874 | 2.7 |  |
| Hexare | 0.5. 4 | 44,00 | 550 | 1.9 |  |
| Hep lore | 0.101 | +4,900 | 575 | 1.1 |  |
| >>lere | 0.98 | 40,800 | 870 | 1.4 |  |
| Acelone | 0.041 | 25,800 | 791 | 1.9 |  |
| Dloware <br> DkIy Ely | 0.018 | 25,200 34,200 | 1036 | 5.4 0.7 |  |
| Dely Elw Bencte | 0.085 0.048 | 34,200 44,700 | 874 | 0.7 3.5 |  |
| Eencte Garclive | 0.048 | +4,700 43,00 | 770 | 3.5 2.1 |  |
| Gavaline Verosire | 0.065 0.159 | +3,700 | 740 320 | 2.1 3.5 |  |
| Desel | 0.045 | 44,400 | 918 | 2.1 |  |
| JP-4 | 0.561 | 43,500 | 760 | 3.5 |  |
| JP-5 | 0.554 | 43,000 | 810 | 1.6 |  |
| Trantismer Oll, Hydrocation | 0.589 | 45,000 | 760 | 0.7 |  |
| 361 allan Traytormer Fkid | 0.05 | 28,150 | 960 | 100 |  |
| Fux O1, Hesry | 0.035 | 39,000 | 970 | 1.7 |  |
| Cruse oll | 0.0335 | +2,900 | 355 | 28 |  |
| libe ol | 0.139 | $45,000$ | 760 | $0.7$ |  |
| User Geedred Vake | Eler VJut | Enter Vaske | Erer value | Eler Vatue |  |

## ESTIMAT ING POOL FIRE HEAT RELEASE RATE

Rềrerce: SFPEhivctiook of Fie Pocrection Exiheenty, 3 Eillon, 2002, Page 3-25
$Q=m^{*} \Delta H_{\text {cin }}\left(1-e^{-b_{i}}\right) A_{\text {dsat }}$
Where $\quad Q$-pooltre teat release rate (kW)

$\Delta H_{\text {call }}=$ e Hectre leat of comblston of tre l (kJ kg )

$k \beta=$ emplrtalconstant $\mathrm{on}^{-}$)
$\mathrm{D}=$ dameter of pooltie (diameter livolved in vaportation, clros lar pool t assumed (in)
Pool Rre Clameter Calculation
$A_{\text {data }}=\quad \quad D^{2} / 4$
Where $\quad A_{\text {cisu }}=\delta 1$ itace area of pooltre $\mathrm{mm}^{2}$
D = pool fire dlamer (n)
$D=V\left(4 A_{t s i s}\right)$
$D=\quad 0.596$
m

 boalted te aling lo adtue Igylone
$Q=2259.31 \mathrm{~kW} \quad 245.78 \mathrm{Btu} / \mathrm{sec} \quad$ Answer

## ESTIMAT ING POOL FIRE BURNING DURATION


$\mathrm{t}=4 \mathrm{~V} / \pi \mathrm{D}^{2} \mathrm{v}$
Where $\quad t=b i n i g d i n t h o t$ ofpoolfire $\leqslant e c$ )
$V=$ volume of lkuk $\mathrm{kl} \mathrm{m}^{\text {² }}$
D=pool dametr (m)
$v=$ regressbor rat (m/sec)
Calculation for Regre silon Rate
$v=\quad \mathrm{m} / \mathrm{p}$

Where $\quad v=$ regressbir rate in/sec)
$\mathrm{m}^{*}=$ mass bunluq rat oftiel $\left(\mathrm{m}\left(\mathrm{m} \mathrm{m}^{2}-\mathrm{sec}\right)\right.$

$0.000062 \mathrm{~m} / \mathrm{sec}$
Burning Duration Calculation
$t=4 V / a D^{2}$

| $t=$ | $0.00 \mathrm{~s} \theta \mathrm{c}$ | 0.00 minute: |
| :--- | :--- | :--- |
| Answer |  |  |

Mok tal alkud pod te wi ha given amonil of tel can buntor lory perlods of the over ansll aea or ior storil pertals of the over a bage aea.

