Introduction to Fire Dynamics Tools (NUREG-1805)

Shahina Kurien, M.Eng
Fire Protection Program Authority (CNL)
Sam Shalabi, P.Eng, M.Eng
Fire Protection Engineer (CNL)

- **December 10th /2014**

Agenda:

Introduction
NUREG 1805 Example
Group Example

Introduction

- The U.S. Nuclear Regulatory Commission (NRC) created the Fire Dynamics Tools (FDTs) quantitative methods, to help out in performing Fire Hazard Analyses (FHAs) known as NUREG 1805.
- This methodology has been implemented by populated *Excel* spreadsheets.
- The dynamic nature of fire is a quantitative and mathematically complex subject. It combines physics, chemistry, mathematics, and engineering principles.
- The objective of NUREG 1805 is to provide first-order calculations of potential fire scenarios at nuclear power plants.

Introduction

List of Fire Dynamics Tools:

FDT^{s}* *indicated revised spreadsheet	Chapter and Related Calculation Method(s)
	Chapter 2. Predicting Hot Gas Layer Temperature and Smoke Layer Height in a Room Fire with Natural and Forced Ventilation
02.1_Temperature_NV_Sup1.xls	Method of McCaffrey, Quintiere, and Harkleroad (MQH) • Natural Ventilation
02.2_Temperature_FV_Sup1.xls*	Method of Foote, Pagni, and Alvares (FPA) • Forced Ventilation Method of Deal and Beyler • Forced Ventilation
02.3_Temperature_CC._Sup1.xls*	Method of Beyler • Fire in a Compartment with a Door Closed but with Sufficient Leaks to Prevent Pressure Buildup; Leakage is Ignored

Introduction

List of Fire Dynamics Tools:

FDTs* *indicated revised spreadsheet	Chapter and Related Calculation Method(s)
03_HRR_Flame_Height_Burning_ Duration_Calculation_Sup1.xls*	**Chapter 3.** Estimating Burning Characteristics of Liquid Pool Fire, Heat Release Rate, Burning Duration and Flame Height
04_Flame_Height_Calculations_Sup1.xls	**Chapter 4.** Estimating Wall Fire Flame Height, Line Fire Flame Height Against the Wall, and Corner Fire Flame Height
	Chapter 5. Estimating Radiant Heat Flux from Fire to a Target Fuel
05.1_Heat_Flux_Calculations_Wind_ Free_Sup1.xls	*Wind-Free Condition* • Point Source Radiation Model (Target at Ground Level) • Solid Flame Radiation Model (Target at Ground Level) • Solid Flame Radiation Model (Target Above Ground Level)
05.2_Heat_Flux_Calculations_ Wind_Sup1.xls*	*Presence of Wind* • Solid Flame Radiation Model (Target at Ground Level) • Solid Flame Radiation Model (Target Above Ground Level)
05.3_Thermal_Radiation_From_ Hydrocarbon_Fireballs_Sup1.xls	Estimating Thermal Radiation from Hydrocarbon Fireballs

Introduction

List of Fire Dynamics Tools:

06_Ignition_Time_Calculations_Sup1.xls	**Chapter 6.** Estimating the Ignition Time of a Target Fuel Exposed to a Constant Radiative Heat Flux • Method of Estimating Piloted Ignition Time of Solid Materials Under Radiant Exposures Method of (1) Mikkola and Wichman, (2) Quintiere and Harkleroad, and (3) Janssens • Method of Estimating Piloted Ignition Time of Solid Materials Under Radiant Exposures Method of Toal, Silcock and Shields • Method of Estimating Piloted Ignition Time of Solid Materials Under Radiant Exposures Method of Tewarson
07_Cable_HRR_Calculations_Sup1.xls	**Chapter 7.** Estimating Full-Scale Heat Release Rate of a Cable Tray Fire
08_Burning_Duration_Soild_Sup1.xls	**Chapter 8.** Estimating Burning Duration of Solid Combustibles

Introduction

List of Fire Dynamics Tools:

09_Plume_Temperature_ Calculations_Sup1.xls	**Chapter 9.** Estimating Centerline Temperature of a Buoyant Fire Plume
10_Detector_Activation_Time_Sup1.xls*	Estimating Detector Response Time **Chapter 10.** Estimating Sprinkler Response Time **Chapter 11.** Estimating Smoke Detector Response Time **Chapter 12.** Estimating Heat Detector Response Time
13_Compartment_ Flashover_ Calculations_Sup1.xls	**Chapter 13.** Predicting Compartment Flashover • Compartment Post-Flashover Temperature: Method of Law • Minimum Heat Release Rate Required to Compartment Flashover: Method of (1) McCaffrey, Quintiere, and Harkleroad (MQH); (2) Babrauskas; and (3) Thomas
14_Compartment_Over_Pressure_ Calculations_Sup1.xls	**Chapter 14.** Estimating Pressure Rise Attributable to a Fire in a Closed Compartment
15_Explosion_Claculations_Sup1.xls	**Chapter 15.** Estimating the Pressure Increase and Explosive Energy Release Associated with Explosions
16_Battery_Room_Flammable_Gas_ Conc_Sup1.xls*	**Chapter 16.** Calculating the Rate of Hydrogen Gas Generation in Battery Rooms • Method of Estimating Hydrogen Gas Generation Rate in Battery Rooms • Method of Estimating Flammable Gas and Vapor Concentration Buildup in Enclosed Spaces • Method of Estimating Flammable Gas and Vapor Concentration Buildup Time in Enclosed Spaces

Introduction

List of Fire Dynamics Tools:

17.1_FR_Beams_Columns_ Substitution_Correlation_Sup1.xls* 17.2_FR_Beams_Columns_Quasi_ Steady_State_Spray_Insulated_Sup1.xls* 17.3_FR_Beams_Columns_Quasi_ Steady_State_Board_Insulated_Sup1.xls* 17.4_FR_Beams_Columns_Quasi_ Steady_State_Uninsulated_Sup1.xls*	**Chapter 17.** Calculating the Fire Resistance of Structural Steel Members • Empirical Correlations • Beam Substitution Correlation (Spray-Applied Materials) • Column Substitution Correlation (Spray-Applied Materials) • Heat Transfer Analysis using Numerical Methods Protected Steel Beams and Columns (Spray-Applied) • Heat Transfer Analysis using Numerical Methods Protected Steel Beams and Columns (Board Materials) • Heat Transfer Analysis using Numerical Methods Unprotected Steel Beams and Columns
18_Visibility_Through_Smoke_Sup1.xls	**Chapter 18.** Estimating Visibility Through Smoke
19_THIEF_of_Cables_Calculations_ Sup1.xls	**Chapter 19.** Estimating the Thermally-Induced Electrical Failure (THIEF) of Cables

Introduction

Advantages of NUREG 1805:

- User-friendly, Pre-programmed Excel spreadsheets based on fire dynamics equation/correlations.
- Quick application of fire dynamics principles.
- Protected spreadsheets prevents tampering.
- Automatic unit conversion.
- Fire materials properties data for generally used in nuclear power plants programmed within each spreadsheet.
- Pull-down menus decreases input errors.
- Spreadsheets are available in English and SI Units.

Agenda:

Introduction

NUREG 1805 Example

Group Example

NUREG 1805 Example

Room 135 contains switchgear equipment as well as three transformers contained in a fenced section of the room. The room has approximate LxWxH dimensions of 19 x 20 x 12 ft (5.8 x 6.1 x 3.6 m) [8.2.1]. The room has no mechanical ventilation but is provided with a 18"x12" vent for natural ventilation. The walls and roof of the room are of wooden construction. It should be noted as well there is no rooms or spaces above the ceiling.

The combustible material observed in the room is comprised of the electrical equipment and three cable spools. There were no other large sources of combustibles present within the room. Ignition sources in this room consist of the electrical equipment present as well as two heaters suspended from the ceiling during the building walkdown.

Since the room is normally unoccupied the fire will be detected by the smoke detectors observed during the building walkdown and the sprinkler system activating. The design fire is assumed to start within one of the switchgears. In the absence of specific information, the design fire will be approximated as a large electrical cabinet fire with a heat release rate of 1300 kW (this is equivalent to Test 24 of Table G-6 in [8.3.9]).

NUREG 1805 Example

Sample of NUREG spreadsheets used in Fire Scenario 4

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

Version 1805.0

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

INPUT PARAMETERS

MATERIAL FLAME SPREAD PROPERTIES

Material Flux Time Product (FTP)	42025.00	$(kW\text{-}sec/m^2)^n$
Material Critical Heat Flux for Ignition ($q''_{critical}$)	10.00	kW/m^2
Flux Time Product Index (n)	2.00	
Exposure or External Radiative Heat Flux (q''_e)	31.00	kW/m^2