ESTIMATING POOL FIRE FLAME HEIGHT
METHOD OF HESKESTAD


$$
\begin{aligned}
& \mathrm{H}=0.235 \mathrm{Q}^{26}-1.02 \mathrm{D} \\
& \text { Wher } \quad H=\text { poolfire tame letit (in) } \\
& Q=\text { pool tire leat re lease rate (NW) } \\
& \text { D = pooltre diameter (in) }
\end{aligned}
$$

Pool Rre Rame Helcht Calculation
$\mathrm{H}_{1}=0.235 \mathrm{Q}^{-2}-1.02 \mathrm{D}$

| $\mathrm{H}_{t}=$ | 1.56 m |
| :--- | :--- |
| Anımar |  |

METHOD OF THOMAS


Wher $\quad H=$ poolfire thame letgit (in)

$\rho_{\mathrm{A}}=$ ambe italidesty (g.m)
D = pooltre dameter (m)

Pool Rre Rame Helght Calculation

$\mathrm{H}_{\mathrm{H}}=\quad 1.38 \mathrm{~m}$
Aniwer

## Flams Halght Caiculation - summary ot Resulti

| Calculation Method | Fame Hight (ft) |
| :--- | :---: |
| METHODOF HESKESTAD | 5.13 |
| METHODOF THOMAS | 4.54 |

ESTIMATING POOL FIRE RESULTS FOR RANDOMSIZE SPILLS USING INPUT PARAMETERS

| Area (tt) | Area ( $\mathrm{m}^{2}$ ) | Clameter (m) | Q (kW) | $\mathrm{t}_{0}(\mathrm{sec})$ | $\mathrm{H}_{\text {( }}$ (t) (He: He stad) | $\mathrm{H}_{4}$ (t) (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 | 0.45 | 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 randomsized spilk. 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 wolume spilk 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, Ind Edition, 1995.
Calcuations are based on certain assumptions and have inherent lirritaions. The results of such calculations may or maynot have reasonable predictive capabilities for a given stuation, and should onlybe interpreted by an informed user.
Athough each calculation in the spreadsheet has been verived with the results of hand calculation, there is no absolute guarantee of the accuracy ofthese calculations.
Anyquestions, comments, concems, and suggestions, or to report an error(s) in the
spreadsteets, please send an email to nxibrce gov or mos 3 Mre gov.

(b) $\mathrm{FDT}^{\text {s. }}$ : 08_Burning_Duration_Solid.xls

CHAPTER 8. ESTIMATIIIG BURIIIIG DURATIOH OF SOLD COMBUSTIBLES
Version 18050
The to bywing cabulatons prukles an approx matbu of the buning di ktbu of solkicombusthes basedon tee buring rat with agtes suthoe ar a.
Parameters in YELLOWCELL \& are Entered by the User.
Parameters in GREENCELLS are Autbmatcally selected tom the DROP DOWN MENU tor the Materlal selected


The chaptr the NUREG storklbe radbe bre at anal, t t made.

## IIIPUT PARAMETERS

COMPARTNEIT IIIFCRMATIOI


Heat pelease Rate per Un F Fgor AR a (C)
Etectue He atot'Combstons ( $\Delta \mathrm{H}_{\mathrm{cat}}$ )
Calculate
0.2 $\mathrm{m}^{\mathrm{m}}$