Calculate

FLAME SPREAD PROPERTIES OF COMMON MATERIALS

Materials	Flux Time Product (FTP) $(kW\text{-}sec/m^2)^n$	Critical Heat Flux for Ignition $q''_{critical}$ (kW/m^2)	Flux Time Product Index n
Chipboard	5,370	6.4	1.49
Chipboard (Horizontal) (15 mm)	9,921	9.0	1.70
Chipboard (Vertical) (15 mm)	11,071	10.0	1.70
Fiberboard	3,981	8.3	1.66
Hardboard	8,127	8.1	1.49
Hardboard (Painted Gloss)	9,332	8.1	1.51
Hardwood	2,818	8.1	1.50
Plywood	8,164	10.8	1.51
Plywood (Horizontal) (12 mm)	5,409	8.5	1.50
Plywood (Vertical) (12 mm)	42,025	10.0	2.00
Plywood (Painted Gloss)	6,761	11.4	1.50
PMMA (cast) (3 mm)	3,100	5.0	1.25
PMMA (extruded) (2 mm)	1,290	9.0	1.00
Polyethylene (2 mm)	2,220	12.8	1.00
Polypropylene (3.3 mm)	8,110	6.5	1.50
PVC (Extruded Gray) (3 mm)	5,130	15.0	1.50
PVC (Pressed White) (3 mm)	95,000	8.0	2.00
Softwood	5,130	13.7	1.53
Softwood (Horizontal) (20 mm)	44,079	10.0	2.20
Softwood (Vertical) (20 mm)	16,502	12.0	1.90
Softwood Intumescent Paint	4,559	13.0	1.50
User Specified Value	Enter Value	Enter Value	Enter Value

Select Material
Plywood (Vertical) (12 mm)
Scroll to desired material then Click on selection

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 20.

METHOD OF TOAL, SILCOCK AND SHIELDS
THERMALLY THICK MATERIALS

Reference: SFPE Engineering Guide, "Piloted Ignition of Solid Materials Under Radiant Exposure," 2002, Page 17.

$t_{ig} = FTP_n / (q_e'' - q''_{critical})^n$

Where

t_{ig} = material ignition time (sec)
FTP_n = flux time product $(kW\text{-}sec/m^2)^n$ for the given index
q_e'' = exposure or external heat flux (kW/m^2)
$q''_{critical}$ = material critical heat flux for ignition (kW/m^2)
n = flux time product index (n ? 1)

$t_{ig} = FTP_n / (q_e'' - q''_{critical})^n$

t_{ig} =	95.29 sec	1.59 minute	Answer

NUREG 1805 Example

CHAPTER 9. ESTIMATING CENTERLINE TEMPERATURE OF A BUOYANT FIRE PLUME
Version 1805.0

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

INPUT PARAMETERS

Heat Release Rate of the Fire (Q)	1300.00	kW	
Elevation Above the Fire Source (z)	6.00	ft	1.83 m
Area of Combustible Fuel (A_c)	15.00	ft²	1.39 m²
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C
	Calculate		298.00 K

AMBIENT CONDITIONS

Specific Heat of Air (c_p)	1.00	kJ/kg-K
Ambient Air Density (ρ_∞)	1.18	kg/m³
Acceleration of Gravity (g)	9.81	m/sec²
Convective Heat Release Fraction (χ_c)	0.70	

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

ESTIMATING PLUME CENTERLINE TEMPERATURE

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

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

Where
- $T_{p(centerline)}$ = plume centerline temperature (°C)
- Q_c = convective portion of the heat release rate (kW)
- T_a = ambient air temperature (K)
- g = acceleration of gravity (m/sec²)
- c_p = specific heat of air (kJ/kg-K)
- ρ_∞ = ambient air density (kg/m³)
- z = distance from the top of the fuel package to the ceiling (m)
- z_0 = hypothetical virtual origin of the fire (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c\,Q$

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

Q_c = 910 kW

Fire Diameter Calculation

$A_c = \pi D^2/4$

Where
- A_c = area of combustible fuel (m²)
- D = fire diameter (m)

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

D = 1.33 m

Hypothetical Virtual Origin Calculation

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

Where
- z_0 = virtual origin of the fire (m)
- Q = heat release rate of fire (kW)
- D = fire diameter (m)

z_0/D = 0.08

z_0 = 0.10 m

Centerline Plume Temperature Calculation

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

$T_{p(centerline)} - T_a$ = 958.56

$T_{p(centerline)}$ = 1256.56 K

$T_{p(centerline)}$ =	983.56 °C	1802.41 °F	Answer

NUREG 1805 Example

CHAPTER 10. ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.0

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

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1300.00	kW	
Sprinkler Response Time Index (RTI)	130	$(m\text{-}sec)^{1/2}$	
Activation Temperature of the Sprinkler ($T_{activation}$)	165	°F	73.89 °C
Height of Ceiling above Top of Fuel (H)	6.00	ft	1.83 m
Radial Distance to the Detector (r) "never more than 0.707 or 1/2?2 of the listed spacing"	8.00	ft	2.44 m
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K

Convective Heat Release Rate Fraction χ_c) 0.70

r/H = 1.33

Calculate

GENERIC SPRINKLER RESPONSE TIME INDEX (RTI)*

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

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

Reference: Madrzykowski, D., "Evaluation of Sprinkler Activation Prediction Methods" ASIAFLAM'95, International Conference on Fire Science and Engineering, 1st Proceeding, March 15-16, 1995, Kowloon, Hong Kong, pp. 211-218.

*Note: The actual RTI should be used when the value is available.

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

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

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

Reference: Automatic Sprinkler Systems Handbook, 6th Edition, National Fire Protection Association, Quincy, Massachusetts, 1994, Page 67.

*Note: The actual temperature rating should be used when the value is available.

ESTIMATING SPRINKLER RESPONSE TIME

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

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

Where $t_{activation}$ = sprinkler activation response time (sec)
RTI = sprinkler response time index $(m\text{-}sec)^{1/2}$
u_{jet} = ceiling jet velocity (m/sec)
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
$T_{activation}$ = activation temperature of sprinkler (°C)

NUREG 1805 Example

Ceiling Jet Temperature Calculation

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

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

Where T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
Q_c = convective portion of the heat release rate (kW)
H = height of ceiling above top of fuel (m)
r = radial distance from the plume centerline to the sprinkler (m)

Convective Heat Release Rate Calculation

$Q_c = {}^{\circ}{}_c\,Q$

Where Q_c = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
$^{\circ}{}_c$ = convective heat release rate fraction

Q_c = **910** kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.33 r/H > 0.15

$T_{jet} - T_a$ = {5.38 (Qc/r)^2/3}/H
$T_{jet} - T_a$ = 152.49
T_{jet} = **177.49** (°C)

Ceiling Jet Velocity Calculation

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

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

Where u_{jet} = ceiling jet velocity (m/sec)
Q = heat release rate of the fire (kW)
H = height of ceiling above top of fuel (m)
r = radial distance from the plume centerline to the sprinkler (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.33 r/H > 0.15

u_{jet} = (0.195 Q^1/3 H^1/2)/r^5/6
u_{jet} = **1.369** m/sec

Sprinkler Activation Time Calculation

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

$t_{activation}$ = 42.94 sec

The sprinkler will respond in approximately 0.72 minutes **Answer**

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

NUREG 1805 Example

CHAPTER 11. ESTIMATING SMOKE DETECTOR RESPONSE TIME

Version 1805.0

The following calculations estimate smoke detector response time.

Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.

All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).

The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1300.00	kW	1232.17 Btu/sec
Radial Distance to the Detector (r) **never more than 0.707 or 1/2?2 of the listed spacing**	10.00	ft	3.05 m
Height of Ceiling above Top of Fuel (H)	6.00	ft	1.83 m
Activation Temperature of the Smoke Detector ($T_{activation}$)	86.00	°F	30.00 °C
Smoke Detector Response Time Index (RTI)	5.00	(m-sec)^1/2	
Ambient Air Temperature (T_a)	77.00	°F	25.00 °C 298.00 K
Convective Heat Release Rate Fraction (χ_c)	0.70		
Plume Lag Time Constant (C_{pl}) (Experimentally Determined)	0.67		
Ceiling Jet Lag Time Constant (C_{cj}) (Experimentally Determined)	1.2		
Temperature Rise of Gases Under the Ceiling (ΔT_c) for Smoke Detector to Activate	18.00	°F	10 °C

r/H = 1.67

Calculate

ESTIMATING SMOKE DETECTOR RESPONSE TIME
METHOD OF ALPERT

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

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

This method assume smoke detector is a low RTI device with a fixed activation temperature

Where
- $t_{activation}$ = detector activation time (sec)
- RTI = detector response time index $(m\text{-}sec)^{1/2}$
- u_{jet} = ceiling jet velocity (m/sec)
- T_{jet} = ceiling jet temperature (°C)
- T_a = ambient air temperature (°C)
- $T_{activation}$ = activation temperature of detector (°C)

Ceiling Jet Temperature Calculation

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

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

Where
- T_{jet} = ceiling jet temperature (°C)
- T_a = ambient air temperature (°C)
- Q_c = convective portion of the heat release rate (kW)
- H = height of ceiling above top of fuel (m)
- r = radial distance from the plume centerline to the detector (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c Q$