| Matikt | HRR per Unit Fbor ARa ( $\times$ W) $Q^{*}\left(W h m^{2}\right)$ | $\begin{aligned} & \text { Heat of Comblstil } \\ & \Delta \mathrm{H} \text { adkg } \end{aligned}$ |
| :---: | :---: | :---: |
| P E/PVC | 569 | 24000 |
| XPEFRXPE | 475 | 28300 |
| XPE/MOOPR IE | 354 | 10300 |
| P E, M/Dı/PVC, $\mathrm{N} / \mathrm{l}$ / | 231 | 9200 |
| Tetbi | 96 | 3200 |
| Dotalie tr plwood | 221 | 17600 |
| FIr etaklartteat didwood | 81 | 13500 |
| P article Board, 19 mm tick | 1900 | 17500 |
| WVbl 6.6 | 1313 | 32000 |
| Polme tumetiacylat (PMMA4) | 665 | 26000 |
| Pohprcpye re (PP) | 1509 | 43200 |
| Podstrene PS) | 1101 | 42000 |
| P olvetrylete (PE) | 1408 | 46500 |
| P olvcantorate | 420 | 24400 |
| Polvretuate | 710 | +5000 |
| P olvivicl brke (PVC) Fexble | 237 | 15700 |
| Steredritarie Copohmer SBR | 163 | 41000 |
|  | 956 | 28000 |
| Emot Caitus 15 ttikil | 1700 | 12700 |
| Noodpallet, stacked 1.5 th th | 1420 | 14000 |
| Noodpalkt, stacked5 thkl | 3970 | 14000 |
| Noodpallet, stacked 10 t I th User Sreched valie | $6000$ <br> Eit rvalue | 14000 Eı Er Value |

Select Materlal
Ucer opeolied walue
Scroll to de slred materlal then
Cack on selection



CAC Prase 1832



Gray mot Editors Elewer Appled Scenca 332

## BURNING DURATION OF SOLID COMBUSTIBLES

Reterice: Buchanan, A.H, "Stuctual Design tor Flie Satety," 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 dur ation is given by:
$\mathrm{Q}=\mathrm{E} / \mathrm{t}_{\mathrm{fol}} \mathrm{d}$
or
$\mathrm{t}_{\text {scld }}=(E) /\left(Q^{\prime \prime} A_{\mathrm{F}}(\mathrm{El})\right.$
Where trodd = burning duration of solid combustible (sec)
$E=m f u x d H c=$ total energy contained in the fuel $(\mathrm{kJ})$
$\mathrm{Q}=$ heat releare rate of fire (kion)
$Q^{\prime \prime}=$ heat release rate per unit floor area of fuel $\left(\mathrm{k}_{\mathrm{i}} \mathrm{N}_{\mathrm{\prime}} \mathrm{~m}^{2}\right)$
$A_{\text {fut }}=$ exposed floor area (length $\times$ width) of fuel( $\mathrm{m}^{2}$ )
trold $=(m f(e l) \Delta H c) /\left(Q^{\prime \prime} A F(x)\right)$
whihere $\quad m_{\text {fux }}=$ mass of solid fuel ( kg )
$\Delta H_{c}=$ fuel effective heat of combustion (kJikg)
$t_{\text {cold }}=\left(m_{\text {row }} \Delta H_{c}\right) /\left(Q^{\prime \prime} A_{s o m}\right)$
$\mathrm{t}_{\text {cold }}=\quad 5228.92 \mathrm{sec} \quad 87.15$ minutes $\quad$ Answer

## NOTE

The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are bas ed 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 acouracy of these calculations. Any questiors, comments, concerns, and suggestions, or to report an error(s) in the spreadsheet, please send an email to nxi@nre.gov or mos3@nre.gov.