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

Q_c = 910 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.67 r/H > 0.15

>0.15	131.41	<0.15	580.28

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

$T_{jet} - T_a$ = 131.41

T_{jet} = 156.41 (°C)

NUREG 1805 Example

Ceiling Jet Velocity Calculation

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

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

Where
- u_{jet} = ceiling jet velocity (m/sec)
- Q = heat release rate of the fire (kW)
- H = height of ceiling above top of fuel (m)
- r = radial distance from the plume centerline to the detector (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.67 r/H > 0.15

>0.15	1.14	<0.15	8.57

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

u_{jet} = **1.137** m/sec

Smoke Detector Response Time Calculation

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

$t_{activation}$ =	**0.18 sec**	**Answer**

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

METHOD OF MOWRER

References: Mowrer, F., "Lag Times Associated With Fire Detection and Suppression," Fire Technology, August 1990, p. 244

$t_{activation} = t_{pl} + t_{cj}$

Where
- $t_{activation}$ = detector activation time (sec)
- t_{pl} = transport lag time of plume (sec)
- t_{cj} = transport lag time of ceiling jet (sec)

Transport Lag Time of Plume Calculation

$t_{pl} = C_{pl}\ (H)^{4/3}/(Q)^{1/3}$

Where
- t_{pl} = transport lag time of plume (sec)
- C_{pl} = plume lag time constant
- H = height of ceiling above top of fuel (m)
- Q = heat release rate of the fire (kW)

t_{pl} = **0.14** sec

Transport Lag Time of Ceiling Jet Calculation

$t_{cj} = (r)^{11/6}/(C_{cj})\ (Q)^{1/3}\ (H)^{1/2}$

Where
- t_{cj} = transport lag time of ceiling jet (sec)
- C_{cj} = ceiling jet lag time constant
- r = radial distance from the plume centerline to the detector (m)
- H = height of ceiling above top of fuel (m)
- Q = heat release rate of the fire (kW)

t_{cj} = **0.44** sec

Smoke Detector Response Time Calculation

$t_{activation} = t_{pl} + t_{cj}$

$t_{activation}$ =	**0.57 sec**	**Answer**

NUREG 1805 Example

METHOD OF MILKE

References: Milke, J., "Smoke Management for Covered Malls and Atria," Fire Technology, August 1990, p. 223
NFPA 92B, "Guide for Smoke Management Systems in Malls, Atria, and Large Areas," 2000 Edition, Section A.3.4

$t_{activation} = X H^{4/3}/Q^{1/3}$

Where
- $t_{activation}$ = detector activation time (sec)
- $X = 4.6\ 10^{-4}\ Y^2 + 2.7\ 10^{-15}\ Y^6$
- H = height of ceiling above top of fuel (ft)
- Q = heat release rate from steady fire (Btu/sec)

Where
- $Y = \Delta T_c H^{5/3} / Q^{2/3}$
- ΔT_c = temperature rise of gases under the ceiling for smoke detector to activate (°F)

Before estimating smoke detector response time, stratification effects can be calculated. NFPA 92B, 2000 Edition, Section A.3.4 provides following correlation to estimate smoke stratification in a compartment.

$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f-c}^{3/5}$

Where
- H_{max} = the maximum ceiling clearance to which a plume can rise (ft)
- Q_c = convective portion of the heat release rate (Btu/sec)
- ΔT_{f-c} = difference in temperature due to fire between the fuel location and ceiling level (°F)

Convective Heat Release Rate Calculation

$Q_c = Q\ \chi_c$

Where
- Q_c = convective portion of the heat release rate (Btu/sec)
- Q = heat release rate of the fire (Btu/sec)
- χ_c = convective heat releas rate fraction

Q_c = 862.52 Btu/sec

Difference in Temperature Due to Fire Between the Fuel Location and Ceiling Level

$\Delta T_{f-c} = 1300\ Q_c^{2/3} / H^{5/3}$

Where
- ΔT_{f-c} = difference in temperature due to fire between the fuel location and ceiling level (°F)
- Q_c = convective portion of the heat release rate (Btu/sec)
- H = ceiling height above the fire source (ft)

ΔT_{f-c} = 3945.70 °F

Smoke Stratification Effects

$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f-c}^{3/5}$

H_{max} = 6.01 ft

In this case the highest point of smoke rise is estimated to be 6.01 ft
Thus, the smoke would be expected to reach the ceiling mounted smoke detector.