## Additional Problems

1. Consider a pool fire caused by a 38.0 liters ( 10 gallons) spill of flammable liquid (kerosine oil) in a $0.55-\mathrm{m}^{2}\left(6.0-\mathrm{ft}^{2}\right)$ 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 $\times 6.0 \mathrm{~m}$ long $\times 3.7 \mathrm{~m}$ high ( 20.0 ft wide $\times 20.0 \mathrm{ft}$ long $\times 12.0 \mathrm{ft}$ high ). Two cable trays are located above the pool fire at heights of $2.15 \mathrm{~m}(7.0 \mathrm{ft})$ and $3.0 \mathrm{~m}(10.0 \mathrm{ft})$, 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 $113.0 \mathrm{~m}^{2}\left(1261.0 \mathrm{ft}^{2}\right)$ 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 $\operatorname{HRR}(\dot{Q})$ of $1,500 \mathrm{~kW}$ occurs in an NPP backup power battery room protected with the fixed temperature heat detectors with an RTI of $165(\mathrm{~m}-\mathrm{sec})^{1 / 2}$. Calculate the activation time for the detectors, using listed spacing of $3.05 \mathrm{~m}(20.0 \mathrm{ft})$ with a ceiling height of $4.60 \mathrm{~m}(15 \mathrm{ft})$. Assume that the detectors have an activation temperature of $57^{\circ} \mathrm{C}\left(135^{\circ} \mathrm{F}\right)$ and the ambient temperature is $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$.
4. A fire scenario arises from the failure of a $4,160 \mathrm{~V}$ 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 $4,160 \mathrm{~V}$ breaker. Assume that the breaker fire produces a maximum flame heat flux $50 \mathrm{~kW} / \mathrm{m}^{2}$ and the surface of the cable trays initially at $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$. Calculate the ignition time ( $\mathrm{t}_{\mathrm{ig}}$ ) 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 $1.4 \mathrm{~m}^{2}\left(15 \mathrm{ft}^{2}\right)$. A safety-related cable tray is located $5.5 \mathrm{~m}(18 \mathrm{ft})$ above the pool fire. Calculate the wall flame height $\left(\mathrm{H}_{\mathrm{f}(\text { wall }}\right)$ 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 $0.75 \mathrm{~m}^{2}\left(8.0 \mathrm{ft}^{2}\right)$. A cable tray is located 3.0 m ( 10.0 ft ) above the fire. Calculate the flame height of the line fire $\left(\mathrm{H}_{f(\text { (wall line) }}\right)$, 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 $0.55 \mathrm{~m}^{2}$ $\left(6.0 \mathrm{ft}^{2}\right)$. A cable tray is located $5.5 \mathrm{~m}(18 \mathrm{ft})$ above the fire. Calculate the corner fire flame height ( $\mathrm{H}_{\mathrm{f}(\mathrm{corner})}$ ), and determine whether flame will impinge upon the cable tray.
8. Consider a compartment that is 9.0 m wide $\times 9.0 \mathrm{~m}$ long $\times 3.7 \mathrm{~m}$ high ( 30.0 ft wide $\times 30.0 \mathrm{ft}$ long $\times 12.0 \mathrm{ft}$ high) $\left(\mathrm{w}_{\mathrm{c}} \times \mathrm{I}_{\mathrm{c}} \times \mathrm{h}_{\mathrm{c}}\right)$ with a door vent that is $0.91 \mathrm{~m}(3.0 \mathrm{ft})$ wide $\times 2.15 \mathrm{~m}(7.0 \mathrm{ft})$ high $\left(w_{v} \times h_{v}\right)$. The fire is constant with an $\operatorname{HRR}(\dot{\mathrm{Q}})$ of $1,500 \mathrm{~kW}$. Compute the hot gas temperature $\left(T_{g}\right)$ 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 $\times 12.2 \mathrm{~m}$ long $\times 3.0 \mathrm{~m}$ high ( 40.0 ft wide $\times 40.0 \mathrm{ft}$ long $\times 10.0 \mathrm{ft}$ high) $\left(\mathrm{w}_{\mathrm{c}} \times \mathrm{I}_{\mathrm{c}} \times \mathrm{h}_{\mathrm{c}}\right)$ with a door vent that is ( 4.0 ft ) wide $\times(8.0 \mathrm{ft})$ high $\left(\mathrm{w}_{\mathrm{v}} \times \mathrm{h}_{\mathrm{v}}\right)$. The fire is constant with an $\operatorname{HRR}(\dot{\mathrm{Q}})$ of $2,000 \mathrm{~kW}$. Compute the hot gas temperature ( $\mathrm{T}_{\mathrm{g}}$ ) 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 $\times 12.2 \mathrm{~m}$ long $\times 3.7 \mathrm{~m}$ high ( 50.0 ft wide $\times 40.0$ ft long $\times 12.0 \mathrm{ft}$ high $)\left(\mathrm{w}_{\mathrm{c}} \times \mathrm{I}_{\mathrm{c}} \times \mathrm{h}_{\mathrm{c}}\right)$ with a forced ventilation rate of $1,500 \mathrm{cfm}$. Calculate the hot gas layer temperature $\left(T_{g}\right)$ in the compartment for a fire size $(\mathbb{Q})$ of $1,800 \mathrm{~kW}$ 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 $\times 15.25 \mathrm{~m}$ long $\times 3.35 \mathrm{~m}$ high ( 45.0 ft wide $\times 50.0$ ft long $\times 11.0 \mathrm{ft}$ high $)\left(\mathrm{w}_{\mathrm{c}} \times \mathrm{I}_{\mathrm{c}} \times \mathrm{h}_{\mathrm{c}}\right)$ with a forced ventilation rate of $1,800 \mathrm{cfm}$. Calculate the hot gas layer temperature ( $\mathrm{T}_{\mathrm{g}}$ ) in the compartment for a fire size ( $\dot{\mathrm{Q}}$ ) of $2,200 \mathrm{~kW}$ 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 30.30 liters ( 8.0 gallons) spill of flammable liquid (lube oil) in $0.38 \mathrm{~m}^{2}$ ( $4.0 \mathrm{ft}^{2}$ ) 