$Y = \Delta T_c H^{5/3} / Q^{2/3}$

Y = 3.10

$X = 4.6\ 10^{-4}\ Y^2 + 2.7\ 10^{-15}\ Y^6$

X = 0.00

Smoke Detector Response Time Calculation

$t_{activation} = X H^{4/3}/Q^{1/3}$

$t_{activation}$ = 0.00 sec **Answer**

Summary of Result

Calculation Method	Smoke Detector Response Time (sec)
METHOD OF ALPERT	0.18
METHOD OF MOWRER	0.57
METHOD OF MILKE	0.00

NUREG 1805 Example

CHAPTER 13. PREDICTING COMPARTMENT FLASHOVER HEAT RELEASE RATE
Version 1805.0

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

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft	6.096 m
Compartment Length (l_c)	19.00	ft	5.79 m
Compartment Height (h_c)	12.00	ft	3.6576 m
Vent Width (w_v)	1.50	ft	0.457 m
Vent Height (h_v)	1.00	ft	0.30 m
Interior Lining Thickness (δ)	0.75	in	0.01905 m
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K	

Calculate

THERMAL PROPERTIES DATA

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

Select Material
Plywood
Scroll to desired material then Click on selection

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

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

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

$Q_{FO} = 610\ ?(h_k A_T A_v (?h_v))$

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

NUREG 1805 Example

Heat Transfer Coefficient Calculation

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

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

h_k = **0.009** kW/m^2-K

Area of Ventilation Opening Calculation

$A_v = (w_v)(h_v)$

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

A_v = **0.14** m^2

Area of Compartment Enclosing Surface Boundaries

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

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

A_T = **157.42** m^2

Minimum Heat Release Rate for Flashover

Q_{FO} = 610 ?(h_k A_T A_v (?h_v))

Q_{FO} =	200.54 kW	Answer

METHOD OF BABRAUSKAS

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

Q_{FO} = 750 A_v (?h_v)

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

Minimum Heat Release Rate for Flashover

Q_{FO} = 750 A_v (?h_v)

Q_{FO} =	57.70 kW	Answer

METHOD OF THOMAS

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

Q_{FO} = 7.8 A_T + 378 A_v (?h_v)

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

Minimum Heat Release Rate for Flashover

Q_{FO} = 7.8 A_T + 378 A_v (?h_v)

Q_{FO} =	1256.99 kW	Answer

Summary of Results

Calculation Method	Flashover HRR (kW)
METHOD OF MQH	201
METHOD OF BABRAUSKAS	58
METHOD OF THOMAS	1257

NUREG 1805 Example

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN A ROOM FIRE WITH NATURAL VENTILATION

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

Version 1805.0

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.

Parameters in YELLOW CELLS are Entered by the User.

Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.

All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s).
The chapter in the NUREG should be read before an analysis is made.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft	6.096 m
Compartment Length (l_c)	19.00	ft	5.7912 m
Compartment Height (h_c)	12.00	ft	3.6576 m
Vent Width (w_v)	1.50	ft	0.457 m
Vent Height (h_v)	1.00	ft	0.305 m
Top of Vent from Floor (V_T)	8.00	ft	2.438 m
Interior Lining Thickness (\)	0.75	in	0.01905 m

AMBIENT CONDITIONS

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Interior Lining Thermal Inertia (k\ c)	0.16	(kW/m²-K)²-sec
Interior Lining Thermal Conductivity (k)	0.00012	kW/m-K
Interior Lining Specific Heat (c)	2.5	kJ/kg-K
Interior Lining Density (\ )	540	kg/m³

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

EXPERIMENTAL THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material: Plywood

Scroll to desired material then Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	1300.00	kW

Calculate

NUREG 1805 Example

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

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

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

Where $\square T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_v = area of ventilation opening (m²)
h_v = height of ventilation opening (m)
h_k = convective heat transfer coefficient (kW/m²-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m²)

Area of Ventilation Opening Calculation

$A_v = (w_v)(h_v)$

Where A_v = area of ventilation opening (m²)
w_v = vent width (m)
h_v = vent height (m)

A_v = 0.14 m²

Thermal Penetration Time Calculation

$t_p = (\square c_p/k)(\square/2)^2$

Where t_p = thermal penetration time (sec)
□ = interior construction density (kg/m³)
c_p = interior construction heat capacity (kJ/kg-K)
k = interior construction thermal conductivity (kW/m-K)
□ = interior construction thickness (m)

t_p = 1020.66 sec

Heat Transfer Coefficient Calculation

h_k = ?(k□c/t) for t < t_p or (k/□) for t > t_p

Where h_k = heat transfer coefficient (kW/m²-K)
k□c = interior construction thermal inertia (kW/m²-K)²-sec
(a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)
See table below for results

Area of Compartment Enclosing Surface Boundaries

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

Where A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m²)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)
A_v = area of ventilation opening (m²)

A_T = 157.42 m²

Compartment Hot Gas Layer Temperature With Natural Ventilation

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

$\square T_g = T_g - T_a$

$T_g = \square T_g + T_a$

Results

Time After Ignition (t)		h_k	$\square T_g$	T_g	T_g	T_g
(min)	(sec)	(kW/m²-K)	(K)	(K)	(°C)	(°F)
0	0.00	-	-	298.00	25.00	77.00
1	60	0.05	954.09	1252.09	979.09	1794.37
2	120	0.04	1070.93	1368.93	1095.93	2004.68
3	180	0.03	1145.81	1443.81	1170.81	2139.45
4	240	0.03	1202.08	1500.08	1227.08	2240.75
5	300	0.02	1247.63	1545.63	1272.63	2322.74
10	600	0.02	1400.42	1698.42	1425.42	2597.75
15	900	0.01	1498.33	1796.33	1523.33	2773.99
20	1200	0.01	1923.79	2221.79	1948.79	3539.82
25	1500	0.01	1923.79	2221.79	1948.79	3539.82
30	1800	0.01	1923.79	2221.79	1948.79	3539.82
35	2100	0.01	1923.79	2221.79	1948.79	3539.82
40	2400	0.01	1923.79	2221.79	1948.79	3539.82
45	2700	0.01	1923.79	2221.79	1948.79	3539.82
50	3000	0.01	1923.79	2221.79	1948.79	3539.82

NUREG 1805 Example

Based on a point source radiant heat flux model presented in Appendix B, the heat flux at a specified distance can be obtained. This indicates the design fires ability to jump between fire sources, not the fires ability spread to connected fuel sources. The time to ignition of an object (plywood and polyethylene) shown in Table 7 is found using equation 7 in Appendix B. From the table below, it can be seen that plywood walls will catch fire as well adjacent switchgears are also likely to catch fire.

		Ignition time (min)	
Radius (m)	heat flux (kW/m^2)	Plywood (12mm)	Polyethylene (2mm)
1	31.0	1.6	2
2	7.8	will not ignite	will not ignite
3	3.4	will not ignite	will not ignite
4	1.9	will not ignite	will not ignite
5	1.2	will not ignite	will not ignite

Table 7: Ignition times of plywood and polyethylene exposed to Fire Scenario 4

NUREG 1805 Example

From a fire of this size the plume temperature at 6 ft above the fuel source (assumed to be the distance to the roof) is 983°C [8.3.6] which is above the 600°C auto ignition temperature of plywood indicating that the ceiling will catch fire as a result of this design fire.

Using formulas 1-3 in Appendix B, the sprinkler activation time can be predicted. The radial distance from a sprinkler was established as 8 ft (2.4 m) which is approximated from the sprinkler plan drawing [8.2.11] since the sprinkler layout details of the active machine shop sprinkler system were unavailable. The resulting sprinkler response time is 0.72 minutes. The smoke detectors assuming a 10 ft. radial distance (exact locations could not be found on drawings) have a response time of less then 1 second, indicating they will alarm before the fire reaches its full size.

Flashover is associated with a hot gas layer temperature of 600°C. Using the methods predicted in NUREG 1805 [8.3.6], the minimum required heat flux will be reached. The minimum required heat fluxes using the three provided methods are 201, 58 and 1257 kW. The same result is obtained using a natural ventilation model and predicting the hot gas layer temperature. It can be concluded that flashover will occur in this compartment as a result of a fire of this size, excluding sprinkler response.

NUREG 1805 Example

Fire spread to adjacent compartments is considered unlikely since plywood walls can be assigned a fire resistance rating of at least 10 minutes according to D-2.3.4.A of the building code [8.1.1]. Since there is a sheet of plywood on each side of the wall this give the wall a fire resistance rating of approximately 20 minutes. This is approximately double the time it will take the fire department to respond.