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 $\times 3.7 \mathrm{~m}$ long $\times 3.0 \mathrm{~m}$ high ( 16.0 ft wide $\times 12.0 \mathrm{ft}$ long $\times 10.0 \mathrm{ft}$ high). Two cable trays are located above the pool fire at heights of $1.8 \mathrm{~m}(6.0 \mathrm{ft})$ and $2.5 \mathrm{~m}(8.0 \mathrm{ft})$, 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 $2.5 \mathrm{~m}(8.0 \mathrm{ft})$ beneath a horizontal cable tray. Assumed that the trash fire ignites an area of approximately $0.92 \mathrm{~m}^{2}\left(10.0 \mathrm{ft}^{2}\right)$ of the cable tray, and the cables in the tray are Id PE. Compute the full-scale HRR of Id PE cable insulation. The bench-scale HRR ( $\dot{Q}_{\mathrm{w}}$ ) of the Id PE type cable material is $1,071 \mathrm{~kW} / \mathrm{m}^{2}$.
14. Assume that heptane from a tank spills on a concrete floor, forming a $0.92 \mathrm{~m}^{2}\left(10.0 \mathrm{ft}^{2}\right)$ 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 $3.7 \mathrm{~m}(12.0 \mathrm{ft})$. 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 $\left(T_{p(c e n t e r i n e)}\right)$ at the ceiling of a $4.6-\mathrm{m}(15.0-\mathrm{ft})$ high room above a $1,500-\mathrm{kW}$ fire involving a $1 \frac{1}{2}-\mathrm{ft}$ high stack of wood pallets in a $0.92-\mathrm{m}^{2}\left(10.0-\mathrm{ft}^{2}\right)$ pallet area. Assume that the ambient temperature is $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$.
16. A fire with $\dot{Q}=3,000 \mathrm{~kW}$ occurs in a makeup pump room protected with a wet pipe sprinkler system. Fire sprinklers are rated at $74{ }^{\circ} \mathrm{C}\left(165{ }^{\circ} \mathrm{F}\right)$ [standard response bulb with RTI 235 $(\mathrm{m}-\mathrm{sec})^{1 / 2}$ ] 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 480 V 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 $30 \mathrm{~kW} / \mathrm{m}^{2}$ and the surface of the cable trays is initially at $25^{\circ} \mathrm{C}\left(77^{\circ} \mathrm{F}\right)$. Calculate the ignition time ( $\mathrm{t}_{\mathrm{ig}}$ ) 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 $1.4 \mathrm{~m}^{2}\left(15.0 \mathrm{ft}^{2}\right)$. A safety-related cable tray is located $4.6 \mathrm{~m}(15.0 \mathrm{ft})$ 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 $0.75 \mathrm{~m}^{2}\left(8.0 \mathrm{ft}^{2}\right)$. A cable tray is located $3.7 \mathrm{~m}(12.0 \mathrm{ft})$ 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 $0.55 \mathrm{~m}^{2}\left(6 \mathrm{ft}^{2}\right)$. A cable tray is located $4.3 \mathrm{~m}(14.0 \mathrm{ft})$ 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 $\left(\mathrm{Q}_{\mathrm{FO}}\right)$ in a compartment that is 5.5 m wide $\times 6.0 \mathrm{~m}$ long $\times 3.7 \mathrm{~m}$ high ( 18.0 ft wide $\times 20.0 \mathrm{ft}$ long $\times 12.0 \mathrm{ft}$ high ) $\left(\mathrm{w}_{\mathrm{c}} \times \mathrm{I}_{\mathrm{c}} \times \mathrm{h}_{\mathrm{c}}\right)$, with an opening that is $0.60 \mathrm{~m}(2.0 \mathrm{ft})$ wide $\times 1.83 \mathrm{~m}(6.0 \mathrm{ft})$ high $\left(\mathrm{w}_{\mathrm{v}} \times \mathrm{h}_{\mathrm{v}}\right)$. Assume that the boundary material is concrete and the door is open.
22. Calculate the HRR necessary for flashover $\left(\dot{\mathrm{Q}}_{\mathrm{FO}}\right)$ in a cable spreading room (CSR) that is 15.3 m wide $\times 24.4 \mathrm{~m}$ long $\times 6.0 \mathrm{~m}$ high ( 50.0 ft wide $\times 80.0 \mathrm{ft}$ long $\times 20.0 \mathrm{ft}$ high ) $\left(\mathrm{w}_{\mathrm{c}} \times \mathrm{I}_{\mathrm{c}} \times \mathrm{h}_{\mathrm{c}}\right)$ with a door opening $1.2 \mathrm{~m}(4.0 \mathrm{ft})$ wide $\times 3.0 \mathrm{~m}(10.0 \mathrm{ft})$ high ( $\mathrm{w}_{\mathrm{v}} \times \mathrm{h}_{\mathrm{v}}$ ). 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 $\times 2.7 \mathrm{~m}$ long $\times 2.5 \mathrm{~m}$ high ( 10.0 ft wide $\times 9.0 \mathrm{ft}$ long $\times 8.0 \mathrm{ft}$ high) $\left(\mathrm{w}_{\mathrm{c}} \times \mathrm{I}_{\mathrm{c}} \times \mathrm{h}_{\mathrm{c}}\right.$ ). 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 $6.35 \mathrm{~cm}(21 / 2 \mathrm{in})$ thickness of fire protection insulation on all of the beams. The size of the tested beam was $\mathrm{W} 12 \times 26$. Determine whether the $6.35 \mathrm{~cm}(21 / 2 \mathrm{in})$ thickness of fire protection insulation is acceptable for a beam that is W8 $\times 13$.
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 $\times 15.25 \mathrm{~m}$ long $\times 3.7 \mathrm{~m}$ high ( 50 ft wide $\times 50 \mathrm{ft}$ long $\times 12 \mathrm{ft}$ 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, $\mathrm{A}-7$
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, $\mathrm{B}-17$
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, $\mathrm{B}-16$
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, $\mathrm{H}-1-\mathrm{H}-33$

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, $\mathrm{J}-1-\mathrm{J}-134$
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, $\mathrm{C}-9-\mathrm{C}-11$
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, $\mathrm{B}-17$
classification, $\mathrm{B}-17$
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, $\mathrm{C}-2$
duration, $\mathrm{C}-2, \mathrm{C}-3$
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
0
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 <br> (2-89) <br> NRCM 1102, <br> 3201, 3202 U.S. NUCLEAR REGULATORY COMMISSION | 1. REPORT NUMBER <br> (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers. if anv.) <br> NUREG-1805 |
| :---: | :---: |
| 2. TITLE AND SUBTITLE |  |
| Fire Dynamics Tools (FDTs): <br> Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program | 3. DATE REPORT PUBLISHED |
|  | MONTH <br> December YEAR <br> 2004 |
| Final Report | 4. FIN OR GRANT NUMBER |
| 5. AUTHOR(S) <br> 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.) <br> Same as 8, above |  |
|  |  |
| 10. SUPPLEMENTARY NOTES <br> Sunil Weerakkody, NRC Project Manager and Fire Protection Section Chief |  |
| 11. ABSTRACT (200 words or less) <br> 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.) <br> Fire Dynamics <br> Hazard Analysis <br> Inspection <br> Significance Determination Process <br> 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.


[^0]:    *spreadsheet calculations attached on next page

[^1]:    *spreadsheet calculations attached at the end of the problem