Area 135

Combustible Type	Units of Measure	Heat of Combustion (Btu/Unit)	Combustible Load (kg/Unit)	Quantity	Contribution (BTU)	Contribution (kg)
Power Cord - 1/2" Diameter	Feet	366	0.034405	2750	1.01E+06	9.46E+01
Rubber Hose - 1/2" Diameter	Feet	1170	0.027656	20	2.34E+04	5.53E-01
Fluorescent Light Fixture	Fixture(s)	19800	1	2	3.96E+04	2.00E+00

Total Combustible Load **1.07E+06 BTU**
1.01E+06 kJ
9.72E+01 kg

Agenda:

Introduction

NUREG 1805 Example

Group Example

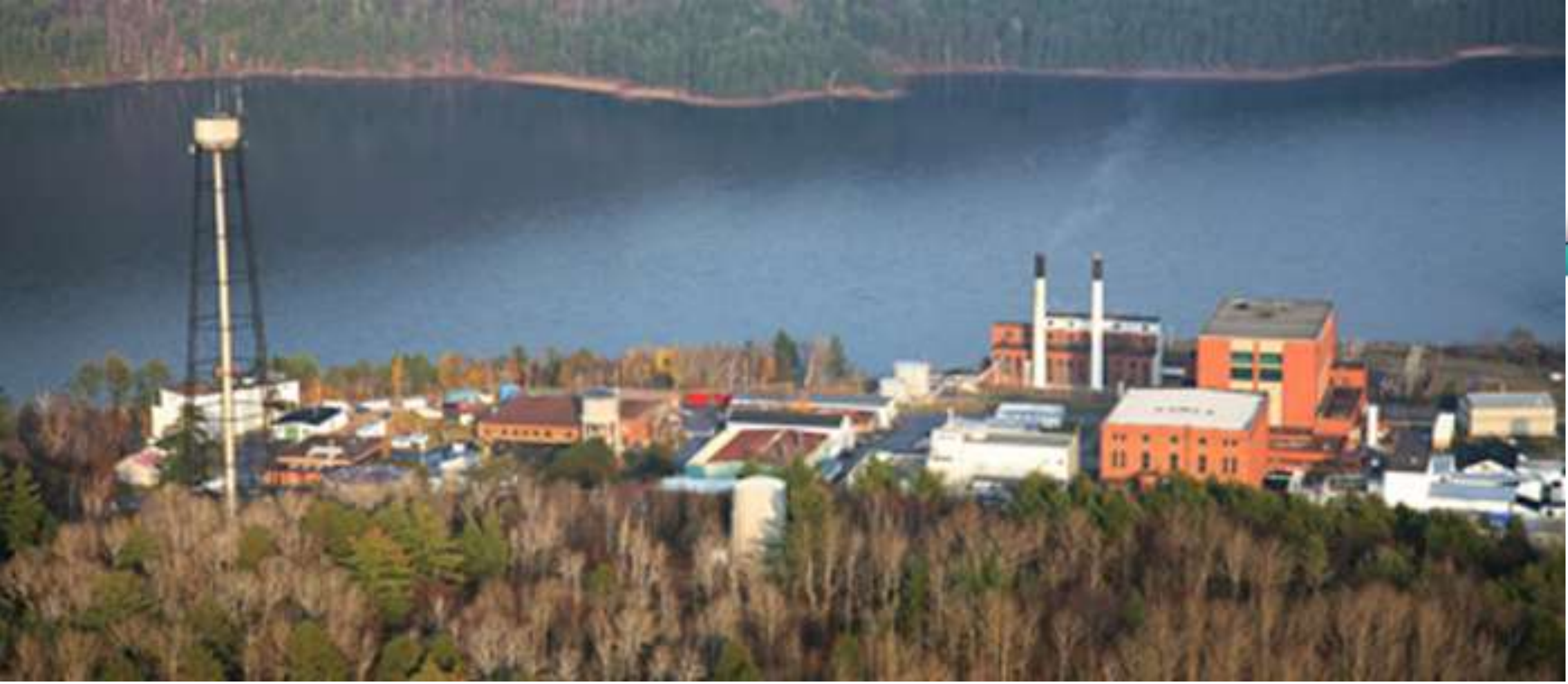
Group Example

- The room has approximate LxWxH dimension of 19 x 20 x 12 ft (5.8 x 6.1 x 3.6 m).
- A small non-mechanical vent with dimensions 18 x 12 inches (Natural ventilation) and top of vent from floor is 8 ft or 2.438m.
- Interior lining thickness 0.75 inch or 0.019m
- The walls and roof of the room are of wooden construction.(Plywood 12mm)
- The combustibles in the room are compromised of electrical equipment and 3 cables.
- Area of combustibles is 1.39 m2.

Group Example

Using NUREG 1805 spread-sheet, Calculate:

- The heat release rate (HRR)?
- The centreline temperature of the plume at 6ft or 1.83m?
- The smoke detector response time? (with radial distance from the detector of 10ft or 3.05m and room temperature 25C)
- The ignition time of target fuel from radiant heat flux?
- Smoke layer height?



Thank you

Questions?

Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens