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United States Nuclear Regulatory Commission
Protecting People and the Environment

NUREG-1805
Supplement 1, Vol. 2

Fire Dynamics Tools (FDT^{s}) Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program

Supplement 1

Appendices

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Appendices

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ABSTRACT

The U.S. Nuclear Regulatory Commission (NRC) has developed quantitative methods, known as "Fire Dynamics Tools" (FDT^s), for analyzing the impact of fire and fire protection systems in nuclear power plants (NPPs). These methods have been implemented in spreadsheets and taught at the NRC's quarterly regional inspector workshops. The FDT^s were developed using state-of-the-art fire dynamics equations and correlations that were preprogrammed and locked into Microsoft Excel® spreadsheets. These FDT^s enable inspectors to perform quick, easy, first-order calculations for potential fire scenarios using today's state-of-the-art principles of fire dynamics. Each FDT^s spreadsheet also contains a list of the physical and thermal properties of the materials commonly encountered in NPPs.

This NUREG-series report documents a new spreadsheet that has been added to the FDT^s suite and describes updates, corrections, and improvements to the existing spreadsheets. The majority of the original FDT^s were developed using principles and information from the Society of Fire Protection Engineers (SFPE) *Handbook of Fire Protection Engineering*, the National Fire Protection Association (NFPA) *Fire Protection Handbook*, and other fire science literature. The new spreadsheet predicts the behavior of power cables, instrument cables, and control cables during a fire. The thermally-induced electrical failure (THIEF) model was developed by the National Institute of Standards and Technology (NIST) as part of the Cable Response to Live Fire (CAROLFIRE) program sponsored by the NRC. The experiments for CAROLFIRE were conducted at Sandia National Laboratories, Albuquerque, New Mexico. THIEF model predictions have been compared to experimental measurements of instrumented cables in a variety of configurations, and the results indicate that the model is an appropriate analysis tool for NPP applications. The accuracy and simplicity of the THIEF model have been shown to be comparable to that of the activation algorithms for various fire protection devices (e.g., sprinklers, heat and smoke detectors).

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EXECUTIVE SUMMARY

The U.S. Nuclear Regulatory Commission (NRC) has developed quantitative methods, known as “Fire Dynamics Tools” (FDT^s), for analyzing the impact of fire and fire protection systems in nuclear power plants (NPPs). These methods have been implemented in spreadsheets and taught at the NRC’s quarterly regional inspector workshops. The goal of the training is to assist inspectors in calculating the quantitative aspects of a postulated fire and its effects on safe NPP operation. The FDT^s were developed using state-of-the-art fire dynamics equations and correlations that were preprogrammed and locked into Microsoft Excel® spreadsheets. These FDT^s enable inspectors to perform quick, easy, first-order calculations for potential fire scenarios using today’s state-of-the-art principles of fire dynamics. Each FDT^s spreadsheet also contains a list of the physical and thermal properties of the materials commonly encountered in NPPs.

The FDT^s are intended to assist fire protection inspectors in performing risk-informed evaluations of credible fires that may cause critical damage to essential safe-shutdown equipment, as required by the reactor oversight process (ROP) defined in the NRC’s inspection manual. In the ROP, the NRC is moving toward a more risk-informed, objective, predictable, understandable, and focused regulatory process. Key features of the program are a risk-informed regulatory framework, risk-informed inspections, a significance determination process (SDP) to evaluate inspection findings, performance indicators, a streamlined assessment process, and more clearly defined actions that the NRC will take for plants based on their performance.

This NUREG-series report documents a new spreadsheet that has been added to the FDT^s suite and describes updates, corrections and improvements for the existing spreadsheets. The majority of the original FDT^s were developed from the Society of Fire Protection Engineers (SFPE) *Handbook of Fire Protection Engineering*, the National Fire Protection Association (NFPA) *Fire Protection Handbook*, and other fire science literature. The new spreadsheet predicts the behavior of power cables, instrument cables, and control cables during a fire. The thermally-induced electrical failure (THIEF) model was developed by the National Institute of Standards and Technology (NIST) as part of the Cable Response to Live Fire (CAROLFIRE) program sponsored by the NRC.

The primary objective of CAROLFIRE was to characterize the various modes of electrical failure (e.g. hot shorts, shorts to ground) within bundles of power, control and instrument cables. A secondary objective of the project was to develop a simple model to predict thermally-induced electrical failure (THIEF) when a given interior region of the cable reaches an empirically determined threshold temperature. The experiments for CAROLFIRE were conducted at Sandia National Laboratories.

The THIEF model for cables has been shown to work effectively in realistic fire environments. The THIEF model is essentially a numerical solution of the one dimensional heat conduction equation within a homogenous cylinder with fixed, temperature independent properties. THIEF model predictions have been compared to experimental measurements of instrumented cables in a variety of configurations, and the results indicate that the model is an appropriate analysis tool for NPP applications. The model is of comparable accuracy and simplicity to the activation algorithms for various fire protection devices (e.g., sprinklers, heat and smoke detectors).

ACKNOWLEDGMENTS

Since the publication of NUREG-1805, *Fire Dynamics Tools (FDT^s) Quantitative Fire Hazard Analysis Methods for the U.S. Nuclear Regulatory Commission Fire Protection Inspection Program*, numerous comments and suggestions for additions, improvements, and a few corrections have been received from users throughout the world. This supplement addresses many of the issues identified by users and adds a new spreadsheet to the suite of FDT^s. The authors thank the internal and external stakeholders who have taken the time to provide comments and suggestions on the original report. We hope this supplement will receive similar attention and appreciate any feedback from users of the material in this supplement.

The authors gratefully acknowledge the support and assistance provided by Naeem Iqbal and Mark Henry Salley of the U.S. Nuclear Regulatory Commission (NRC). They published the original NUREG-1805 in December 2004. The general concepts used in creating and developing the FDT^s spreadsheets were similar to those taught by Dr. Frederick Mowrer whose fire modeling course they had attended during their postgraduate studies at the University of Maryland.

We acknowledge and appreciate the contributions of Mollie Semmes, a fire protection engineering student at the University of Maryland. Mollie's hard work and diligence during her summer internships at NRC ensured that this report was published in a timely fashion and with completely revised and tested spreadsheets. The authors also thank Nicolas Melly, David Gennardo, and Kendra Hill in the Fire Research Branch of the NRC Office of Nuclear Regulatory Research for their comments and testing of the spreadsheets.

The new spreadsheet added to the FDT^s implements a methodology for estimating the thermally-induced electrical failure of cables. This THIEF model was derived from an algorithm developed by Dr. Kevin McGrattan at the National Institute of Standards and Technology based on data obtained from cable tests conducted at Sandia National Laboratories by Mr. Steven Nowlen.

Finally, the authors would like to thank H.W. 'Roy' Woods who provided invaluable support in publishing this report. In addition, we greatly appreciate the efforts of Guy Beltz, NRC printing specialist, and Tojuana Fortune-Grasty, NRC NUREG technical editor, whose expertise were critical to ensuring the quality of the published manuscript.

ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
ACRS	Advisory Committee on Reactor Safeguards (NRC)
ADAMS	Agencywide Documents Access and Management System (NRC)
ADS	Automatic Depressurization System
AFFF	Aqueous Film Forming Foam
AFT	Adiabatic Flame Temperature
AFW	Auxiliary Feedwater
AGA	American Gas Association
AHJ	Authority Having Jurisdiction
AISI	American Iron and Steel Institute
AL	Administrative Letter
ALC	Approximate Lethal Concentration
ANS	American Nuclear Society
ANSI	American National Standards Institute
API	American Petroleum Institute
ASCE	American Society of Civil Engineers
ASCOS	Analysis of Smoke Control Systems
ASET	Available Safe Egress Time
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASMET	Atria Smoke Management Engineering Tools
ASTM	American Society for Testing and Materials
AT	Auxiliary Transformer
ATF&E	Alcohol, Tobacco, Firearms, and Explosives
AWG	American Wire Gauge
BFC	Bromochlorodifluoro-methane
BFNP	Browns Ferry Nuclear Power Plant
BFRL	Building and Fire Research Laboratory
BL	Bulletin
BLEVE	Boiling Liquid, Expanding Vapor Explosion
BOCA	Building Officials & Code Administration International
BREAK1	Berkeley Algorithm for Breaking Window Glass in a Compartment Fire
BS	British Standard
BTP	Branch Technical Position
BTU	British Thermal Unit
BWR	Boiling-Water Reactor
CAROLFIRE	Cable Response to Live Fire
CCW	Component Cooling Water
CFAST	Consolidate Model of Fire Growth and Smoke Transport
CFD	Computational Fluid Dynamics
CFI	Certified Fire Inspector
CFO	Chief Financial Officer (NRC)
CFR	*Code of Federal Regulations*
CHF	Critical Heat Flux
CIB	Conseil Internationale du Batiment
CIBSI	Chartered Institution of Building Services Engineers
CIO	Chief Information Officer (NRC)
CL.S.PE	Chlorosulfonated Polyethylene

CO	Carbon Monoxide
CO2	Carbon Dioxide
CP	Construction Permit
CPCV	Chlorinated Polyvinylchloride
CPE	Chlorinated Polyethylene
CPSC	Consumer Product Safety Commission
CR	Circular or Neoprene or Chloroprene Rubber
CSNI	Committee on the Safety of Nuclear Installations
CSP	Chlorosulfonated Polyethylene Rubber (Kel-F®)
CSR	Cable Spreading Room
CTEF	Chlorotrifluoroethylene
DDT	Deflagration to Detonation Transition
DETACT-QS	Detector Actuation Quasi-Steady
DETACT-T2	Detector Actuation Time Square
DID	Defense-in-Depth
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
DSSA	Division of Systems Safety and Analysis (NRC)
ECCS	Emergency Core Cooling System
EDG	Emergency Diesel Generator
EDO	Executive Director for Operations (NRC)
ELVAC	Elevator Evacuation
EMI/RFI	Electromagnetic or Radio-Frequency Interface
EPA	Environmental Protection Agency
EPR	Ethylene-Propylene Rubber
EPRI	Electrical Power Research Institute
EQ	Equipment Qualification
ESFR	Early Suppression Fast Response
ETFE	Ethylenetetrafluoroethylene (Tefzel®)
EVA	Ethylvinyl Acetate FAA Federal Aviation Administration
FDI	Fire Detection Institute
FDM	Fire Demand Model
FDS	Fire Dynamics Simulator
FDTs	Fire Dynamics Tools
FEM	Finite Element Method
FEMA	Federal Emergency Management Agency
FEP	Fluorinated Polyethylene Propylene (Teflon®)
FFFP	Film-Forming Fluoroprotein Foam
FHA	Fire Hazard Analysis
FIGARO II	Fire and Gas Spread in Room (model)
FIPEC	Fire Performance of Electrical Cables
FIRES-T3	Fire Response of Structures-Thermal Three (model)
FIVE	Fire Induced Vulnerability Evaluation
FMRC	Factory Mutual Research Corporation
FPA	Foote, Pagni, and Alvares
FPE	Fire Protection Engineer(ing)
FPETOOL	Fire Protection Engineering Tool
FPP	Fire Protection Program
FPS	Fire Protection System
FR	Fire-Retardant
FRP	Fiberglass Reinforced Polyester (Plastic)

FRXPE	Fire-Retardant Crosslinked Polyethylene
FSSD	Post-Fire Safe-Shutdown
FTA	Federal Transit Authorization
FTMS	Federal Test Method Standard
GDC	General Design Criteria
GL	Generic Letter
GSA	General Service Administration
GSI	Generic Safety Issue
H2O	Water
HBr	Hydrogen Bromide
HCI	Hydrogen Chloride
HCN	Hydrogen Cyanide
HEPA	High-Efficiency Particulate Air Filter
HF	Hydrogen Fluoride
HPCI	High Pressure Cooling Injection
HRR	Heat Release Rate
HTGR	High-Temperature Gas-Cooled Reactor
HVAC	Heating, Ventilation, and Air Conditioning
IAFSS	International Association of Fire Safety Science
IBC	International Building Code
ICBO	International Conference of Building Officials
ICS	Integrated Control System
ICSDTS	International Committee for the Study and Development of Tubular Structures
IE	Initiative Events
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IN	Information Notice
INEEL	Idaho National Engineering and Environmental Laboratory
IPEEE	Individual Plant Examination of External Events
ISO	International Organization for Standardization
LAVENT	Link Actuation Vents
LC	Lethal Concentration LCL Lethal Concentration Low
LD	Lethal Dose
LDL	Lethal Dose Low
LEL	Lower Explosive Limit
LER	Licensee Event Report
LFL	Lower Flammability Limit
LIFT	Lateral Ignition and Flame Spread (ASTM E 1321 Standard Test Method)
LLNL	Lawrence Livermore National Laboratory
LNG	Liquified Natural Gas
LOC	Limiting Oxidant Concentration
LOCA	Loss-of-Coolant Accident
LPG	Liquid Propane Gas
LWR	Light-Water Reactor
MCC	Motor Control Center
MCR	Main Control Room
MESG	Maximum Experimental Safe Gap
MOV	Motor-Operated Valve
MQH	McCaffrey, Quintiere, and Harkleroad
NBC	National Building Code
NBR	Nitrile

NBS	National Bureau of Standards
NEA	Nuclear Energy Agency
NEI	Nuclear Energy Institute
NEMA	National Electrical Manufacturers Association
NFC	National Fire Code
NFPA	National Fire Protection Association
NIOSH	National Institute of Occupational Safety and Health
NIST	National Institute of Standards and Technology
NO2	Nitrogen Dioxide
NOUN	Notification of Unusual Event
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
NRR	Office of Nuclear Reactor Regulation (NRC)
NUREG	NUclear REGulatory Guide
OCIO	Office of Chief Information Officer (NRC)
OL	Operating License
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OSU	Ohio State University
PASS	Personal Alert Safety System
PC	Polycarbonate
PDA	Primary Disconnect Assembly
PE	Polyethylene
PEF	Polyethylene Fluoride
PES	Polyethersulphone
PFA	Perfluoroalkoxy Branched Polymers
PMMA	Polymethylmethacrylate
PP	Polypropylene
PPE	Polytetrafluoroethylene
PRA	Probabilistic Risk Assessment
PS	Polystyrene
PTEF	Polytetrafluoroethylene (Teflon®)
PU	Polyurethane
PVC	Polyvinylchloride
PVF	Polyvinylfluoride
RCP	Reactor Coolant Pump
RES	Office of Nuclear Regulatory Research (NRC)
RG	Regulatory Guide
RHR	Residual Heat Removal
RIS	Regulatory Issue Summary
RMV	Respiratory Minute Volume
ROP	Reactor Oversight Process
RTECS	Registry of the Toxic Effects of Chemical Substance
RTI	Response Time Index
RWFD	Red Wing Fire Department
S/G	Steam Generator
SBC	Standard Building Code
SBCCI	Southern Building Code Congress International
SBDG	Standby Diesel Generator
SBR	Styrene Butadiene Rubber
SCBA	Self-Contained Breathing Apparatus

SDP	Significance Determination Process
SER	Significant Event Report
SFPE	Society of Fire Protection Engineers
SI	System International
SNL	Sandia National Laboratories
SOLAS	Safety of Lives at Sea
SONGS	San Onofre Nuclear Generating Station
SPLB	Plant Systems Branch (NRC)
SRP	Standard Review Plan (NUREG-0800)
SSC	Structure, System, and/or Component
TASEF	Temperature Analysis of Structure Exposed to Fire
TCL	Toxic Concentration Low
TDL	Toxic Dose Low
TFE	Tetrafluoroethylene (Teflon®)
THIEF	Thermally-Induced Electrical Failure
TLC	Toxic Concentration Low
TLV	Threshold Limit Value
TNT	Trinitrotoluene
TP	Thermoplastic
TRP	Thermal Response Parameter
TS	Thermoset
TSC	Technical Support Center
TTC	Time-Temperature Curve
TVA	Tennessee Valley Authority
TVAN	Tennessee Valley Authority Nuclear Program
UBC	Uniform Building Code
UEL	Upper Explosive Limit
UFC	Uniform Fire Code
UFL	Upper Flammability Limit
UL	Underwriters Laboratories
UPS	Uninterruptible Power Supply
USFA	United States Fire Administration
UVCE	Unconfined Vapor Cloud Explosion
V&V	Verification and Validation
VRLA	Valve-Regulated Lead Acid
W/D	Weight-to-Heated Perimeter Ratio
XLPE	Crosslinked Polyethylene
XLPO	Crosslinked Polyolefin

NOMENCLATURE

A_c	Compartment floor area
A_e	Surface of element
A_f	Horizontal burning area of fuel
A_H	Ampere hours
A_s	Cross sectional area
A_T	Area of compartment enclosing surfaces (excluding vent areas)
A_v	Area of ventilation openings
B	Flame spread parameter
C	Gas concentration by volume
C	Thermal capacity
C_i	Specific heat of insulation
C_p	Specific heat
C_s	Specific heat of steel
C_v	Specific heat at constant volume
C_{HF}	Critical heat flux for ignition
D	Diameter
D	Heated parameter
D_{SC}	Scaled distance
E	Emissive power
E	Explosive energy released
F	Configuration or shape factor
F	Fire resistance time
F_{TP}	Flux time product
F_c	Float Current per 100 AH
g	Acceleration of gravity
G	Gas discharge rate
H	Thickness of insulation
h	Heat flux time product index
h_c	Compartment height
h_{eff}	Effective heat transfer coefficient
h_{ig}	Heat transfer coefficient at ignition
h_k	Convective heat transfer coefficient
h_v	Height of ventilation opening
H	Thermal capacity of steel section at ambient
H	Height
H_g	Hydrogen gas generation
h_f	Flame height
$h_{f(wall)}$	Wall flame height
$h_{f(wall,line)}$	Line fire flame height
$h_{f(corner)}$	Corner fire flame height
k	Thermal conductivity
k_i	Thermal conductivity of insulation
$k\rho c$	Thermal inertia
K	Mixing efficiency factor
K	Proportionality constant
L_c	Compartment length
L	Length
LFL	Lower flammability limit

m	mass
m_f	Mass of fuel vapor
m_f	Mass of fuel burned
m_p	Mass concentration of particulate
m	Mass flow rate
m_e	Mass entrainment rate
m_f	Mass flow rate of fuel
m_o	Mass flow rate out of enclosure
m_p	Plume mass flow rate
m''	Mass loss rate per unit area
M_p	Mass of particulates produced
N	Number of cells (batteries)
N	Number of theoretical air changes
P	Pressure
q''	Heat flux
q''_{crit}	Critical heat flux
q''_e	External heat flux
q''_{min}	Minimum heat flux required for ignition
q''_r	Radiative heat flux
Q	Volume of air
Q_{total}	Total energy release
Q	Heat release rate or energy release rate
Q_c	Convective energy release rate
Q_{FO}	Energy release rate to cause flashover
Q_{fs}	Full-scale energy release rate
Q_{bs}	Bench-scale energy release rate
R	Radius
R	Radial distance
R	Fire Resistance
RTI	Response time index
S	Visibility
T	Time
T_b	Burning duration
t_D	Detection time
t_{ig}	Ignition time
t_p	Thermal penetration time
t_r	Detector response time
t_t	Smoke transit time
$t_{activation}$	Sprinkler activation time
T	Temperature
T_a	Ambient temperature
T_f	Fire temperature
$T_{FO(max)}$	Post-flashover compartment temperature
T_g	Gas temperature
T_s	Steel temperature
T_{jet}	Ceiling jet temperature
$T_{p(centerline)}$	Plume centerline temperature
$T_{activation}$	Activation temperature
U_{jet}	Ceiling jet velocity
U_w	Wind velocity
U_o	Gas velocity

u^*	Nondimensional wind velocity
V	Volume
V_{def}	Volume of gas for deflagration
W	Fuel exposed width
W_c	Compartment width
W	Weight of steel column per linear foot
W_{TNT}	Weight of TNT
Y_p	Particulate yield
Z	Height of smoke layer interface above floor
Z_o	Hypothetical virtual origin of fire source
Z_p	Fireball flame height
ΔH_c	Heat of Combustion
$\Delta Hc_{,eff}$	Effective heat of combustion
Δt	Time step
ΔT_g	Gas temperature above ambient
ΔT_{ig}	Ignition temperature above ambient
α	Heat transfer coefficient for steel I
α	Yield (fraction of available energy participating in blast wave generation)
α_m	Specific extinction coefficient
χ_r	Fraction of total energy radiated
δ	Thickness
ε	Flame emissivity
Ω	Ventilation factor
θ	Flame title or angle of deflection
ρ	Density
ρ_a	Density of Ambient Air
ρ_c	Density of combustion products
ρ_c	Density of concrete
ρ_F	Density of fuel vapor
ρ_g	Density of gas
ρ_i	Density of insulation
σ	Stefan-Boltzmann constant
τ_o	Detector time constant
ν	Regression rate

Subscripts

a	Ambient
bs	Bench-scale
c	Compartment
c	Combustion
c	Concrete
c	Current
D	Detection
def	Deflagration
e	Convective
e	External
eff	Effective
e	Entrainment

f	Fire
f	Flame
f	Fuel
f(corner)	Corner flame
f(wall)	Wall flame
f(wall,line)	Line fire flame
FO	Flashover
fs	Full-scale
g	Gas
H	Hours
I	Insulation
ig	Ignition
jet	Ceiling jet
m	Extinction
min	Minimum
o	Out
p	Specific
p	Particulate
p	Plume
p	Penetration
r	Radiative
r	Response
SC	Scale
s	Steel
T	Total
Total	Total
t	Transient
TNT	Trinitrotoluene
v	Vent
v	Volume
w	Wind

Superscripts

$(\dot{\ })$	Per unit time
$(\ )''$	Per unit area
$(\dot{\ })''$	Per unit area, per unit time
*	Nondimensional

APPENDIX A

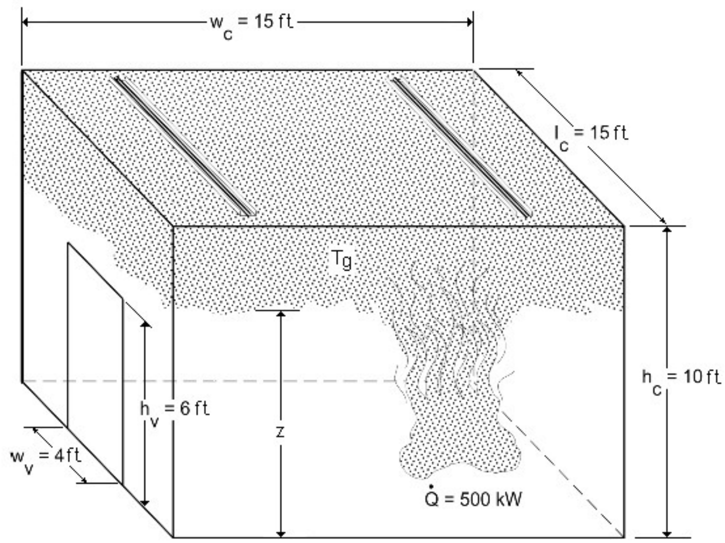
REVISED SPREADSHEETS – EXAMPLE PROBLEMS (ENGLISH UNITS)

2.16 Problems

2.16.1 Natural Ventilation

Example Problem 2.16.1-1

Problem Statement
Consider a compartment that is 15 ft wide x 15 ft long x 10 ft high (w_c x l_c x h_c), with a simple vent that is 4 ft wide x 6 ft tall (w_v x h_v). The fire is constant with an HRR of 500 kW. Compute the hot gas layer temperature in the compartment and smoke layer height at 2 minutes assuming that the compartment interior boundary material is (a) 1 ft thick concrete and (b) 1.0 inch thick gypsum board. Assume that the top of the vent is 6 ft.



Example Problem 2-1: Compartment with Natural Ventilation

Solution

Purpose:

For two different interior boundary materials determine following:

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

Assumptions:

(1) Air properties (ambient) at 77 °F
(2) Simple rectangular geometry (no beam pockets)
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant heat release rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) For concrete: 02.1_Temperature_NV_Sup1.xls
(b) For gypsum board: 02.1_Temperature_NV_Sup1.xls

FDT Input Parameters: (for both spreadsheets)
- Compartment Width (w_c) = 15 ft
- Compartment Length (l_c) = 15 ft
- Compartment Height (h_c) = 10 ft
- Vent Width (w_v) = 4 ft
- Vent Height (h_v) = 6 ft
- Top of Vent from Floor (V_T) = 6 ft
- Interior Lining Thickness (δ) = 12 in (concrete) and 1 in. (gypsum board)
- Ambient Air Temperature (T_a) = 77 °F
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Concrete** and **Gypsum Board** on the respective FDT^s
- Fire Heat Release Rate ($\dot{Q}$) = 500 kW
- Time after ignition (t) = 2 min

Results*

Interior Boundary Material	Hot Gas Layer Temperature (T_g) (Method of MQH) (°F)	Smoke Layer Height (z) (Method of Yamana and Tanaka) (ft)
Concrete	296	6.00 (smoke exiting vent, z < V_T)
Gypsum Board	425	6.00 (compartment filled with smoke

*see spreadsheet on next page at t = 2 min

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.1-1a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	15.00	ft
Compartment Length (l_c)	15.00	ft
Compartment Height (h_c)	10.00	ft
Vent Width (w_v)	4.00	ft
Vent Height (h_v)	6.00	ft
Top of Vent from Floor (V_T)	6.00	ft
Interior Lining Thickness (δ)	12.00	in

AMBIENT CONDITIONS

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

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Concrete

Scroll to desired material
Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 500.00 kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

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

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

Where,

ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

Where,

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

A_v = 2.23 m^2

Thermal Penetration Time Calculation

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

Where,

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 26128.98 sec

Heat Transfer Coefficient Calculation

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

Where,

h_k = heat transfer coefficient (kW/m²-K)

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

t = time after ignition (sec)

See table below for results (column 3)

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 = 95.32 m^2

COMPARTMENT HOT GAS LAYER TEMPERATURE WITH NATURAL

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

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Results	Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
	(min)	(sec)	(kW/m^2-K)	(°K)	(°K)	(°C)	(°F)
	0	0.00	-	-	298.00	25.00	77.00
	1	60	0.22	108.34	406.34	133.34	272.02
	2	120	0.16	121.61	419.61	146.61	295.90
	3	180	0.13	130.11	428.11	155.11	311.20
	4	240	0.11	136.50	434.50	161.50	322.70
	5	300	0.10	141.67	439.67	166.67	332.01
	10	600	0.07	159.02	457.02	184.02	363.24
	15	900	0.06	170.14	468.14	195.14	383.26
	20	1200	0.05	178.50	476.50	203.50	398.30
	25	1500	0.04	185.26	483.26	210.26	410.47
	30	1800	0.04	190.98	488.98	215.98	420.76
	35	2100	0.04	195.95	493.95	220.95	429.71
	40	2400	0.03	200.36	498.36	225.36	437.64
	45	2700	0.03	204.33	502.33	229.33	444.79
	50	3000	0.03	207.95	505.95	232.95	451.31
	55	3300	0.03	211.28	509.28	236.28	457.30
	60	3600	0.03	214.37	512.37	239.37	462.86

ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANA AND TANAKA

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

Where,

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

Compartment Area Calculation

$$Ac = (w_c)(l_c)$$

Where,

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

A_c = 20.90 m^2

Hot Gas Layer Density Calculation

$$\rho_g = 353/T_g$$

Calculation for Constant K

$$k = 0.076/\rho_g$$

SMOKE GAS LAYER HEIGHT WITH NATURAL VENTILATION

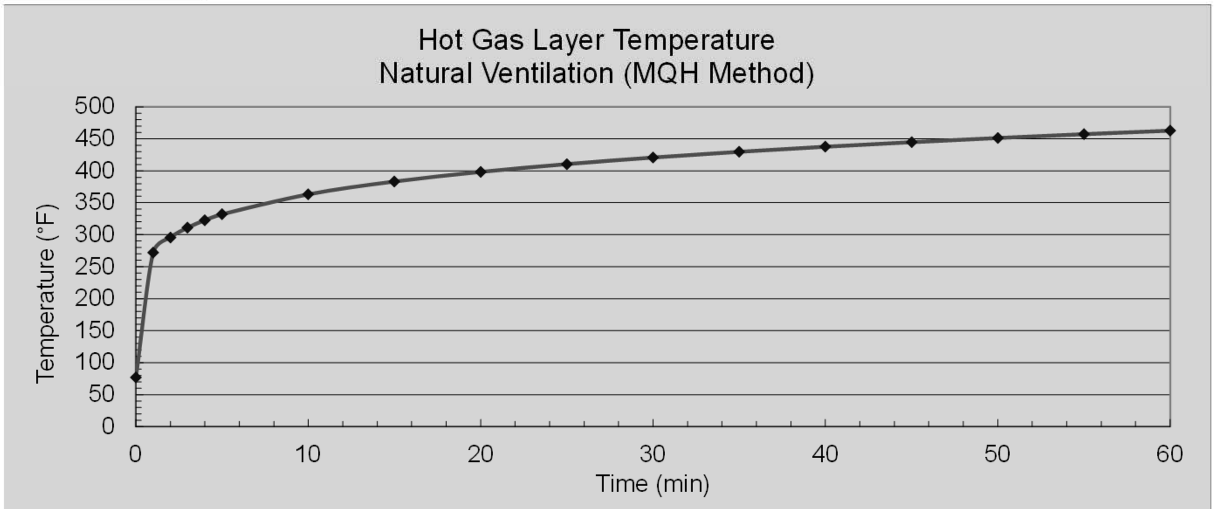
$$z = [(2kQ^{1/3}t/(3A_c)] + (1/h_c^{2/3})^{-3/2}$$

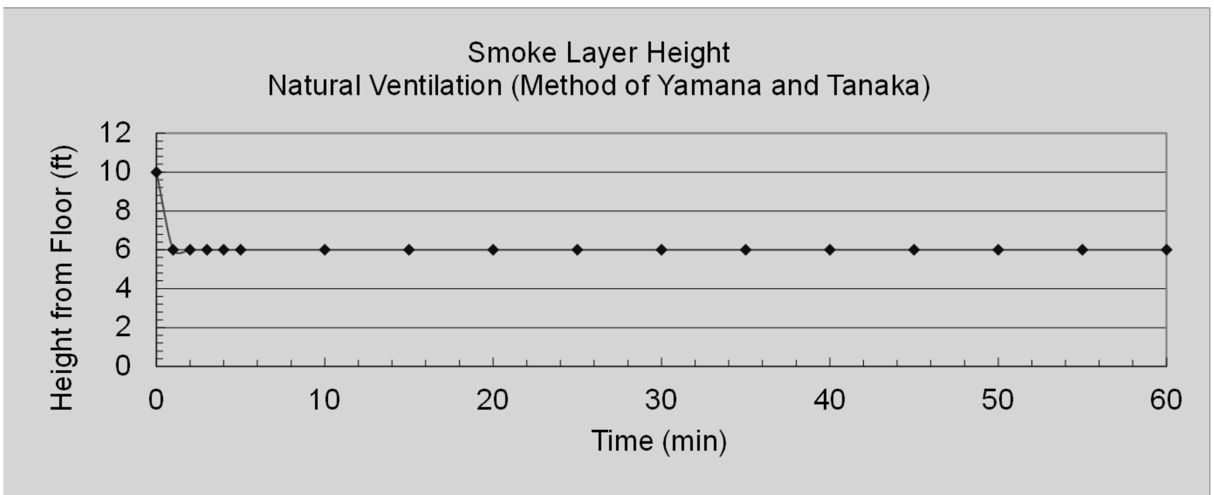
Results

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

Time (min)	ρ_g (kg/m^3)	Constant (k) (kW/m-K)	Smoke Layer Height z (m)	Smoke Layer Height z (ft)	
0	1.18	0.064	3.05	10.00	
1	0.87	0.087	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
2	0.84	0.090	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
3	0.82	0.092	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
4	0.81	0.094	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
5	0.80	0.095	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
10	0.77	0.098	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
15	0.75	0.101	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
20	0.74	0.103	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
25	0.73	0.104	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
30	0.72	0.105	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
35	0.71	0.106	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
40	0.71	0.107	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
45	0.70	0.108	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
50	0.70	0.109	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
55	0.69	0.110	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
60	0.69	0.110	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT

Summary of Results





NOTE:

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

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

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

Version 1805.1
(English Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.1-1b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	15.00	ft
Compartment Length (l_c)	15.00	ft
Compartment Height (h_c)	10.00	ft
Vent Width (w_v)	4.00	ft
Vent Height (h_v)	6.00	ft
Top of Vent from Floor (V_T)	6.00	ft
Interior Lining Thickness (δ)	1.00	in

AMBIENT CONDITIONS

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

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Gypsum Board

Scroll to desired material
Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 500.00 kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

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

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

Where,

ΔT_g = $T_g - T_a$ = upper layer gas temperature rise above ambient (K)

Q = heat release rate of the fire (kW)

A_v = area of ventilation opening (m^2)

h_v = height of ventilation opening (m)

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

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

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

Where,

A_v = area of ventilation opening (m^2)

w_v = vent width (m)

h_v = vent height (m)

A_v = **2.23** m^2

Thermal Penetration Time Calculation

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

Where,

t_p = thermal penetration time (sec)

ρ = interior lining density (kg/m^3)

c_p = interior lining specific heat (kJ/kg-K)

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

δ = interior lining thickness (m)

t_p = **1001.90** sec

Heat Transfer Coefficient Calculation

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

Where,

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia ($(kW/m^2\text{-}K)^2$-sec) (a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)

See table below for results (column 3)

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 = **95.32** m^2

COMPARTMENT HOT GAS LAYER TEMPERATURE WITH NATURAL

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

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Results	Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
	(min)	(sec)	(kW/m²-K)	(°K)	(°K)	(°C)	(°F)
	0	0.00	-	-	298.00	25.00	77.00
	1	60	0.05	172.18	470.18	197.18	386.92
	2	120	0.04	193.27	491.27	218.27	424.88
	3	180	0.03	206.78	504.78	231.78	449.20
	4	240	0.03	216.93	514.93	241.93	467.48
	5	300	0.02	225.15	523.15	250.15	482.28
	10	600	0.02	252.73	550.73	277.73	531.91
	15	900	0.01	270.39	568.39	295.39	563.71
	20	1200	0.01	346.98	644.98	371.98	701.56
	25	1500	0.01	346.98	644.98	371.98	701.56
	30	1800	0.01	346.98	644.98	371.98	701.56
	35	2100	0.01	346.98	644.98	371.98	701.56
	40	2400	0.01	346.98	644.98	371.98	701.56
	45	2700	0.01	346.98	644.98	371.98	701.56
	50	3000	0.01	346.98	644.98	371.98	701.56
	55	3300	0.01	346.98	644.98	371.98	701.56
	60	3600	0.01	346.98	644.98	371.98	701.56

ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANA AND TANAKA

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

Where,

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

Compartment Area Calculation

$$Ac = (w_c)\ (l_c)$$

Where,

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

A_c = 20.90 m^2

Hot Gas Layer Density Calculation

$$\rho_g = 353/T_g$$

Calculation for Constant K

$$k = 0.076/\rho_g$$

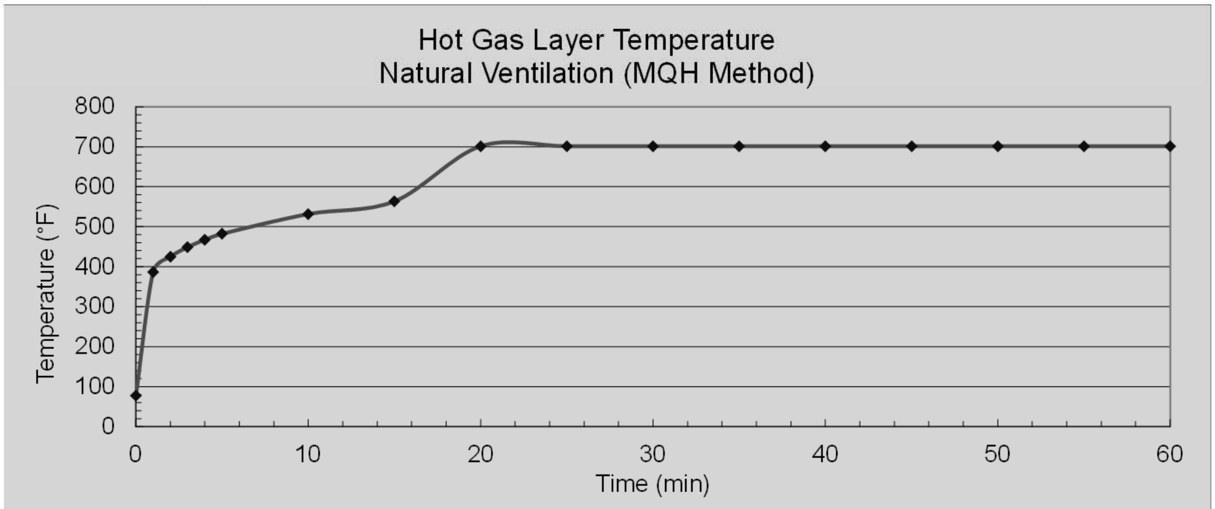
SMOKE GAS LAYER HEIGHT WITH NATURAL VENTILATION

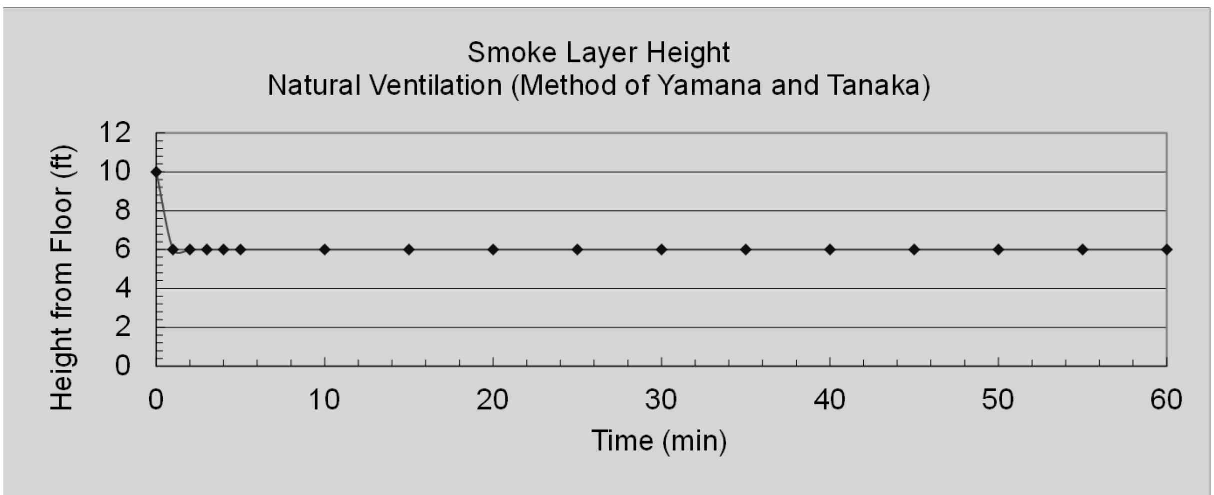
$$z = [(2kQ^{1/3}t/(3A_c)] + (1/h_c^{2/3})^{-3/2}$$

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

Time (min)	ρ_g (kg/m^3)	Constant (k) (kW/m-K)	Smoke Layer Height z (m)	Smoke Layer Height z (ft)	
0	1.18	0.064	3.05	10.00	
1	0.75	0.101	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
2	0.72	0.106	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
3	0.70	0.109	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
4	0.69	0.111	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
5	0.67	0.113	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
10	0.64	0.119	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
15	0.62	0.122	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
20	0.55	0.139	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
25	0.55	0.139	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
30	0.55	0.139	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
35	0.55	0.139	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
40	0.55	0.139	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
45	0.55	0.139	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
50	0.55	0.139	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
55	0.55	0.139	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT
60	0.55	0.139	1.83	6.00	CAUTION: SMOKE IS EXITING OUT VENT

Summary of Results





NOTE:
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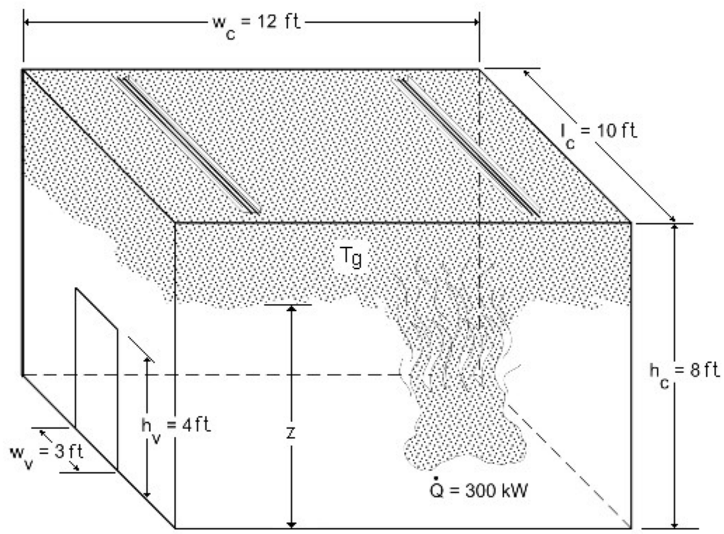
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 2.16.1-2

Problem Statement
Consider a compartment that is 12 ft wide x 10 ft long x 8 ft high (w_c x l_c x h_c) with a simple vent 3 ft wide x 4 ft tall (w_v x h_v). The construction is essentially 0.5 ft thick gypsum board. The fire is constant with an HRR of 300 kW. Assume that the top of the vent is 4 ft. Compute the hot gas temperature in the compartment, as well as the smoke layer height at 2 minutes.



Example Problem 2-2: Compartment with Natural Ventilation

Solution

Purpose:
(1) The hot gas layer temperature in the compartment (T_g) at t = 2 min after ignition
(2) The smoke layer height (z) at t = 2 min after ignition

Assumptions:
(1) Air properties (ambient) at 77 °F
(2) Simple rectangular geometry (no beam pockets)
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 02.1_Temperature_NV_Sup1.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 12 ft
- Compartment Length (l_c) = 10 ft
- Compartment Height (h_c) = 8 ft
- Vent Width (w_v) = 3 ft
- Vent Height (h_v) = 4 ft
- Top of Vent from Floor (V_T) = 4 ft
- Interior Lining Thickness (δ) = 6 in
- Ambient Air Temperature (T_a) = 77 °F
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Gypsum Board** on the FDT^s
- Fire Heat Release Rate ($\dot{Q}$) = 300 kW

Results*

Hot Gas Layer Temperature (T_g) (Method of MQH) (°F)	Smoke Layer Height (z) (Method of Yamana and Tanaka) (ft)
480	4.00 (smoke exiting vent, $z < V_T$)

*see attached spreadsheet on next page at t = 2 min

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

Version 1805.1 (English Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.1-2**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	12.00	ft
Compartment Length (l_c)	10.00	ft
Compartment Height (h_c)	8.00	ft
Vent Width (w_v)	3.00	ft
Vent Height (h_v)	4.00	ft
Top of Vent from Floor (V_T)	4.00	ft
Interior Lining Thickness (δ)	6.00	in

AMBIENT CONDITIONS

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

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Gypsum Board

Scroll to desired material
Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 300.00 kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

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

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

Where,
ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

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

A_v = 1.11 m^2

Thermal Penetration Time Calculation

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

Where,
t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 36068.24 sec

Heat Transfer Coefficient Calculation

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

Where,

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec
(a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)

See table below for results (column 3)

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 = 53.88 m^2

COMPARTMENT HOT GAS LAYER TEMPERATURE WITH NATURAL

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

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Results	Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
	(min)	(sec)	(kW/m²-K)	(°K)	(°K)	(°C)	(°F)
	0	0.00	-	-	298.00	25.00	77.00
	1	60	0.05	199.69	497.69	224.69	436.44
	2	120	0.04	224.14	522.14	249.14	480.45
	3	180	0.03	239.81	537.81	264.81	508.66
	4	240	0.03	251.59	549.59	276.59	529.86
	5	300	0.02	261.12	559.12	286.12	547.02
	10	600	0.02	293.10	591.10	318.10	604.58
	15	900	0.01	313.59	611.59	338.59	641.46
	20	1200	0.01	328.99	626.99	353.99	669.19
	25	1500	0.01	341.46	639.46	366.46	691.63
	30	1800	0.01	351.99	649.99	376.99	710.59
	35	2100	0.01	361.16	659.16	386.16	727.08
	40	2400	0.01	369.28	667.28	394.28	741.71
	45	2700	0.01	376.60	674.60	401.60	754.89
	50	3000	0.01	383.28	681.28	408.28	766.90
	55	3300	0.01	389.41	687.41	414.41	777.94
	60	3600	0.01	395.10	693.10	420.10	788.18

ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANA AND TANAKA

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

Where,

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

Compartment Area Calculation

$$Ac = (w_c)\ (l_c)$$

Where,

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

A_c = 11.15 m^2

Hot Gas Layer Density Calculation

$$\rho_g = 353/T_g$$

Calculation for Constant K

$$k = 0.076/\rho_g$$

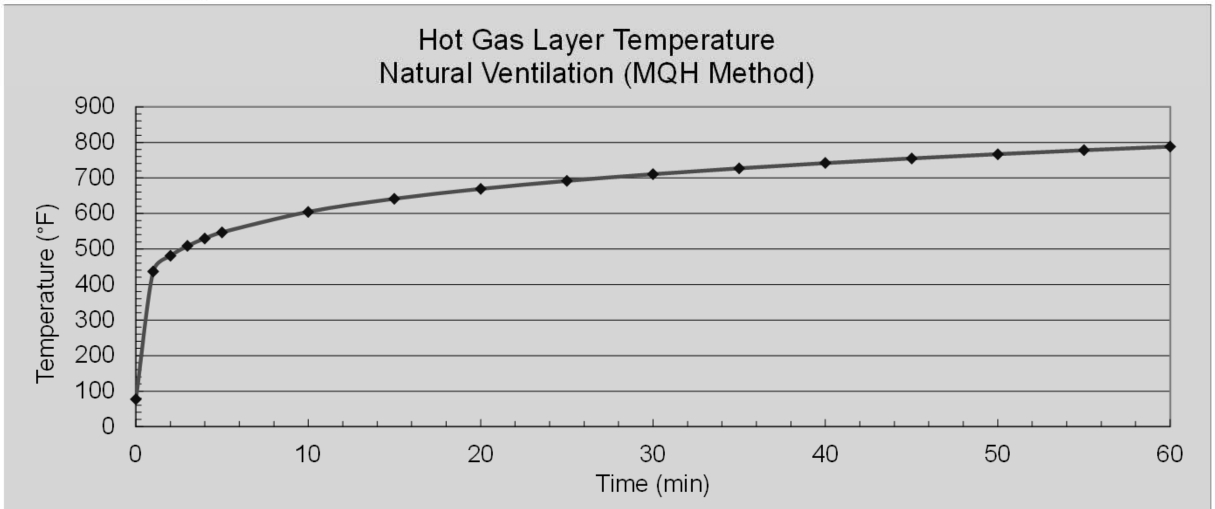
SMOKE GAS LAYER HEIGHT WITH NATURAL VENTILATION

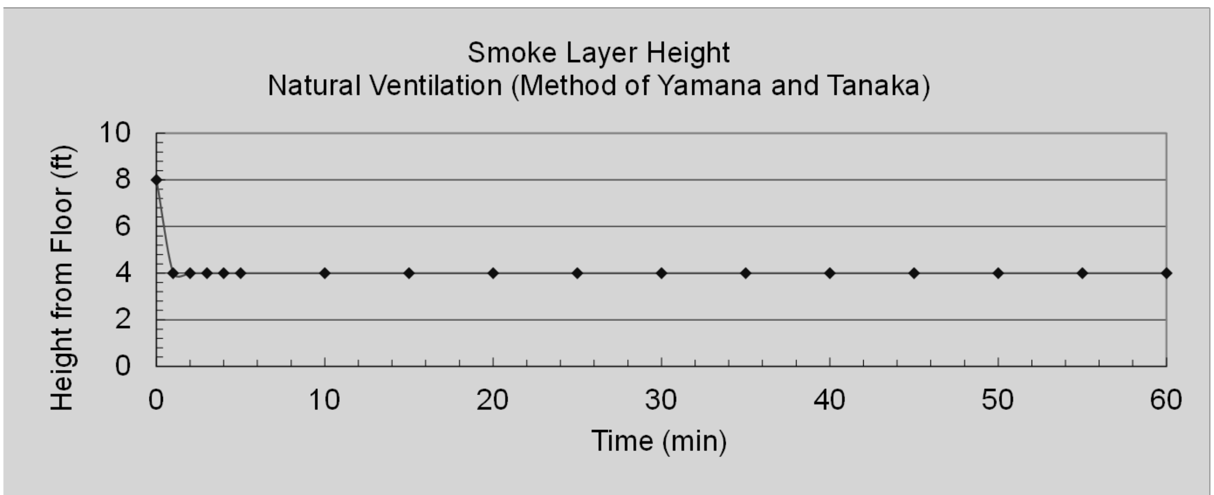
$$z = [(2kQ^{1/3}t/(3A_c)] + (1/h_c^{2/3})^{-3/2}$$

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

Time (min)	ρ_g (kg/m^3)	Constant (k) (kW/m-K)	Smoke Layer Height z (m)	Smoke Layer Height z (ft)	
0	1.18	0.064	2.44	8.00	
1	0.71	0.107	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
2	0.68	0.112	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
3	0.66	0.116	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
4	0.64	0.118	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
5	0.63	0.120	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
10	0.60	0.127	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
15	0.58	0.132	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
20	0.56	0.135	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
25	0.55	0.138	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
30	0.54	0.140	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
35	0.54	0.142	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
40	0.53	0.144	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
45	0.52	0.145	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
50	0.52	0.147	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
55	0.51	0.148	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT
60	0.51	0.149	1.22	4.00	CAUTION: SMOKE IS EXITING OUT VENT

Summary of Results





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

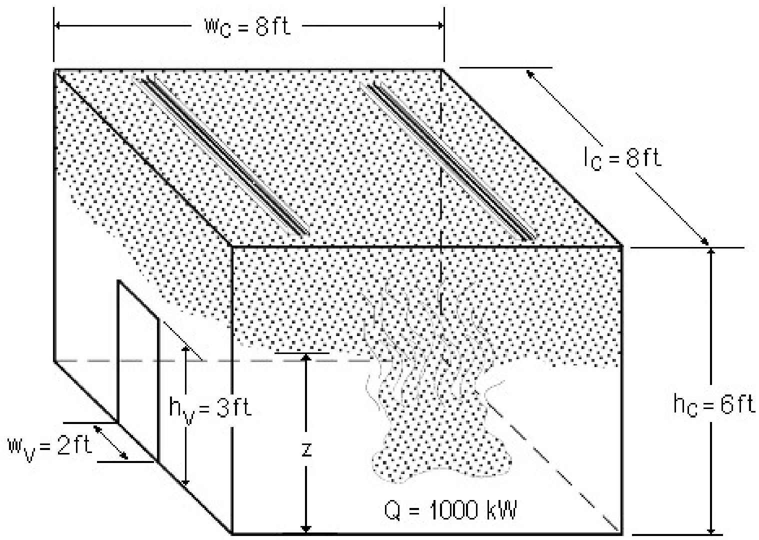
Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 2.16.1-3

Problem Statement
Consider a compartment that is 8 ft wide x 8 ft long x 6 ft high (w_c x l_c x h_c) with a simple vent that is 2 ft wide x 3 ft tall (w_v x h_v). The construction is essentially 0.75 ft thick concrete. The fire is constant with an HRR of 1,000 kW. Assume that the top of the vent is 3 ft. Compute the hot gas temperature in the compartment, as well as the smoke layer height at 3 minutes.



Example Problem 2-3: Compartment with Natural Ventilation

Solution

Purpose:
(1) Determine the hot gas layer temperature in the compartment (T_g) at t = 3 min after ignition
(2) Determine the smoke layer height (z) at t = 3 min after ignition

Assumptions:
(1) Air properties (ambient) at 77 °F
(2) Simple rectangular geometry (no beam pockets)
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 02.1_Temperature_NV_Sup1.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 8 ft
- Compartment Length (l_c) = 8 ft
- Compartment Height (h_c) = 6 ft
- Vent Width (w_v) = 2 ft
- Vent Height (h_v) = 3 ft
- Top of Vent from Floor (V_T) = 3 ft
- Interior Lining Thickness (δ) = 9 in
- Ambient Air Temperature (T_a) = 77 °F
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Concrete** on the FDT^s
- Fire Heat Release Rate ($\dot{Q}$) = 1,000 kW

Results*:

Hot Gas Layer Temperature (T_g) (Method of MQH) (°F)	Smoke Layer Height (z) (Method of Yamana and Tanaka) (ft)
1,060	3.00 compartment filled with smoke)

*see spreadsheet on next page at t = 3 min

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

Version 1805.1
(English Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.1-3**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	8.00	ft
Compartment Length (l_c)	8.00	ft
Compartment Height (h_c)	6.00	ft
Vent Width (w_v)	2.00	ft
Vent Height (h_v)	3.00	ft
Top of Vent from Floor (V_T)	3.00	ft
Interior Lining Thickness (δ)	9.00	in

AMBIENT CONDITIONS

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

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Concrete

Scroll to desired material
Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 1000.00 kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

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

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

Where,

ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

Where,

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

A_v = 0.56 m^2

Thermal Penetration Time Calculation

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

Where,

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 14697.55 sec

Heat Transfer Coefficient Calculation

$$h_k = \sqrt{(k\rho c/t)} \;\text{ for } t < t_p \quad \text{or} \quad (k/\delta) \;\text{ for } t > t_p$$

Where,

h_k = heat transfer coefficient (kW/m²-K)
$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec
(a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)

See table below for results (column 3)

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 = **29.17** m^2

COMPARTMENT HOT GAS LAYER TEMPERATURE WITH NATURAL

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

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Results	Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
	(min)	(sec)	(kW/m²-K)	(°K)	(°K)	(°C)	(°F)
	0	0.00	-	-	298.00	25.00	77.00
	1	60	0.22	454.72	752.72	479.72	895.50
	2	120	0.16	510.41	808.41	535.41	995.74
	3	180	0.13	546.09	844.09	571.09	1059.97
	4	240	0.11	572.91	870.91	597.91	1108.25
	5	300	0.10	594.62	892.62	619.62	1147.32
	10	600	0.07	667.44	965.44	692.44	1278.39
	15	900	0.06	714.10	1012.10	739.10	1362.39
	20	1200	0.05	749.18	1047.18	774.18	1425.52
	25	1500	0.04	777.56	1075.56	802.56	1476.62
	30	1800	0.04	801.56	1099.56	826.56	1519.80
	35	2100	0.04	822.42	1120.42	847.42	1557.35
	40	2400	0.03	840.92	1138.92	865.92	1590.66
	45	2700	0.03	857.59	1155.59	882.59	1620.67
	50	3000	0.03	872.79	1170.79	897.79	1648.02
	55	3300	0.03	886.76	1184.76	911.76	1673.17
	60	3600	0.03	899.72	1197.72	924.72	1696.49

ESTIMATING SMOKE LAYER HEIGHT METHOD OF YAMANA AND TANAKA

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

Where,

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

Compartment Area Calculation

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

Where,

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

A_c = 5.95 m^2

Hot Gas Layer Density Calculation

$$\rho_g = 353/T_g$$

Calculation for Constant K

$$k = 0.076/\rho_g$$

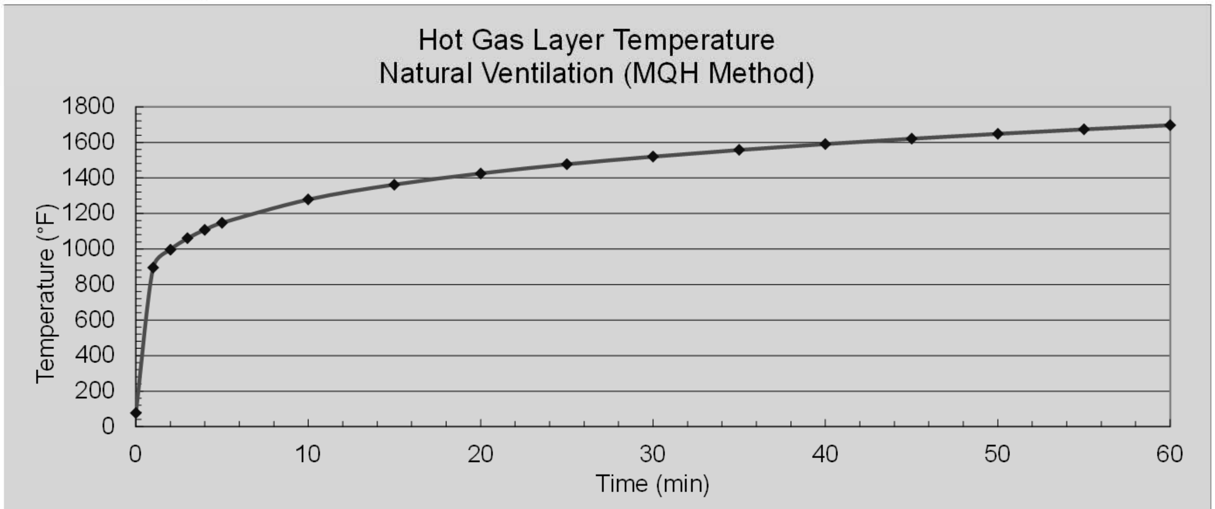
SMOKE GAS LAYER HEIGHT WITH NATURAL VENTILATION

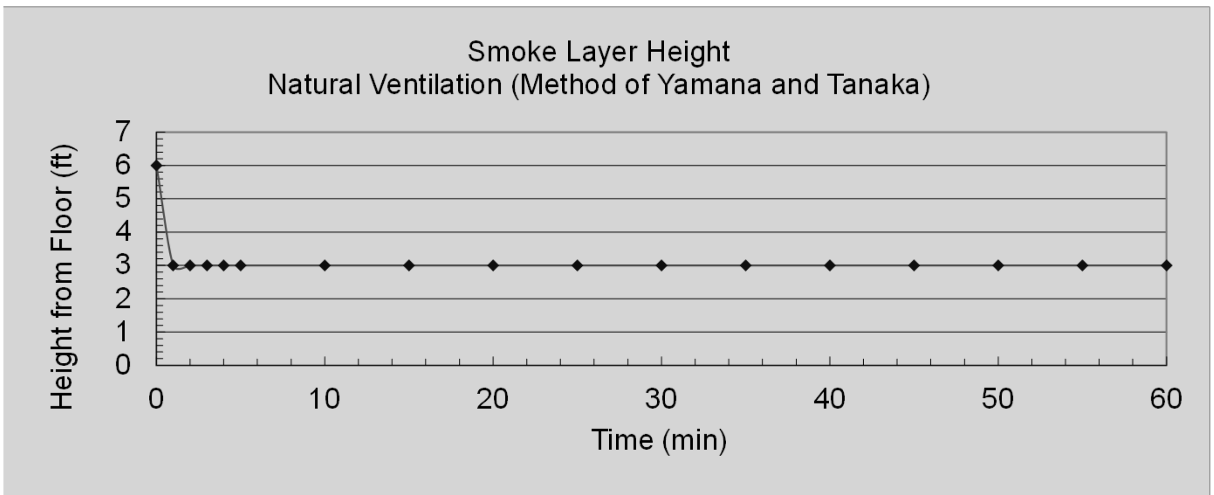
$$z = [(2kQ^{1/3}t/(3A_c)] + (1/h_c^{2/3})^{-3/2}$$

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

Time (min)	ρ_g (kg/m³)	Constant (k) (kW/m-K)	Smoke Layer Height z (m)	Smoke Layer Height z (ft)	
0	1.18	0.064	1.83	6.00	
1	0.47	0.162	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
2	0.44	0.174	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
3	0.42	0.182	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
4	0.41	0.188	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
5	0.40	0.192	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
10	0.37	0.208	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
15	0.35	0.218	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
20	0.34	0.225	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
25	0.33	0.232	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
30	0.32	0.237	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
35	0.32	0.241	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
40	0.31	0.245	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
45	0.31	0.249	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
50	0.30	0.252	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
55	0.30	0.255	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT
60	0.29	0.258	0.91	3.00	CAUTION: SMOKE IS EXITING OUT VENT

Summary of Results





NOTE:

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Prepared by: ______ Date: ______ Organization: ______

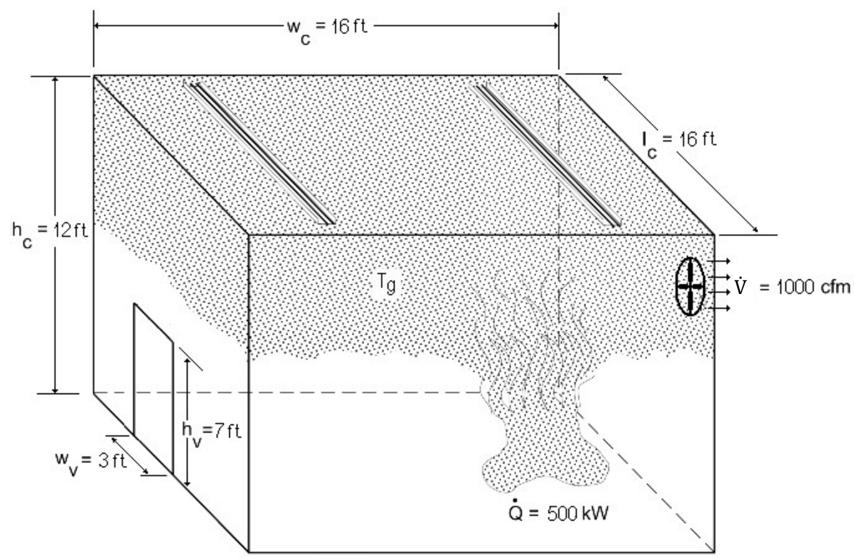
Checked by: ______ Date: ______ Organization: ______

Additional Information:

2.16.2 Forced Ventilation

Example Problem 2.16.2-1

Problem Statement
Consider a compartment that is 16 ft wide x 16 ft long x 12 ft high (w_c x l_c x h_c), with a vent opening that is 3 ft wide x 7 ft tall (w_v x h_v). The forced ventilation rate is 1,000 cfm (exhaust). Calculate the hot gas layer temperature for a fire size of 500 kW at 2 minutes after ignition. The compartment boundaries are made of (a) 1 ft thick concrete and (b) 0.7 inch thick gypsum board.



Example Problem 2-4: Compartment with Forced Ventilation

Solution

Purpose:
For two different interior lining materials determine the hot gas layer temperature in the compartment (T_g) at t = 2 min after ignition.

Assumptions:
(1) Air properties (ambient) at 77 °F
(2) Simple rectangular geometry (no beam pockets)
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls
(6) The bottom of the vent is at the floor level
(7) The compartment is open to the outside at the inlet (pressure = 1 atm)

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) For Concrete:
02.2_Temperature_FV_Sup1.xls

(b) For Gypsum Board:
02.2_Temperature_FV_Sup1.xls

Note: The spreadsheet has two methods for calculating the hot gas layer temperature (T_g). We are going to use both methods to compare the results.

FDT^s Input Parameters: (for both spreadsheets)

- Compartment Width (w_c) = 16 ft
- Compartment Length (l_c) = 16 ft
- Compartment Height (h_c) = 12 ft
- Interior Lining Thickness (δ) = 12 in (concrete) and 0.7 in (gypsum board)
- Ambient Air Temperature (T_a) = 77 °F
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Concrete** and **Gypsum Board** on the respective FDT^s
- Compartment Ventilation Rate ($\dot{V}$) = 1,000 cfm
- Fire Heat Release Rate ($\dot{Q}$) = 500 kW
- Time after Ignition (t) = 2 min.

Results*

Boundary Material	Hot Layer Gas Temperature (T_g) (°F)	
	Method of Foote, Pagni & Alvares (FPA)	Method of Deal & Beyler
Concrete	288	190
Gypsum Board	426	452

*see spreadsheets on next page at t = 2 min.

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION

Version 1805.1 (English Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.2-1a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	16.00	ft
Compartment Length (l_c)	16.00	ft
Compartment Height (h_c)	12.00	ft
Interior Lining Thickness (δ)	12.00	in

AMBIENT CONDITIONS

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

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

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Concrete

Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m)	1000.00	cfm

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	500.00	kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

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

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

Where

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

Thermal Penetration Time Calculation

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

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 26128.98 sec

Heat Transfer Coefficient Calculation

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

Where

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

Area of Compartment Enclosing Surface Boundaries

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

Where

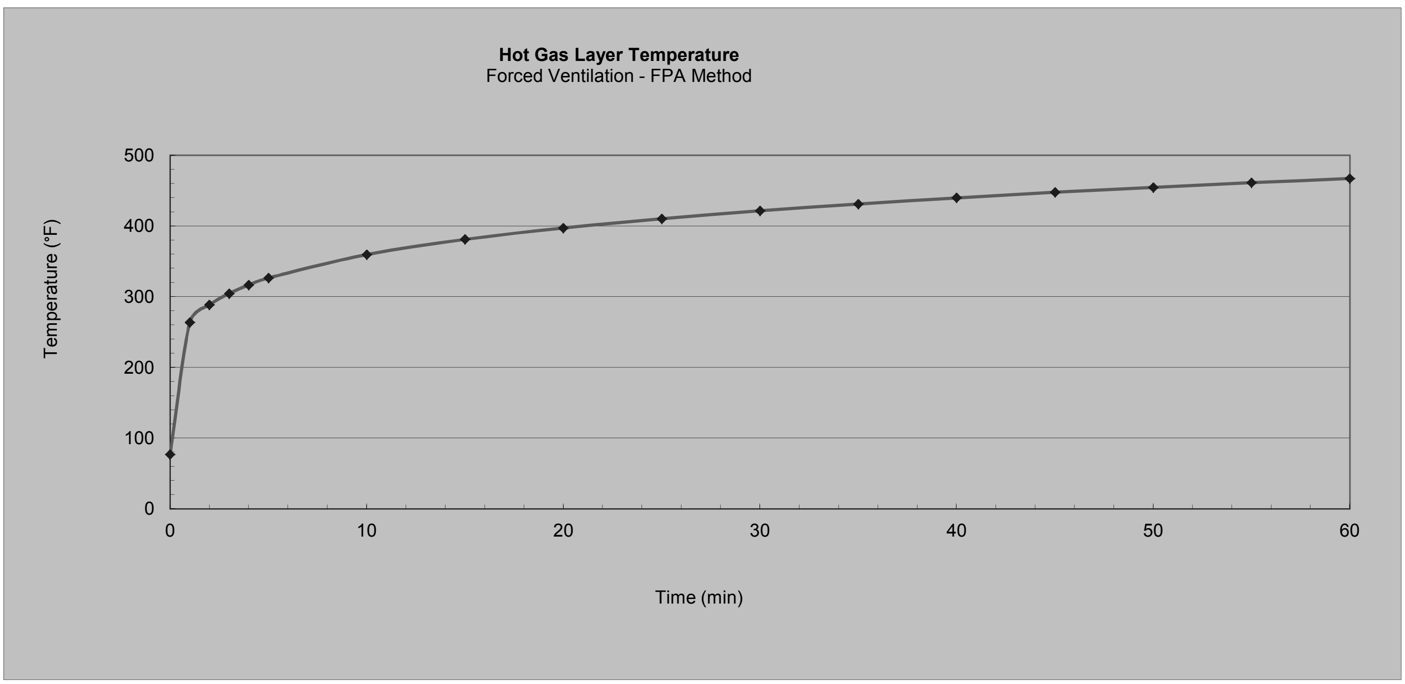
A_T = total area of the compartment enclosing surface boundaries (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

A_T = 118.92 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

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

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.22	0.35	103.76	401.76	128.76	263.77
2	120	0.16	0.39	117.55	415.55	142.55	288.59
3	180	0.13	0.42	126.45	424.45	151.45	304.61
4	240	0.11	0.45	133.17	431.17	158.17	316.71
5	300	0.10	0.47	138.63	436.63	163.63	326.54
10	600	0.07	0.53	157.05	455.05	182.05	359.70
15	900	0.06	0.57	168.94	466.94	193.94	381.10
20	1200	0.05	0.60	177.92	475.92	202.92	397.26
25	1500	0.04	0.62	185.21	483.21	210.21	410.39
30	1800	0.04	0.64	191.39	489.39	216.39	421.51
35	2100	0.04	0.66	196.78	494.78	221.78	431.20
40	2400	0.03	0.68	201.57	499.57	226.57	439.82
45	2700	0.03	0.69	205.88	503.88	230.88	447.59
50	3000	0.03	0.70	209.83	507.83	234.83	454.69
55	3300	0.03	0.72	213.46	511.46	238.46	461.22
60	3600	0.03	0.73	216.83	514.83	241.83	467.29



METHOD OF DEAL AND BEYLER

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

Thermal Penetration Time Calculation

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

Where
t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining heat capacity (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 26128.98 sec

Heat Transfer Coefficient Calculation

$$h_k = 0.4\sqrt{(k\rho c / t)} \quad \text{for } t < t_p \quad \text{or} \quad 0.4(k/\delta) \quad \text{for } t > t_p$$

Where
h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)
See table below for results

Area of Compartment Enclosing Surface Boundaries

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

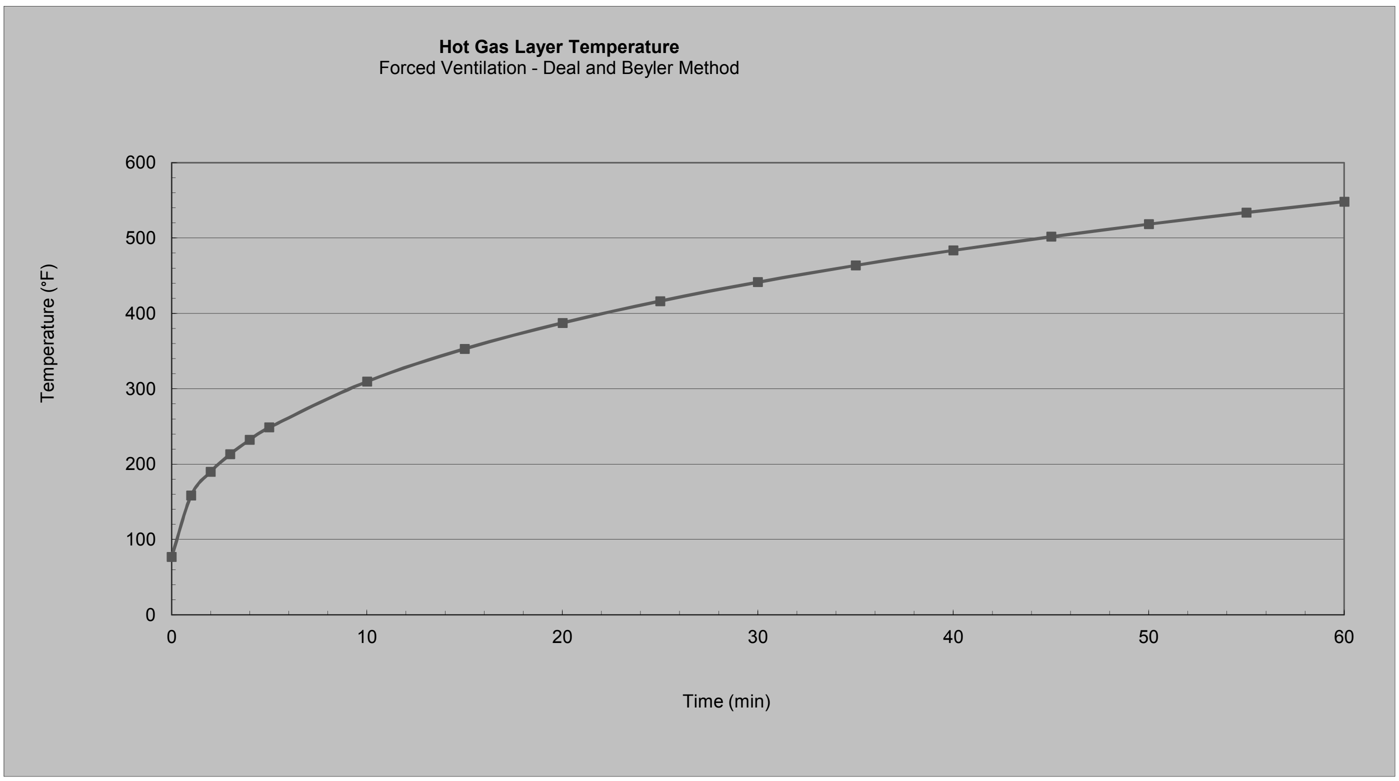
A_T = 118.92 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

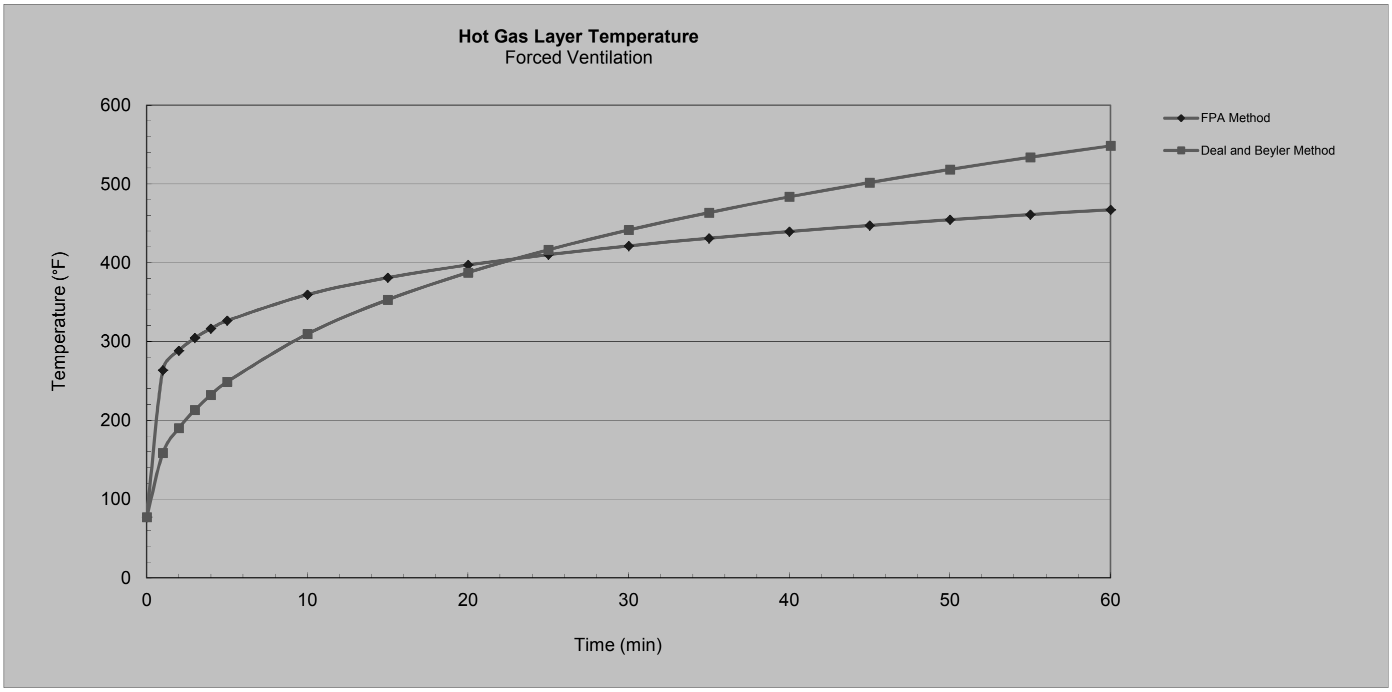
$$\Delta T_g = Q / (mc_a + h_k A_T)$$

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

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m²-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.09	45.39	343.39	70.39	158.70
2	120	0.06	62.87	360.87	87.87	190.16
3	180	0.05	75.80	373.80	100.80	213.43
4	240	0.04	86.39	384.39	111.39	232.50
5	300	0.04	95.50	393.50	120.50	248.90
10	600	0.03	129.33	427.33	154.33	309.80
15	900	0.02	153.41	451.41	178.41	353.15
20	1200	0.02	172.57	470.57	197.57	387.62
25	1500	0.02	188.64	486.64	213.64	416.55
30	1800	0.02	202.57	500.57	227.57	441.62
35	2100	0.01	214.90	512.90	239.90	463.82
40	2400	0.01	225.99	523.99	250.99	483.78
45	2700	0.01	236.08	534.08	261.08	501.94
50	3000	0.01	245.34	543.34	270.34	518.62
55	3300	0.01	253.92	551.92	278.92	534.06
60	3600	0.01	261.90	559.90	286.90	548.43



Summary of Results



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

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE
IN A ROOM FIRE
WITH FORCED VENTILATION

Version 1805.1
(English Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection **Title:** **Example 2.16.2-1b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	16.00	ft
Compartment Length (l_c)	16.00	ft
Compartment Height (h_c)	12.00	ft
Interior Lining Thickness (δ)	0.70	in

AMBIENT CONDITIONS

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia ($k\rho c$)	0.18	$(kW/m^2\text{-}K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K
Interior Lining Specific Heat (c_p)	1.10	kJ/kg-K
Interior Lining Density (ρ)	960	kg/m^3

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

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

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m) 1000.00 cfm

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 500.00 kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

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

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

Where

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

Thermal Penetration Time Calculation

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

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 490.93 sec

Heat Transfer Coefficient Calculation

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

Where

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

Area of Compartment Enclosing Surface Boundaries

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

Where

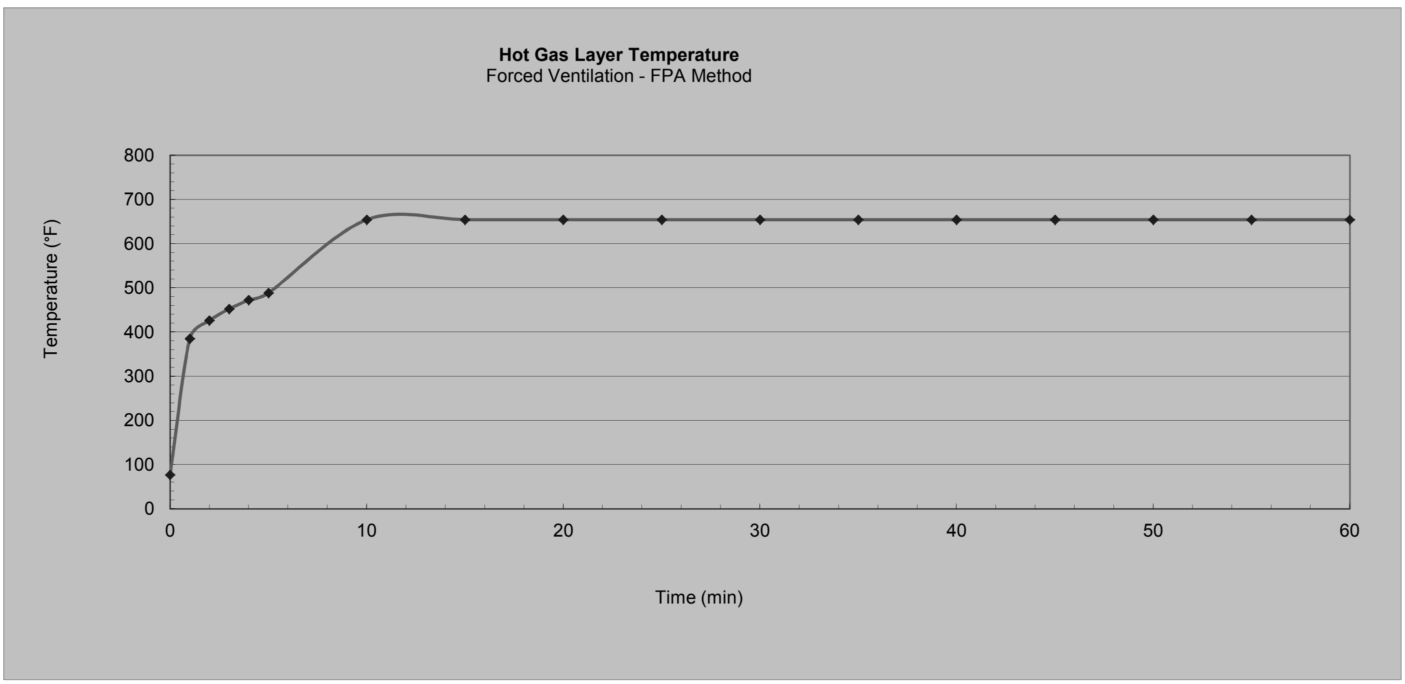
A_T = total area of the compartment enclosing surface boundaries (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

A_T = 118.92 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

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

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.05	0.57	171.13	469.13	196.13	385.04
2	120	0.04	0.65	193.87	491.87	218.87	425.97
3	180	0.03	0.70	208.55	506.55	233.55	452.39
4	240	0.03	0.74	219.63	517.63	244.63	472.34
5	300	0.02	0.77	228.64	526.64	253.64	488.54
10	600	0.01	1.08	320.79	618.79	345.79	654.43
15	900	0.01	1.08	320.79	618.79	345.79	654.43
20	1200	0.01	1.08	320.79	618.79	345.79	654.43
25	1500	0.01	1.08	320.79	618.79	345.79	654.43
30	1800	0.01	1.08	320.79	618.79	345.79	654.43
35	2100	0.01	1.08	320.79	618.79	345.79	654.43
40	2400	0.01	1.08	320.79	618.79	345.79	654.43
45	2700	0.01	1.08	320.79	618.79	345.79	654.43
50	3000	0.01	1.08	320.79	618.79	345.79	654.43
55	3300	0.01	1.08	320.79	618.79	345.79	654.43
60	3600	0.01	1.08	320.79	618.79	345.79	654.43



METHOD OF DEAL AND BEYLER

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

Thermal Penetration Time Calculation

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

Where
t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining heat capacity (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 490.928809 sec

Heat Transfer Coefficient Calculation

$$h_k = 0.4\,\sqrt{(k\rho c / t)} \quad \text{for } t < t_p \qquad \text{or} \qquad 0.4(k/\delta) \quad \text{for } t > t_p$$

Where
h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)
See table below for results

Area of Compartment Enclosing Surface Boundaries

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

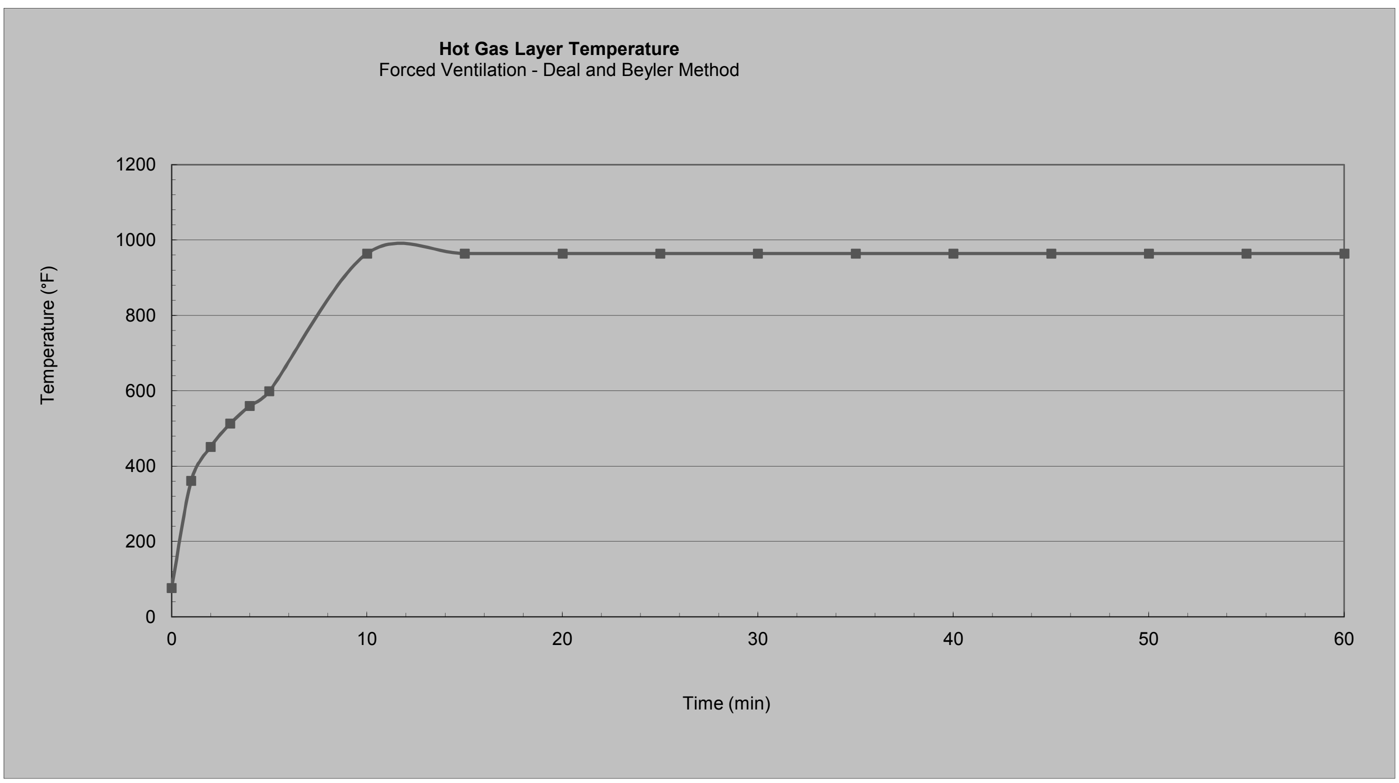
A_T = 118.92 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

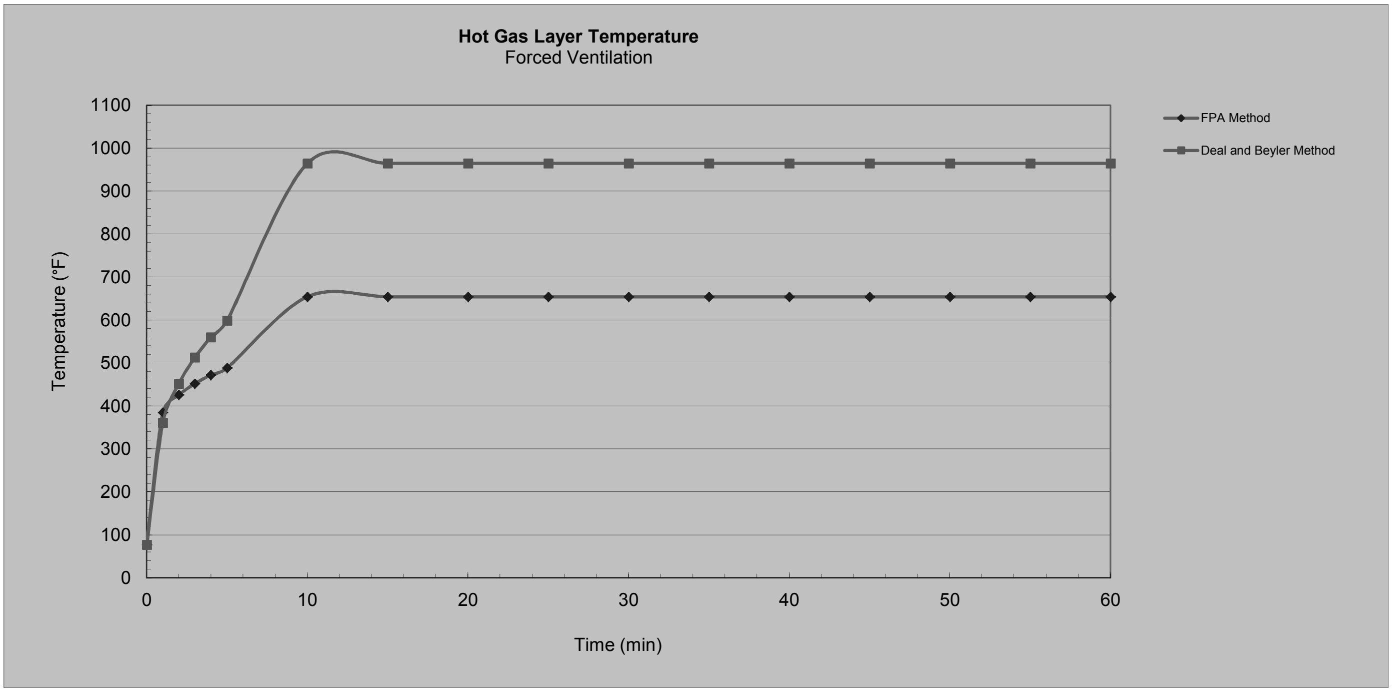
$$\Delta T_g = Q / (mc_a + h_k A_T)$$

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

Time After Ignition (t) (min)	(sec)	h_k (kW/m^2-K)	ΔT_g (K)	T_g (K)	T_g (°C)	T_g (°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.02	158.01	456.01	183.01	361.42
2	120	0.02	208.22	506.22	233.22	451.80
3	180	0.01	242.34	540.34	267.34	513.21
4	240	0.01	268.57	566.57	293.57	560.43
5	300	0.01	289.99	587.99	314.99	598.99
10	600	0.00	493.17	791.17	518.17	964.71
15	900	0.00	493.17	791.17	518.17	964.71
20	1200	0.00	493.17	791.17	518.17	964.71
25	1500	0.00	493.17	791.17	518.17	964.71
30	1800	0.00	493.17	791.17	518.17	964.71
35	2100	0.00	493.17	791.17	518.17	964.71
40	2400	0.00	493.17	791.17	518.17	964.71
45	2700	0.00	493.17	791.17	518.17	964.71
50	3000	0.00	493.17	791.17	518.17	964.71
55	3300	0.00	493.17	791.17	518.17	964.71
60	3600	0.00	493.17	791.17	518.17	964.71



Summary of Results



NOTE:

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

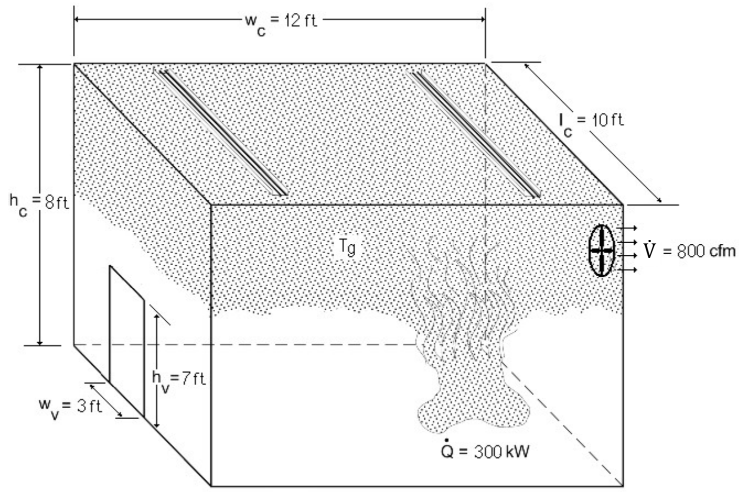
Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 2.16.2-2

Problem Statement
Consider a compartment that is 12 ft wide x 10 ft long x 8 ft high (w_c x l_c x h_c) with a vent opening that is 3 ft wide x 7 ft tall (w_v x h_v). The compartment boundaries are made of 0.5 ft thick gypsum board. The forced ventilation rate is 800 cfm (exhaust). Calculate the hot gas layer temperature in the compartment for a fire size of 300 kW at 2 minutes.



Example Problem 2-5: Compartment with Forced Ventilation

Solution

Purpose:
(1) Determine the hot gas layer temperature in the compartment (T_g) at t = 2 min after ignition.

Assumptions:
(1) Air properties (ambient) at 77 °F
(2) Simple rectangular geometry: no beam pockets
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls
(6) The bottom of the vent is at the floor level
(7) The compartment is open to the outside at the inlet (pressure = 1 atm)

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 02.2_Temperature_FV_Sup1.xls

Note: The spreadsheet has two different methods for calculating the hot gas layer temperature. Both methods are presented for comparison.

FDT^s Input Parameters:

- Compartment Width (w_c) = 12 ft
- Compartment Length (l_c) = 10 ft
- Compartment Height (h_c) = 8 ft
- Interior Lining Thickness (δ) = 6 in
- Ambient Air Temperature (T_a) = 77 °F
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Gypsum Board** on the FDT^s
- Compartment Ventilation Rate ($\dot{V}$) = 800 cfm
- Fire Heat Release Rate ($\dot{Q}$) = 300 kW

Results*

Boundary Material	Hot Layer Gas Temperature (T_g) (°F)	
	Method of Foote, Pagni & Alvares (FPA)	Method of Deal & Beyler
Gypsum Board	423	493

*see spreadsheet on next page at t = 2 min

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION

Version 1805.1
(English Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection **Title:** **Example 2.16.2-2**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	12.00	ft
Compartment Length (l_c)	10.00	ft
Compartment Height (h_c)	8.00	ft
Interior Lining Thickness (δ)	6.00	in

AMBIENT CONDITIONS

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia ($k\rho c$)	0.18	$(kW/m^2\text{-}K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K
Interior Lining Specific Heat (c_p)	1.10	kJ/kg-K
Interior Lining Density (ρ)	960	kg/m^3

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Gypsum Board

Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m)	800.00	cfm

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	300.00	kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

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

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

Where

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

Thermal Penetration Time Calculation

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

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 36068.24 sec

Heat Transfer Coefficient Calculation

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

Where

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

Area of Compartment Enclosing Surface Boundaries

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

Where

A_T = total area of the compartment enclosing surface boundaries (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

A_T = 55.00 m^2

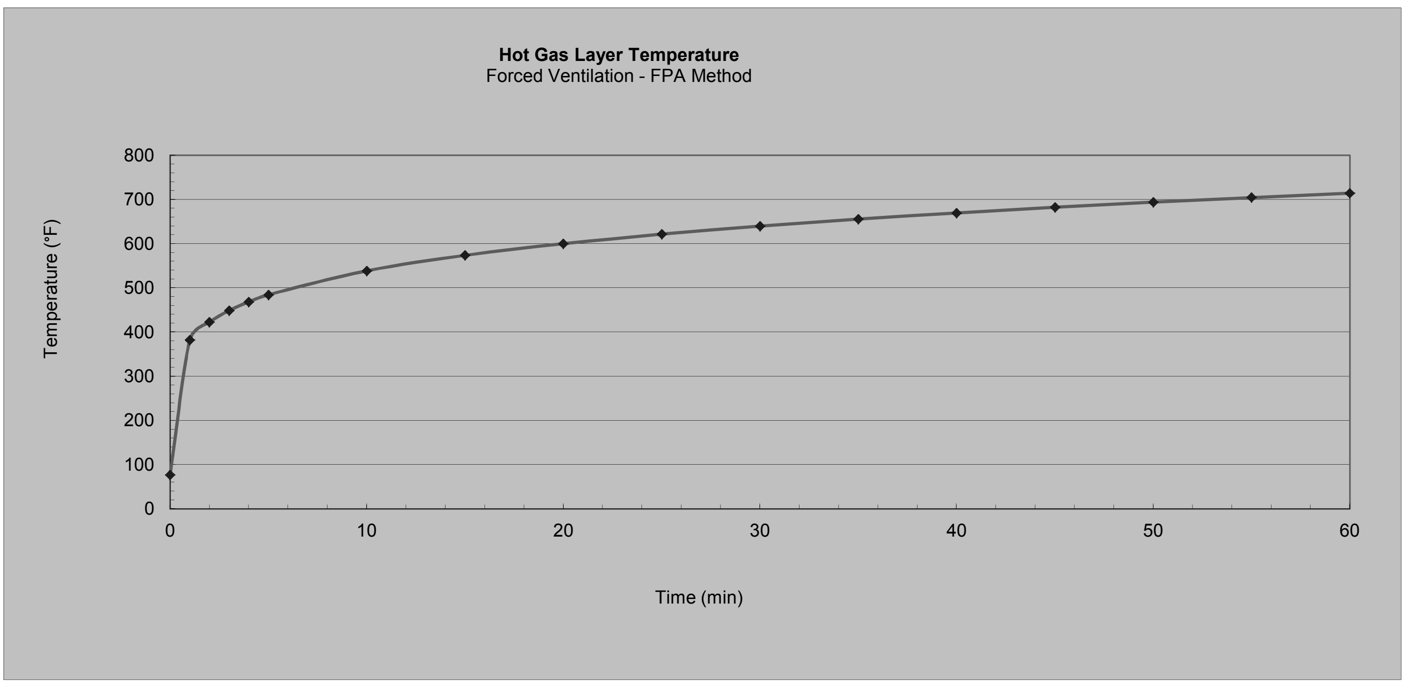
Compartment Hot Gas Layer Temperature With Forced Ventilation

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

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.05	0.57	169.45	467.45	194.45	382.01
2	120	0.04	0.64	191.97	489.97	216.97	422.54
3	180	0.03	0.69	206.50	504.50	231.50	448.71
4	240	0.03	0.73	217.48	515.48	242.48	468.46
5	300	0.02	0.76	226.39	524.39	251.39	484.50
10	600	0.02	0.86	256.47	554.47	281.47	538.65
15	900	0.01	0.93	275.89	573.89	300.89	573.61
20	1200	0.01	0.98	290.56	588.56	315.56	600.00
25	1500	0.01	1.01	302.46	600.46	327.46	621.44
30	1800	0.01	1.05	312.56	610.56	337.56	639.60
35	2100	0.01	1.08	321.35	619.35	346.35	655.43
40	2400	0.01	1.10	329.17	627.17	354.17	669.50
45	2700	0.01	1.13	336.22	634.22	361.22	682.20
50	3000	0.01	1.15	342.66	640.66	367.66	693.78
55	3300	0.01	1.17	348.59	646.59	373.59	704.46
60	3600	0.01	1.19	354.09	652.09	379.09	714.36



METHOD OF DEAL AND BEYLER

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

Thermal Penetration Time Calculation

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

Where
t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining heat capacity (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 36068.2391 sec

Heat Transfer Coefficient Calculation

$$h_k = 0.4\sqrt{(k\rho c / t)} \quad \text{for } t < t_p \qquad \text{or} \qquad 0.4(k/\delta) \quad \text{for } t > t_p$$

Where
h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)
See table below for results

Area of Compartment Enclosing Surface Boundaries

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

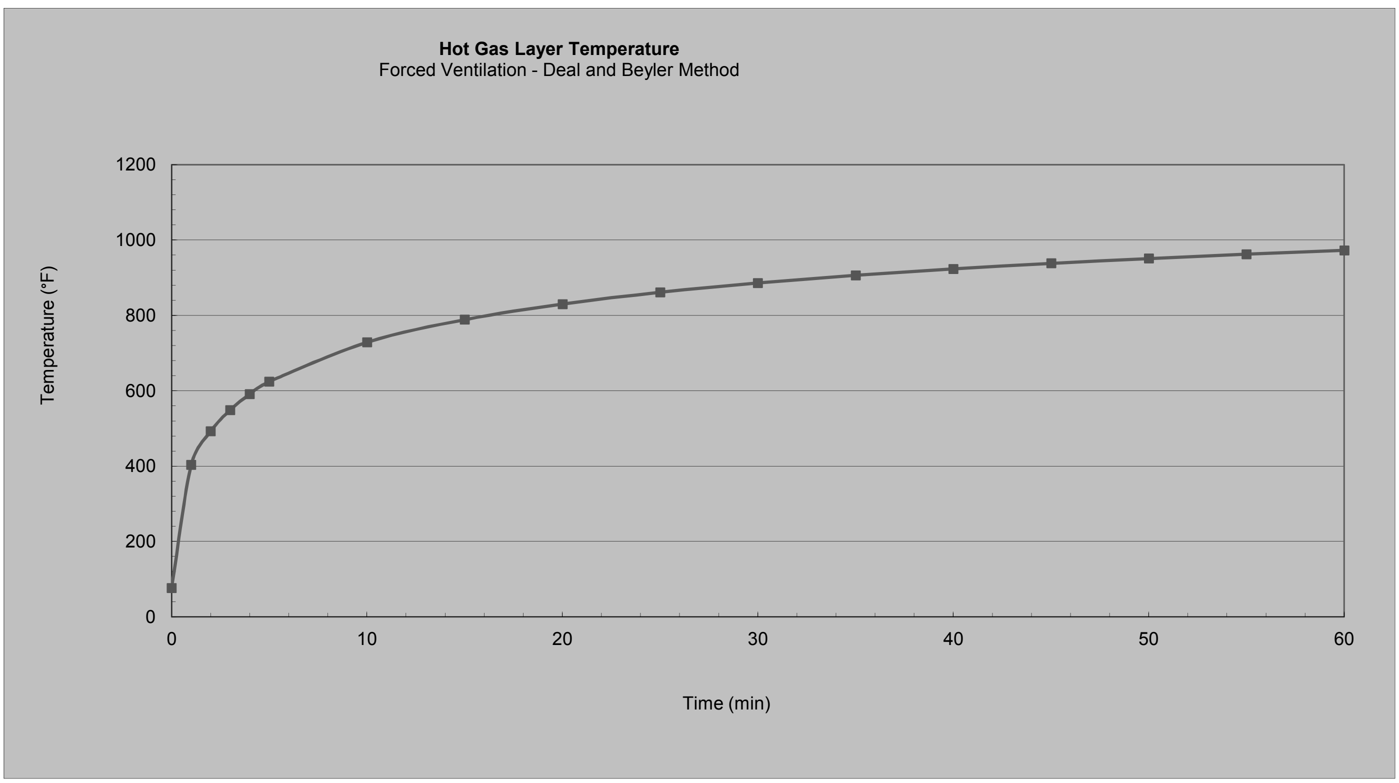
A_T = 55.00 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g = Q / (mc_a + h_k A_T)$$

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

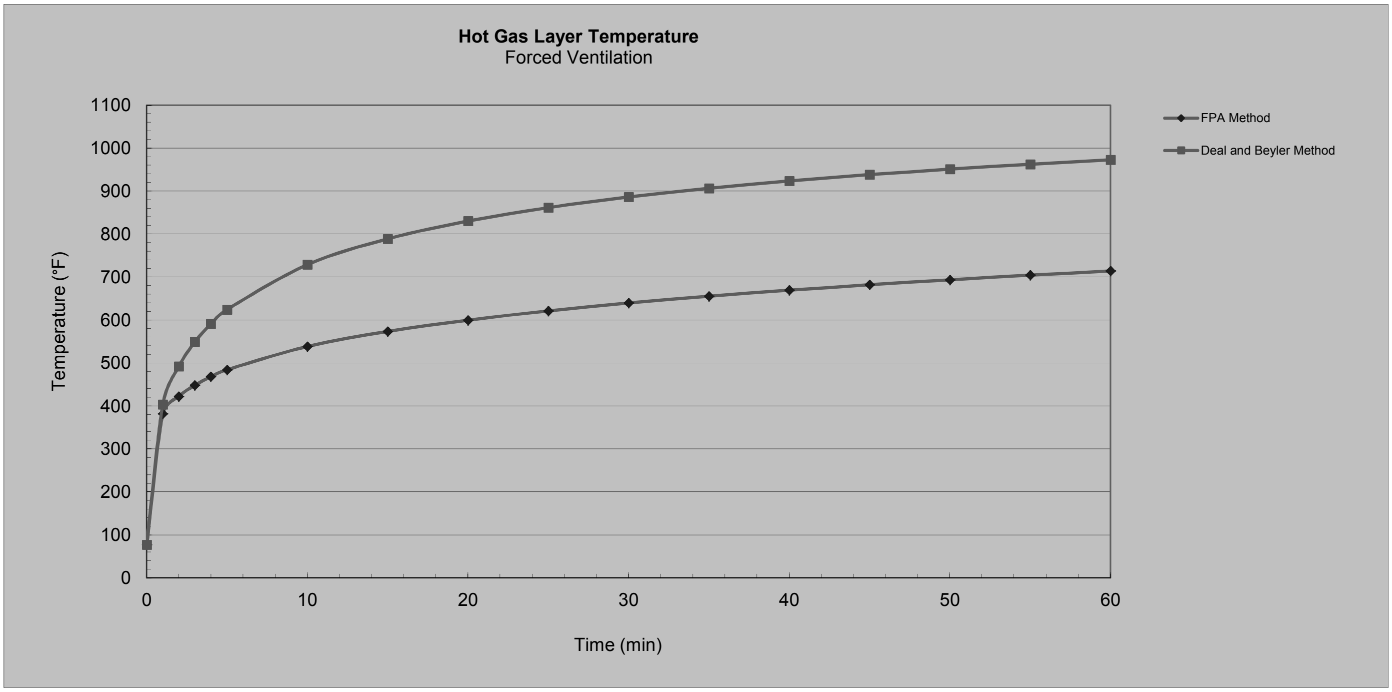
Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.02	181.58	479.58	206.58	403.84
2	120	0.02	230.90	528.90	255.90	492.62
3	180	0.01	262.48	560.48	287.48	549.47
4	240	0.01	285.79	583.79	310.79	591.42
5	300	0.01	304.22	602.22	329.22	624.60
10	600	0.01	362.20	660.20	387.20	728.95
15	900	0.01	395.59	693.59	420.59	789.06
20	1200	0.00	418.60	716.60	443.60	830.48
25	1500	0.00	435.90	733.90	460.90	861.62
30	1800	0.00	449.62	747.62	474.62	886.31
35	2100	0.00	460.89	758.89	485.89	906.60
40	2400	0.00	470.39	768.39	495.39	923.71
45	2700	0.00	478.57	776.57	503.57	938.43
50	3000	0.00	485.71	783.71	510.71	951.28
55	3300	0.00	492.03	790.03	517.03	962.66
60	3600	0.00	497.68	795.68	522.68	972.82



CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION

Version 1805.1
(English Units)

Summary of Results



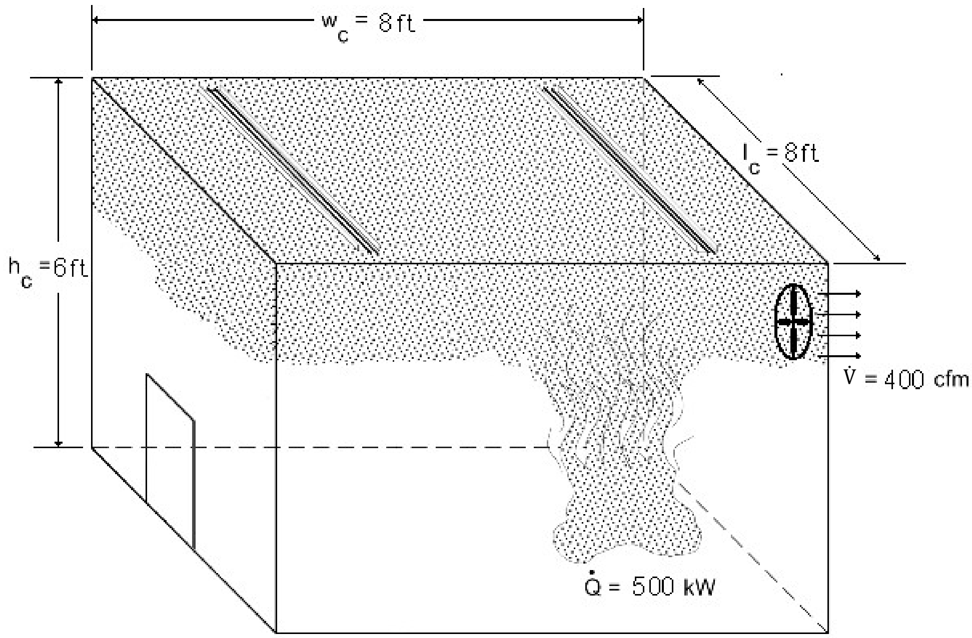
NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for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

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Problem 2.16.2-3

Problem Statement
Consider a compartment that is 8 ft wide x 8 ft long x 6 ft high (w_c x l_c x h_c). The compartment boundaries are made of 0.75 ft thick brick. The forced ventilation rate is 400 cfm (exhaust). Calculate the hot gas layer temperature in the compartment for a fire size of 500 kW at 2 minutes.



Example Problem 2-6: Compartment with Forced Ventilation

Solution

Purpose:

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

Assumptions:

(1) Air properties (ambient) at 77 °F
(2) Simple rectangular geometry (no beam pockets)
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls
(6) The bottom of the vent is at the floor level
(7) The compartment is open to the outside at the inlet (pressure = 1 atm)

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 02.2_Temperature_FV_Sup1.xls

Note: The spreadsheet has two different methods for calculating the hot gas layer temperature. We are going to use both methods to compare values.

FDT^s Input Parameters:
- Compartment Width (w_c) = 8 ft
- Compartment Length (l_c) = 8 ft
- Compartment Height (h_c) = 6 ft
- Interior Lining Thickness (δ) = 9 in
- Ambient Air Temperature (T_a) = 77 °F
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Brick** on the FDT^s
- Compartment Ventilation Rate ($\dot{V}$) = 400 cfm
- Fire Heat Release Rate ($\dot{Q}$) = 500 kW

Results*

Boundary Material	Hot Layer Gas Temperature (T_g) (°F)	
	Method of Foote, Pagni & Alvares (FPA)	Method of Deal & Beyler
Brick	611	626

*see spreadsheet on next page at t = 2 min.

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION

Version 1805.1 (English Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.2-3**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	8.00	ft
Compartment Length (l_c)	8.00	ft
Compartment Height (h_c)	6.00	ft
Interior Lining Thickness (δ)	9.00	in

AMBIENT CONDITIONS

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia ($k\rho c$)	1.7	$(kW/m^2\text{-}K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.0008	kW/m-K
Interior Lining Specific Heat (c_p)	0.80	kJ/kg-K
Interior Lining Density (ρ)	2600	kg/m^3

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Brick

Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m) 400.00 cfm

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 500.00 kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

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

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

Where

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

Thermal Penetration Time Calculation

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

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 33967.67 sec

Heat Transfer Coefficient Calculation

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

Where

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

Area of Compartment Enclosing Surface Boundaries

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

Where

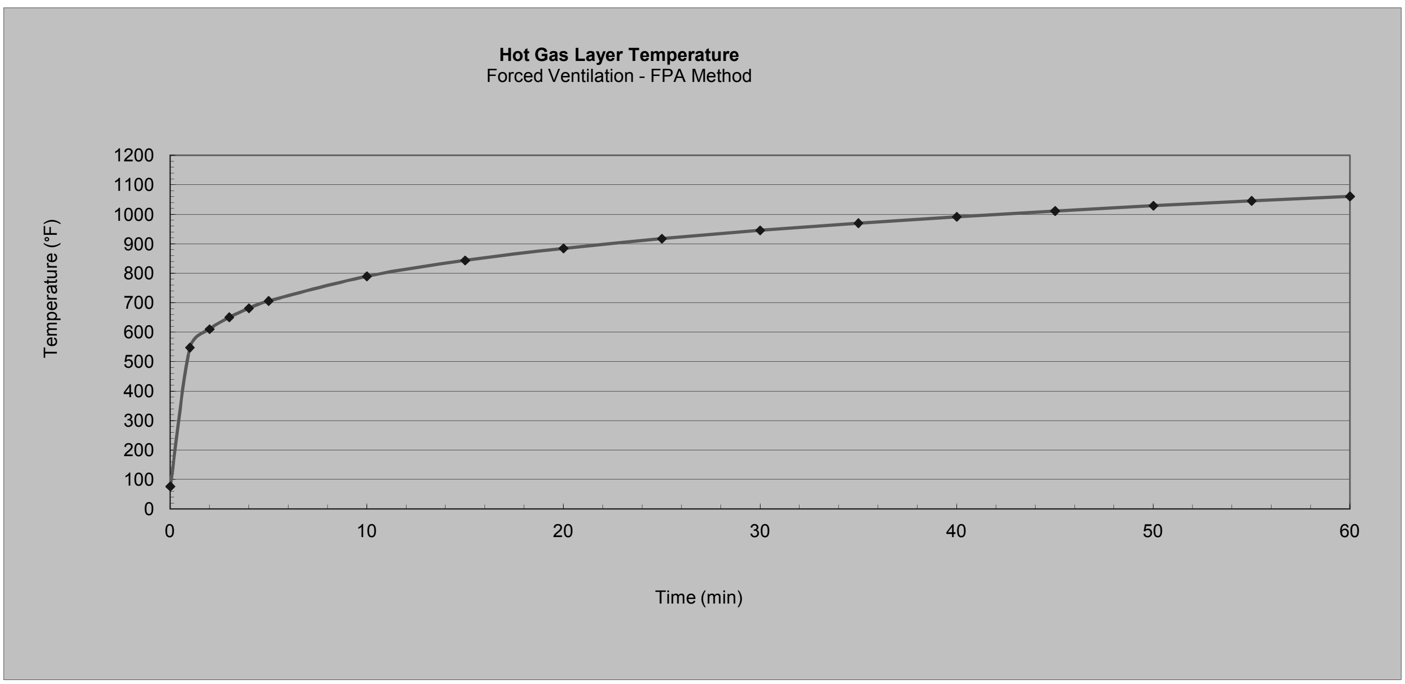
A_T = total area of the compartment enclosing surface boundaries (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

A_T = 29.73 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

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

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.17	0.88	261.70	559.70	286.70	548.05
2	120	0.12	0.99	296.47	594.47	321.47	610.65
3	180	0.10	1.07	318.92	616.92	343.92	651.05
4	240	0.08	1.13	335.87	633.87	360.87	681.56
5	300	0.08	1.17	349.63	647.63	374.63	706.34
10	600	0.05	1.33	396.09	694.09	421.09	789.97
15	900	0.04	1.43	426.08	724.08	451.08	843.95
20	1200	0.04	1.51	448.73	746.73	473.73	884.71
25	1500	0.03	1.57	467.12	765.12	492.12	917.81
30	1800	0.03	1.62	482.70	780.70	507.70	945.86
35	2100	0.03	1.67	496.28	794.28	521.28	970.31
40	2400	0.03	1.71	508.36	806.36	533.36	992.04
45	2700	0.03	1.74	519.25	817.25	544.25	1011.65
50	3000	0.02	1.78	529.19	827.19	554.19	1029.54
55	3300	0.02	1.81	538.35	836.35	563.35	1046.02
60	3600	0.02	1.84	546.84	844.84	571.84	1061.32



METHOD OF DEAL AND BEYLER

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

Thermal Penetration Time Calculation

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

Where
t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining heat capacity (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 33967.674 sec

Heat Transfer Coefficient Calculation

$$h_k = 0.4\ \sqrt{(k\rho c / t)} \quad \text{for } t < t_p \qquad \text{or} \qquad 0.4(k/\delta) \quad \text{for } t > t_p$$

Where
h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)
See table below for results

Area of Compartment Enclosing Surface Boundaries

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

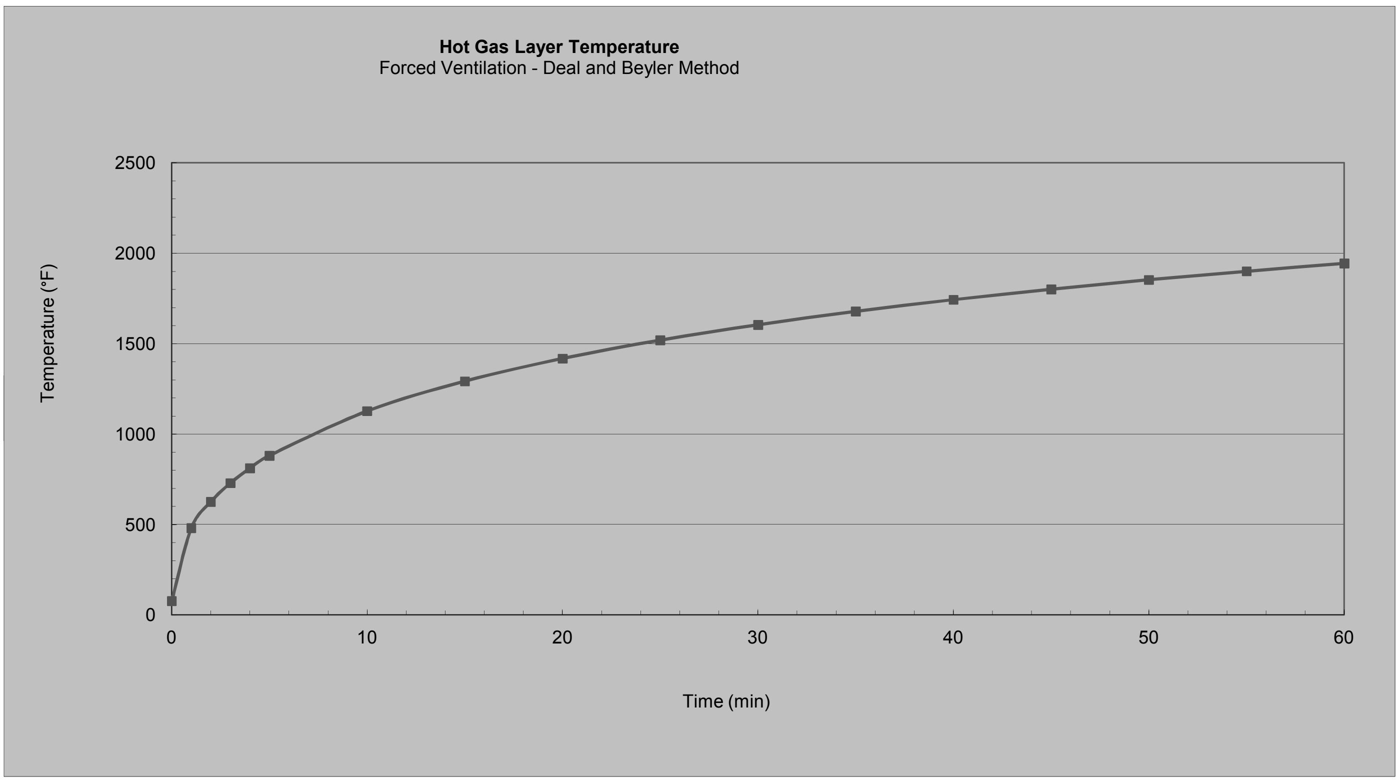
A_T = 29.73 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g = Q / (mc_a + h_k A_T)$$

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

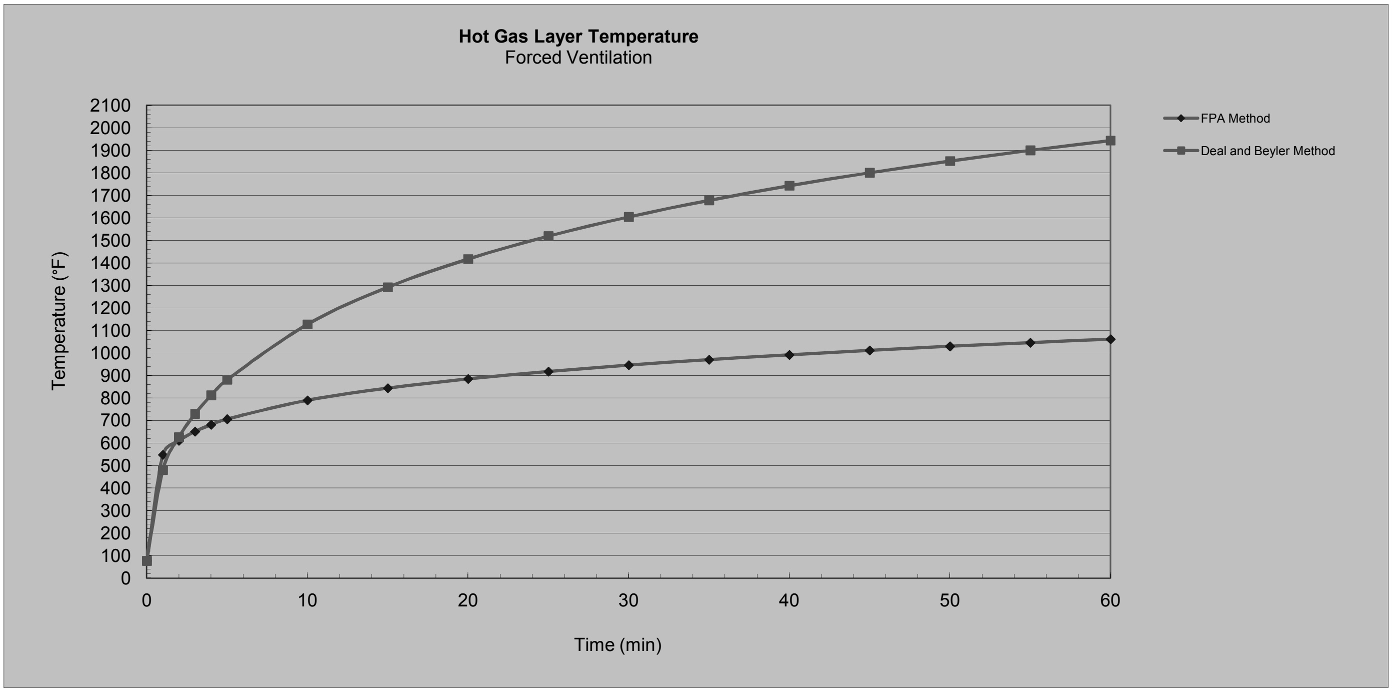
Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m²-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.07	224.69	522.69	249.69	481.44
2	120	0.05	305.06	603.06	330.06	626.11
3	180	0.04	362.51	660.51	387.51	729.52
4	240	0.03	408.35	706.35	433.35	812.03
5	300	0.03	446.91	744.91	471.91	881.44
10	600	0.02	583.70	881.70	608.70	1127.67
15	900	0.02	675.27	973.27	700.27	1292.48
20	1200	0.02	744.93	1042.93	769.93	1417.87
25	1500	0.01	801.34	1099.34	826.34	1519.42
30	1800	0.01	848.79	1146.79	873.79	1604.83
35	2100	0.01	889.74	1187.74	914.74	1678.53
40	2400	0.01	925.74	1223.74	950.74	1743.33
45	2700	0.01	957.84	1255.84	982.84	1801.11
50	3000	0.01	986.78	1284.78	1011.78	1853.21
55	3300	0.01	1013.12	1311.12	1038.12	1900.62
60	3600	0.01	1037.27	1335.27	1062.27	1944.09



CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION

Version 1805.1 (English Units)

Summary of Results



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

Prepared by: ______ Date: ______ Organization: ______

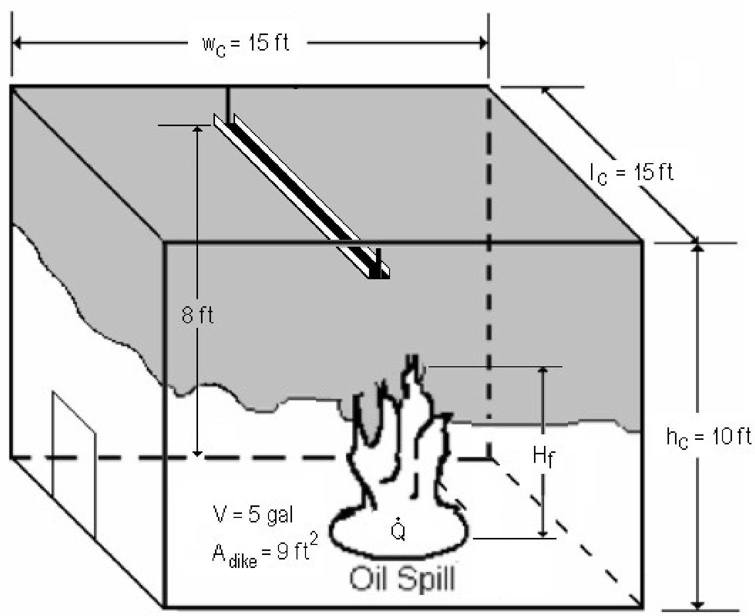
Checked by: ______ Date: ______ Organization: ______

Additional Information:

3.11 Problems

Example Problem 3.11-1

Problem Statement
A pool fire scenario arises from a breach (leak or rupture) in an auxiliary cooling water pump oil tank. This event allows the fuel contents of the pump to spill and spread over the compartment floor. A 5 gallon, 9.0 ft^2 surface area spill of flammable liquid (lubricating oil) leads to consideration of a pool fire in a compartment with a concrete floor. The fuel 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 15 ft wide x 15 ft deep x 10 ft high. The cable tray is located 8 ft above the pool fire. Determine whether the flame will impinge upon the cable tray. Assume instantaneous and complete involvement of the liquid pool with no fire growth and no intervention by the plant fire department or automatic suppression systems.



Example Problem 3-1: Compartment with Pool Fire

Solution

Purpose:
(1) Determine the Heat Release Rate (HRR) of the fire source.
(2) Determine the burning duration of the pool fire.
(3) Determine the flame height of the pool fire.
(4) Determine whether the flame will impinge upon the cable tray.

Assumptions:
(1) Instantaneous and complete involvement of the liquid in the pool fire
(2) The pool fire is burning in the open
(3) No fire growth period (instantaneous HRR_{max})
(4) The pool is circular or nearly circular and contains a fixed mass of liquid volume
(5) The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations_Sup1.xls

FDT^s Input Parameter:
- Fuel Spill Volume (V) = 5 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 9.0 ft^2
- Select Fuel Type: **Lube Oil**

Results*

Heat Release Rate (HRR) ($\dot{Q}$) kW (Btu/sec)	Burning Duration (t_b) (min.)	Pool Fire Flame Height (H_f) (ft)	
		Method of Heskestad	Method of Thomas
772 (731)	7.35	7.6	8.75

*see spreadsheet on next page

Both methods for pool fire flame height estimation show that pool fire flames will impinge upon the cable tray.

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.

Project / Inspection Title: **Example 3.11-1**

INPUT PARAMETERS

Fuel Spill Volume (V)	5.00	gallons
Fuel Spill Area or Dike Area (A_{dike})	9.00	ft^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Fuel Density (ρ)	760	kg/m^3
Empirical Constant ($k\beta$)	0.7	m^{-1}
Ambient Air Temperature (T_a)	77.00	°F
Gravitational Acceleration (g)	9.81	m/sec^2
Ambient Air Density (ρ_a)	1.18	kg/m^3

Calculate

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

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

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

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

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

ESTIMATING POOL FIRE HEAT RELEASE RATE

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

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

Where

Q = pool fire heat release rate (kW)

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

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

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

kb = empirical constant (m^{-1})

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

Pool Fire Diameter Calculation

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

Where

Adike = surface area of pool fire (m^2)

D = pool fire diameter (m)

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

D = 1.032 m

Heat Release Rate Calculation

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

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

Q = 731.26 Btu/sec 771.52 kW

ESTIMATING POOL FIRE BURNING DURATION

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

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

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

Calculation for Regression Rate

$$\nu = m''/\rho$$

Where
ν = regression rate (m/sec)
m" = mass burning rate of fuel (kg/m^2-sec)
ρ = liquid fuel density (kg/m^3)

ν = **0.000051 m/sec**

Burning Duration Calculation

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

t_b = **441.07 sec** **7.35 minutes**

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

ESTIMATING POOL FIRE FLAME HEIGHT

METHOD OF HESKESTAD

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

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

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

Pool Fire Flame Height Calculation

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

H_f =	7.56 ft	2.31 m

METHOD OF THOMAS

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

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

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

Pool Fire Flame Height Calculation

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

H_f =	8.75 ft	2.67 m

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

Version 1805.1
(English Units)

Summary of Results

Heat Release Rate Calculation

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

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

Answer	Q=	731.26 Btu/sec	771.52 kW

Burning Duration Calculation

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

Answer	t_b=	441.07 sec	7.35 minutes

Flame Height Calculation

Method of Heskestad

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

Method of Thomas

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

Answer		
	METHOD OF HESKESTAD	7.56 ft
	METHOD OF THOMAS	8.75 ft

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	35.66	3969.67	2.07	4.08
2	0.19	0.49	96.19	1984.84	3.16	5.19
3	0.28	0.60	170.49	1323.22	4.03	5.97
4	0.37	0.69	254.77	992.42	4.77	6.60
5	0.46	0.77	346.90	793.93	5.43	7.13
6	0.56	0.84	445.52	661.61	6.02	7.60
7	0.65	0.91	549.63	567.10	6.57	8.02
8	0.74	0.97	658.49	496.21	7.08	8.40
9	0.84	1.03	771.52	441.07	7.56	8.75
10	0.93	1.09	888.26	396.97	8.01	9.07
11	1.02	1.14	1008.32	360.88	8.44	9.38
12	1.11	1.19	1131.38	330.81	8.85	9.67
13	1.21	1.24	1257.17	305.36	9.24	9.94
14	1.30	1.29	1385.45	283.55	9.62	10.20
15	1.39	1.33	1516.02	264.64	9.97	10.45
20	1.86	1.54	2197.59	198.48	11.60	11.55
25	2.32	1.72	2916.42	158.79	12.99	12.48
50	4.65	2.43	6814.63	79.39	18.19	15.87
75	6.97	2.98	10946.20	52.93	21.86	18.28
100	9.29	3.44	15166.14	39.70	24.75	20.20

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

NOTE:

The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

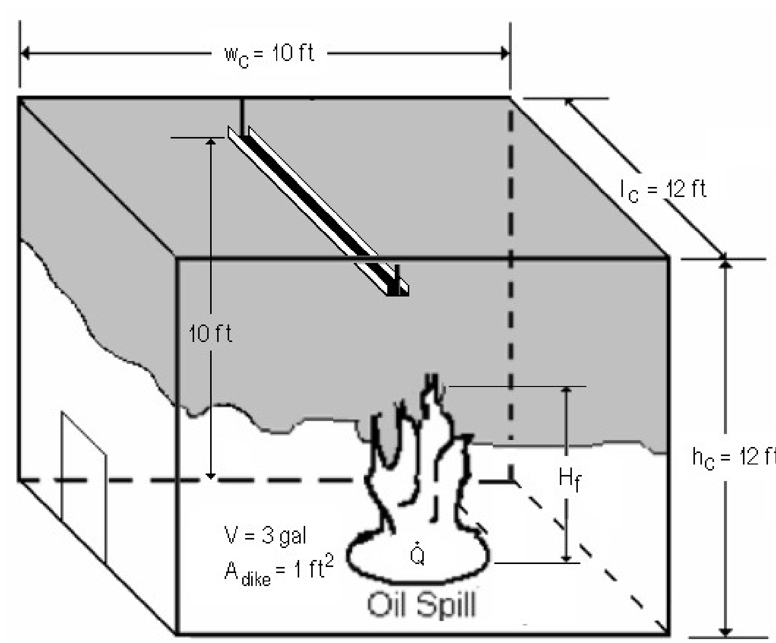
Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 3.11-2

Problem Statement
A standby diesel generator (SBDG) room in a power plant has a 3 gallon spill of diesel fuel over a 1 ft^2 dike area. This event allows the diesel fuel to form a pool. The diesel is ignited and fire 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 10 ft wide x 12 ft deep x 12 ft high. The cable tray is located 10 ft above the pool fire. Determine whether flame will impinge upon the cable tray. Also, determine the minimum area required of the pool fire for the flame to impinge upon the cable tray. Assume instantaneous, complete involvement of the liquid pool with no fire growth and no intervention by plant fire department or automatic suppression.



Example Problem 3-2: Compartment with Pool Fire

Solution

Purpose:
(1) Determine the Heat Release Rate (HRR) of the fire source.
(2) Determine the burning duration of the pool fire.
(3) Determine the flame height of the pool fire.
(4) Determine whether the flame will impinge upon the cable tray.
(5) Determine the minimum dike area required for the flame to impinge upon the cable tray.

Assumptions:
(1) Instantaneous and complete involvement of the liquid in the pool fire
(2) The pool fire is burning in the open
(3) No fire growth period (instantaneous HRR_{max})
(4) The pool is circular or nearly circular and contains a fixed mass of liquid volume
(5) The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations_Sup1.xls

FDT^s Input Parameter:
- Fuel Spill Volume (V) = 3 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 1.0 ft^2
- Select Fuel Type: **Diesel**

Results*

Heat Release Rate (HRR) ($\dot{Q}$) kW (Btu/sec)	Burning Duration (t_b) (min.)	Pool Fire Flame Height (H_f) (ft)	
		Method of Heskestad	Method of Thomas
95 (90)	42	3.6	4.5

*see spreadsheet on next page

Both methods for pool fire flame height estimation show that the pool fire flame will not impinge the cable tray.

To determine the minimum dike area required for the flame to impinge upon the cable tray, the user must substitute different values for the area in the spreadsheet until we obtain a flame height value of 10 ft (cable tray height). The user must keep the input values used for the previous results, and change only the area value. This trial and error procedure is shown in the following table.

Trial	A_{dike} (ft^2)	Pool Fire Flame Height (H_f) (ft)	
		Method of Heskestad	Method of Thomas
1	7	9.7	8.8
2	8	10.3	9.2
3	9	10.8	9.6

To be conservative, we are going to consider the method that gets the first 10 ft flame height. The method of Heskestad tells that the pool fire flame will impinge upon the cable tray if the dike area is 7.6 ft^2. For practical purposes, we could say that a spill pool area around 7 to 8 ft^2 would be a risk for the cable tray integrity.

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

Version 1805.1 (English Units)

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.

Project / Inspection Title: **Example 3.11-2**

INPUT PARAMETERS

Fuel Spill Volume (V)	3.00	gallons
Fuel Spill Area or Dike Area (A_{dike})	1.00	ft^2
Mass Burning Rate of Fuel (m")	0.045	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	44400	kJ/kg
Fuel Density (ρ)	918	kg/m^3
Empirical Constant ($k\beta$)	2.1	m^{-1}
Ambient Air Temperature (T_a)	77.00	°F
Gravitational Acceleration (g)	9.81	m/sec^2
Ambient Air Density (ρ_a)	1.18	kg/m^3

Calculate

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

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

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

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

Select Fuel Type

Diesel

Scroll to desired fuel type
Click on selection

ESTIMATING POOL FIRE HEAT RELEASE RATE

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

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

Where

Q = pool fire heat release rate (kW)

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

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

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

kb = empirical constant (m^{-1})

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

Pool Fire Diameter Calculation

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

Where

Adike = surface area of pool fire (m^2)

D = pool fire diameter (m)

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

D = 0.344 m

Heat Release Rate Calculation

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

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

Q = 90.49 Btu/sec 95.47 kW

ESTIMATING POOL FIRE BURNING DURATION

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

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

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

Calculation for Regression Rate

$$\nu = m''/\rho$$

Where
ν = regression rate (m/sec)
m" = mass burning rate of fuel (kg/m^2-sec)
ρ = liquid fuel density (kg/m^3)

ν = **0.000049 m/sec**

Burning Duration Calculation

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

t_b = **2493.37 sec** **41.56 minutes**

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

ESTIMATING POOL FIRE FLAME HEIGHT

METHOD OF HESKESTAD

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

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

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

Pool Fire Flame Height Calculation

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

H_f = 3.62 ft 1.10 m

METHOD OF THOMAS

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

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

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

Pool Fire Flame Height Calculation

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

H_f = 4.45 ft 1.36 m

Summary of Results

Heat Release Rate Calculation

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

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

Answer	Q=	90.49 Btu/sec	95.47 kW

Burning Duration Calculation

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

Answer	t_b=	2493.37 sec	41.56 minutes

Flame Height Calculation

Method of Heskestad

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

Method of Thomas

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

Answer		
	METHOD OF HESKESTAD	3.62 ft
	METHOD OF THOMAS	4.45 ft

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	95.47	2493.37	3.62	4.45
2	0.19	0.49	237.56	1246.69	5.25	5.66
3	0.28	0.60	397.47	831.12	6.45	6.52
4	0.37	0.69	567.36	623.34	7.44	7.20
5	0.46	0.77	743.51	498.67	8.28	7.78
6	0.56	0.84	923.86	415.56	9.02	8.29
7	0.65	0.91	1107.11	356.20	9.68	8.75
8	0.74	0.97	1292.42	311.67	10.28	9.16
9	0.84	1.03	1479.22	277.04	10.84	9.55
10	0.93	1.09	1667.09	249.34	11.35	9.90
11	1.02	1.14	1855.75	226.67	11.83	10.24
12	1.11	1.19	2044.96	207.78	12.28	10.55
13	1.21	1.24	2234.57	191.80	12.71	10.85
14	1.30	1.29	2424.46	178.10	13.11	11.13
15	1.39	1.33	2614.53	166.22	13.49	11.40
20	1.86	1.54	3565.55	124.67	15.17	12.60
25	2.32	1.72	4515.13	99.73	16.58	13.61
50	4.65	2.43	9224.83	49.87	21.58	17.32
75	6.97	2.98	13894.78	33.24	25.04	19.94
100	9.29	3.44	18548.48	24.93	27.79	22.04

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

NOTE:

The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

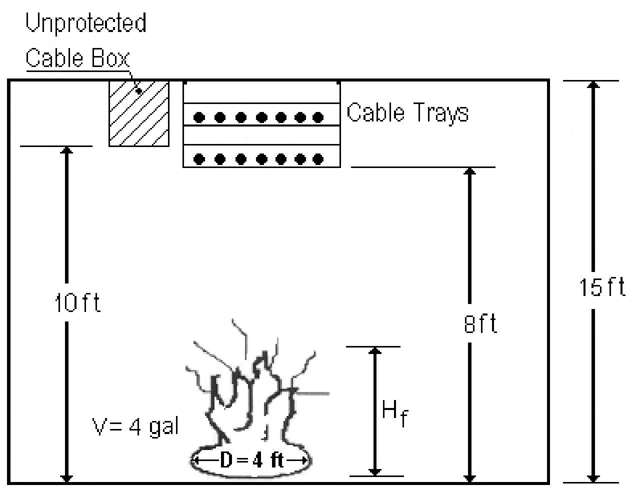
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 3.11-3

Problem Statement
In one NPP, it was important to determine whether a fire involving a 4 gallon spill of lubricating oil from an auxiliary feed water (AFW) pump could cause damage to an unprotected electrical cable pull box and cable trays. The unprotected pull box and cable trays were located 10 ft and 8 ft above the AFW pump, respectively. The pump room had a floor area of 20 ft x 20 ft and a ceiling height of 15 ft with a vent opening of 5 ft x 15 ft. Compute the HRR, burning duration, and flame height of the pool fire with a diameter of 4 ft. The lowest cable tray is located 8 ft above the pool. Determine whether flame will impinge upon the cable tray or cable pull box. Assume instantaneous, complete involvement of the liquid pool with no fire growth and no intervention by the plant fire department or automatic suppression systems.



Example 3-3: Compartment with Pool Fire

Solution

Purpose:
(1) Determine the Heat Release Rate (HRR) of the fire source.
(2) Determine the burning duration of the pool fire.
(3) Determine the flame height of the pool fire.
(4) Determine whether the flame will impinge upon the cable tray or cable pull box.

Assumptions:
(1) Instantaneous and complete involvement of the liquid in the pool fire
(2) The pool fire is burning in the open
(3) No fire growth period (instantaneous HRR_{max})
(4) The pool is circular or nearly circular and contains a fixed mass of liquid volume
(5) The fire is located at the center of the compartment or away from the walls

Pre FDT^s Calculations:
The input parameters of the FDT^s assigned for this problem are the fuel spill volume, dike area and fuel material. As we can see, the problem statement does not give the dike area but the pool diameter is given. The dike area can be obtained from the formula of the area of a circle, since we assume that the pool has circular shape.

$$A_{dike} = \frac{\pi}{4} D^2 = \frac{\pi}{4} (\,4\,ft)^2 = 12.56\,ft^2$$

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations_Sup1.xls

FDT^s Inputs: (for both spreadsheets)
- Fuel Spill Volume (V) = 4 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 12.56 ft^2
- Select Fuel Type: **Lube Oil**

Results*

Heat Release Rate (HRR) ($\dot{Q}$) kW (Btu/sec)	Burning Duration (t_b) (min.)	Pool Fire Flame Height (H_f) (ft)	
		Method of Heskestad	Method of Thomas
1,202 (1,139)	4.2	9.1	9.8

*see spreadsheet on next page

Both methods for pool fire flame height estimation show that the pool fire flame will impinge upon the cable tray and cable pull box.

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

Version 1805.1 (English Units)

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.

Project / Inspection Title: **Example 3.11-3**

INPUT PARAMETERS

Fuel Spill Volume (V)	4.00	gallons
Fuel Spill Area or Dike Area (A_{dike})	12.56	ft^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Fuel Density (ρ)	760	kg/m^3
Empirical Constant ($k\beta$)	0.7	m^{-1}
Ambient Air Temperature (T_a)	77.00	°F
Gravitational Acceleration (g)	9.81	m/sec^2
Ambient Air Density (ρ_a)	1.18	kg/m^3

Calculate

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

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

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

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

Select Fuel Type

Lube Oil

Scroll to desired fuel type

Click on selection

ESTIMATING POOL FIRE HEAT RELEASE RATE

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

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

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

Pool Fire Diameter Calculation

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

Where
Adike = surface area of pool fire (m^2)
D = pool fire diameter (m)

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

D = 1.219 m

Heat Release Rate Calculation

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

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

Q = 1138.81 Btu/sec 1201.50 kW

ESTIMATING POOL FIRE BURNING DURATION

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

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

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

Calculation for Regression Rate

$$\nu = m''/\rho$$

Where
ν = regression rate (m/sec)
m" = mass burning rate of fuel (kg/m^2-sec)
ρ = liquid fuel density (kg/m^3)

ν = 0.000051 m/sec

Burning Duration Calculation

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

t_b = 252.85 sec 4.21 minutes

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

ESTIMATING POOL FIRE FLAME HEIGHT

METHOD OF HESKESTAD

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

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

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

Pool Fire Flame Height Calculation

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

H_f = 9.07 ft 2.77 m

METHOD OF THOMAS

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

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

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

Pool Fire Flame Height Calculation

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

H_f = 9.82 ft 2.99 m

Summary of Results

Heat Release Rate Calculation

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

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

Answer	Q=	1138.81 Btu/sec	1201.50 kW

Burning Duration Calculation

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

Answer	t_b=	252.85 sec	4.21 minutes

Flame Height Calculation

Method of Heskestad

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

Method of Thomas

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

Answer		
	METHOD OF HESKESTAD	9.07 ft
	METHOD OF THOMAS	9.82 ft

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (ft) (Heskestad)	H_f (ft) (Thomas)
1	0.09	0.34	35.66	3175.74	2.07	4.08
2	0.19	0.49	96.19	1587.87	3.16	5.19
3	0.28	0.60	170.49	1058.58	4.03	5.97
4	0.37	0.69	254.77	793.93	4.77	6.60
5	0.46	0.77	346.90	635.15	5.43	7.13
6	0.56	0.84	445.52	529.29	6.02	7.60
7	0.65	0.91	549.63	453.68	6.57	8.02
8	0.74	0.97	658.49	396.97	7.08	8.40
9	0.84	1.03	771.52	352.86	7.56	8.75
10	0.93	1.09	888.26	317.57	8.01	9.07
11	1.02	1.14	1008.32	288.70	8.44	9.38
12	1.11	1.19	1131.38	264.64	8.85	9.67
13	1.21	1.24	1257.17	244.29	9.24	9.94
14	1.30	1.29	1385.45	226.84	9.62	10.20
15	1.39	1.33	1516.02	211.72	9.97	10.45
20	1.86	1.54	2197.59	158.79	11.60	11.55
25	2.32	1.72	2916.42	127.03	12.99	12.48
50	4.65	2.43	6814.63	63.51	18.19	15.87
75	6.97	2.98	10946.20	42.34	21.86	18.28
100	9.29	3.44	15166.14	31.76	24.75	20.20

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

NOTE:

The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

4.9 Problems

Example Problem 4.9-1

Problem Statement
A pool fire scenario arises from a breach (leak or rupture) in an oil-filled transformer. This event allows the fuel contents of the transformer to spill 2 gallons along a wall with an area of 9 ft^2. A cable tray is located 8 ft above the fire. Calculate the wall flame height of the fire and determine whether the flame will impinge upon the cable tray.

Solution

Purpose:
(1) Calculate the wall flame height.
(2) Determine whether the flame will impinge upon the cable tray.

Assumptions:
(1) Air is entrained only from one side during the combustion process.
(2) The fire is located at or near a wall configuration of a compartment that affects the spread of the fire.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 04_Flame_Height_Calculations_Sup1.xls (click on *Wall_Flame_Height*)

FDT^s Input Parameters:
- Fuel spill volume (V) = 2 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 9.0 ft^2
- Select Fuel Type: **Transformer Oil, Hydrocarbon**

Results*

Fuel	Wall Fire Flame Height ($H_{f(Wall)}$) (ft)	Cable Tray Impingement
Transformer Oil, Hydrocarbon	10.0	Yes

*see spreadsheet on next page

CHAPTER 4
ESTIMATING WALL FIRE
FLAME HEIGHT

Version 1805.1
(English Units)

The following calculations estimate the wall fire flame height.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 4.9-1**

INPUT PARAMETERS

Fuel Spill Volume (V)	2.00	gallons
Fuel Spill Area or Dike Area (A_{dike})	9.00	ft^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Empirical Constant ($k\beta$)	0.7	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

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

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

Select Fuel Type

Transformer Oil, Hydrocarbon

Scroll to desired fuel type **then Click** on selection

Heat Release Rate Calculation

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

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

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

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

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

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

D = 1.032 m

Heat Release Rate Calculation

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

Q = 771.52 kW 731.26 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

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

Fire Source Length Calculation

$L \times W = A_{dike}$

$L \times W =$ 0.836 m^2

L = 0.914 m

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

Q' = 843.75 kW/m

ESTIMATING WALL FIRE FLAME HEIGHT

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

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

Where,
$H_{f(wall)}$ = wall fire flame height (m)
Q' = rate of heat release per unit length of the fire (kW/m)

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

Answer	$H_{f(wall)}$ =	9.96 ft	3.04 m

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

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Example Problem 4.9-2

Problem Statement
A pool fire scenario arises from a transient combustible liquid spill. This event allows the fuel contents of a 15 gallon can to form along a wall with an area of 30 ft^2. A cable tray is located 12 ft above the fire. Determine the line wall fire flame height and whether the flame will impinge upon the cable tray if the spilled liquids are (a) diesel, (b) acetone, and (c) methanol.

Solution

Purpose:
(1) Calculate the line wall fire flame height using three transient combustibles.
(2) Determine whether the flame will impinge upon the cable tray in each case.

Assumptions:
(1) Air is entrained only from one side during the combustion process.
(2) The fire is located at or near a wall configuration of a compartment that affects the spread of the fire.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 04_Flame_Height_Calculations_Sup1.xls (click on *Wall_Line_Flame_Height*)

FDT^s Input Parameters:
- Fuel spill volume (V) = 15 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 30.0 ft^2
- Select Fuel Type: **Diesel**, **Acetone**, and **Methanol**

Results*

Fuel	Wall Line Fire Height ($H_{f(Wall\ Line)}$) (ft)	Cable Tray Impingement
Diesel	12.3	Yes
Acetone	8.0	No
Methanol	3.8	No

*see spreadsheets on next page

CHAPTER 4
ESTIMATING LINE FIRE FLAME HEIGHT AGAINST THE WALL

Version 1805.1 (English Units)

The following calculations estimate the line fire flame height against the wall.

Parameters in YELLOW CELLS are Entered by the User.

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

Project / Inspection Title: **Example 4.9-2a**

INPUT PARAMETERS

Fuel Spill Volume (V)	15.00	gallons
Fuel Spill Area or Dike Area (A_{dike})	30.00	ft^2
Mass Burning Rate of Fuel (m")	0.045	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	44400	kJ/kg
Empirical Constant (kβ)	2.1	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

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

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

Select Fuel Type

Diesel

Scroll to desired fuel type **then Click** on selection

Heat Release Rate Calculation

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

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

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

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

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

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

D = 1.884 m

Heat Release Rate Calculation

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

Q = 5462.02 kW 5177.01 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

Where,

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

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

L = length of the fire source (m)

Fire Source Length Calculation

$$L \times W = A_{dike}$$

L x W = 2.787 m^2

L = 1.669 m

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

Q' = 3271.73 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

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

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

Where,
$H_{f(wall\ line)}$ = wall fire flame height (m)
Q' = rate of heat release per unit length of the fire (kW/m)

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

Answer	$H_{f(wall\ line)}$ =	**12.29 ft**	**3.75 m**

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

CHAPTER 4
ESTIMATING LINE FIRE
FLAME HEIGHT AGAINST THE WALL

Version 1805.1
(English Units)

The following calculations estimate the line fire flame height against the wall.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 4.9-2b**

INPUT PARAMETERS

Fuel Spill Volume (V)	15.00	gallons
Fuel Spill Area or Dike Area (A_{dike})	30.00	ft^2
Mass Burning Rate of Fuel (m")	0.041	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	25800	kJ/kg
Empirical Constant ($k\beta$)	1.9	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

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

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

Select Fuel Type

Acetone

Scroll to desired fuel type **then Click** on selection

Heat Release Rate Calculation

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

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

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

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

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

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

D = 1.884 m

Heat Release Rate Calculation

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

Q = 2865.94 kW   2716.39 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

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

Fire Source Length Calculation

$L \times W = A_{dike}$

$L \times W =$ 2.787 m^2

$L =$ 1.669 m

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

$Q' =$ 1716.69 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

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

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

Where,
$H_{f(wall\ line)}$ = wall fire flame height (m)
Q' = rate of heat release per unit length of the fire (kW/m)

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

Answer	$H_{f(wall\ line)}$ =	8.00 ft	2.44 m

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

The following calculations estimate the line fire flame height against the wall.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: Example 4.9-2c

INPUT PARAMETERS

Fuel Spill Volume (V)	15.00	gallons
Fuel Spill Area or Dike Area (A_{dike})	30.00	ft^2
Mass Burning Rate of Fuel (m")	0.017	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	20000	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

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

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

Select Fuel Type

Methanol

Scroll to desired fuel type **then Click** on selection

Heat Release Rate Calculation

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

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

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

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

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

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

D = 1.884 m

Heat Release Rate Calculation

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

Q = 947.61 kW 898.16 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

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

Fire Source Length Calculation

$$L \times W = A_{dike}$$

$L \times W =$ 2.787 m^2

$L =$ 1.669 m

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

$Q' =$ 567.62 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

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

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

Where,
$H_{f(wall\ line)}$ = wall fire flame height (m)
Q' = rate of heat release per unit length of the fire (kW/m)

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

Answer	$H_{f(wall\ line)}$ =	3.82 ft	1.17 m

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

Prepared by: ____ Date: ____ Organization: ____

Checked by: ____ Date: ____ Organization: ____

Additional Information:

Example Problem 4.9-3

Problem Statement

A pool fire scenario arises from a rupture in a diesel generator fuel line. This event allows diesel fuel to spill 1.5 gallons along the corner of walls with an area of 10 ft^2. An unprotected junction box is located 12 ft above the fire. Determine whether the flame will impinge upon the junction box.

Solution

Purpose:
(1) Calculate the line wall fire flame height.
(2) Determine whether the flame will impinge upon the junction box.

Assumptions:
(1) Air is entrained only from one side during the combustion process.
(2) The fire is located at or near a wall configuration of a compartment that affects the spread of the fire.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 04_Flame_Height_Calculations_Sup1.xls (click on *Corner_Flame _Height*)

FDT^s Input Parameters:
- Fuel spill volume (V) = 1.5 gallons
- Fuel Spill Area or Dike Area (A_{dike}) = 10 ft^2
- Select Fuel Type: **Diesel**

Results*

Fuel	Corner Fire Flame Height ($H_{f(Corner)}$) (ft)	Junction Box Impingement
Diesel	21.1	Yes

*see spreadsheet on next page

CHAPTER 4
ESTIMATING CORNER FIRE FLAME HEIGHT

Version 1805.1
(English Units)

The following calculations estimate the corner fire flame height.

Parameters in YELLOW CELLS are Entered by the User.

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

Project / Inspection Title: **Example 4.9-3**

INPUT PARAMETERS

Fuel Spill Volume (V)	1.50	gallons
Fuel Spill Area or Dike Area (A_{dike})	10.00	ft^2
Mass Burning Rate of Fuel (m")	0.045	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	44400	kJ/kg
Empirical Constant ($k\beta$)	2.1	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

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

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

Select Fuel Type

Diesel

Scroll to desired fuel type **then Click** on selection

Heat Release Rate Calculation

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

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

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

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

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

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

D = 1.088 m

Heat Release Rate Calculation

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

Q = 1667.09 kW 1580.10 Btu/sec

ESTIMATING CORNER FIRE FLAME HEIGHT

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

$$H_{f(corner)} = 0.075\ Q^{3/5}$$

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

$$H_{f(corner)} = 0.075\ Q^{3/5}$$

Answer	$H_{f(corner)} =$	21.10 ft	6.43 m

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and Hesemi and Tokunage, 1983. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

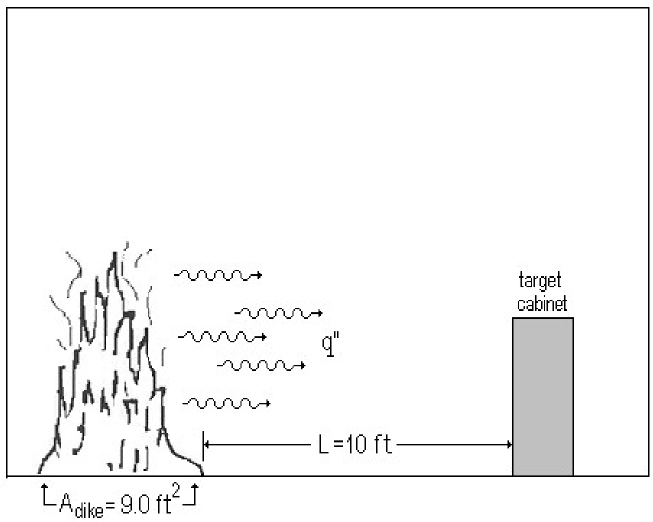
Additional Information:

5.11 Problems

Example Problem 5.11-1

Problem Statement

A pool fire scenario arises from a breach (leak or rupture) in a transformer. This event allows the fuel contents of the transformer to spill and spread over the compartment floor. The compartment is very large and has a high ceiling (e.g., typical reactor building elevation of a BWR, turbine building open area). A pool fire ensues with a spill area of 9.0 ft^2 on the concrete floor. Calculate the flame radiant heat flux to a target (cabinet) at ground level with no wind using: a) point source radiation model and b) solid flame radiation model. The distance between the fire source and the target edge is assumed to be 10 ft.



Example Problem 5-1: Radiant Heat Flux from a Pool Fire to a Target Fuel

Solution

Purpose:

(1) Calculate the radiant heat flux from the pool fire to the target cabinet using the point source and solid flame radiation models.

Assumptions:

(1) The pool is circular or nearly circular.
(2) Radiation to the surroundings can be approximated as being isotropic or emanating from a point source (valid for point source radiation model only).
(3) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1.xls
(click on *Point Source* and *Solid Flame 1* for point source and solid flame analysis respectively).

FDT^s Input Parameters: (For both spreadsheets)

- Fuel Spill Area or Curb Area (A_{curb}) = 9.0 ft
- Distance between Fire Source and Target (L) = 10 ft
- Select Fuel Type: **Transformer Oil, Hydrocarbon**

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)
Point Source	1.45
Solid Flame	3.05

* see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS POINT SOURCE RADIATION MODEL

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-1a**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Empirical Constant ($k\beta$)	0.7	m^{-1}
Heat Release Rate (Q)	771.52	kW
Fuel Area or Dike Area (A_{dike})	9.00	ft^2
Distance between Fire and Target (L)	10.00	ft
Radiative Fraction (χ_r)	0.30	

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

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

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

Select Fuel Type
Transformer Oil, Hydrocarbon
Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-272.*

POINT SOURCE RADIATION MODEL

$$q'' = Q \chi_r / 4 \pi R^2$$

Where
q" = incident radiative heat flux on the target (kW/m^2)
Q = pool fire heat release rate (kW)
χr = radiative fraction
R = distance from center of the pool fire to edge of the target (m)

Pool Fire Diameter Calculation

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

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

D = 1.03 m

Heat Release Rate Calculation

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

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

Q = 771.5 kW

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

$$R = L+D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = 3.56 m

RADIATIVE HEAT FLUX CALCULATION

$$q'' = Q \chi_r / 4 \pi R^2$$

Answer	$q'' =$	0.13	Btu/ft^2-sec	1.45	kW/m^2

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-1b**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Empirical Constant ($k\beta$)	0.7	m^{-1}
Heat Release Rate (Q)	771.52	kW
Fuel Area or Dike Area (A_{dike})	9.00	ft^2
Distance between Fire and Target (L)	10.00	ft

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → | | kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

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

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

Select Fuel Type

Transformer Oil, Hydrocarbon

Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\to 2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\to 2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

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

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

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

D = 1.03 m

Emissive Power Calculation

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

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.88 kW/m²

View Factor Calculation

$$F_{1\to 2,H} = (B-1/S)/\pi(B^2-1)^{1/2} \tan^{-1} ((B+1)(S-1)/(B-1)(S+1))^{1/2} - (A-1/S)/(\pi(A^2-1)^{1/2}) \tan^{-1} ((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$F_{1\to 2,V} = 1/(\pi S) \tan^{-1}(h/(S^2-1)^{1/2}) - (h/\pi S) \tan^{-1} ((S-1)/(S+1))^{1/2} + Ah/\pi S(A^2-1)^{1/2} \tan^{-1} ((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$A = (h^2+S^2+1)/2S$$

$$B = (1+S^2)/2S$$

$$S = 2R/D$$

$$h = 2H_f/D$$

$$F_{1\to 2,max} = \sqrt{(F^2_{1\to 2,H} + F^2_{1\to 2,V})}$$

Where
$F_{1\to 2,H}$ = horizontal view factor
$F_{1\to 2,V}$ = vertical view factor
$F_{1\to 2,max}$ = maximum view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

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

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 3.564 m

Heat Release Rate Calculation

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

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

Q = 771.52 kW

Pool Fire Flame Height Calculation

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

Where
Hf = flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

H_f = 2.305 m

$S = 2R/D =$	6.908
$h = 2H_f/D =$	4.468
$A = (h^2+S^2+1)/2S =$	4.971
$B = (1+S^2)/2S =$	3.526
$F_{1\to2,H} =$	0.016
$F_{1\to2,V} =$	0.051
$F_{1\to2,\max} = \sqrt{(F^2_{1\to2,H} + F^2_{1\to2,V})} =$	0.054

F_{H1}	F_{H2}	F_{H3}	F_{H4}	$F_{1\to2,H}$
0.318	0.858	0.315	0.814	0.016
F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\to2,V}$
0.027	0.147	0.210	0.814	0.051

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(English Units)

RADIATIVE HEAT FLUX CALCULATION

$$q'' = EF_{1->2}$$

Answer	q" =	0.27	Btu/ft^2-sec	3.05	kW/m^2

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

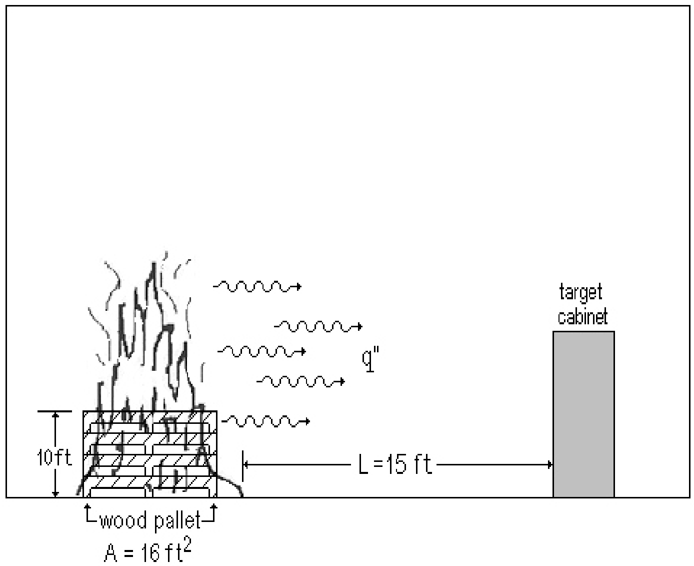
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 5.11-2

Problem Statement
A transient combustible fire scenario may arise from burning wood pallets (4 ft x 4 ft = 16 ft^2), stacked 10 ft high on the floor of a compartment with a very high ceiling. Calculate the flame radiant heat flux to a target (safety-related cabinet) at ground level with no wind, using the point source radiation model and the solid flame radiation model. The distance between the fire source and the target edge (L) is assumed to be 15 ft.



Example Problem 5-2: Radiant Heat Flux from a Burning Pallet to a Target Fuel

Solution

Purpose:

(1) Calculate the radiant heat flux from the fire source to the target cabinet using the point source and solid flame radiation models.

Assumptions:

(1) The fire source will be nearly circular.
(2) Radiation to the surroundings can be approximated as being isotropic or emanating from a point source (valid for point source radiation model only).
(3) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1.xls
(click on *Point Source* and *Solid Flame 1* for point source and solid flame analysis, respectively)

FDTs Inputs: (For both spreadsheets)

- Fuel Spill Area or Curb Area (A_{curb}) = 16 ft^2
- Distance between Fire Source and Target (L) = 15 ft
- Select Fuel Type: **Douglas Fir Plywood**

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)
Point Source	0.15
Solid Flame	0.45

*see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
POINT SOURCE RADIATION MODEL

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-2a**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.01082	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	10900	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}
Heat Release Rate (Q)	175.31	kW
Fuel Area or Dike Area (A_{dike})	16.00	ft^2
Distance between Fire and Target (L)	15.00	ft
Radiative Fraction (χ_r)	0.30	

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → _____ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

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

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

Select Fuel Type

Douglas Fir Plywood

Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-272.*

POINT SOURCE RADIATION MODEL

$$q'' = Q\,\chi_r / 4\,\pi\,R^2$$

Where
q" = incident radiative heat flux on the target (kW/m^2)
Q = pool fire heat release rate (kW)
χr = radiative fraction
R = distance from center of the pool fire to edge of the target (m)

Pool Fire Diameter Calculation

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

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

D = 1.38 m

Heat Release Rate Calculation

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

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

Q = 175.3 kW

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

$$R = L+D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = 5.26 m

RADIATIVE HEAT FLUX CALCULATION

$$q'' = Q\,\chi_r / 4\,\pi\,R^2$$

Answer	q'' =	0.01 Btu/ft^2-sec	0.15 kW/m^2

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

Prepared by: | Date: | Organization:

Checked by: | Date: | Organization:

Additional Information:

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-2b**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.01082	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	10900	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}
Heat Release Rate (Q)	175.31	kW
Fuel Area or Dike Area (A_{dike})	16.00	ft^2
Distance between Fire and Target (L)	15.00	ft

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

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

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

Select Fuel Type

Douglas Fir Plywood

Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\text{->}2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\text{->}2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

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

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

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

D = 1.38 m

Emissive Power Calculation

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

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.51 kW/m^2

View Factor Calculation

$$F_{1\text{->}2,H} = (B-1/S)/\pi(B^2-1)^{1/2}\tan^{-1}((B+1)(S-1)/(B-1)(S+1))^{1/2}-(A-1/S)/(\pi(A^2-1)^{1/2})\tan^{-1}((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$F_{1\text{->}2,V} = 1/(\pi S)\tan^{-1}(h/(S^2-1)^{1/2})-(h/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2} + Ah/\pi S(A^2-1)^{1/2}\tan^{-1}((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$A = (h^2+S^2+1)/2S$$

$$B = (1+S^2)/2S$$

$$S = 2R/D$$

$$h = 2H_f/D$$

$$F_{1\text{->}2,max} = \sqrt{(F^2_{1\text{->}2,H} + F^2_{1\text{->}2,V})}$$

Where
$F_{1\text{->}2,H}$ = horizontal view factor
$F_{1\text{->}2,V}$ = vertical view factor
$F_{1\text{->}2,max}$ = maximum view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

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

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 5.260 m

Heat Release Rate Calculation

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

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

Q = 175.31 kW

Pool Fire Flame Height Calculation

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

Where
Hf = flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

H_f = 0.453 m

$S = 2R/D$ =	7.647
$h = 2H_f/D$ =	0.658
$A = (h^2+S^2+1)/2S$ =	3.917
$B = (1+S^2)/2S$ =	3.889
$F_{1\to2,H}$ =	0.000
$F_{1\to2,V}$ =	0.008
$F_{1\to2,\,max} = \sqrt{(F^2_{1\to2,H} + F^2_{1\to2,V})}$ =	0.008

F_{H1}	F_{H2}	F_{H3}	F_{H4}	$F_{1\to2,H}$
0.318	0.851	0.318	0.850	0.000
F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\to2,V}$
0.004	0.020	0.028	0.850	0.008

RADIATIVE HEAT FLUX CALCULATION

$$q'' = EF_{1\text{->}2}$$

Answer	q" =	0.04	Btu/ft^2-sec	0.45	kW/m^2

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

Prepared by: ____ Date: ____ Organization: ____

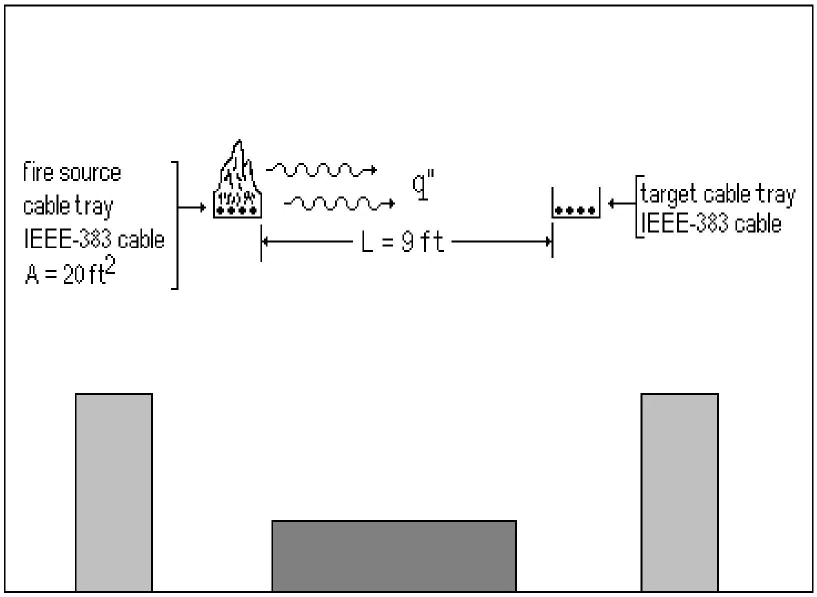
Checked by: ____ Date: ____ Organization: ____

Additional Information:

Example Problem 5.11-3

Problem Statement

A fire scenario may arise from a horizontal cable tray burning in a very large compartment. The cables in the tray are IEEE-383 unqualified and made of PE/PVC insulation material (assume that the exposed area of the cable is 20 ft^2). Another safety-related cable tray also filled with IEEE-383 unqualified made of PE/PVC insulation material is located at a radial distance (L) of 9 ft from the fire source. Calculate the flame radiant heat flux to a target (safety-related cable tray) using the point source radiation model and solid flame radiation model. Is this heat flux sufficient to ignite the cable tray?



Example Problem 5-3: Radiant Heat Flux from a Burning Cable Tray to a Target Fuel

Solution

Purpose:

(1) Calculate the radiant heat flux from the burning cable tray to the target cable tray using the point source and solid flame radiation models.
(2) Determine if the heat flux is sufficient to ignite the cable tray.

Assumptions:

(1) The fire source will be nearly circular.
(2) Radiation to the surroundings can be approximated as being isotropic or emanating from a point source (point source radiation model only).
(3) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1.xls
(click on *Point Source* and *Solid Flame 1* for point source and solid flame analysis, respectively).

FDT^s Inputs: (For both spreadsheets)

- Mass Burning Rate of Fuel ($\dot{m}''$) = 0.0044 kg/m^2-sec
- Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$) = 25,100 kJ/kg
- Empirical Constant (kβ) = 100 (use this if actual value is unknown)
- Fuel Spill Area or Curb Area (A_{curb}) = 20 ft^2
- Distance between Fire Source and Target (L) = 9 ft

Note: Since the insulation material (PE/PVC) is not available in the thermal properties data of the spreadsheet, we have to input the mass burning rate and effective heat of combustion in the spreadsheet. Values of cable materials properties are available in Table 3-4. Select **User-Specified Value**, and enter the respective values.

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)
Point Source	0.4
Solid Flame	1.1

*see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
POINT SOURCE RADIATION MODEL

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-3a**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.0044	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	25100	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}
Heat Release Rate (Q)	205.20	kW
Fuel Area or Dike Area (A_{dike})	20.00	ft^2
Distance between Fire and Target (L)	9.00	ft
Radiative Fraction (χ_r)	0.30	

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ____ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

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

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

Select Fuel Type
User Specified Value
Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-272.*

POINT SOURCE RADIATION MODEL

$$q'' = Q \chi_r / 4 \pi R^2$$

Where
q" = incident radiative heat flux on the target (kW/m^2)
Q = pool fire heat release rate (kW)
χr = radiative fraction
R = distance from center of the pool fire to edge of the target (m)

Pool Fire Diameter Calculation

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

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

D = 1.54 m

Heat Release Rate Calculation

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

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

Q = 205.2 kW

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

$$R = L+D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = 3.51 m

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
POINT SOURCE RADIATION MODEL

Version 1805.1
(English Units)

RADIATIVE HEAT FLUX CALCULATION

$$q'' = Q\,\chi_r / 4\,\pi\,R^2$$

Answer	q'' =	0.03	Btu/ft^2-sec	0.40	kW/m^2

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-3b**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.0044	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	25100	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}
Heat Release Rate (Q)	205.20	kW
Fuel Area or Dike Area (A_{dike})	20.00	ft^2
Distance between Fire and Target (L)	9.00	ft

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

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

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

Select Fuel Type

User Specified Value

Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\text{->}2}$$

Where
q" = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\text{->}2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

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

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

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

D = 1.54 m

Emissive Power Calculation

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

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.33 kW/m^2

View Factor Calculation

$F_{1\text{->}2,H}$ = $(B-1/S)/\pi(B^2-1)^{1/2}\ \tan^{-1}\ ((B+1)\ (S-1)/(B-1)(S+1))^{1/2}-(A-1/S)/(\pi(A^2-1)^{1/2})\ \tan^{-1}\ ((A+1)(S-1)/(A-1)(S+1))^{1/2}$

$F_{1\text{->}2,V}$ = $1/(\pi S)\ \tan^{-1}(h/(S^2-1)^{1/2})-(h/\pi S)\ \tan^{-1}\ ((S-1)/(S+1))^{1/2} + Ah/\pi S(A^2-1)^{1/2}\ \tan^{-1}\ ((A+1)(S-1)/(A-1)(S+1))^{1/2}$

A = $(h^2+S^2+1)/2S$

B = $(1+S^2)/2S$

S = $2R/D$

h = $2H_f/D$

$F_{1\text{->}2,max}$ = $\sqrt{(F^2_{1\text{->}2,H} + F^2_{1\text{->}2,V})}$

Where
$F_{1\text{->}2,H}$ = horizontal view factor
$F_{1\text{->}2,V}$ = vertical view factor
$F_{1\text{->}2,max}$ = maximum view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

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

$R = L + D/2$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

$R = L+D/2 =$ 3.512 m

Heat Release Rate Calculation

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

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

Q = 205.20 kW

Pool Fire Flame Height Calculation

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

Where
Hf = flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

$H_f =$ 0.408 m

$S = 2R/D =$	**4.567**
$h = 2H_f/D =$	**0.530**
$A = (h^2+S^2+1)/2S =$	**2.424**
$B = (1+S^2)/2S =$	**2.393**
$F_{1\text{->}2,H} =$	**0.001**
$F_{1\text{->}2,V} =$	**0.020**
$F_{1\text{->}2,max} = \sqrt{(F^2_{1\text{->}2,H} + F^2_{1\text{->}2,V})} =$	**0.020**

F_{H1}	F_{H2}	F_{H3}	F_{H4}	$F_{1\text{->}2,H}$
0.318	0.896	0.318	0.893	0.001
F_{V1}	**F_{V2}**	**F_{V3}**	**F_{V4}**	**$F_{1\text{->}2,V}$**
0.008	0.025	0.041	0.893	0.020

RADIATIVE HEAT FLUX CALCULATION

$$q'' = EF_{1\text{->}2}$$

Answer	q" =	0.10	Btu/ft^2-sec	1.10	kW/m^2

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

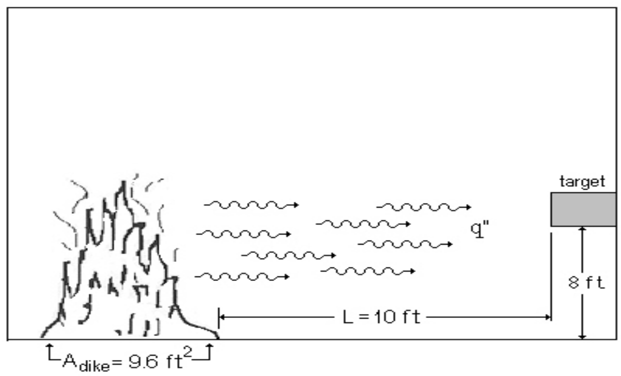
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 5.11-4

Problem Statement
A pool fire scenario may arise from a leak in a pump. This event allows the lubricating oil to spill and spread over the compartment floor. A pool fire ensues with a spill of 9.6 ft^2 is considered in a compartment with a concrete floor. The distance (L) between the pool fire and the target edge is assumed to be 10 ft. Calculate the flame radiant heat flux to a vertical target (safety-related) 8 ft high above the floor with no wind, using the solid flame radiation model. If the vertical target contains IEEE-383 unqualified cables ($\dot{q}''_{critical} = 5\ kW/m^2$), could there be cable failure in this fire scenario?



Example Problem 5-4: Radiant Heat Flux from a Pool Fire to a Vertical Target Fuel

Solution

Purpose:
(1) Calculate the radiant heat flux from the pool fire to the vertical target using the solid flame radiation model.
(2) Determine if the IEEE-383 unqualified cables are damaged.

Assumptions:
(1) The fire source will be nearly circular.
(2) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1.xls (click on *Solid Flame 2*)

FDT^s Inputs:
- Fuel Spill Area or Curb Area (A_{curb}) = 9.6 ft^2
- Distance between Fire Source and Target (L) = 10 ft
- Vertical Distance of Target from Ground ($H_1 = H_{f1}$) = 8 ft
- Select Fuel Type: **Lube Oil**

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)	Cable Failure
Solid Flame	3.0	No, $\dot{q}''_r < \dot{q}''_{critical}$

*see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-4**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Empirical Constant ($k\beta$)	0.7	m^{-1}
Heat Release Rate (Q)	841.15	kW
Fuel Area or Dike Area (A_{dike})	9.60	ft^2
Distance between Fire and Target (L)	10.00	ft
Vertical Distance of Target from Ground ($H_t = H_{f1}$)	8.00	ft

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

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

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

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

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\to 2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\to 2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

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

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

D = 1.07 m

Emissive Power Calculation

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

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.84 (kW/m^2)

View Factor Calculation

$$F_{1\to 2,V1} = 1/(\pi S)\tan^{-1}(h_1/(S^2-1)^{1/2})-(h_1/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_1h_1/\pi S(A_1^2-1)^{1/2}\tan^{-1}((A_1+1)(S-1)/(A_1-1)(S+1))^{1/2}$$
$$F_{1\to 2,V2} = 1/(\pi S)\tan^{-1}(h_2/(S^2-1)^{1/2})-(h_2/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_2h_2/\pi S(A_2^2-1)^{1/2}\tan^{-1}((A_2+1)(S-1)/(A_2-1)(S+1))^{1/2}$$
$$A_1 = (h_1^2+S^2+1)/2S$$
$$A_2 = (h_2^2+S^2+1)/2S$$
$$B = (1+S^2)/2S$$
$$S = 2R/D$$
$$h_1 = 2H_{f1}/D$$
$$h_2 = 2H_{f2}/D$$
$$F_{1\to 2,V} = F_{1\to 2,V1} + F_{1\to 2,V2}$$

Where
$F_{1\to 2,V}$ = total vertical view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

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

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 3.581 m

Heat Release Rate Calculation

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

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

Q = 841.15 kW

Pool Fire Flame Height Calculation

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

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

H_f = 2.389 m

$S = 2R/D =$		6.721					
$h_1 = 2H_{f1}/D =$		4.576					
$h_2 = 2H_{f2}/D =$	$2(H_f - H_{f1})/D =$	-0.094					
$A_1 = (h_1^2+S^2+1)/2S =$		4.993					
$A_2 = (h_2^2+S^2+1)/2S =$		3.435					
$B = (1+S^2)/2S =$		3.435					
			F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V1}$
$F_{1\text{->}2,V1} =$	0.054		0.029	0.154	0.221	0.812	0.054
$F_{1\text{->}2,V2} =$	-0.002		F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V2}$
$F_{1\text{->}2,V} = F_{1\text{->}2,V1} + F_{1\text{->}2,V2} =$	0.053		-0.001	-0.003	-0.005	0.860	-0.002

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(English Units)

RADIATIVE HEAT FLUX CALCULATION

$q'' = EF_{1->2}$

Answer	q" =	0.26	Btu/ft²-sec	2.99	kW/m²

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

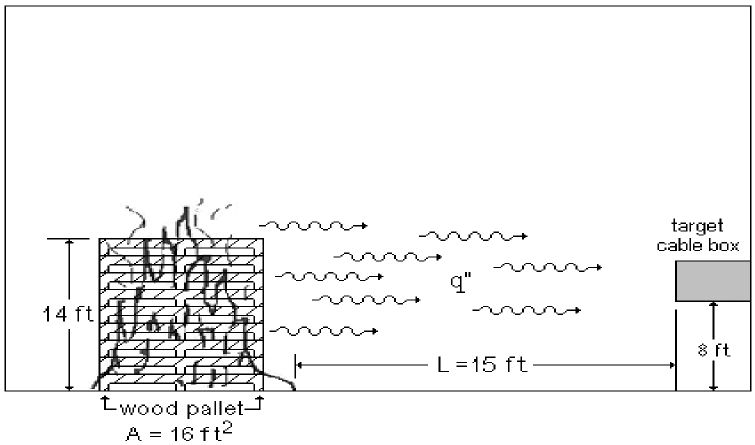
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 5.11-5

Problem Statement
A transient combustible fire scenario may arise from burning wood pallets (4 ft x 4 ft = 16 ft^2), stacked 14 ft high on the floor of a compartment. Calculate the flame radiant heat flux from exposure fire to a vertical target (safety-related electrical junction box) located 8 ft high above the floor, with no wind, using the solid flame radiation model. The distance (L) between the transient fire and the target edge is assumed to be 15 ft.



Example Problem 5-5: Radiant Heat Flux from a Burning Pallet to a Vertical Target Fuel

Solution

Purpose:
(1) Calculate the radiant heat flux from the burning pallet to the vertical target fuel using the solid flame radiation model.

Assumptions:
(1) The fire source will be nearly circular.
(2) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1.xls (click on *Solid Flame 2*)

FDT^s Inputs:
- Fuel Spill Area or Curb Area (A) = 16 ft^2
- Distance between Fire Source and Target (L) = 15 ft
- Vertical Distance of Target from Ground ($H_1 = H_{f1}$) = 8 ft
- Select Fuel Type: **Douglas Fir Plywood**

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)
Solid Flame	0.30

*see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1 (English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-5**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.01082	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	10900	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}
Heat Release Rate (Q)	175.31	kW
Fuel Area or Dike Area (A_{dike})	16.00	ft^2
Distance between Fire and Target (L)	15.00	ft
Vertical Distance of Target from Ground ($H_1 = H_{f1}$)	8.00	ft

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

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

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

Select Fuel Type
Douglas Fir Plywood
Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\to 2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\to 2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

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

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

D = 1.38 m

Emissive Power Calculation

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

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.51 (kW/m^2)

View Factor Calculation

$$F_{1\to 2,V1} = 1/(\pi S)\tan^{-1}(h_1/(S^2-1)^{1/2})-(h_1/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_1h_1/\pi S(A_1^2-1)^{1/2}\tan^{-1}((A_1+1)(S-1)/(A_1-1)(S+1))^{1/2}$$
$$F_{1\to 2,V2} = 1/(\pi S)\tan^{-1}(h_2/(S^2-1)^{1/2})-(h_2/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_2h_2/\pi S(A_2^2-1)^{1/2}\tan^{-1}((A_2+1)(S-1)/(A_2-1)(S+1))^{1/2}$$
$$A_1 = (h_1^2+S^2+1)/2S$$
$$A_2 = (h_2^2+S^2+1)/2S$$
$$B = (1+S^2)/2S$$
$$S = 2R/D$$
$$h_1 = 2H_{f1}/D$$
$$h_2 = 2H_{f2}/D$$
$$F_{1\to 2,V} = F_{1\to 2,V1} + F_{1\to 2,V2}$$

Where
$F_{1\to 2,V}$ = total vertical view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1 (English Units)

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

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 5.260 m

Heat Release Rate Calculation

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

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

Q = 175.31 kW

Pool Fire Flame Height Calculation

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

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

H_f = 0.453 m

$S = 2R/D =$		7.647					
$h_1 = 2H_{f1}/D =$		3.545					
$h_2 = 2H_{f2}/D =$	$2(H_f - H_{f1})/D =$	-2.887					
$A_1 = (h_1^2+S^2+1)/2S =$		4.710					
$A_2 = (h_2^2+S^2+1)/2S =$		4.434					
$B = (1+S^2)/2S =$		3.889					
			F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V1}$
$F_{1\text{->}2,V1} =$	0.037		0.018	0.106	0.151	0.827	0.037
$F_{1\text{->}2,V2} =$	-0.032		F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V2}$
$F_{1\text{->}2,V} = F_{1\text{->}2,V1} + F_{1\text{->}2,V2} =$	0.005		-0.015	-0.086	-0.123	0.834	-0.032

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(English Units)

RADIATIVE HEAT FLUX CALCULATION

$q'' = EF_{1->2}$

Answer	q" =	0.03	Btu/ft²-sec	0.30	kW/m²

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

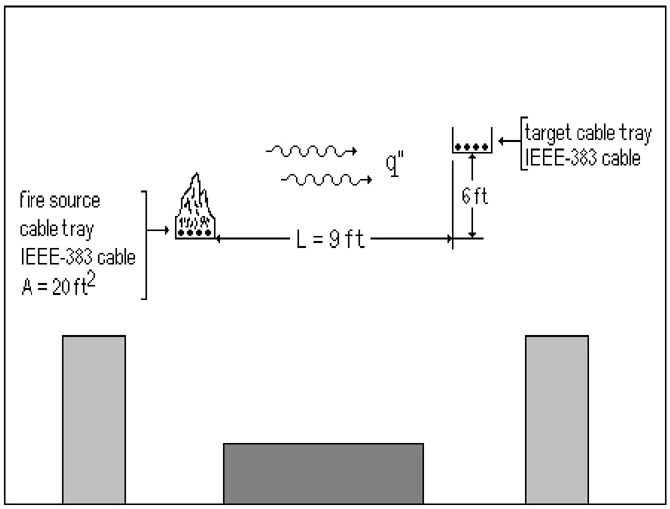
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 5.11-6

Problem Statement
A fire scenario may arise from a horizontal cable tray burning in a very large compartment. The cables in the tray are IEEE-383 unqualified ($\dot{q}''_{critical} = 5\ kW/m^2$) and made of XPE/FRXPE insulation material (assume that the exposed area of the cable is 20 ft^2). A safety-related cable tray is also filled with IEE E-383 qualified ($\dot{q}''_{critical} = 10\ kW/m^2$) made of XLPE insulation material located at a radial distance (L) of 9 ft from the fire source and 6 ft above the fire source. Calculate the flame radiant heat flux to a target (safety-related cable tray) using the solid flame radiation model. Is the IEEE-383 qualified cable tray damaged?



Example Problem 5-6: Radiant Heat Flux from a Burning Cable Tray to a Vertical Target Fuel

Solution

Purpose:
(1) Calculate the radiant heat flux from the burning cable tray to the vertical target cable tray using the solid flame radiation model.
(2) Determine if the IEEE-383 cable tray (target) is damaged.

Assumptions:
(1) The fire source will be nearly circular.
(2) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1.xls (click on *Solid Flame 2*)

FDT^s Inputs:
- Mass Burning Rate of Fuel ($\dot{m}''$) = 0.0037 kg/m^2-sec
- Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$) = 28,300 kJ/kg
- Fuel Spill Area or Curb Area (A_{curb}) = 20 ft^2
- Distance between Fire Source and Target (L) = 9 ft
- Vertical Distance of Target from Ground ($H_1 = H_{f1}$) = 6 ft

Note: Since the insulation material (XPE/FRXPE) is not available in the thermal properties data of the spreadsheet, we have to input the mass burning rate and effective heat of combustion in the spreadsheet. Values of cable materials properties are available in Table 3-4. Select **User-Specified Value**, and enter the $\dot{m}''$ and $\Delta H_{c,eff}$ values from Table 3-4.

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)	Cable Failure
Solid Flame	0.6	No, $\dot{q}_r'' < \dot{q}_{critical}''$

*see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1 (English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-6**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.0037	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	28300	kJ/kg
Empirical Constant (kβ)	20	m^{-1}
Heat Release Rate (Q)	194.56	kW
Fuel Area or Dike Area (A_{dike})	20.00	ft^2
Distance between Fire and Target (L)	9.00	ft
Vertical Distance of Target from Ground ($H_t = H_{f1}$)	6.00	ft

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

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

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

Select Fuel Type

User Specified Value

Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\to 2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\to 2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

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

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

D = 1.54 m

Emissive Power Calculation

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

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.33 (kW/m^2)

View Factor Calculation

$F_{1\to 2,V1}$ = $1/(\pi S)\tan^{-1}(h_1/(S^2-1)^{1/2})-(h_1/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_1h_1/\pi S(A_1^2-1)^{1/2}\tan^{-1}((A_1+1)(S-1)/(A_1-1)(S+1))^{1/2}$
$F_{1\to 2,V2}$ = $1/(\pi S)\tan^{-1}(h_2/(S^2-1)^{1/2})-(h_2/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_2h_2/\pi S(A_2^2-1)^{1/2}\tan^{-1}((A_2+1)(S-1)/(A_2-1)(S+1))^{1/2}$
A_1 = $(h_1^2+S^2+1)/2S$
A_2 = $(h_2^2+S^2+1)/2S$
B = $(1+S^2)/2S$
S = $2R/D$
h_1 = $2H_{f1}/D$
h_2 = $2H_{f2}/D$
$F_{1\to 2,V}$ = $F_{1\to 2,V1} + F_{1\to 2,V2}$

Where
$F_{1\to 2,V}$ = total vertical view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

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

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 3.512 m

Heat Release Rate Calculation

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

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

Q = 194.56 kW

Pool Fire Flame Height Calculation

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

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

H_f = 0.366 m

$S = 2R/D =$			4.567					
$h_1 = 2H_{f1}/D =$			2.378					
$h_2 = 2H_{f2}/D =$	$2(H_f-H_{f1})/D =$		-1.902					
$A_1 = (h_1^2+S^2+1)/2S =$			3.012					
$A_2 = (h_2^2+S^2+1)/2S =$			2.789					
$B = (1+S^2)/2S =$			2.393					
				F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V1}$
$F_{1\text{->}2,V1} =$		0.071		0.034	0.112	0.176	0.846	0.071
$F_{1\text{->}2,V2} =$		-0.061		F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V2}$
$F_{1\text{->}2,V} = F_{1\text{->}2,V1} + F_{1\text{->}2,V2} =$		0.010		-0.028	-0.089	-0.142	0.861	-0.061

Version 1805.1
(English Units)

RADIATIVE HEAT FLUX CALCULATION

$q'' = EF_{1\text{->}2}$

Answer	q" =	0.05 Btu/ft²-sec	0.57 kW/m²

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

6.11 Problems

Example Problem 6.11-1

Problem Statement
Calculate the ignition time for a PVC/PE power cable, assuming that a 6.5 ft diameter pool fire produces a 25 kW/m^2 heat flux.

Solution

Purpose:
(1) Calculate the ignition time for a PVC/PE power cable.

Assumptions:
(1) The material is infinitely thick.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 06_Ignition_Time_Calculations_Sup1.xls (click on *Ignition_Time_Calculations3*)

FDT^s Input Parameters:
- Exposure or External Radiative Heat Flux to Target Fuel ($\dot{q}_e''$) = 25 kW/m^2
- Click on the option button for Electrical Cables - Power
- Select Material: **PVC/PE**

Results*

Material	Ignition Time (t_{ig}) (Method of Tewarson) (min.)
PVC/PE	9.0

*see spreadsheet on next page

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

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 6.11-1**

INPUT PARAMETERS

Exposure or External Radiative Heat Flux to Target Fuel (q''_e)	25.00	kW/m^2
Target Critical Heat Flux for Ignition (CHF)	15.00	kW/m^2
Target Thermal Response Parameter (TRP)	263	$kW\text{-}sec^{1/2}/m^2$

Calculate

CRITICAL HEAT FLUX AND THERMAL RESPONSE PARAMETER FOR MATERIALS

Materials	Critical Heat Flux for Ignition CHF (kW/m^2)	Thermal Response Parameter (TRP) ($kW\text{-}sec^{1/2}/m^2$)
Electrical Cables - Power		
PVC/PVC	19.00	248.5
PE/PVC	15.00	232.5
PVC/PE	15.00	263
Silicone/PVC	19.00	212
Silicone/crosslinked polyolefin (XLPO)	27.50	446
EPR (ethylene-propylene rubber/EPR)	21.50	517
XLPE/XLPE	22.50	329.5
XLPE/EVA (ethyl-vinyl acetate)	17.00	472.5
XLPE/Neoprene	15.00	291
XLPO/XLPO	20.50	498
XLPO, PVF (polyvinylidine fluoride)/XLPO	15.50	526
EPR/Chlorosulfonated PE	16.50	349.5
EPR, FR	21.00	368.5
User Specified Value	Enter Value	Enter Value
Electrical Cables - Communications		
PVC/PVC	15.00	131
PE/PVC	20.00	183
XLPE/XLOP	20.00	498
Si/XLOP	20.00	457
EPR-FR	19.00	295
Chlorinated PE	12.00	217
ETFE/EVA	22.00	454
PVC/PVF	30.00	264
FEP/FEP	36.00	645
User Specified Value	Enter Value	Enter Value
Synthetic Materials		
Polypropylene	15.00	193
Nylon	15.00	270
Polymethylmethacrylate (PMMA)	11.00	274
Polycarbonate	15.00	331
Polycarbonate panel	16.00	420
User Specified Value	Enter Value	Enter Value
Natural Materials		
Wood (red oak)	10.00	134
Wood (douglas fir)	10.00	138
Wood (douglas fir/fire retardant, FR)	10.00	251
Corrugated paper (light)	10.00	152
User Specified Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-58.*

Select Material
PVC/PE
Scroll to desired material then Click on selection

Select Material
Scroll to desired material then Click on selection

Select Material
Scroll to desired material then Click on selection

Select Material
Scroll to desired material then Click on selection

Version 1805.1
(English Units)

ESTIMATING IGNITION TIME FOR COMBUSTIBLES
METHOD OF TEWARSON
THERMALLY THICK MATERIALS

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-83.*

$$\sqrt{(1/t_{ig})} = (\sqrt{(4/\pi)}\,(q''_e - CHF))/TRP$$

$$t_{ig} = (\pi/4)\,(TRP)^2/(q''_e - CHF)^2$$

Where
t_{ig} = target ignition time (sec)
q''_e = external radiative heat flux to target (kW/m^2)
CHF = target critical heat flux for ignition (kW/m^2)
TRP = thermal response parameter of target material ($kW\text{-}sec^{2}/m^{2}$)

$$t_{ig} = (\pi/4)\,(TRP)^2/(q''_e - CHF)^2$$

Answer	t_{ig} =	543.25 sec	9.05 minutes

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

Prepared by: ____________ Date: ______ Or ______

Checked by: ____________ Date: ______ Or ______

Additional Information:

Example Problem 6.11-2

Problem Statement
Determine the time for 2 inch thick Douglas fir plywood to ignite when it is subjected to a flame heat flux of 25 kW/m^2, assuming the surface of the plywood is initially at 68 °F.

Solution

Purpose:
(1) Calculate the ignition time of Douglas fir plywood.

Assumptions:
(1) The material is infinitely thick.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 06_Ignition_Time_Calculations_Sup1.xls (click on *Ignition_Time_Calculations3*)

FDT^s Input Parameters:
- Exposure or External Radiative Heat Flux to Target Fuel = 25 kW/m^2
- Click on the option button for Natural Materials
- Select Material: **Wood (Douglas fir)**

Note: The ignition time calculation method (Tewarson) provided in the spreadsheet *Ignition_Time_Calculations3* does not require the material thickness or initial surface temperature; therefore, material thickness and temperature are additional information only. However, if the initial temperature of the material is relatively high (compare with ambient temperature range), the ignition time value definitely will not be realistic based on this method. Also, we are assuming the material as infinitely thick to use the method; thus, we do not have to consider the thickness for this problem.

Results*

Material	Ignition Time (t_{ig}) (Method of Tewarson) (min.)
Wood (Douglas fir)	1.11

*see spreadsheet on next page

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

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 6.11-2**

INPUT PARAMETERS

Exposure or External Radiative Heat Flux to Target Fuel (q''_e)	25.00	kW/m^2
Target Critical Heat Flux for Ignition (CHF)	10.00	kW/m^2
Target Thermal Response Parameter (TRP)	138	$kW\text{-}sec^{1/2}/m^2$

Calculate

CRITICAL HEAT FLUX AND THERMAL RESPONSE PARAMETER FOR MATERIALS

Materials	Critical Heat Flux for Ignition CHF (kW/m^2)	Thermal Response Parameter (TRP) ($kW\text{-}sec^{1/2}/m^2$)
Electrical Cables - Power		
PVC/PVC	19.00	248.5
PE/PVC	15.00	232.5
PVC/PE	15.00	263
Silicone/PVC	19.00	212
Silicone/crosslinked polyolefin (XLPO)	27.50	446
EPR (ethylene-propylene rubber/EPR)	21.50	517
XLPE/XLPE	22.50	329.5
XLPE/EVA (ethyl-vinyl acetate)	17.00	472.5
XLPE/Neoprene	15.00	291
XLPO/XLPO	20.50	498
XLPO, PVF (polyvinylidine fluoride)/XLPO	15.50	526
EPR/Chlorosulfonated PE	16.50	349.5
EPR, FR	21.00	368.5
User Specified Value	Enter Value	Enter Value
Electrical Cables - Communications		
PVC/PVC	15.00	131
PE/PVC	20.00	183
XLPE/XLOP	20.00	498
Si/XLOP	20.00	457
EPR-FR	19.00	295
Chlorinated PE	12.00	217
ETFE/EVA	22.00	454
PVC/PVF	30.00	264
FEP/FEP	36.00	645
User Specified Value	Enter Value	Enter Value
Synthetic Materials		
Polypropylene	15.00	193
Nylon	15.00	270
Polymethylmethacrylate (PMMA)	11.00	274
Polycarbonate	15.00	331
Polycarbonate panel	16.00	420
User Specified Value	Enter Value	Enter Value
Natural Materials		
Wood (red oak)	10.00	134
Wood (douglas fir)	10.00	138
Wood (douglas fir/fire retardant, FR)	10.00	251
Corrugated paper (light)	10.00	152
User Specified Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-58.*

Select Material
Scroll to desired material then Click on selection

Select Material
Scroll to desired material then Click on selection

Select Material
Scroll to desired material then Click on selection

Select Material
Wood (douglas fir)
Scroll to desired material then Click on selection

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

Version 1805.1
(English Units)

ESTIMATING IGNITION TIME FOR COMBUSTIBLES
METHOD OF TEWARSON
THERMALLY THICK MATERIALS

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-83.*

$$\sqrt{(1/t_{ig})} = (\sqrt{(4/\pi)}\,(q''_e - CHF))/TRP$$

$$t_{ig} = (\pi/4)\,(TRP)^2/(q''_e - CHF)^2$$

Where
t_{ig} = target ignition time (sec)
q''_e = external radiative heat flux to target (kW/m^2)
CHF = target critical heat flux for ignition (kW/m^2)
TRP = thermal response parameter of target material ($kW\text{-}sec^{2}/m^2$)

$$t_{ig} = (\pi/4)\,(TRP)^2/(q''_e - CHF)^2$$

Answer	t_{ig} =	66.48 sec	1.11 minutes

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

Prepared by: Date: Or

Checked by: Date: Or

Additional Information:

7.12 Problems

Example Problem 7.12-1

Problem Statement
A 32 gallon trash can exposure fire source is located 6.5 ft beneath a horizontal cable tray. It is assumed that the trash fire ignites an area of approximately 21 ft^2 of the cable tray. The cables in the tray are IEEE-383 unqualified and made of PE/PVC insulation material. Compute the full-scale HRR of the PE/PVC cable insulation. The bench-scale HRR of PE/PVC is 589 kW/m^2.

Solution

Purpose:
(1) Calculate the full-scale HRR of the PE/PVC insulation material.

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

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 07_Cable_HRR Calculations_Sup1.xls

FDT^s Input Parameters:
- Exposure Cable Tray Burning Area (A_f) = 21 ft^2
- Select Material: **PE/PVC** (the one with a bench-scale HRR of 589 kW/m^2)

Results*

Cable Insulation	Full Scale HRR ($\dot{Q}_{fs}$) (kW)
PE/PVC	517

*see spreadsheet on next page

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

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 7.12.-1**

INPUT PARAMETERS

Cable Bench-Scale HRR (Q_{bs}'')	589	kW/m^2
Exposed Floor Area (Length x Width) of Burning Cable Tray (A_f)	21.00	ft^2

Calculate

HEAT RELEASE RATE DATA FOR CABLE TRAY FIRE

BENCH-SCALE HRR OF CABLE TRAY FIRE

Cable Type	Bench-Scale HRR per Unit Floor Area (L x W) Q''_{bs} (kW/m^2)
FRXPE/Cl.S.PE	258
ld PE	1071
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218
PE, PP/Cl.S.PE	345
PE, PP/Cl.S.PE	299
PE, PP/Cl.S.PE	271
PE, PP/Cl.S.PE	177
PE/PVC	589
PE/PVC	395
PE/PVC	359
PE/PVC	312
Silicone, glass braid	128
Silicone, glass braid, asbestos	182
Teflon	98
XPE/Cl.S.PE	204
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
User Specified Value	Enter Value

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

Select Cable Type

PE/PVC

Scroll to desired cable type **then Click** on selection

ESTIMATING FULL-SCALE CABLE TRAY HEAT RELEASE RATE

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

$$Q_{fs} = 0.45\ Q_{bs}''\ A_f$$

Where,
Q_{fs} = cable tray full-scale HRR (kW)
Q_{bs}'' = cable tray bench-scale HRR (kW/m^2)
A_f = exposed floor area (length x width) of burning cable tray (m^2)

Heat Release Rate Calculation

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

Answer	Q_{fs} =	490.12 Btu/sec	517.10 kW

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

Prepared by: ___ Date: ___ Organization: ___

Checked by: ___ Date: ___ Organization: ___

Additional Information:

Example Problem 7.12-2

Problem Statement
A 1.5 ft high stack of untreated wood pallets (exposure fire source) from a recent plant modification ignites and is located 5 ft beneath a horizontal cable tray. It is assumed that the wood pallets ignite an area of approximately 43 ft^2 of the cable tray. The cables in the tray are IEEE-383 qualified and made of PE insulation material. Compute the full-scale HRR of PE cable insulation. The bench-scale HRR of PE material is 1,071 kW/m^2.

Solution

Purpose:
(1) Calculate the full-scale HRR of the PE insulation material.

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

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 07_Cable_HRRCalculations_Sup1.xls

FDT^s Input Parameters:
- Exposure Cable Tray Burning Area (A_f) = 43 ft^2
- Select Material: **Id PE**

Results*

Cable Insulation	Full Scale HRR ($\dot{Q}_{fs}$) (kW)
Id PE	1,925

*see spreadsheet on next page

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

Version 1805.1 (English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 7.12.-2**

INPUT PARAMETERS

Cable Bench-Scale HRR (Q_{bs}")	1071	kW/m^2
Exposed Floor Area (Length x Width) of Burning Cable Tray (A_f)	43.00	ft^2

Calculate

HEAT RELEASE RATE DATA FOR CABLE TRAY FIRE

BENCH-SCALE HRR OF CABLE TRAY FIRE

Cable Type	Bench-Scale HRR per Unit Floor Area (L x W) Q''_{bs} (kW/m^2)
FRXPE/Cl.S.PE	258
Id PE	1071
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218
PE, PP/Cl.S.PE	345
PE, PP/Cl.S.PE	299
PE, PP/Cl.S.PE	271
PE, PP/Cl.S.PE	177
PE/PVC	589
PE/PVC	395
PE/PVC	359
PE/PVC	312
Silicone, glass braid	128
Silicone, glass braid, asbestos	182
Teflon	98
XPE/Cl.S.PE	204
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
User Specified Value	Enter Value

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

Select Cable Type

Id PE

Scroll to desired cable type **then Click** on selection

ESTIMATING FULL-SCALE CABLE TRAY HEAT RELEASE RATE

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

$$Q_{fs} = 0.45\, Q_{bs}''\, A_f$$

Where,
Q_{fs} = cable tray full-scale HRR (kW)
Q_{bs}'' = cable tray bench-scale HRR (kW/m^2)
A_f = exposed floor area (length x width) of burning cable tray (m^2)

Heat Release Rate Calculation

$$Q_{fs} = 0.45\, Q_{bs}\, A_f$$

Answer	Q_{fs} =	1824.85 Btu/sec	1925.31 kW

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

Prepared by: ____ Date: ____ Organization: ____

Checked by: ____ Date: ____ Organization: ____

Additional Information:

Example Problem 7.12-3

Problem Statement
A 3.5 ft diameter flammable liquid (lubricating oil) pool fire arises from a breach in an auxiliary cooling water pump oil tank. The pool fire is located on the floor, 10 ft beneath a horizontal cable tray. It is assumed that the pool fire ignites an area of approximately 10.8 ft^2 of the cable tray. The cables in the tray are IEEE-383 unqualified and made of XPE/FRXPE insulation material. Compute the full scale HRR of XPE/FRXPE cable insulation. The bench-scale HRR of XPE/FRXPE is 475 kW/m^2.

Solution

Purpose:
(1) Calculate the full-scale HRR of the XPE/FRXPE insulation material.

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

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 07_Cable_HRR Calculations_Sup1.xls

FDT^s Input Parameters:
- Exposure Cable Tray Burning Area (A_f) = 10.8 ft^2
- Select Material: **XPE/FRXPE**

Results*

Cable Insulation	Full Scale HRR ($\dot{Q}_{fs}$) (kW)
XPE/FRXPE	214

*see spreadsheet on next page

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

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: Example 7.12.-3

INPUT PARAMETERS

Cable Bench-Scale HRR (Q_{bs}'')	475	kW/m^2
Exposed Floor Area (Length x Width) of Burning Cable Tray (A_f)	10.80	ft^2

Calculate

HEAT RELEASE RATE DATA FOR CABLE TRAY FIRE

BENCH-SCALE HRR OF CABLE TRAY FIRE

Cable Type	Bench-Scale HRR per Unit Floor Area (L x W) Q''_{bs} (kW/m^2)
FRXPE/Cl.S.PE	258
ld PE	1071
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218
PE, PP/Cl.S.PE	345
PE, PP/Cl.S.PE	299
PE, PP/Cl.S.PE	271
PE, PP/Cl.S.PE	177
PE/PVC	589
PE/PVC	395
PE/PVC	359
PE/PVC	312
Silicone, glass braid	128
Silicone, glass braid, asbestos	182
Teflon	98
XPE/Cl.S.PE	204
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
User Specified Value	Enter Value

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

Select Cable Type

XPE/FRXPE

Scroll to desired cable type **then Click** on selection

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

Version 1805.1
(English Units)

ESTIMATING FULL-SCALE CABLE TRAY HEAT RELEASE RATE

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

$$Q_{fs} = 0.45\ Q_{bs}''\ A_f$$

Where,
Q_{fs} = cable tray full-scale HRR (kW)
Q_{bs}'' = cable tray bench-scale HRR (kW/m^2)
A_f = exposed floor area (length x width) of burning cable tray (m^2)

Heat Release Rate Calculation

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

Answer	Q_{fs} =	203.28 Btu/sec	214.47 kW

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

8.9 Problems

Example Problem 8.9-1

Problem Statement
A horizontal power cable fails as a result of self-initiated fire and burn in a compartment. Compute the burning duration of a cable tray with an exposed surface area of 1 ft^2 filled with 10 lb of non-IEEE-383 qualified PE/PVC cables. The heat release per unit floor area of PE/PVC is 589 kW/m^2, and the heat of combustion is 24,000 kJ/kg.

Solution

Purpose:
(1) Calculate the burning duration of the cable material (PE/PVC).

Assumptions:
(1) Combustion is incomplete and takes place entirely within the confines of the compartment.
(2) Virtually all of the potential energy in the fuel is released in the involved compartment.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 08_Burning_Duration Solid_Sup1.xls

FDT^s Input Parameters:
- Mass of Solid Fuel (m_{solid}) = 10 lb
- Exposure Fuel Surface Area (A_{fuel}) = 1 ft^2
- Select Material: **PE/PVC**

Results*

Material	Burning Duration (t_{solid}) (min.)
PE/PVC	33

*see spreadsheet on next page

CHAPTER 8
ESTIMATING BURNING DURATION
OF
SOLID COMBUSTIBLES

Version 1805.1
(English Units)

The following calculations provides an approximation of the burning duration of solid combustibles based on free burning rate with a given surface area.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 8.9-1**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Mass of Solid Fuel (m_{solid})	10.00	lb
Exposed Floor Area (Length x Width) of Fuel (A_{fuel})	1.00	ft^2
Heat Release Rate (HRR) per Unit Floor Area (Q")	589	kW/m^2
Effective Heat of Combustion ($\Delta H_{c,eff}$)	24000	kJ/kg

Calculate

THERMAL PROPERTIES OF SOLID COMBUSTIBLE MATERIALS

Material	HRR per Unit Floor Area Q" (kW/m^2)	Heat of Combustion ΔH_c (kJ/kg)
Douglas Fir Plywood	221	17600
Empty Cartons 15 ft high	1700	12700
Ethylene Propylene Dien Rubber (EPDM)	956	28800
Fire Retardant Treated Plywood	81	13500
Nylon 6/6	1313	32000
Particle Board, 19 mm thick	1900	17500
PE, Nylon/PVC, Nylon	231	9200
PE/PVC	589	24000
Polycarbonate	420	24400
Polyethylene (PE)	1408	46500
Polymethlmethacrylate (PMMA)	665	26000
Polypropylene (PP)	1509	43200
Polystyrene (PS)	1101	42000
Polyurethane	710	45000
Polyvinyl Chloride (PVC) Flexible	237	15700
Strene-Butadiene Copolymers (SBR)	163	44000
Teflon	98	3200
Wood Pallets, stacked 1.5 ft high	1420	14000
Wood Pallets, stacked 5 ft high	3970	14000
Wood Pallets, stacked 10 ft high	6800	14000
XPE/FRXPE	475	28300
XPE/Neoprene	354	10300
User Specified Value	Enter Value	Enter Value

Select Material

PE/PVC

Scroll to desired material **then**
Click on selection

CHAPTER 8
ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.1 (English Units)

References:

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

Karlsson and Quantiere, Enclosure Fire Dynamics, Chapter 3: Energy Release Rate," CRC Press, 1999.

Johnson, D. G., "Combustion Properties of Plastics," Journal of Applied Fire Science, Volume 4, No. 3, 1994-95, pp. 185-201.

Hirschler, M. M., "Heat Release from Plastic Materials," Heat Release in Fires, Babrauskas and Grayson, Editors, Elsevier Applied Science, 1992.

BURNING DURATION OF SOLID COMBUSTIBLES

Reference: Buchanan, A. H., "Structural Design for Fire Safety," 2001, Page 38.

The burning duration of a solid fuel can be calculated if the total energy contained in the fuel and HRR are known.
The burning duration is given by:

$$Q = E / t_{solid} \quad \text{or} \quad t_{solid} = (E) / (Q'' A_{Fuel})$$

Where,
t_{solid} = burning duration of solid combustible (sec)
E = $m_{Fuel}\,\Delta H_c$ = total energy contained in the fuel (kJ)
Q = heat release rate of fire (kW)
Q'' = heat release rate per unit floor area of fuel (kW/m^2)
A_{Fuel} = exposed floor area (length x width) of fuel (m^2)

$$t_{solid} = (m_{Fuel}\,\Delta H_c) / (Q'' A_{Fuel})$$

Where,
m_{Fuel} = mass of solid fuel (kg)
ΔH_c = fuel effective heat of combustion (kJ/kg)

$$t_{solid} = (m_{solid}\,\Delta H_c) / (Q'' A_{solid})$$

Answer	t_{solid} =	1989.44 sec	33.16 min

NOTE:
The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ___ Date: ___ Organization: ___

Checked by: ___ Date: ___ Organization: ___

Additional Information:

Example Problem 8.9-2

Problem Statement
A horizontal cable tray filled with non-IEEE-383 qualified XPE/FRXPE cables are ignited as a result of overhead welding and burn in a compartment 20 ft wide x 20 ft deep x 10 ft high. The cable tray has a nominal width of 2 ft and a linear length of 24 ft (i.e., exposed surface area of 48 ft^2). Compute the burning duration of XPE/FRXPE cables assuming the mass of cables is 50 lb. The heat release per unit area of XPE/FRXPE is 475 kW/m^2 and heat of combustion is 28,300 kJ/kg.

Solution

Purpose:
(1) Calculate the burning duration of the cable material (XPE/FRXPE).

Assumptions:
(1) Combustion is incomplete and takes place entirely within the confines of the compartment.
(2) Virtually all of the heat energy in the fuel is released in the involved compartment.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 08_Burning_Duration Solid_Sup1.xls

FDT^s Input Parameters:
- Mass of Solid Fuel (m_{solid}) = 50 lb
- Exposure Fuel Surface Area (A_{fuel}) = 48 ft^2
- Select Material: **XPE/FRXPE**

Results*

Material	Burning Duration (t_{solid}) (min.)
XPE/FRXPE	5.1

*see spreadsheet on next page

CHAPTER 8
ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.1
(English Units)

The following calculations provides an approximation of the burning duration of solid combustibles based on free burning rate with a given surface area.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: Example 8.9-2

INPUT PARAMETERS

COMPARTMENT INFORMATION

Mass of Solid Fuel (m_{solid})	50.00	lb
Exposed Floor Area (Length x Width) of Fuel (A_{fuel})	48.00	ft^2
Heat Release Rate (HRR) per Unit Floor Area (Q")	475	kW/m^2
Effective Heat of Combustion ($\Delta H_{c,eff}$)	28300	kJ/kg

Calculate

THERMAL PROPERTIES OF SOLID COMBUSTIBLE MATERIALS

Material	HRR per Unit Floor Area Q" (kW/m^2)	Heat of Combustion ΔH_c (kJ/kg)
Douglas Fir Plywood	221	17600
Empty Cartons 15 ft high	1700	12700
Ethylene Propylene Dien Rubber (EPDM)	956	28800
Fire Retardant Treated Plywood	81	13500
Nylon 6/6	1313	32000
Particle Board, 19 mm thick	1900	17500
PE, Nylon/PVC, Nylon	231	9200
PE/PVC	589	24000
Polycarbonate	420	24400
Polyethylene (PE)	1408	46500
Polymethlmethacrylate (PMMA)	665	26000
Polypropylene (PP)	1509	43200
Polystyrene (PS)	1101	42000
Polyurethane	710	45000
Polyvinyl Chloride (PVC) Flexible	237	15700
Strene-Butadiene Copolymers (SBR)	163	44000
Teflon	98	3200
Wood Pallets, stacked 1.5 ft high	1420	14000
Wood Pallets, stacked 5 ft high	3970	14000
Wood Pallets, stacked 10 ft high	6800	14000
XPE/FRXPE	475	28300
XPE/Neoprene	354	10300
User Specified Value	Enter Value	Enter Value

Select Material

XPE/FRXPE

Scroll to desired material **then Click** on selection

CHAPTER 8
ESTIMATING BURNING DURATION
OF
SOLID COMBUSTIBLES

Version 1805.1
(English Units)

References:

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

Karlsson and Quantiere, Enclosure Fire Dynamics, Chapter 3: Energy Release Rate," CRC Press, 1999.

Johnson, D. G., "Combustion Properties of Plastics," Journal of Applied Fire Science, Volume 4, No. 3, 1994-95, pp. 185-201.

Hirschler, M. M., "Heat Release from Plastic Materials," Heat Release in Fires, Babrauskas and Grayson, Editors, Elsevier Applied Science, 1992.

BURNING DURATION OF SOLID COMBUSTIBLES

Reference: Buchanan, A. H., "Structural Design for Fire Safety," 2001, Page 38.

The burning duration of a solid fuel can be calculated if the total energy contained in the fuel and HRR are known.
The burning duration is given by:

$$Q = E / t_{solid} \quad \text{or} \quad t_{solid} = (E) / (Q'' A_{Fuel})$$

Where,
t_{solid} = burning duration of solid combustible (sec)
E = $m_{Fuel}\,\Delta H_c$ = total energy contained in the fuel (kJ)
Q = heat release rate of fire (kW)
Q'' = heat release rate per unit floor area of fuel (kW/m^2)
A_{Fuel} = exposed floor area (length x width) of fuel (m^2)

$$t_{solid} = (m_{Fuel}\,\Delta H_c) / (Q''\,A_{Fuel})$$

Where,
m_{Fuel} = mass of solid fuel (kg)
ΔH_c = fuel effective heat of combustion (kJ/kg)

$$t_{solid} = (m_{solid}\,\Delta H_c) / (Q''\,A_{solid})$$

Answer	t_{solid} =	303.01 sec	5.05 min

NOTE:
The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 8.9-3

Problem Statement
A fire involving a 1.5 ft high stack of wood pallets is located in a compartment 40 ft wide x 40 ft deep x 10 ft high. The mass of the wood pallets is 30 lb. Compute the burning duration of the wood pallet fire in the compartment. The exposed surface area of the wood pallets is 4 ft x 4 ft or 16 ft^2.

Solution

Purpose:
(1) Calculate the burning duration of the stack of wood pallets.

Assumptions:
(1) Combustion is incomplete and takes place entirely within the confines of the compartment.
(2) Virtually all of the heat energy in the fuel is released in the involved compartment.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 08_Burning_Duration Solid_Sup1.xls

FDT^s Input Parameters:
- Mass of Solid Fuel (m_{solid}) = 30 lb
- Exposure Fuel Surface Area (A_{fuel}) = 16 ft^2
- Select Material: **Wood pallet, stacked 1.5 ft high**

Results*

Material	Burning Duration (t_{solid}) (min.)
Wood pallet, stacked 1.5 ft high	1.5

*see spreadsheet on next page

CHAPTER 8
ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.1
(English Units)

The following calculations provides an approximation of the burning duration of solid combustibles based on free burning rate with a given surface area.

Parameters in YELLOW CELLS are Entered by the User.

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

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

Project / Inspection Title: **Example 8.9-3**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Mass of Solid Fuel (m_{solid})	30.00	lb
Exposed Floor Area (Length x Width) of Fuel (A_{fuel})	16.00	ft^2
Heat Release Rate (HRR) per Unit Floor Area (Q")	1420	kW/m^2
Effective Heat of Combustion ($\Delta H_{c,eff}$)	14000	kJ/kg

Calculate

THERMAL PROPERTIES OF SOLID COMBUSTIBLE MATERIALS

Material	HRR per Unit Floor Area Q" (kW/m^2)	Heat of Combustion ΔH_c (kJ/kg)
Douglas Fir Plywood	221	17600
Empty Cartons 15 ft high	1700	12700
Ethylene Propylene Dien Rubber (EPDM)	956	28800
Fire Retardant Treated Plywood	81	13500
Nylon 6/6	1313	32000
Particle Board, 19 mm thick	1900	17500
PE, Nylon/PVC, Nylon	231	9200
PE/PVC	589	24000
Polycarbonate	420	24400
Polyethylene (PE)	1408	46500
Polymethlmethacrylate (PMMA)	665	26000
Polypropylene (PP)	1509	43200
Polystyrene (PS)	1101	42000
Polyurethane	710	45000
Polyvinyl Chloride (PVC) Flexible	237	15700
Strene-Butadiene Copolymers (SBR)	163	44000
Teflon	98	3200
Wood Pallets, stacked 1.5 ft high	1420	14000
Wood Pallets, stacked 5 ft high	3970	14000
Wood Pallets, stacked 10 ft high	6800	14000
XPE/FRXPE	475	28300
XPE/Neoprene	354	10300
User Specified Value	Enter Value	Enter Value

Select Material

Wood Pallets, stacked 1.5 ft high

Scroll to desired material **then Click** on selection

CHAPTER 8
ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.1
(English Units)

References:

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

Karlsson and Quantiere, Enclosure Fire Dynamics, Chapter 3: Energy Release Rate," CRC Press, 1999.

Johnson, D. G., "Combustion Properties of Plastics," Journal of Applied Fire Science, Volume 4, No. 3, 1994-95, pp. 185-201.

Hirschler, M. M., "Heat Release from Plastic Materials," Heat Release in Fires, Babrauskas and Grayson, Editors, Elsevier Applied Science, 1992.

BURNING DURATION OF SOLID COMBUSTIBLES

Reference: Buchanan, A. H., "Structural Design for Fire Safety," 2001, Page 38.

The burning duration of a solid fuel can be calculated if the total energy contained in the fuel and HRR are known.
The burning duration is given by:

$$Q = E / t_{solid} \quad \text{or} \quad t_{solid} = (E) / (Q'' A_{Fuel})$$

Where,
t_{solid} = burning duration of solid combustible (sec)
E = $m_{Fuel}\, \Delta H_c$ = total energy contained in the fuel (kJ)
Q = heat release rate of fire (kW)
Q'' = heat release rate per unit floor area of fuel (kW/m^2)
A_{Fuel} = exposed floor area (length x width) of fuel (m^2)

$$t_{solid} = (m_{Fuel}\, \Delta H_c) / (Q'' A_{Fuel})$$

Where,
m_{Fuel} = mass of solid fuel (kg)
ΔH_c = fuel effective heat of combustion (kJ/kg)

$$t_{solid} = (m_{solid}\, \Delta H_c) / (Q'' A_{solid})$$

Answer	t_{solid} =	**90.26 sec**	**1.50 min**

NOTE:
The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

9.11 Problems

Example Problem 9.11-1

Problem Statement
A steel beam is located 25 ft above the floor. Calculate the temperature of the beam exposed from a 34.5 ft^2 lube oil pool fire. Assume the HRR of the fire is 5,000 kW.

Solution

Purpose:
(1) Determine the plume centerline temperature for the pool fire scenario.

Assumptions:
(1) All heat is released at a point.
(2) Buoyant forces are more significant than momentum forces.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 09_Plume_Temperature_Calculations_Sup1.xls

FDT^s Input Parameters:
- Heat Release Rate ($\dot{Q}$) = 5,000 kW
- Distance from the Top of the Fuel to the Ceiling (z) = 25 ft
- Area of Combustible Fuel (A_c) = 34.5 ft^2

Results*

Heat Release Rate ($\dot{Q}$) (kW)	Plume Centerline Temperature ($T_{p(centerline)}$) (°F)
5,000	471

*see spreadsheet on next page

CHAPTER 9
ESTIMATING CENTERLINE TEMPERATURE OF A BUOYANT FIRE PLUME

Version 1805.1 (English Units)

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

Project / Inspection Title: **Example 9.11-1**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q)	5000.00	kW
Elevation Above the Fire Source (z)	25.00	ft
Area of Combustible Fuel (A_c)	34.50	ft^2
Ambient Air Temperature (T_a)	77.00	°F

Calculate

AMBIENT CONDITIONS

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

NOTE: **Ambient Air Density (ρ_a) 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.

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

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

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\,Q$$

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

Q_c = 3500 kW

Fire Diameter Calculation

$$A_c = \pi D^2/4$$
$$D = \sqrt{(4\,A_c/\pi)}$$

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

D = 2.02 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)

$z_0/D =$ 0.22

$z_0 =$ 0.44 m

Mean Flame Height Calculation

$$L = -1.02D + 0.235\,(Q^{2/5})$$

Where,
L = mean flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

L = 5.03 m

CHAPTER 9
ESTIMATING CENTERLINE TEMPERATURE
OF A
BUOYANT FIRE PLUME

Version 1805.1
(English Units)

ESTIMATING PLUME CENTERLINE TEMPERATURE

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

$T_{p(centerline)} - T_a =$ 218.97 °K

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

$T_{p(centerline)} =$ 516.97 °K

ESTIMATED PLUME CENTERLINE TEMPERATURE

Answer	$T_{p(centerline)} =$	471.15 °F	243.97 °C

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 9.11-2

Problem Statement
Estimate the maximum plume temperature at the ceiling of an 8 ft high room above a 1,000 kW trash fire with an area of 10 ft^2. Assume that the ambient air temperature is 77 °F.

Solution

Purpose:
(1) Determine the maximum plume centerline temperature for the transient combustible fire scenario.

Assumptions:
(1) All heat is released at a point.
(2) Buoyant forces are more significant than momentum forces.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 09_Plume_Temperature_Calculations_Sup1.xls

FDT^s Input Parameters:
- Heat Release Rate ($\dot{Q}$) = 1000 kW
- Distance from the Top of the Fuel to the Ceiling (z) = 8 ft
- Area of Combustible Fuel (A_c) = 10 ft^2

Results*

Heat Release Rate ($\dot{Q}$) (kW)	Plume Centerline Temperature ($T_{p(centerline)}$) (°F)
1,000	1,021

*see spreadsheet on next page

CHAPTER 9
ESTIMATING CENTERLINE TEMPERATURE OF A BUOYANT FIRE PLUME

Version 1805.1 (English Units)

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

Project / Inspection Title: **Example 9.11-2**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q)	1000.00	kW
Elevation Above the Fire Source (z)	8.00	ft
Area of Combustible Fuel (A_c)	10.00	ft^2
Ambient Air Temperature (T_a)	77.00	°F

Calculate

AMBIENT CONDITIONS

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

NOTE: **Ambient Air Density (ρ_a) 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.

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

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

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\,Q$$

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

Q_c = 700 kW

Fire Diameter Calculation

$$A_c = \pi D^2/4$$
$$D = \sqrt{(4\,A_c/\pi)}$$

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

D = 1.09 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 = 0.19

z_0 = 0.21 m

Mean Flame Height Calculation

$$L = -1.02D + 0.235\,(Q^{2/5})$$

Where,
L = mean flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

L = 2.62 m

CHAPTER 9
ESTIMATING CENTERLINE TEMPERATURE
OF A
BUOYANT FIRE PLUME

Version 1805.1
(English Units)

ESTIMATING PLUME CENTERLINE TEMPERATURE

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

$T_{p(centerline)} - T_a =$ 524.40 °K

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

$T_{p(centerline)} =$ 822.40 °K

ESTIMATED PLUME CENTERLINE TEMPERATURE

Answer	$T_{p(centerline)} =$	1020.92 °F	549.40 °C

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

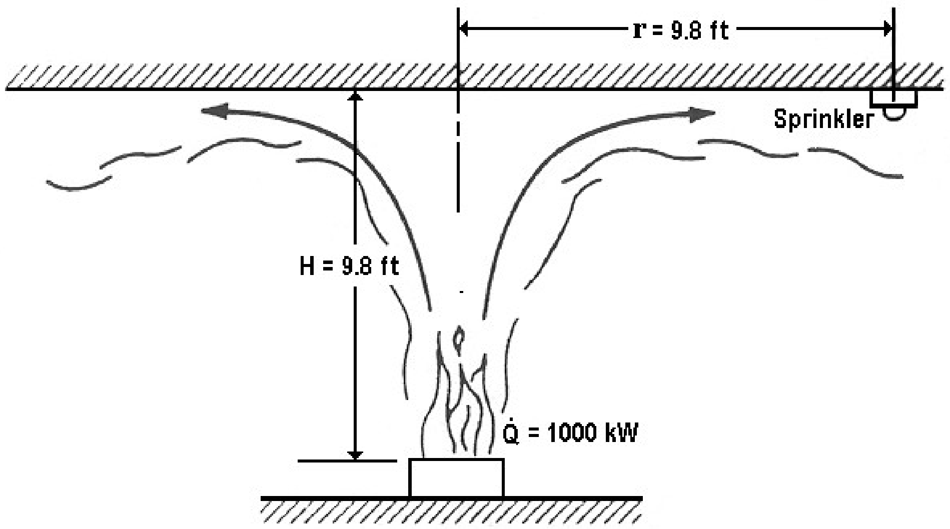
Additional Information:

10.10 Problems

Example Problem 10.10-1

Problem Statement

A fire with $\dot{Q}$ = 1,000 kW occurs in a space that is protected with sprinklers. Sprinklers are rated at 165 °F [standard response link with RTI = 130 (m-sec)^{½}] and located 9.8 ft on center. The ceiling is 9.8 ft above the fire. The ambient temperature is 77 °F. Would the sprinklers activate, and if so how long would it take for them to activate?



Example Problem 10-1: Fire Scenario with Sprinkler

Solution

Purpose:
(1) Determine if the sprinklers will be activated for the fire scenario.
(2) If the sprinkles are activated, how long would it take for them to activate?

Assumptions:
(1) The fire is located away from walls and corners.
(2) The fire is steady state.
(3) The ceiling is unconfined.
(4) Only convective heat transfer from the hot fire gases is considered.
(5) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1.xls (click on *Sprinkler*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 1,000 kW
- Distance from the Top of the Fuel Package to the Ceiling (H) = 9.8 ft
- Radial Distance from the Plume Centerline to the Sprinkler (r) = 9.8 ft
- Ambient Air Temperature (T_a) = 77 °F
- Select Type of Sprinkler = Standard response link
- Select Sprinkler Classification = Ordinary

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

Results*

Sprinkler Type	Sprinkler Activation Time ($t_{activation}$) (min.)
Standard Response Link	1.5

*see spreadsheet on next page

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 10.10-1**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW
Sprinkler Response Time Index (RTI)	130	$(m\text{-}sec)^{1/2}$
Activation Temperature of the Sprinkler ($T_{activation}$)	165	°F
Height of Ceiling above Top of Fuel (H)	9.80	ft
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	9.80	ft
Ambient Air Temperature (T_a)	77.00	°F
Convective Heat Release Rate Fraction (χ_c)	0.70	

r/H = **1.00**

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, 1 st Proceeding, March 15-16, 1995, Kowloon, Hong Kong, pp. 211-218.*

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

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

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

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

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

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

ESTIMATING SPRINKLER RESPONSE TIME

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

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

Where

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

Ceiling Jet Temperature Calculation

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \leq 0.18$$
$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

Where

T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where

Qc = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release rate fraction

Q_c = 700 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.00 r/H > 0.18

>0.18	**86.84**	**<0.18**	**272.78**

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

$T_{jet} - T_a$ = 86.84

T_{jet} = 111.84 (°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
ujet = 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 = 1.00 r/H > 0.15

>0.15	**1.35**	**<0.15**	**6.665880958**

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

u_{jet} = 1.354 m/sec

SPRINKLER ACTIVATION TIME CALCULATION

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

$t_{activation}$ **92.48 sec**

Answer	The sprinkler will respond in approximately	1.54 minutes

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

NOTE:

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 10.10-2

Problem Statement
If the sprinklers in Problem10-1 are replaced by sprinklers with a response time index (RTI) of 235 $(m\text{-}sec)^{1/2}$, how long would it take for them to activate?

Solution

Purpose:

(1) Determine the activation time for the specified sprinkles under the fire scenario of Problem 10-1.

Assumptions:

(1) The fire is located away from walls and corners.
(2) The fire is steady state.
(3) The ceiling is unconfined.
(4) Only convective heat transfer from the hot fire gases is considered.
(5) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 10_Detector_Activation_Time_Sup1.xls (click on *Sprinkler*)

FDT^s Input Parameters:

- Heat Release Rate of the Fire ($\dot{Q}$) = 1000 kW
- Distance from the Top of the Fuel Package to the Ceiling (H) = 9.8 ft
- Radial Distance from the Plume Centerline to the Sprinkler (r) = 9.8 ft
- Ambient Air Temperature (T_a) = 77 °F
- Select Type of Sprinkler = Standard Response Bulb
- Select Sprinkler Classification = Ordinary

Note: The RTI value of 235 $(m\text{-}sec)^{1/2}$ corresponds to standard response bulb sprinkler. Ordinary classification has been selected because the rated value for the sprinklers in this problem (165 °F, same as Problem10-1) is within the range of temperature ratings for ordinary sprinklers (135 °F – 170 °F).

Results*

Sprinkler Type	Sprinkler Activation Time ($t_{activation}$) (min.)
Standard Response Bulb	2.8

*see spreadsheet on next page

Version 1805.1 (English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 10.10-2**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW
Sprinkler Response Time Index (RTI)	235	$(m\text{-}sec)^{1/2}$
Activation Temperature of the Sprinkler ($T_{activation}$)	165	°F
Height of Ceiling above Top of Fuel (H)	9.80	ft
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	9.80	ft
Ambient Air Temperature (T_a)	77.00	°F
Convective Heat Release Rate Fraction (χ_c)	0.70	

r/H = **1.00**

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 bulb
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, 1 st Proceeding, March 15-16, 1995, Kowloon, Hong Kong, pp. 211-218.*

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

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

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

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

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

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

ESTIMATING SPRINKLER RESPONSE TIME

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

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

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

Ceiling Jet Temperature Calculation

$$T_{jet} - T_a = 16.9 (Q)^{2/3}/H^{5/3} \quad \text{for } r/H \le 0.18$$
$$T_{jet} - T_a = 5.38 (Q/r)^{2/3}/H \quad \text{for } r/H > 0.18$$

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

Convective Heat Release Rate Calculation

$$Q_c = \chi_c Q$$

Where
Qc = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release rate fraction

Q_c = 700 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.00 r/H > 0.18

>0.18	86.84	<0.18	272.78

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

$T_{jet} - T_a =$ 86.84

$T_{jet} =$ 111.84 (°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
ujet = 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 = 1.00 r/H > 0.15

>0.15	1.35	<0.15	6.665880958

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

$u_{jet} =$ 1.354 m/sec

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SPRINKLER ACTIVATION TIME CALCULATION

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

$t_{activation}$ **167.18 sec**

Answer	The sprinkler will respond in approximately	2.79 minutes

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

NOTE:

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

Prepared by: Date: Organization:

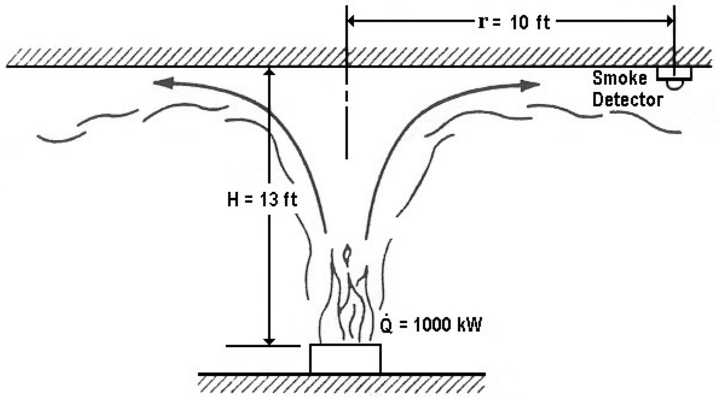
Checked by: Date: Organization:

Additional Information:

11.12 Problems

Example Problem 11.12-1

Problem Statement
Estimate the response time of a smoke detector that is located 10 ft radially from the centerline of a 1,000 kW pool fire in a 13 ft tall compartment.



Example Problem 11-1: Fire Scenario with Smoke Detector

Solution

Purpose:
(1) Determine the response time of the smoke detector for the fire scenario.

Assumptions:
(1) The fire is steady state
(2) The forced ventilation system is off
(3) There is no heavily obstructed overhead

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1.xls (click on *Smoke_Detector*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 1,000 kW
- Ceiling Height (H) = 13 ft
- Radial Distance from the Plume Centerline to the Smoke Detector (r) = 10 ft

Results*

Heat Release Rate ($\dot{Q}$) (kW)	Smoke Detector Activation Time (t_R) (sec)		
	Method of Alpert	Method of Mowrer	Method of Milke
1,000	0.33	0.74	0.26

*see spreadsheet on next page

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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

Project / Inspection Title: **Example 11.12-1**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	10.00	ft
Height of Ceiling above Top of Fuel (H)	13.00	ft
Activation Temperature of the Smoke Detector ($T_{activation}$)	86.00	°F
Smoke Detector Response Time Index (RTI)	5.00	$(m\text{-}sec)^{1/2}$
Ambient Air Temperature (T_a)	77.00	°F
Convective Heat Release Rate Fraction (χ_c)	0.70	
Plume Leg 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

r/H = **0.77**

Calculate

ESTIMATING SMOKE DETECTOR RESPONSE TIME
METHOD OF ALPERT

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

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

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-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

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

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

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

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where
Qc = 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 = 700 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H =	0.77	r/H > 0.18	
>0.18	64.59	<0.18	170.33

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

$T_{jet} - T_a =$ 64.59

$T_{jet} =$ 89.59 (°C)

Ceiling Jet Velocity Calculation

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

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

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

Radial Distance to Ceiling Height Ratio Calculation

r/H =	0.77	r/H > 0.15	
>0.15	1.53	<0.15	6.07

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

$u_{jet} =$ 1.533 m/sec

Smoke Detector Response Time Calculation

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

$t_{activation} =$ **0.33 sec**

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

t_{pl} = 0.42 sec

Transport Lag Time of Ceiling Jet Calculation

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

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

t_{cj} = 0.32 sec

Smoke Detector Response Time Calculation

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

$t_{activation}$ = 0.74 sec

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 Mall, Atria, and Large Areas," 2000 Edition, Section A.3.4.

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

Where
tactivation = 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 = $Y = \Delta T_c\ H^{5/3} / Q^{2/3}$
ΔTc = 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.

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

Where
Hmax = H_{max} = the maximum ceiling clearance to which a plume can rise (ft)
Qc = Q_c = convective portion of the heat release rate (Btu/sec)
ΔTf->c = $\Delta T_{f\text{->}c}$ = 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 = 663.47 Btu/sec

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

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

Where
$\Delta T_{f\text{->}c}$ = 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)

$\Delta T_{f\text{->}c}$ = **1375.90 °F**

Smoke Stratification Effects

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

H_{max} = **13.03 ft**

In this case the highest point of smoke rise is estimated to be **13.03** 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 = **13.41**

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

X = **0.08**

Smoke Detector Response Time Calculation

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

$t_{activation}$ = **0.26 sec**

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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	Calculation Method	Smoke Detector Response Time (sec)
Summary of Results	**METHOD OF ALPERT**	**0.33**
	METHOD OF MOWRER	**0.74**
	METHOD OF MILKE	**0.26**

NOTE:

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 11.12-2

Problem Statement
During a routine inspection, an NRC resident inspector finds a stack of 4 ft high wood pallets left in the NPP after a recent MOV modification. When the inspector questions the licensee about this transient combustible, the licensee assures the inspector that if the transient ignited, the smoke detection system would alarm in less than 1 minute.

The SFPE Handbook provides test data for a stack of 4 ft high wood pallets, from which the HRR can be estimated at 3.5 MW.

The compartment has a 25 ft ceiling with the smoke detectors spaced 30 ft on center. The pallets are located in the worst position (i.e., in the center of four smoke detectors).

How long does it take the smoke detector to alarm?

Solution

Purpose:
(1) Determine the response time of the smoke detector for the fire scenario.

Assumptions:
(1) The fire is steady-state.
(2) The forced ventilation system is off.
(3) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1.xls (click on *Smoke_Detector*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 3,500 kW
- Ceiling Height (H) = 25 ft
- Radial Distance from the Plume Centerline to the Smoke Detector (r) = 21.2 ft

Results*

Heat Release Rate ($\dot{Q}$) (kW)	Smoke Detector Activation Time (t_R) (sec)		
	Method of Alpert	Method of Mowrer	Method of Milke
3,500	0.43	1.27	0.67

*see spreadsheets on next page

Therefore, it can be assumed that the smoke detectors would alarm within 1 minute.

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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(English Units)

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

Project / Inspection Title: **Example 11.12-2**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	3500.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	21.20	ft
Height of Ceiling above Top of Fuel (H)	25.00	ft
Activation Temperature of the Smoke Detector ($T_{activation}$)	86.00	°F
Smoke Detector Response Time Index (RTI)	5.00	$(m\text{-}sec)^{1/2}$
Ambient Air Temperature (T_a)	77.00	°F
Convective Heat Release Rate Fraction (χ_c)	0.70	
Plume Leg 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

r/H = 0.85

Calculate

ESTIMATING SMOKE DETECTOR RESPONSE TIME
METHOD OF ALPERT

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

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

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-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

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

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

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

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where
Qc = 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 = 2450 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H =	0.85	r/H > 0.18	
>0.18	46.91	<0.18	132.03

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

$T_{jet} - T_a =$ 46.91

$T_{jet} =$ 71.91 (°C)

Ceiling Jet Velocity Calculation

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

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

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

Radial Distance to Ceiling Height Ratio Calculation

r/H =	0.85	r/H > 0.15	
>0.15	1.73	<0.15	7.41

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

$u_{jet} =$ 1.726 m/sec

Smoke Detector Response Time Calculation

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

$t_{activation} =$ **0.43 sec**

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

t_{pl} = **0.66 sec**

Transport Lag Time of Ceiling Jet Calculation

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

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

t_{cj} = **0.61 sec**

Smoke Detector Response Time Calculation

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

$t_{activation}$ = **1.27 sec**

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 Mall, Atria, and Large Areas," 2000 Edition, Section A.3.4.

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

Where
tactivation = 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 = $Y = \Delta T_c\ H^{5/3} / Q^{2/3}$
ΔTc = 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.

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

Where
Hmax = H_{max} = the maximum ceiling clearance to which a plume can rise (ft)
Qc = Q_c = convective portion of the heat release rate (Btu/sec)
ΔTf->c = $\Delta T_{f\text{->}c}$ = 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 = 2322.16 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
$\Delta T_{f->c}$ = 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)

$\Delta T_{f->c}$ = **1066.53 °F**

Smoke Stratification Effects

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

H_{max} = **25.05 ft**

In this case the highest point of smoke rise is estimated to be **25.05** 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 = **17.30**

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

X = **0.14**

Smoke Detector Response Time Calculation

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

$t_{activation}$ = **0.67 sec**

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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	Calculation Method	Smoke Detector Response Time (sec)
Summary of Results	**METHOD OF ALPERT**	**0.43**
	METHOD OF MOWRER	**1.27**
	METHOD OF MILKE	**0.67**

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 11.12-3

Problem Statement
During a triennial inspection, an NRC inspector discovers that every other smoke detector has inadvertently been painted and is not functional. The detection system in the compartment is single-zoned to arm a pre-action sprinkler system. The detectors are 20 ft on center. The ceiling is 23 ft. The sprinkler system uses 165 °F sprinklers, 10 ft on center, 4 inches from the ceiling. The licensee states that even with half the smoke detectors inoperable, a smoke detector would alarm and charge the pre-action system before a quick-response link-type sprinkler head fuses. The expected fire in the compartment is approximately 750 kW. Is the licensee's statement true?

Solution

Purpose:
(1) Determine the response time of the smoke detector for the fire scenario.
(2) Determine the response time of the sprinkler system.

Assumptions:
(1) The fire is steady-state.
(2) The forced ventilation system is off.
(3) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1.xls (click on *Smoke-Detector*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 750 kW
- Ceiling Height (H) = 23 ft
- Radial Distance from the Plume Centerline to the Smoke Detector (r) = 20 ft

(b) 10_Detector_Activation_Time_Sup1.xls (click on *Sprinkler*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 750 kW
- Select Quick Response Link
- Select Ordinary
- Ceiling Height (H) = 23 ft
- Radial Distance from the Plume Centerline to the Sprinkler (r) = 7.1 ft

Results*

Heat Release Rate ($\dot{Q}$) (kW)	Smoke Detector Activation Time (t_R) (sec)		
750	Method of Alpert	Method of Mowrer	Method of Milke
	1.5	1.94	6.0

*see spreadsheet on next page

The sprinkler heads do not activate. Therefore, the licensee's statement is true; however, the non-activation of the sprinkler heads should be of great concern.

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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

Project / Inspection Title: **Example 11.12-3a**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	750.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	20.00	ft
Height of Ceiling above Top of Fuel (H)	23.00	ft
Activation Temperature of the Smoke Detector ($T_{activation}$)	86.00	°F
Smoke Detector Response Time Index (RTI)	5.00	$(m\text{-}sec)^{1/2}$
Ambient Air Temperature (T_a)	77.00	°F
Convective Heat Release Rate Fraction (χ_c)	0.70	
Plume Leg 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

r/H = **0.87**

Calculate

ESTIMATING SMOKE DETECTOR RESPONSE TIME
METHOD OF ALPERT

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

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

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

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \leq 0.18$$
$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

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

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where
Qc = 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 = 525 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H =	0.87	r/H > 0.18	
>0.18	18.98	<0.18	54.33

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

$T_{jet} - T_a =$ 18.98

$T_{jet} =$ 43.98 (°C)

Ceiling Jet Velocity Calculation

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

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

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

Radial Distance to Ceiling Height Ratio Calculation

r/H =	0.87	r/H > 0.15	
>0.15	1.04	<0.15	4.56

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

$u_{jet} =$ 1.040 m/sec

Smoke Detector Response Time Calculation

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

$t_{activation} =$ 1.50 sec

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

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

t_{pl} = 0.99 sec

Transport Lag Time of Ceiling Jet Calculation

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

Where

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

t_{cj} = 0.95 sec

Smoke Detector Response Time Calculation

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

$t_{activation}$ = 1.94 sec

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 Mall, Atria, and Large Areas," 2000 Edition, Section A.3.4.

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

Where
tactivation = 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 = $Y = \Delta T_c\ H^{5/3} / Q^{2/3}$
ΔTc = 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.

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

Where
Hmax = H_{max} = the maximum ceiling clearance to which a plume can rise (ft)
Qc = Q_c = convective portion of the heat release rate (Btu/sec)
ΔTf->c = $\Delta T_{f\text{->}c}$ = 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 = 497.61 Btu/sec

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

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

Where
$\Delta T_{f\text{->}c}$ = 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)

$\Delta T_{f\text{->}c}$ = **438.85 °F**

Smoke Stratification Effects

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

H_{max} = **23.05 ft**

In this case the highest point of smoke rise is estimated to be **23.05** 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 = **42.04**

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

X = **0.81**

Smoke Detector Response Time Calculation

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

$t_{activation}$ = **5.96 sec**

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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	Calculation Method	Smoke Detector Response Time (sec)
Summary of Results	**METHOD OF ALPERT**	**1.50**
	METHOD OF MOWRER	**1.94**
	METHOD OF MILKE	**5.96**

NOTE:

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 11.12-3b**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	750.00	kW
Sprinkler Response Time Index (RTI)	34	$(m\text{-}sec)^{1/2}$
Activation Temperature of the Sprinkler ($T_{activation}$)	165	°F
Height of Ceiling above Top of Fuel (H)	23.00	ft
Radial Distance to the Detector (r) **never more than 0.707 or $1/2\sqrt{2}$ of the listed spacing**	7.10	ft
Ambient Air Temperature (T_a)	77.00	°F

Convective Heat Release Rate Fraction (χ_c) 0.70

r/H = **0.31**

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
Quick 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, 1 st Proceeding, March 15-16, 1995, Kowloon, Hong Kong, pp. 211-218.*

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

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

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

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

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

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

ESTIMATING SPRINKLER RESPONSE TIME

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

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

Where

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

Ceiling Jet Temperature Calculation

$$T_{jet} - T_a = 16.9\,(Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \leq 0.18$$
$$T_{jet} - T_a = 5.38\,(Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

Where

T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\, Q$$

Where

Qc = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release rate fraction

Q_c = 525 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.31 r/H > 0.18

>0.18	37.86	<0.18	54.33

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

$T_{jet} - T_a =$ 37.86

$T_{jet} =$ 62.86 (°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
ujet = ceiling jet velocity (m/sec)
Q = heat release rate of the fire (kW)
H = height of ceiling above top of fuel (m)
r = radial distance from the plume centerline to the sprinkler (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.31 r/H > 0.15

>0.15	2.47	<0.15	4.55733256

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

$u_{jet} =$ 2.465 m/sec

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SPRINKLER ACTIVATION TIME CALCULATION

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

$t_{activation}$ #NUM! sec

Answer	The sprinkler will respond in approximately	#NUM!	minutes

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

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

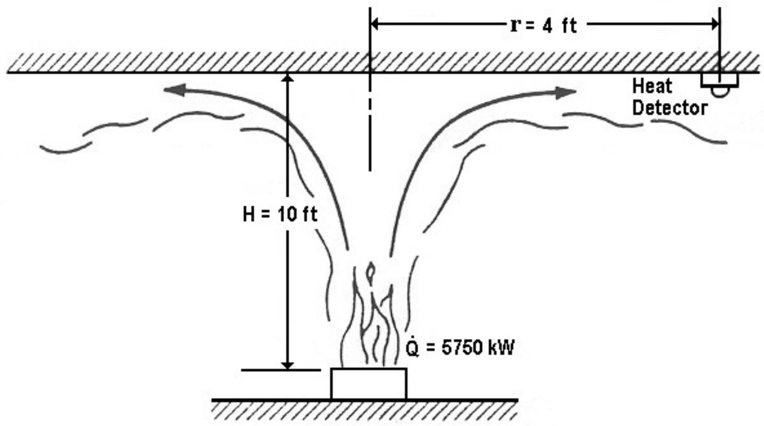
Additional Information:

12.12 Problems

Example Problem 12.12-1

Problem Statement

A 34.5 ft^2 lube oil pool fire with $\dot{Q}$ = 5,750 kW occurs in a space protected with fixed-temperature heat detectors. Calculate the activation time for the fixed-temperature heat detectors, using 10 ft spacing, in an area with a ceiling height 10 ft. The detector activation temperature is 128 °F, the radial distance to the detector is 4 ft, and the ambient temperature is 77 °F.



Example Problem 12-1: Fire Scenario with Heat Detectors

Solution

Purpose:

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

Assumptions:

(1) The fire is located away from walls and corners.
(2) The fire is steady state and plume is under unconfined ceiling.
(3) Only convective heat transfer from the hot fire gases is considered.
(4) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1.xls (click on *FTHDetector*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 5,750 kW
- Radial Distance to the Detector (r) = 4 ft
- Activation Temperature of the Fixed-Temperature Heat Detector ($T_{activation}$) = 128 °F
- Distance from the Top of the Fuel Package to the Ceiling (H) = 10 ft
- Ambient Air Temperature (T_a) = 77 °F
- Click on the option button for FTH detectors with $T_{activation}$ = 128 °F
- Select Detector Spacing: 10

Results*

Detector Type	Heat Detector Activation Time ($t_{activation}$) (min.)
Fixed-Temperature	0.2

*see spreadsheet on next page

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 12.12-1**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	5750.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	4.00	ft
Activation Temperature of the Fixed Temperature Heat Detector ($T_{activation}$)	128	°F
Detector Response Time Index (RTI)	490.00	$(m\text{-}sec)^{1/2}$
Height of Ceiling above Top of Fuel (H)	10.00	ft
Ambient Air Temperature (T_a)	77.00	°F
Convective Heat Release Fraction (χ_c)	0.70	
r/H = **0.40**	Calculate	

INPUT DATA FOR ESTIMATING HEAT DETECTOR RESPONSE TIME

Activation Temperature $T_{activation}$

T= 128 F

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

Select Detector Spacing

10

Scroll to desired spacing then Click on selection

T= 135 F

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

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 145 F

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

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 160 F

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

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 170 F

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

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 196 F

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

Select Detector Spacing

Scroll to desired spacing then

Click on selection

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

ESTIMATING FIXED TEMPERATURE HEAT DETECTOR RESPONSE TIME

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

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

Where

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

Ceiling Jet Temperature Calculation

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

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

Where

T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where

Qc = convective heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release fraction

Q_c = 4025 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.40 r/H > 0.18

>0.18	496.40	<0.18	846.53

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

$T_{jet} - T_a =$ 496.40

$T_{jet} =$ 521.40 (°C)

Ceiling Jet Velocity Calculation

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

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

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

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.40 r/H > 0.15

>0.15	5.17	<0.15	11.862

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

$u_{jet} =$ 5.171 m/sec

DETECTOR ACTIVATION TIME CALCULATION

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

$t_{activation}$ = 12.66 sec

Answer	The detector will respond in approximately	0.21 minutes

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

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

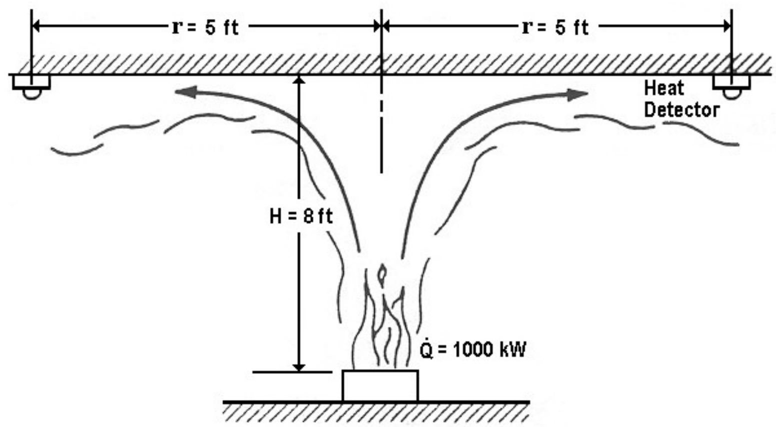
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 12.12-2

Problem Statement
A trash fire with $\dot{Q}$ = 1,000 kW occurs in a space protected with fixed-temperature heat detectors. Calculate the activation time for the fixed-temperature heat detectors, using 10 ft spacing, in an area with a ceiling height of 8 ft. The fire is located directly between heat detectors. The detector activation temperature is 160 °F, and the ambient temperature is 77 °F.



Example Problem 12-2: Fire Scenario with heat detectors equidistant from the fire source

Solution

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

Assumptions:
(1) The fire is located away from walls and corners.
(2) The fire is steady state and plume is under unconfined ceiling.
(3) Only convective heat transfer from the hot fire gases is considered.
(4) There is no heavily obstructed overhead.

Spreadsheet (FDT[s]) Information:

Use the following FDT[s]:
(a) 10_Detector_Activation_Time_Sup1.xls (click on *FTHDetector*)

FDT[s] Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 1,000 kW
- Radial Distance to the Detector (r) = 5 ft
- Activation Temperature of the Fixed-Temperature Heat Detector ($T_{activation}$) = 160 °F
- Distance from the Top of the Fuel Package to the Ceiling (H) = 8 ft
- Ambient Air Temperature (T_a) = 68 °F
- Click on the option button for FTH detectors with $T_{activation}$ = 160 °F
- Select Detector Spacing: 10

Results*

Detector Type	Heat Detector Activation Time ($t_{activation}$) (min.)
Fixed-Temperature	1.00

*see spreadsheet on next page

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 12.12-2**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	5.00	ft
Activation Temperature of the Fixed Temperature Heat Detector ($T_{activation}$)	160	°F
Detector Response Time Index (RTI)	239.00	$(m\text{-}sec)^{1/2}$
Height of Ceiling above Top of Fuel (H)	8.00	ft
Ambient Air Temperature (T_a)	68.00	°F
Convective Heat Release Fraction (χ_c)	0.70	

r/H = **0.63**

Calculate

INPUT DATA FOR ESTIMATING HEAT DETECTOR RESPONSE TIME

Activation Temperature $T_{activation}$

T= 128 F

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

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 135 F

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

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 145 F

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

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 160 F

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

Select Detector Spacing

10

Scroll to desired spacing then Click on selection

T= 170 F

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

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 196 F

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

Select Detector Spacing

Scroll to desired spacing then Click on selection

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

ESTIMATING FIXED TEMPERATURE HEAT DETECTOR RESPONSE TIME

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

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

Where

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

Ceiling Jet Temperature Calculation

$$T_{jet} - T_a = 16.9 (Q)^{2/3}/H^{5/3} \quad \text{for } r/H \le 0.18$$
$$T_{jet} - T_a = 5.38 (Q/r)^{2/3}/H \quad \text{for } r/H > 0.18$$

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

Convective Heat Release Rate Calculation

$$Q_c = \chi_c Q$$

Where
Qc = convective heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release fraction

Q_c = 700 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H =		0.63	r/H > 0.18	
>0.18	166.60		<0.18	382.57

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

$T_{jet} - T_a =$ 166.60

$T_{jet} =$ 186.60 (°C)

Ceiling Jet Velocity Calculation

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

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

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

Radial Distance to Ceiling Height Ratio Calculation

r/H =		0.63	r/H > 0.15	
>0.15	2.14		<0.15	7.1324

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

$u_{jet} =$ 2.143 m/sec

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(English Units)

DETECTOR ACTIVATION TIME CALCULATION

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

$t_{activation} =$ 59.82 sec

Answer The detector will respond in approximately **1.00 minutes**

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

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

13.10 Problems

Example Problem 13.10-1

Problem Statement
Consider a compartment 20 ft wide x 25 ft long x 12 ft high (w_c x l_c x h_c), with an opening 3 ft wide and 8 ft high (w_v x h_v). The interior lining material of the compartment is 6 in. concrete. Calculate the HRR necessary for flashover, $\dot{Q}_{FO}$, and the post-flashover compartment temperature, T_{PFO}.

Solution

Purpose:
(1) Determine the heat release rate for flashover for the given compartment.

Assumptions:
(1) Natural Ventilation

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 13_Compartment_Flashover_Calculations_Sup1.xls
(click on *Post_Flashover_Temperature* to calculate the post-flashover temperature)
(click on *Flashover-HRR* to calculate the HRR for flashover)

FDT^s Input Parameters:
-Compartment Width (w_c) = 20 ft
-Compartment Length (l_c) = 25 ft
-Compartment Height (h_c) = 12 ft
-Vent Width (w_v) = 3 ft
-Vent Height (h_v) = 8 ft
-Interior Lining Thickness (δ) = 6 in. (Flashover-HRR only)
-Select Material: **Concrete** (Flashover-HRR only)

Results*

Post-Flashover Compartment Temperature (T_{PFO}) (°F)	HRR for Flashover ($\dot{Q}_{FO}$) (kW)		
Method of Law	Method of MQH	Method of Babrauskas	Method of Thomas
1,492	1,612	2,611	2,806

*see spreadsheet on next page

CHAPTER 13
PREDICTING COMPARTMENT
POST-FLASHOVER TEMPERATURE

Version 1805.1
(English Units)

The following calculations estimate the compartment post-flashover temperature.

Parameters in YELLOW CELLS are Entered by the User.

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

Project / Inspection Title: **Example 13.10-1a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft
Compartment Length (l_c)	25.00	ft
Compartment Height (h_c)	12.00	ft
Vent Width (w_v)	3.00	ft
Vent Height (h_v)	8.00	ft

Calculate

METHOD OF MARGARET LAW

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

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

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

Ventilation Factor

$$\Omega = (A_T - A_v) / A_v\,(\sqrt{h_v})$$

Where,
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\,(h_v)$$

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

A_v = 2.23 m^2

Area of Compartment Enclosing Surface Boundaries

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

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

A_T = 191.01 m^2

Ventilation Factor Calculation

$$\Omega = (A_T - A_v) / A_v (\sqrt{h_v})$$

Where,

Ω = ventilation factor
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = vent height (m)

Ω = 54.22 $m^{-1/2}$

COMPARTMENT POST-FLASHOVER TEMPERATURE

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

Answer	$T_{PFO\,(max)}$ =	1492.23 °F	811.24 °C

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

CHAPTER 13
PREDICTING COMPARTMENT FLASHOVER
HEAT RELEASE RATE

Version 1805.1
(English Units)

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.

Project / Inspection Title: **Example 13.10-1b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft
Compartment Length (l_c)	25.00	ft
Compartment Height (h_c)	12.00	ft
Vent Width (w_v)	3.00	ft
Vent Height (h_v)	8.00	ft
Interior Lining Thickness (δ)	6.00	in
Interior Lining Thermal Conductivity (k)	0.0016	kW/m-K

Calculate

THERMAL PROPERTIES DATA

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

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

Select Material

Concrete

Scroll to desired material
Click on selection

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

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

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

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

Heat Transfer Coefficient Calculation

$$h_k = k/\delta$$

Assuming that compartment has been heated thoroughly before flashover, i.e., t > tp.

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

h_k = 0.010 kW/m^2-K

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

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

A_v = 2.23 m^2

Area of Compartment Enclosing Surface Boundaries

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

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

A_T = 191.01 m^2

MINIMUM HEAT RELEASE RATE FOR FLASHOVER

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

Q_{FO} = 1611.84 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF BABRAUSKAS

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

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

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

Minimum Heat Release Rate for Flashover

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

Q_{FO} = 2611.29 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF THOMAS

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

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

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

Minimum Heat Release Rate for Flashover

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

Q_{FO} = 2805.96 kW

Summary of Results

CALCULATION METHOD	Flashover HRR	
	Btu/sec	kW
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)	1528	1612
METHOD OF BABRAUSKAS	2475	2611
METHOD OF THOMAS	2660	2806

NOTE:
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Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 13.10-2

Problem Statement
Consider a compartment 20 ft wide x 25 ft long x 12 ft high (w_c x l_c x h_c), with an opening 3 ft wide and 8 ft high (w_v x h_v). The interior lining material of the compartment is 5/8 in. gypsum. Calculate the HRR necessary for flashover, $\dot{Q}_{FO}$, and the post-flashover compartment temperature, T_{PFO}.

Solution

Purpose:
(1) Determine the heat release rate for flashover for the given compartment.

Assumptions:
(1) Natural Ventilation

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 13_Compartment_Flashover_Calculations_Sup1.xls
(click on *Post_Flashover_Temperature* to calculate the post-flashover temperature)
(click on *Flashover-HRR* to calculate the HRR for flashover)

FDTs Input Parameters:
- Compartment Width (w_c) = 20 ft
- Compartment Length (l_c) = 25 ft
- Compartment Height (h_c) = 12 ft
- Vent Width (w_v) = 3 ft
- Vent Height (h_v) = 8 ft
- Interior Lining Thickness (δ) = 0.63 in. (Flashover-HRR only)
- Select Material: **Gypsum Board** (Flashover-HRR only)

Results*

Post-Flashover Compartment Temperature (T_{PFO}) (°F)	HRR for Flashover ($\dot{Q}_{FO}$) (kW)		
Method of Law	Method of MQH	Method of Babrauskas	Method of Thomas
1,492	1,621	2,611	2,806

*see spreadsheet on next page

CHAPTER 13
PREDICTING COMPARTMENT
POST-FLASHOVER TEMPERATURE

Version 1805.1
(English Units)

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

Project / Inspection Title: **Example 13.10-2a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft
Compartment Length (l_c)	25.00	ft
Compartment Height (h_c)	12.00	ft
Vent Width (w_v)	3.00	ft
Vent Height (h_v)	8.00	ft

Calculate

METHOD OF MARGARET LAW

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

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

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

Ventilation Factor

$$\Omega = (A_T - A_v) / A_v\,(\sqrt{h_v})$$

Where,
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\,(h_v)$$

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

A_v = **2.23 m^2**

Area of Compartment Enclosing Surface Boundaries

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

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

A_T = **191.01 m^2**

Ventilation Factor Calculation

$$\Omega = (A_T - A_v) / A_v (\sqrt{h_v})$$

Where,

Ω = ventilation factor

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

A_v = area of ventilation opening (m^2)

h_v = vent height (m)

Ω = 54.22 $m^{-1/2}$

COMPARTMENT POST-FLASHOVER TEMPERATURE

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

Answer	$T_{PFO\,(max)}$ =	1492.23 °F	811.24 °C

NOTE:

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

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.

Project / Inspection Title: **Example 13.10-2b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft
Compartment Length (l_c)	25.00	ft
Compartment Height (h_c)	12.00	ft
Vent Width (w_v)	3.00	ft
Vent Height (h_v)	8.00	ft
Interior Lining Thickness (δ)	0.63	in
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K

Calculate

THERMAL PROPERTIES DATA

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

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

Select Material

Gypsum Board

Scroll to desired material
Click on selection

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

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

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

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

Heat Transfer Coefficient Calculation

$$h_k = k/\delta$$

Assuming that compartment has been heated thoroughly before flashover, i.e., t > tp.

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

h_k = 0.011 kW/m^2-K

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

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

A_v = 2.23 m^2

Area of Compartment Enclosing Surface Boundaries

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

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

A_T = 191.01 m^2

MINIMUM HEAT RELEASE RATE FOR FLASHOVER

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

Q_{FO} = 1621.40 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF BABRAUSKAS

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

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

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

Minimum Heat Release Rate for Flashover

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

Q_{FO} = 2611.29 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF THOMAS

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

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

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

Minimum Heat Release Rate for Flashover

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

Q_{FO} = 2805.96 kW

Summary of Results

CALCULATION METHOD	Flashover HRR	
	Btu/sec	kW
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)	1537	1621
METHOD OF BABRAUSKAS	2475	2611
METHOD OF THOMAS	2660	2806

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 13.10-3

Problem Statement
Consider a compartment 20 ft wide x 25 ft long x 12 ft high (w_c x l_c x h_c), with an opening 6 ft wide and 8 ft high (w_v x h_v). The interior lining material of the compartment is 6 in. concrete. Calculate the HRR necessary for flashover, $\dot{Q}_{FO}$, and the post-flashover compartment temperature, T_{PFO}.

Solution

Purpose:
(1) Determine the heat release rate for flashover for the given compartment.

Assumptions:
(1) Natural Ventilation

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 13.1_Compartment_Flashover_Calculations_Sup1.xls
(click on *Post_Flashover_Temperature* to calculate the post-flashover temperature)
(click on *Flashover-HRR* to calculate the HRR for flashover)

FDT^s Input Parameters:
-Compartment Width (w_c) = 20 ft
-Compartment Length (l_c) = 25 ft
-Compartment Height (h_c) = 12 ft
-Vent Width (w_v) = 6 ft
-Vent Height (h_v) = 8 ft
-Interior Lining Thickness (δ) = 6 in. (Flashover-HRR only)
-Select Material: **Concrete** (Flashover-HRR only)

Results*

Post-Flashover Compartment Temperature (T_{PFO}) (°F)	HRR for Flashover ($\dot{Q}_{FO}$) (kW)		
Method of Law	Method of MQH	Method of Babrauskas	Method of Thomas
1,982	2,266	5,223	4,105

*see spreadsheet on next page

CHAPTER 13
PREDICTING COMPARTMENT
POST-FLASHOVER TEMPERATURE

Version 1805.1
(English Units)

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

Project / Inspection Title: **Example 13.10-3a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft
Compartment Length (l_c)	25.00	ft
Compartment Height (h_c)	12.00	ft
Vent Width (w_v)	6.00	ft
Vent Height (h_v)	8.00	ft

Calculate

METHOD OF MARGARET LAW

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

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

Where,

$T_{PFO\ (max)}$ = maximum compartment post-flashover temperature (°C)

Ω = ventilation factor

Ventilation Factor

$$\Omega = (A_T - A_v) / A_v\ (\sqrt{h_v})$$

Where,

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

A_v = area of ventilation opening (m^2)

h_v = height of ventilation opening (m)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

Where,

A_v = area of ventilation opening (m^2)

w_v = vent width (m)

h_v = vent height (m)

A_v = 4.46 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 = 188.78 m^2

Ventilation Factor Calculation

$$\Omega = (A_T - A_v) / A_v (\sqrt{h_v})$$

Where,

Ω = ventilation factor
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = vent height (m)

Ω = 26.47 $m^{-1/2}$

COMPARTMENT POST-FLASHOVER TEMPERATURE

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

Answer	$T_{PFO\,(max)}$ =	1982.42 °F	1083.57 °C

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

CHAPTER 13
PREDICTING COMPARTMENT FLASHOVER
HEAT RELEASE RATE

Version 1805.1
(English Units)

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.

Project / Inspection Title: **Example 13.10-3b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft
Compartment Length (l_c)	25.00	ft
Compartment Height (h_c)	12.00	ft
Vent Width (w_v)	6.00	ft
Vent Height (h_v)	8.00	ft
Interior Lining Thickness (δ)	6.00	in
Interior Lining Thermal Conductivity (k)	0.0016	kW/m-K

Calculate

THERMAL PROPERTIES DATA

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

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

Select Material

Concrete

Scroll to desired material
Click on selection

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

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

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

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

Heat Transfer Coefficient Calculation

$$h_k = k/\delta$$

Assuming that compartment has been heated thoroughly before flashover, i.e., t > tp.

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

h_k = 0.010 kW/m^2-K

Area of Ventilation Opening Calculation

$$A_v = (w_v)(h_v)$$

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

A_v = 4.46 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 = 188.78 m^2

MINIMUM HEAT RELEASE RATE FOR FLASHOVER

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

Q_{FO} = 2266.14 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF BABRAUSKAS

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

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

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

Minimum Heat Release Rate for Flashover

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

Q_{FO} = 5222.58 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF THOMAS

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

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

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

Minimum Heat Release Rate for Flashover

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

Q_{FO} = 4104.66 kW

Summary of Results

CALCULATION METHOD	Flashover HRR	
	Btu/sec	kW
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)	2148	2266
METHOD OF BABRAUSKAS	4950	5223
METHOD OF THOMAS	3891	4105

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

14.10 Problems

Example Problem 14.10-1

Problem Statement
A closed compartment in a facility pump room has dimensions 10 ft wide x 12 ft long x 10 ft high (w_c x l_c x h_c). A fire starts with a constant HRR of $\dot{Q}$ = 100 kW. Estimate the pressure rise attributable to the expansion of gases after 10 seconds.

Solution

Purpose:
(1) Estimate the pressure rise in the compartment 10 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) Information:

Use the following FDT^s:
(a) 14_Compartment_Over_Pressure_Calculations_Sup1.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 10 ft
- Compartment Length (l_c) = 12 ft
- Compartment Height (h_c) = 10 ft
- Fire Heat Release Rate ($\dot{Q}$) = 100 kW
- Time After Ignition (t) = 10 sec

Results*

Pressure Rise	1.73 psi

*see spreadsheet on next page

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

Version 1805.1
(English Units)

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

Project / Inspection Title: **Example 14.10-1**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	10.00	ft
Compartment Length (l_c)	12.00	ft
Compartment Height (h_c)	10.00	ft
Fire Heat Release Rate (Q)	100.00	kW
Time after Ignition (t)	10.00	sec
Ambient Air Temperature (T_a)	77.00	°F

Calculate

AMBIENT CONDITIONS

Initial Atmospheric Pressure (P_a)	14.70	psi
Specific Heat of Air at Constant Volume (c_v)	0.71	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3

NOTE:

Values of Specific Heat of Air at Constant Volume (c_v) range from 0.71 to 0.85 kJ/kg-k

Ambient Air Density (ρ_a) will automatically correct with Ambient Air Temperature (T_a) Input

METHOD OF KARLSSON AND QUINTIERE

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

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

Where,

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

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

Where,

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

V = 1200 ft^3 33.98 m^3

Pressure Rise in Compartment

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

$(P-P_a)/P_a =$ 0.117 atm

Multiplying by the atmospheric pressure (P_a) = 101 kPa
Gives a pressure difference equal to:

Answer	1.73	psi	11.90	kPa

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

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

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

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Example Problem 14.10-2

Problem Statement
A facility has a sealed compartment (assume zero leakage) with a blowout panel that is designed to fail at two atmospheres. The compartment is 20 ft wide x 25 ft long x 10 ft high. A fire is assumed with a constant heat release rate of 255 kW.

At what time (sec) does the blowout panel fail?

Solution

Purpose:
(1) Estimate the time after ignition the pressure reaches 2 atm (202.5 kPa).

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) Information:

Use the following FDT^s:
(a) 14_Compartment_Over_Pressure_Calculations_Sup1.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 20 ft
- Compartment Length (l_c) = 25 ft
- Compartment Height (h_c) = 10 ft
- Fire Heat Release Rate ($\dot{Q}$) = 255 kW
- Time After Ignition (t) = varies until output is 202.5 kPa

Results*

Time after Ignition	278 sec

*see spreadsheet on next page

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

Version 1805.1 (English Units)

The following calculations estimate the pressure rise in a compartment due to fire and combustion.

Parameters in YELLOW CELLS are Entered by the User.

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

Project / Inspection Title: **Example 14.10-2**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	20.00	ft
Compartment Length (l_c)	25.00	ft
Compartment Height (h_c)	10.00	ft
Fire Heat Release Rate (Q)	255.00	kW
Time after Ignition (t)	278.00	sec
Ambient Air Temperature (T_a)	77.00	°F

Calculate

AMBIENT CONDITIONS

Initial Atmospheric Pressure (P_a)	14.70	psi
Specific Heat of Air at Constant Volume (c_v)	0.71	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3

NOTE:

Values of Specific Heat of Air at Constant Volume (c_v) range from 0.71 to 0.85 kJ/kg-k

Ambient Air Density (ρ_a) will automatically correct with Ambient Air Temperature (T_a) Input

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

Version 1805.1
(English Units)

METHOD OF KARLSSON AND QUINTIERE

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

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

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

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

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

V = 5000 ft^3 141.58 m^3

Pressure Rise in Compartment

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

$(P-P_a)/P_a =$ 1.998 atm

Multiplying by the atmospheric pressure (P_a) = 101 kPa
Gives a pressure difference equal to:

Answer	29.37	psi	202.48	kPa

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

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

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

15.18 Problems

Example Problem 15.18-1

Problem Statement
In an NPP, a liquid propane gas (LPG) driven forklift is used to unload materials from an upcoming outage. Mechanical failure could result in the release of LPG in the area. The maximum fuel capacity of the forklift is 10 gallons. Calculate pressure rise, energy released by expanding LPG, and equivalent TNT charge weight. Assume that the mass of the vapor released is 48 lb.

Solution

Purpose:
(1) Estimate pressure rise, energy released, and TNT equivalent.

Assumptions:
(1) The atmospheric pressure is 14.7 psi.
(2) Ambient air temperature is 77 °F.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 15_Explosion_Calculations_Sup1.xls

FDT^s Input Parameters:
- Select Fuel Type = **Propane**
- Percent yield = 100%
- Mass of flammable vapor release = 48 lb

Results*

Pressure Rise	76.7 psi
Energy Released	957,983 Btu
Equivalent TNT	496 lb

*see spreadsheet on next page

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(English Units)

The following calculations estimate the pressure and energy due to an explosion in a confined space.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 15.18-1**

INPUT PARAMETERS

EXPLOSIVE FUEL INFORMATION

Adiabatic Flame Temperature of the Fuel ((T_{ad})	2338	°F
Heat of Combustion of the Fuel (ΔH_c)	46360	kJ/kg
Yield (α) See Note	100.00	%
Mass of Flammable Vapor Release (m_F)	48.00	lb
Ambient Air Temperature (T_a)	77.00	°F
Initial Atmospheric Pressure (P_a)	14.70	psi

Note: The fraction of available combustion is 1% for unconfined mass release and 100% for confined vapor release energy participating in blast wave generation.

Calculate

THERMAL PROPERTIES FOR FUEL

FUEL FLAMMABILITY DATA

Fuel	Adiabatic Flame Temperature T_{ad} (°F)	Heat of Combustion ΔH_c (kJ/kg)
Acetylene	4779	48,220
Carbon Monoxide	4329	10,100
Ethane	2244	47,490
Ethylene	4152	47,170
Hydrogen	4085	130,800
Methane	2143	50,030
n-Butane	2442	45,720
n-Heptane	2586	44,560
n-Octane	2478	44,440
n-Pentane	2356	44,980
Propane	2338	46,360
Propylene	4050	45,790
User Specified Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 1-86.

Select Fuel Type

Propane

Scroll to desired Fuel Type **then Click** on selection

METHOD OF ZALOSH

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-312.

Pressure Rise from a Confined Explosion

$$(P_{max})/P_a = (T_{ad}/T_a)$$

$$P_{max} = (T_{ad}/T_a)\, P_a$$

Where,
P_{max} = maximum pressure developed at completion of combustion (kPa)
P_a = initial atmospheric pressure (kPa)
T_{ad} = adiabatic flame temperature (K)
T_a = ambient temperature (K)

P_{max} = 528.57 kPa 76.66 psi

Blast Wave Energy Calculation

$$E = \alpha\, \Delta H_c\, m_F$$

Where,
E = blast wave energy (kJ) [E is the Trinitrotoluene (TNT) equivalent energy]
α = yield (a is the fraction of available combustion energy participating in blast wave generation)
ΔH_c = heat of combustion (kJ/kg)
m_F = mass of flammable vapor release (kg)

E = 1011490.91 kJ 957983.04 Btu

TNT Mass Equivalent Calculation

$$W_{TNT} = E/4500$$

Where,
W_{TNT} = weight of TNT (kg)
E = explosive energy release (kJ)

W_{TNT} = 224.78 kg 495.55 lb

Summary of Results

Pressure Rise from a Confined Explosion

$$P_{max} = (T_{ad}/T_a)\, P_a$$

Answer	P_{max} =	76.66 psi	528.57 kPa

Blast Wave Energy

$$E = \alpha\, \Delta H_c\, m_F$$

Answer	E =	957983.04 Btu	1011490.91 kJ

TNT Mass Equivalent

$$W_{TNT} = E/4500$$

Answer	W_{TNT} =	495.55 lb	224.78 kg

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 15.18-2

Problem Statement
An investigator is performing a review of an accident at a facility. The report states that a pipe fitter accidently left his acetylene "B" tank on which leaked its contents and caused the explosion. Assuming the tank was full (40 ft^3 of gas at atmospheric pressure), how large could the explosion have been?

Solution

Purpose:
(1) Estimate energy released, and TNT equivalent.

Assumptions:
(1) The atmospheric pressure is 14.7 psi.
(2) Ambient air temperature is 77 °F.

Spreadsheet (FDT^s) Information:
Use the following FDT^s:
(a) 15_Explosion_Calculations_Sup1.xls

FDT^s Input Parameters:
- Select Fuel Type = **Acetylene**
- Percent yield = 100%
- Mass of vapor release = volume x density (from manufacture's Web site)

$$40\ ft^3 \times .0677\ lb/ft^3 = 2.7\ lb$$

Results*

Energy Released	56,049 Btu
Equivalent TNT	29.0 lb

*see spreadsheet on next page

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(English Units)

The following calculations estimate the pressure and energy due to an explosion in a confined space.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 15.18-2**

INPUT PARAMETERS

EXPLOSIVE FUEL INFORMATION

Adiabatic Flame Temperature of the Fuel ((T_{ad})	4779	°F
Heat of Combustion of the Fuel (ΔH_c)	48220	kJ/kg
Yield (α) See Note	100.00	%
Mass of Flammable Vapor Release (m_F)	2.70	lb
Ambient Air Temperature (T_a)	77.00	°F
Initial Atmospheric Pressure (P_a)	14.70	psi

Note: The fraction of available combustion is 1% for unconfined mass release and 100% for confined vapor release energy participating in blast wave generation.

Calculate

THERMAL PROPERTIES FOR FUEL

FUEL FLAMMABILITY DATA

Fuel	Adiabatic Flame Temperature T_{ad} (°F)	Heat of Combustion ΔH_c (kJ/kg)
Acetylene	4779	48,220
Carbon Monoxide	4329	10,100
Ethane	2244	47,490
Ethylene	4152	47,170
Hydrogen	4085	130,800
Methane	2143	50,030
n-Butane	2442	45,720
n-Heptane	2586	44,560
n-Octane	2478	44,440
n-Pentane	2356	44,980
Propane	2338	46,360
Propylene	4050	45,790
User Specified Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 1-86.

Select Fuel Type

Acetylene

Scroll to desired Fuel Type **then Click** on selection

METHOD OF ZALOSH

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-312.

Pressure Rise from a Confined Explosion

$$(P_{max})/P_a = (T_{ad}/T_a)$$

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Where,
P_{max} = maximum pressure developed at completion of combustion (kPa)
P_a = initial atmospheric pressure (kPa)
T_{ad} = adiabatic flame temperature (K)
T_a = ambient temperature (K)

P_{max} = 989.80 kPa 143.56 psi

Blast Wave Energy Calculation

$$E = \alpha\ \Delta H_c\ m_F$$

Where,
E = blast wave energy (kJ) [E is the Trinitrotoluene (TNT) equivalent energy]
α = yield (a is the fraction of available combustion energy participating in blast wave generation)
ΔH_c = heat of combustion (kJ/kg)
m_F = mass of flammable vapor release (kg)

E = 59179.09 kJ 56048.52 Btu

TNT Mass Equivalent Calculation

$$W_{TNT} = E/4500$$

Where,
W_{TNT} = weight of TNT (kg)
E = explosive energy release (kJ)

W_{TNT} = 13.15 kg 28.99 lb

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(English Units)

Summary of Results

Pressure Rise from a Confined Explosion

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Answer	P_{max} =	143.56 psi	989.80 kPa

Blast Wave Energy

$$E = \alpha\ \Delta H_c\ m_F$$

Answer	E =	56048.52 Btu	59179.09 kJ

TNT Mass Equivalent

$$W_{TNT} = E/4500$$

Answer	W_{TNT} =	28.99 lb	13.15 kg

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 15.18-3

Problem Statement
Which has a larger TNT mass equivalent: 10 lb (mass vapor) of acetylene or 5 lb (mass vapor) of hydrogen?

Solution

Purpose:
(1) Estimate TNT equivalent.

Assumptions:
(1) The atmospheric pressure is 14.7 psi.
(2) Ambient air temperature is 77 °F.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 15_Explosion_Calculations_Sup1.xls

FDT^s Input Parameters:
- Select Fuel Type = **Acetylene**
- Percent yield = 100%
- Mass of flammable vapor release = 10 lb
- Select Fuel Type = **Hydrogen**
- Percent yield = 100%
- Mass of flammable vapor release = 5 lb

Results*

	Acetylene	Hydrogen
Equivalent TNT	107 lb	146 lb

*see spreadsheet on next page

Therefore, 5 lb of hydrogen produces more explosive force than 10 lb of acetylene.

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(English Units)

The following calculations estimate the pressure and energy due to an explosion in a confined space.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 15.18-3a**

INPUT PARAMETERS

EXPLOSIVE FUEL INFORMATION

Adiabatic Flame Temperature of the Fuel ((T_{ad})	4779	°F
Heat of Combustion of the Fuel (ΔH_c)	48220	kJ/kg
Yield (α) See Note	100.00	%
Mass of Flammable Vapor Release (m_F)	10.00	lb
Ambient Air Temperature (T_a)	77.00	°F
Initial Atmospheric Pressure (P_a)	14.70	psi

Note: The fraction of available combustion is 1% for unconfined mass release and 100% for confined vapor release energy participating in blast wave generation.

Calculate

THERMAL PROPERTIES FOR FUEL

FUEL FLAMMABILITY DATA

Fuel	Adiabatic Flame Temperature T_{ad} (°F)	Heat of Combustion ΔH_c (kJ/kg)
Acetylene	4779	48,220
Carbon Monoxide	4329	10,100
Ethane	2244	47,490
Ethylene	4152	47,170
Hydrogen	4085	130,800
Methane	2143	50,030
n-Butane	2442	45,720
n-Heptane	2586	44,560
n-Octane	2478	44,440
n-Pentane	2356	44,980
Propane	2338	46,360
Propylene	4050	45,790
User Specified Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 1-86.

Select Fuel Type

Acetylene

Scroll to desired Fuel Type then Click on selection

METHOD OF ZALOSH

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-312.

Pressure Rise from a Confined Explosion

$$(P_{max})/P_a = (T_{ad}/T_a)$$

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Where,
P_{max} = maximum pressure developed at completion of combustion (kPa)
P_a = initial atmospheric pressure (kPa)
T_{ad} = adiabatic flame temperature (K)
T_a = ambient temperature (K)

P_{max} = 989.80 kPa 143.56 psi

Blast Wave Energy Calculation

$$E = \alpha\ \Delta H_c\ m_F$$

Where,
E = blast wave energy (kJ) [E is the Trinitrotoluene (TNT) equivalent energy]
α = yield (a is the fraction of available combustion energy participating in blast wave generation)
ΔH_c = heat of combustion (kJ/kg)
m_F = mass of flammable vapor release (kg)

E = 219181.82 kJ 207587.10 Btu

TNT Mass Equivalent Calculation

$$W_{TNT} = E/4500$$

Where,
W_{TNT} = weight of TNT (kg)
E = explosive energy release (kJ)

W_{TNT} = 48.71 kg 107.38 lb

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(English Units)

Summary of Results

Pressure Rise from a Confined Explosion

$$P_{max} = (T_{ad}/T_a)\, P_a$$

Answer	P_{max} =	143.56 psi	989.80 kPa

Blast Wave Energy

$$E = \alpha\, \Delta H_c\, m_F$$

Answer	E =	207587.10 Btu	219181.82 kJ

TNT Mass Equivalent

$$W_{TNT} = E/4500$$

Answer	W_{TNT} =	107.38 lb	48.71 kg

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(English Units)

The following calculations estimate the pressure and energy due to an explosion in a confined space.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 15.18-3b**

INPUT PARAMETERS

EXPLOSIVE FUEL INFORMATION

Adiabatic Flame Temperature of the Fuel ((T_{ad})	4085	°F
Heat of Combustion of the Fuel (ΔH_c)	130800	kJ/kg
Yield (α) See Note	100.00	%
Mass of Flammable Vapor Release (m_F)	5.00	lb
Ambient Air Temperature (T_a)	77.00	°F
Initial Atmospheric Pressure (P_a)	14.70	psi

Note: The fraction of available combustion is 1% for unconfined mass release and 100% for confined vapor release energy participating in blast wave generation.

Calculate

THERMAL PROPERTIES FOR FUEL

FUEL FLAMMABILITY DATA

Fuel	Adiabatic Flame Temperature T_{ad} (°F)	Heat of Combustion ΔH_c (kJ/kg)
Acetylene	4779	48,220
Carbon Monoxide	4329	10,100
Ethane	2244	47,490
Ethylene	4152	47,170
Hydrogen	4085	130,800
Methane	2143	50,030
n-Butane	2442	45,720
n-Heptane	2586	44,560
n-Octane	2478	44,440
n-Pentane	2356	44,980
Propane	2338	46,360
Propylene	4050	45,790
User Specified Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 1-86.

Select Fuel Type

Hydrogen

Scroll to desired Fuel Type **then Click** on selection

METHOD OF ZALOSH

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-312.

Pressure Rise from a Confined Explosion

$$(P_{max})/P_a = (T_{ad}/T_a)$$

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Where,
P_{max} = maximum pressure developed at completion of combustion (kPa)
P_a = initial atmospheric pressure (kPa)
T_{ad} = adiabatic flame temperature (K)
T_a = ambient temperature (K)

P_{max} = 858.67 kPa 124.54 psi

Blast Wave Energy Calculation

$$E = \alpha\ \Delta H_c\ m_F$$

Where,
E = blast wave energy (kJ) [E is the Trinitrotoluene (TNT) equivalent energy]
α = yield (a is the fraction of available combustion energy participating in blast wave generation)
ΔH_c = heat of combustion (kJ/kg)
m_F = mass of flammable vapor release (kg)

E = 297272.73 kJ 281547.00 Btu

TNT Mass Equivalent Calculation

$$W_{TNT} = E/4500$$

Where,
W_{TNT} = weight of TNT (kg)
E = explosive energy release (kJ)

W_{TNT} = 66.06 kg 145.64 lb

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(English Units)

Summary of Results

Pressure Rise from a Confined Explosion

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Answer	P_{max} =	124.54 psi	858.67 kPa

Blast Wave Energy

$$E = \alpha\ \Delta H_c\ m_F$$

Answer	E =	281547.00 Btu	297272.73 kJ

TNT Mass Equivalent

$$W_{TNT} = E/4500$$

Answer	W_{TNT} =	145.64 lb	66.06 kg

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

Prepared by: ____________ Date: ________ Organization: ____________

Checked by: ____________ Date: ________ Organization: ____________

Additional Information:

16.14 Problems

Example Problem 16.14-1

Problem Statement
Assume a 60-cell GT-41 (3,730 Ampere-hour) battery near the end of its life, on equalize at 2.33 VPC at an electrolyte temperature of 92 °F. Estimate the rate of hydrogen generation (in cubic feet per minute).

Solution

Purpose:
(1) Estimate the rate of hydrogen generation.

Assumptions:
(1) Old Antimony-type battery

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 16_Battery_Room_Flammable_Gas_Conc_Sup1.xls (click on *Battery_Room_Hydrogen*)

FDT^s Input Parameters:
- Ampere Hours = 3730 Ah
- Number of Cells = 60
- Click on **Old Antimony type** and Select 2.33 VPC

Results*

Generation Rate	0.538 ft^3/min

*see spreadsheet on next page

CHAPTER 16
CALCUALATING THE RATE OF HYDROGEN GAS GENERATION IN BATTERY ROOMS

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 16.14-1**

INPUT PARAMETERS

BATTERY INFORMATION

Float Current (F_C)	450	mA per 100 A_H @ 8-hr. rate
Ampere Hours (A_H)	3730.00	Ampere hours
Number of Cells (N)	60.00	
Constant (K)	0.000267	ft^3

COMPARTMENT INFORMATION

Compartment Width (w_c)	26.00	ft
Compartment Length (l_c)	50.00	ft
Compartment Height (h_c)	12.00	ft

FLAMMABLE GAS INFORMATION

Lower Flammability Limit of Hydrogen (FL)	4.00	%

Calculate

Float Current Demand of Fully Charged Stationary Lead-Acid Cells

Reference: *Yuasa, Inc., Safety Storage, Installation, Operation, and Maintenance Manual, Section 58.00, Heritage Series, Flooded Lead-Acid Batteries, 2000.*

New Antimony	F_C*
Charge Voltage (VPC)	Antimony New
2.15	15
2.17	19
2.20	26
2.23	37
2.25	45
2.27	60
2.33	120
2.37	195
2.41	300
User Specified Value	Enter Value

*(milliamperes per 100 AH @ 8-hr. rate)

Select Charge Current Value

Scroll to desired value then Click on selection

Old Antimony	F_C*
Charge Voltage (VPC)	Antimony Old
2.15	60
2.17	80
2.20	105
2.23	150
2.25	185
2.27	230
2.33	450
2.37	700
2.41	1100
User Specified Value	Enter Value

*(milliamperes per 100 AH @ 8-hr. rate)

Select Charge Current Value

2.33

Scroll to desired value then Click on selection

Calcium	F_C*
Charge Voltage (VPC)	Antimony Calcium
2.15	
2.17	4
2.20	6
2.23	8
2.25	11
2.27	12
2.33	24
2.37	38
2.41	58
User Specified Value	Enter Value

*(milliamperes per 100 AH @ 8-hr. rate)

Select Charge Current Value

Scroll to desired value then Click on selection

METHOD OF YUASA, INC.

Reference: *Yuasa, Inc., Safety Storage, Installation, Operation, and Maintenance Manual, Section 58.00, Heritage Series, Flooded Lead-Acid Batteries, 2000.*

Estimating Hydrogen Gas Generation Rate

$$H_{2(gen)} = F_C/1000 \times A_H/100 \times K \times N$$

This equation is based on when electrolyte temperature is 77 °F (25 °C)

For every 15 °F (8 °C) electrolyte temperature rise the equation will multiply by 2

Where

$H_{2(gen)}$ = hydrogen gas generation rate (ft^3/min)

F_C= float current (mA per 100 A_H @ 8-hr. rate)

A_H = ampere hours (normal 8 hour)

K = constant - 1 A_H = 0.000267 ft^3

N = number of cells

$$H_{2(gen)} = F_C/1000 \times A_H / 100 \times K \times N \times 2$$

Since electrolyte temperature is 92 °F (33 °C) the equation is multiplied by 2

$H_{2(gen)}$ = **0.538** ft^3/min **0.015230** m^3/min

Estimating Hydrogen Gas in Compartment Based on Given Flammability Limit

$$H_{2(comp)} = V \times FL$$

Where

$H_{2(comp)}$ = hydrogen gas in compartment (ft^3)

V = volume of compartment (ft^3)

FL = hydrogen gas flammability limit

$H_{2(comp)}$ = **624** ft^3

Volume of Compartment

$$V = w_c \times l_c \times h_c$$

Where

V = compartment volume (ft^3)

w_c = compartment width (ft)

lc = compartment length (ft)

hc = compartment height (ft)

V = **15600** ft^3

Estimating Time Required to Reach Hydrogen Concentration on Given Flammability Limit

$$t_{H2} = H_{2(comp)} / H_{2(gen)}$$

Where

t_{H2} = time require to reach on given flammability limit (min)

$H_{2(comp)}$ = hydrogen gas in compartment (ft^3)

$H_{2(gen)}$ = hydrogen gas generation rate (ft^3/min)

t_{H2} = **1160.30 min. or approx.** **19 hours**

CHAPTER 16
CALCUALATING THE RATE OF HYDROGEN GAS GENERATION IN BATTERY ROOMS

Version 1805.1
(English Units)

Summary of Results

ESTIMATING HYDROGEN GAS GENERATION RATE

$$H_{2(gen)} = F_C/1000 \times A_H / 100 \times K \times N \times 2$$

Answer	$H_{2(gen)}$ =	0.53779 ft^3/min	0.01523 m^3/min

ESTIMATING TIME REQUIRED TO REACH HYDROGEN CONCENTRATION ON GIVEN FLAMMABILITY LIMIT

$$t_{H2} = H_{2(comp)} / H_{2(gen)}$$

Answer	t_{H2}=	1160.30 min or approx.	19 hours

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 16.14-2

Problem Statement

Consider an enclosure (10 ft wide x 10 ft long x 10 ft high) 1,000 ft^3 in turbine generator area of a nuclear facility in which hydrogen gas is accumulated. Calculate the concentration of hydrogen gas by volume reaching its LFL of 4 percent.

Solution

Purpose:

(1) Estimate the concentration of hydrogen gas in the compartment at LFL.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 16_Battery_Room_Flammable_Gas_Conc_Sup1.xls (click on *Flammable_Gas_Buildup*)

FDT^s Input Parameters:

- Compartment Width (w_c) = 10 ft
- Compartment Length (l_c) = 10 ft
- Compartment Height (h_c) = 10 ft
- Select **Hydrogen**

Results*

Volume	40 ft^3

*see spreadsheet on next page

Therefore, the concentration of hydrogen gas in the 1000 ft^3 compartment is 4% (40/1000).

CHAPTER 16
CALCULATING THE RATE OF HYDROGEN GENERATION IN BATTERY ROOMS

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 16.14-2**

INPUT PARAMETERS

Lower Flammability Limit of Flammable Gas or Vapor (LFL)	4.00	%
Compartment Width (w_c)	10.00	ft
Compartment Length (l_c)	10.00	ft
Compartment Height (h_c)	10.00	ft

Calculate

LOWER FLAMMABILITY DATA FOR GASES AND VAPORS

Gases and Vapors	LFL Volume-Percent
Hydrogen	4.00
Carbon Monoxide	12.50
Methane	5.00
Ethane	3.00
Propane	2.10
n-Butane	1.80
n-Pentane	1.40
n-Hexane	1.20
n-Heptane	1.05
n-Octane	0.95
n-Nonane	0.85
n-Decane	0.75
Ethene	2.70
Propane	2.40
Butene-1	1.70
Acetylene	2.50
Methanol	6.70
Ethanol	3.30
n-Propanol	2.20
Acetone	2.60
Methyl Ethyl Ketone	1.90
Diethyl Ketone	1.60
Benzene	1.30
User Specified Value	Enter Value

Select Gas or Vapor
Hydrogen
Scroll to desired gas or vapor then **Click** on selection

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 2-175.

ESTIMATING FLAMMABLE CONCENTRATION OF GASES USING LIMITS OF FLAMMABILITY

Volume of Gas or Vapor for Deflagration = V x LFL

Where
V = volume of enclosure (ft^3)
LFL= lower flammability of a gas or vapor (percent-volume)

Volume of Compartment

$$V = w_c \times l_c \times h_c$$

Where
V = compartment volume (ft^3)
wc = compartment width (ft)
lc = compartment length (ft)
hc = compartment height (ft)

$V = 1000.00$ ft^3

Volume of Gas or Vapor for Deflagration = V x LFL

Answer	Volume of Gas or Vapor for Deflagration =	40 ft^3	1.13 m^3

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

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 16.14-3

Problem Statement
Assume a leak of 100 ft^3/min of a 15 percent hydrogen gas/air mixture in a compartment that is 29 ft wide x 15 ft long x 12 ft high (w_c x l_c x h_c). How long would it take to reach a hydrogen concentration of 2 percent throughout the enclosure, assuming infiltration through multiple compartment cracks?

Solution

Purpose:
(1) Estimate the time until the room reaches 2% hydrogen concentration.

Assumptions:
(1) Infiltration through compartment leaks.
(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) Information:

Use the following FDT^s:
(a) 16_Battery_Room_Flammable_Gas_Conc_Sup1.xls
(click on *Flammable_Gas_Buildup_Time*)

FDT^s Input Parameters:
- Compartment Width (w_c) = 29 ft
- Compartment Length (l_c) = 15 ft
- Compartment Height (h_c) = 12 ft
- Enter 100 ft^2/min as the Leakage Rate
- Enter 15% as Percent of Combustible Gas/Air Mixture
- Enter 2% as Combustible Gas Concentration (C)
- Click on **Infiltration Through Cracks** and select 0.3 from the drop-down menu

Results*

Time	20.9 minutes

*see spreadsheet on next page

CHAPTER 16
CALCULATING THE RATE OF HYDROGEN GENERATION IN BATTERY ROOMS

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 16.14-3**

INPUT PARAMETERS

COMPARTMENT INFORMATION HYDROGEN LEAK INFORMATION

Compartment Width (w_c)	29.00	ft
Compartment Length (l_c)	15.00	ft
Compartment Height (h_c)	12.00	ft
Leakage Rate	100.00	ft^3/min
Percent of Combustible Gas/Air Mixture	15.00	percent
Combustible Gas Concentration (C)	2.00	percent
Mixing Efficiency Factor (K)	0.3	

Calculate

Mixing Efficiency (K Values) for Various Ventilation Arrangements

Reference: *NFPA 69, "Standard on Explosion Prevention Systems," 1997 Edition.*

Infiltration Through Cracks	K
Single Exhaust Opening	0.2
Multiple Exhaust Openings	0.3

Select Ventilation Arrangement
0.3
Scroll to desired arrangement then **Click** on selection

Open Door, or Windows	K
Single Exhaust Opening	0.2
Multiple Exhaust Openings	0.4

Select Ventilation Arrangement
Scroll to desired arrangement then **Click** on selection

Grill and Registers	K
Single Exhaust Opening	0.3
Multiple Exhaust Openings	0.5

Select Ventilation Arrangement
Scroll to desired arrangement then **Click** on selection

Diffusers	K
Single Exhaust Opening	0.5
Multiple Exhaust Openings	0.7

Select Ventilation Arrangement
Scroll to desired arrangement then **Click** on selection

Perforated Ceiling	K
Single Exhaust Opening	0.8
Multiple Exhaust Openings	0.9

Select Ventilation Arrangement
Scroll to desired arrangement then **Click** on selection

User Specified Value	K
Single Exhaust Opening	Enter Value
Multiple Exhaust Openings	Enter Value

Select Ventilation Arrangement
Enter Value
Scroll to desired arrangement then **Click** on selection

METHOD OF NFPA 69, STANDARD ON EXPLOSION PREVENTION SYSTEMS

Reference: *NFPA 69, "Standard on Explosion Prevention Systems, 1997 Edition, Appendix D.*

Estimating Number of Theoretical Air Changes

ln [1 - (CQ / G)] = - K N

Where
C = combustible gas concentration
Q = air flow rate (fresh air) in enclosure (ft^3/min)
G = combustible gas leakage rate (ft^3/min)
K = mixing efficiency factor (constant)
N = number of theoretical air changes

Q = air flow rate (fresh air) in enclosure

Q = 85.00 ft^3/min

G = combustible gas leakage rate

G = 15 (ft^3/min)

N = number of theoretical air changes

ln [1 - (CQ / G)] = - K N
or
N = - [ln(1 - (CQ/G))]/ K

N = 0.40

Estimating Combustible Gas Concentration Buildup Time

t = (V / leakage rate) * N

Where
t = buildup time (min)
V = compartment volume (ft^3)
leakage rate (ft^3/min)
N = number of theoretical air changes

Volume of Compartment

$V = w_c \times l_c \times h_c$

Where
V = compartment volume (ft^3)
wc = compartment width (ft)
lc = compartment length (ft)
hc = compartment height (ft)

V = 5220.00 ft^3

COMBUSTIBLE GAS CONCENTRATION BUILDUP TIME

t = (V / leakage rate) * N

Answer	t =	20.93 minutes

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

17.14 Problems

Example Problem 17.14-1

Problem Statement
Calculate the thickness of spray-on fire protection required to provide a 2-hour fire resistance for a W12 x 16 beam to be substituted for a W8 x 18 beam requiring 1.44 in. of protection for the same rating.

Solution

Purpose:
(1) Estimate the spray-on thickness required for the beam substitution.

Assumptions:
(1) The 1.44 in. of spray-on provides the W8 x 18 beam 2 hours of fire resistance.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 17.1_FR_Beams_Columns_Substitution_Correlation_Sup1.xls
(click on *Beam*)

FDT^s Input Parameters:
- Known beam insulation thickness
- Select W8 x 18 for Rated Beam
- Select W12 x 16 for Substitute Beam

Results*

Substitute Beam Spray on Thickness	1.6 in

*see spreadsheet on next page

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

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 17.14-1**

INPUT PARAMETERS

Rated Design Thickness of Beam Insulation (T_2)	1.44	in
Known Insulation Rating		
Weight of the Beam (W_2)	18	lb/ft
Heated Perimeter of Beam (D_2)	31.57	in
Unknown Insulation Rating		
Weight of the Beam (W_1)	16.00	lb/ft
Heated Perimeter of Beam (D_1)	35.51	in

SECTIONAL FACTORS FOR STEEL BEAMS

Select the Beam with known rating for insulation thickness
W8 x 18
Subscript 2
(Rated Beam)

Calculate

Select the Beam with unknown rating for insulation thickness
W12 x 16
Subscript 1
(Substitute Beam)

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

Version 1805.1
(English Units)

ESTIMATING THICKNESS OF FIRE PROTECTION INSULATION ON UNRATED BEAM

Reference: *UL Fire Resistance Directory, Volume 1, 1995, Page 19.*

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

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

REQUIRED EQUIVALENT THICKNESS OF FIRE PROTECTION INSULATION ON UNRATED BEAM

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

Answer	T_1 =	1.60 in

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

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

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Example Problem 17.14-2

Problem Statement
Use the quasi-steady-state heat transfer approach to determine the fire resistance of a W24 x 76 steel beam protected with 0.5 in. of spray-on mineral fiber material. Sprayed-on mineral fiber has the following thermal properties:

- Thermal Conductivity (k_i) = 0.06936 Btu/ft-hr-°F
- Specific Heat (c_i) = 0.2868 Btu/lb-°F
- Density (ρ_i) =19.0 lb/ft^3

Solution

Purpose:
(1) Estimate the fire resistance of the beam.

Assumptions:
(1) The heat transfer is quasi-steady-state.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 17.2_FR_Beams_Columns_Quasi_Steady_State_Spray_Insulated_Sup1.xls
(click on *Beam*)

FDTs Input Parameters:
- Select W24 x 76 beam
- Enter 0.5 in spray-on thickness
- Select **Sprayed Mineral Fiber** from Insulation Type drop-down menu

Results*

Fire Resistance	42.5 min

*see spreadsheet on next page

ESTIMATING FIRE RESISTANCE TIME OF STEEL BEAMS PROTECTED BY FIRE PROTECTION INSULATION (QUASI-STEADY-STATE APPROACH)

Version 1805.1
(English Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 17.14-2**

INPUT PARAMETERS

Ratio of Weight of Steel Section per Linear Foot and Heated Perimeter (W/D)		12.34	lb/ft^2
Thickness of Spray-Applied Protection on Steel Beam (h)	**h ≥ 1/16 in**	0.50	in
Density of Spray-Applied Material (ρ_i)		19.00	lb/ft^3
Thermal Conductivity of Spray-Applied Material (k_i)		0.06936	Btu/ft-hr-°F
Specific Heat of Spray-Applied Material (c_i)		0.2868	Btu/lb-°F
Ambient Air Temperature (T_a)		77	°F
Specific Heat of Steel (c_s)		0.132	Btu/lb-°F

Calculate

SECTIONAL FACTORS FOR STEEL BEAMS

Select Beam
24x76
Scroll to desired beam size then Click on selection

THERMAL PROPERTIES OF SPRAY-APPLIED INSULATION MATERIALS

Insulation Material Spray-Applied	Density ρ_i (lb/ft^3)	Thermal Conductivity k_i (Btu/ft-hr-°F)	Specific Heat c_i (Btu/lb-°F)
Sprayed mineral fiber	19	0.06936	0.2868
Perlite or vermiculite	22	0.06936	0.2868
High density perlite or vermiculite	35	0.06936	0.2868
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *Buchanan, A. H., Structural Design for Fire Safety, 2001, Page 179.*

Select Insulation Type
Sprayed mineral fiber
Scroll to desired material then Click on selection

ESTIMATING FIRE RESISTANCE TIME USING QUASI-STEADY-STATE APPROACH

Reference: *"Analytical Methods for Determining Fire Resistance of Steel Members,"*
"SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 4-209.

Temperature Rise in Steel Beam

$$\Delta T_s = (k_i /(c_s\ h\ W/D + 1/2\ c_i\ \rho_i\ h^2))\ (T_f - T_s)\ \Delta t$$

Where
ΔT_s = temperature rise in steel (°F)
k_i = thermal conductivity of spray-applied material (Btu/ft-sec-°F)
ρ_i = density of spray-applied material (lb/ft^3)
c_i = specific heat of spray-applied material (Btu/lb-°F)
c_s = specific heat of steel (Btu/lb-°F)
h = thickness of spray-applied protection on steel beam (in)
W/D = ratio of weight of steel section per linear foot and heated perimeter (lb/ft^2)
T_f = fire exposure temperature (°F)
T_s = steel temperature (°F)
Δt = time step (sec)

$$c_s\ W/D > 2\ c_i\ \rho_i\ h$$

Where
c_s = specific heat of steel (Btu/lb-°F)
W/D = ratio of weight of steel section per linear foot and heated perimeter (lb/ft^2)
ρ_i = density of spray-applied material (lb/ft^3)
c_i = specific heat of spray-applied material (BTU/lb-°F)
h = thickness of spray-applied protection on steel beam (in)

1.63 > 0.45

The Maximum Allowable Time Step

$$\Delta t = 15.9\ W/D$$

Δt = 196 sec
Δt = 3.27 minutes

For ASTM-E-119 exposure, T_f at any time, t, is given by the following expression

$$T_f = C_1\ LOG\ (0.133\ t + 1) + T_a$$

Where
T_f = fire exposure temperature (°F)
C_1 = constant = 620
t = time step (sec)
T_a = ambient air temperature (°F)

$$\Delta T_{s1} = (k_i /(c_s\ h\ W/D + 1/2\ c_i\ \rho_i\ h^2))\ ((C_1\ LOG\ (0.133\ t_1 + 1)+T_a) - T_{s0})\ \Delta t$$

Where
$t_1 = \Delta t/2$
T_{s0} = initial steel temperature (°F)

Caution! This equation is only valid up to 1000 °F (538 °C) where carbon steel structural members begin to fail. Predicted temperatures above 1000 °F (538 °C) are not accurate or valid.

$$\Delta T_{s2} = (k_i /(c_s\ h\ W/D + 1/2\ c_i\ \rho_i\ h^2))\ ((C_1\ LOG\ (0.133\ t_2 + 1)+T_a) - T_s)\ \Delta t$$

Where
$t_2 = t_1 + \Delta t/2$
$T_s = T_{s0} + \Delta T_s$ from previous row

ESTIMATING FIRE RESISTANCE TIME OF STEEL BEAMS PROTECTED BY FIRE PROTECTION INSULATION (QUASI-STEADY-STATE APPROACH)

Version 1805.1 (English Units)

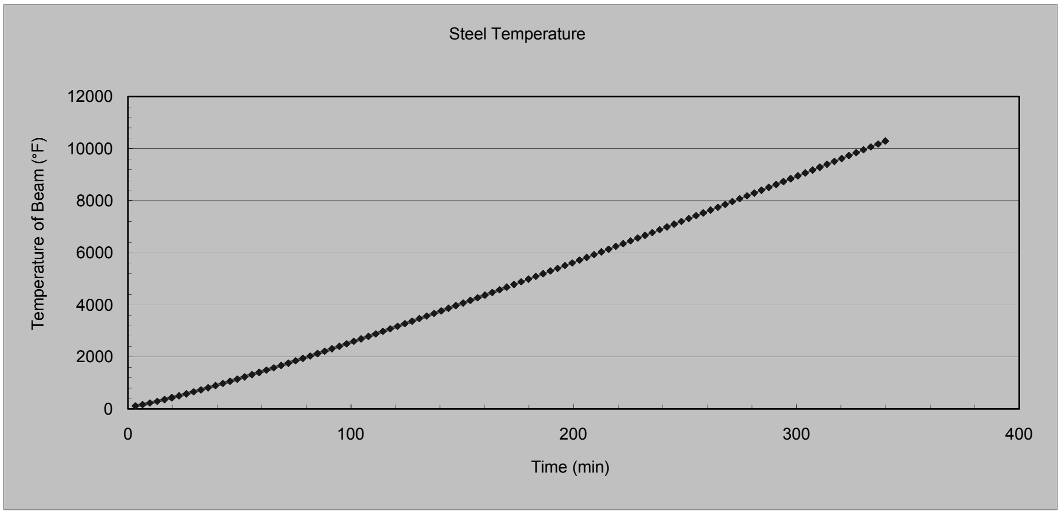
Answer

Time (min)	Time (sec)	ΔT_s (°F)	T_s (°F)	
3.3	196	40	117	
6.5	392	53	170	
9.8	588	60	230	
13.1	785	65	294	
16.3	981	68	362	
19.6	1177	71	433	
22.9	1373	73	506	
26.2	1569	75	581	
29.4	1765	77	658	
32.7	1961	78	737	
36.0	2158	80	817	
39.2	2354	81	898	
42.5	2550	82	980	
45.8	2746	83	1063	Failure of Beam
49.0	2942	84	1148	Failure of Beam
52.3	3138	85	1233	Failure of Beam
55.6	3334	86	1319	Failure of Beam
58.8	3531	87	1406	Failure of Beam
62.1	3727	88	1494	Failure of Beam
65.4	3923	89	1583	Failure of Beam
68.6	4119	89	1672	Failure of Beam
71.9	4315	90	1762	Failure of Beam
75.2	4511	91	1853	Failure of Beam
78.5	4707	91	1944	Failure of Beam
81.7	4904	92	2036	Failure of Beam
85.0	5100	92	2128	Failure of Beam
88.3	5296	93	2221	Failure of Beam
91.5	5492	93	2315	Failure of Beam
94.8	5688	94	2409	Failure of Beam
98.1	5884	94	2503	Failure of Beam
101.3	6080	95	2598	Failure of Beam
104.6	6277	95	2693	Failure of Beam
107.9	6473	96	2789	Failure of Beam
111.1	6669	96	2885	Failure of Beam
114.4	6865	97	2982	Failure of Beam
117.7	7061	97	3079	Failure of Beam
121.0	7257	97	3177	Failure of Beam
124.2	7453	98	3275	Failure of Beam
127.5	7650	98	3373	Failure of Beam
130.8	7846	99	3471	Failure of Beam
134.0	8042	99	3570	Failure of Beam
137.3	8238	99	3670	Failure of Beam
140.6	8434	100	3769	Failure of Beam
143.8	8630	100	3869	Failure of Beam
147.1	8826	100	3969	Failure of Beam
150.4	9023	101	4070	Failure of Beam
153.6	9219	101	4171	Failure of Beam
156.9	9415	101	4272	Failure of Beam
160.2	9611	102	4374	Failure of Beam
163.5	9807	102	4475	Failure of Beam
166.7	10003	102	4578	Failure of Beam
170.0	10199	102	4680	Failure of Beam

Time (min)	Time (sec)	ΔT_s (°F)	T_s (°F)	
173.3	10396	103	4783	Failure of Beam
176.5	10592	103	4885	Failure of Beam
179.8	10788	103	4989	Failure of Beam
183.1	10984	103	5092	Failure of Beam
186.3	11180	104	5196	Failure of Beam
189.6	11376	104	5300	Failure of Beam
192.9	11572	104	5404	Failure of Beam
196.1	11769	104	5508	Failure of Beam
199.4	11965	105	5613	Failure of Beam
202.7	12161	105	5718	Failure of Beam
205.9	12357	105	5823	Failure of Beam
209.2	12553	105	5928	Failure of Beam
212.5	12749	106	6034	Failure of Beam
215.8	12945	106	6139	Failure of Beam
219.0	13142	106	6245	Failure of Beam
222.3	13338	106	6352	Failure of Beam
225.6	13534	106	6458	Failure of Beam
228.8	13730	107	6565	Failure of Beam
232.1	13926	107	6671	Failure of Beam
235.4	14122	107	6778	Failure of Beam
238.6	14318	107	6886	Failure of Beam
241.9	14515	107	6993	Failure of Beam
245.2	14711	108	7101	Failure of Beam
248.4	14907	108	7208	Failure of Beam
251.7	15103	108	7316	Failure of Beam
255.0	15299	108	7424	Failure of Beam
258.3	15495	108	7533	Failure of Beam
261.5	15691	109	7641	Failure of Beam
264.8	15888	109	7750	Failure of Beam
268.1	16084	109	7859	Failure of Beam
271.3	16280	109	7968	Failure of Beam
274.6	16476	109	8077	Failure of Beam
277.9	16672	109	8186	Failure of Beam
281.1	16868	110	8296	Failure of Beam
284.4	17064	110	8406	Failure of Beam
287.7	17261	110	8516	Failure of Beam
290.9	17457	110	8626	Failure of Beam
294.2	17653	110	8736	Failure of Beam
297.5	17849	110	8846	Failure of Beam
300.8	18045	111	8957	Failure of Beam
304.0	18241	111	9067	Failure of Beam
307.3	18437	111	9178	Failure of Beam
310.6	18634	111	9289	Failure of Beam
313.8	18830	111	9400	Failure of Beam
317.1	19026	111	9512	Failure of Beam
320.4	19222	111	9623	Failure of Beam
323.6	19418	112	9734	Failure of Beam
326.9	19614	112	9846	Failure of Beam
330.2	19810	112	9958	Failure of Beam
333.4	20007	112	10070	Failure of Beam
336.7	20203	112	10182	Failure of Beam
340.0	20399	112	10294	Failure of Beam

ESTIMATING FIRE RESISTANCE TIME OF STEEL BEAMS PROTECTED BY FIRE PROTECTION INSULATION (QUASI-STEADY-STATE APPROACH)

Version 1805.1 (English Units)



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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

18.11 Problems

Example Problem 18.11-1

Problem Statement
A compartment is 30 ft wide x 20 ft long x 15 ft high (w_c x l_c x h_c). In the center of the compartment, 1 lb of polypropylene is involved in flaming combustion:

(a) From the center of the compartment, can you see the "Reflecting Exit Sign" at either end of the compartment?

(b) What if you increase the mass of burned fuel (polypropylene) to 2 lbs?

Solution

Purpose:
(1) Determine the visibility of the exit sign.

Assumptions:
(1) Complete burning within the method specified

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 18_Visibility_Through_Smoke_Sup1.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 30 ft
- Compartment Length (l_c) = 20 ft
- Compartment Height (h_c) = 15 ft
- Mass of fuel burn = 1 lb
- Select **Reflecting Signs**
- Select **Flaming Combustion**
- Select **Polypropylene**

Results*

	1 lb of material	2 lb of material
Visible Distance	12.37 ft	6.18 ft

*see spreadsheet on next page

Therefore, the signs placed at either end of the room (10 feet away) are visible with 1 lb of material burning, but would not be visible if 2 lb of material was burned.

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1 (English Units)

The following calculations estimate the smoke obscuration during a fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: **Example 18.11-1a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	30.00	ft
Compartment Length (l_c)	20.00	ft
Compartment Height (h_c)	15.00	ft
Mass of Fuel Burn (M_f)	1.00	lb
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	37000	ft^2/lb
Material / Particulate Yield (y_p)	0.059	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (ft^2/lb)
Flaming Combustion	37000
Smoldering Combustion	21000
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Flaming Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel™)	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon™)	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon™)	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas™)	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.

Select Material / Particulate Yield (y_p)

Polypropylene

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m m_p$$

Where,
S = visibility through smoke (ft)
K = proportionality constant
α_m = specific extinction coefficient (ft^2/lb)
m_p = mass concentration of particulate (lb/ft^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

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

V = 9000.00 ft^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p M_f$$

Where,
M_p = mass of particulates produced (lb)
y_p = particulates yield
M_f = mass of fuel consumed (lb)

M_p = 0.05900 lb

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
m_p = mass concentration of the particulates (lb/ft^3)
M_p = mass of particulates produced (lb)
V = volume of the compartment (m^3)

m_p = 6.55556E-06 lb/ft^3

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

Summary of Results

Visibility Through Smoke Calculation

$$S = K / \alpha_m \, m_p$$

Answer	S =	12.37 ft	3.77 m

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1 (English Units)

The following calculations estimate the smoke obscuration during a fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: Example 18.11-1b

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	30.00	ft
Compartment Length (l_c)	20.00	ft
Compartment Height (h_c)	15.00	ft
Mass of Fuel Burn (M_f)	2.00	lb
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	37000	ft^2/lb
Material / Particulate Yield (y_p)	0.059	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (ft^2/lb)
Flaming Combustion	37000
Smoldering Combustion	21000
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Flaming Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel^{TM})	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon^{TM})	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon^{TM})	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas^{TM})	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.

Select Material / Particulate Yield (y_p)

Polypropylene

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m m_p$$

Where,
S = visibility through smoke (ft)
K = proportionality constant
α_m = specific extinction coefficient (ft^2/lb)
m_p = mass concentration of particulate (lb/ft^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

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

V = 9000.00 ft^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p M_f$$

Where,
M_p = mass of particulates produced (lb)
y_p = particulates yield
M_f = mass of fuel consumed (lb)

M_p = 0.11800 lb

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
m_p = mass concentration of the particulates (lb/ft^3)
M_p = mass of particulates produced (lb)
V = volume of the compartment (m^3)

m_p = 1.31111E-05 lb/ft^3

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

Summary of Results

Visibility Through Smoke Calculation

$$S = K / \alpha_m m_p$$

Answer	S =	6.18 ft	1.88 m

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 18.11-2

Problem Statement
A compartment is 10 ft wide x 30 ft long x 12 ft high (w_c x l_c x h_c). What is the minimum amount (lb) of rigid polyurethane foam involved in smoldering combustion necessary to obstruct the visibility for the length of the compartment to a building compartment in reflective light?

Solution

Purpose:
(1) Determine the minimum mass of burning fuel that will obscure the sign.

Assumptions:
(1) Complete burning within the method specified

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 18_Visibility_Through_Smoke_Sup1.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 10 ft
- Compartment Length (l_c) = 30 ft
- Compartment Height (h_c) = 12 ft
- Mass of fuel burn = variable
- Select **Reflecting Signs**
- Select **Smoldering Combustion**
- Select **Polyurethane Foam (Rigid)**

Results*

Visible Distance	Mass of Fuel Burn
30 ft	0.14 lb

*see spreadsheet on next page

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

The following calculations estimate the smoke obscuration during a fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: **Example 18.11-2**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	10.00	ft
Compartment Length (l_c)	30.00	ft
Compartment Height (h_c)	12.00	ft
Mass of Fuel Burn (M_f)	0.14	lb
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	21000	ft^2/lb
Material / Particulate Yield (y_p)	0.118	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (ft^2/lb)
Flaming Combustion	37000
Smoldering Combustion	21000
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Smoldering Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel^{TM})	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon^{TM})	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon^{TM})	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas^{TM})	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.

Select Material / Particulate Yield (y_p)

Polyurethane Foam (Rigid)

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m m_p$$

Where,
S = visibility through smoke (ft)
K = proportionality constant
α_m = specific extinction coefficient (ft^2/lb)
m_p = mass concentration of particulate (lb/ft^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

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

V = 3600.00 ft^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p M_f$$

Where,
M_p = mass of particulates produced (lb)
y_p = particulates yield
M_f = mass of fuel consumed (lb)

M_p = 0.01652 lb

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
m_p = mass concentration of the particulates (lb/ft^3)
M_p = mass of particulates produced (lb)
V = volume of the compartment (m^3)

m_p = 4.58889E-06 lb/ft^3

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1 (English Units)

Summary of Results

Visibility Through Smoke Calculation

$$S = K / \alpha_m m_p$$

Answer	S =	31.13 ft	9.49 m

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Example Problem 18.11-3

Problem Statement
An inspector finds 5 lbs of PVC pipe in a compartment 10 ft wide x 30 ft long x 12 ft high (w_c x l_c x h_c):

(a) What is the visibility to a reflecting sign given flaming combustion?

(b) What is the visibility to a reflecting sign given smoldering combustion?

Solution

Purpose:
(1) Determine the visibility under the different burning methods.

Assumptions:
(1) Complete burning within the method specified

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 18_Visibility_Through_Smoke_Sup1.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 10 ft
- Compartment Length (l_c) = 30 ft
- Compartment Height (h_c) = 12 ft
- Mass of fuel burn = 5 lbs
- Select **Reflecting Signs**
- Select **Flaming Combustion** (get result)
- Select **Smoldering Combustion** (get result)
- Select **PVC**

Results*

Burning Method	Visibility
Flaming	0.34 ft
Smoldering	0.60 ft

*see spreadsheet on next page

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1 (English Units)

The following calculations estimate the smoke obscuration during a fire.

Parameters in YELLOW CELLS are Entered by the User.

Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: **Example 18.11-3a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	10.00	ft
Compartment Length (l_c)	30.00	ft
Compartment Height (h_c)	12.00	ft
Mass of Fuel Burn (M_f)	5.00	lb
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	37000	ft^2/lb
Material / Particulate Yield (y_p)	0.172	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (ft^2/lb)
Flaming Combustion	37000
Smoldering Combustion	21000
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Flaming Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel^{TM})	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon^{TM})	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon^{TM})	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas^{TM})	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.

Select Material / Particulate Yield (y_p)

Polyvinylchloride (PVC)

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m m_p$$

Where,
S = visibility through smoke (ft)
K = proportionality constant
α_m = specific extinction coefficient (ft^2/lb)
m_p = mass concentration of particulate (lb/ft^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

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

V = 3600.00 ft^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p M_f$$

Where,
M_p = mass of particulates produced (lb)
y_p = particulates yield
M_f = mass of fuel consumed (lb)

M_p = 0.86000 lb

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
m_p = mass concentration of the particulates (lb/ft^3)
M_p = mass of particulates produced (lb)
V = volume of the compartment (m^3)

m_p = 2.38889E-04 lb/ft^3

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

Summary of Results

Visibility Through Smoke Calculation

$$S = K / \alpha_m m_p$$

Answer	S =	0.34 ft	0.10 m

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1 (English Units)

The following calculations estimate the smoke obscuration during a fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: **Example 18.11-3b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	10.00	ft
Compartment Length (l_c)	30.00	ft
Compartment Height (h_c)	12.00	ft
Mass of Fuel Burn (M_f)	5.00	lb
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	21000	ft^2/lb
Material / Particulate Yield (y_p)	0.172	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value
Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.	

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (ft^2/lb)
Flaming Combustion	37000
Smoldering Combustion	21000
User Specified Value	Enter Value
Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.	

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Smoldering Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel^{TM})	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon^{TM})	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon^{TM})	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas^{TM})	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value
Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.	

Select Material / Particulate Yield (y_p)

Polyvinylchloride (PVC)

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m m_p$$

Where,
- S = visibility through smoke (ft)
- K = proportionality constant
- α_m = specific extinction coefficient (ft^2/lb)
- m_p = mass concentration of particulate (lb/ft^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

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

V = 3600.00 ft^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p M_f$$

Where,
- M_p = mass of particulates produced (lb)
- y_p = particulates yield
- M_f = mass of fuel consumed (lb)

M_p = 0.86000 lb

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
- m_p = mass concentration of the particulates (lb/ft^3)
- M_p = mass of particulates produced (lb)
- V = volume of the compartment (m^3)

m_p = 2.38889E-04 lb/ft^3

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1 (English Units)

Summary of Results

Visibility Through Smoke Calculation

$$S = K / \alpha_m m_p$$

Answer	S =	0.60 ft	0.18 m

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

APPENDIX B

REVISED SPREADSHEETS – EXAMPLE PROBLEMS (SI UNITS)

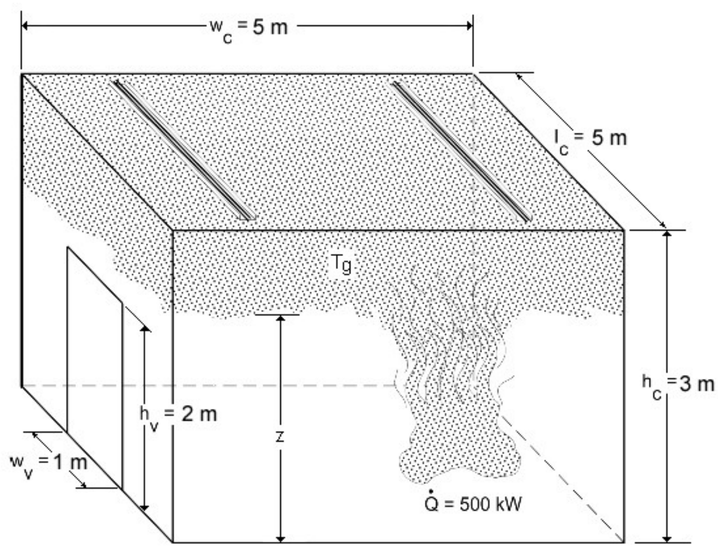
2.16 Problems

2.16.1 Natural Ventilation

Example Problem 2.16.1-1

Problem Statement

Consider a compartment that is 5 m wide x 5 m long x 3 m high (w_c x l_c x h_c), with a simple vent that is 1 m wide x 2 m tall (w_v x h_v). The fire is constant with an HRR of 500 kW. Compute the hot gas layer temperature in the compartment and smoke layer height at 2 minutes assuming that the compartment interior boundary material is (a) 0.3048 m thick concrete and (b) 0.0254 m thick gypsum board. Assume that the top of the vent is 2 m.



Example Problem 2-1: Compartment with Natural Ventilation

Solution

Purpose:

For two different interior boundary materials determine following:

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

Assumptions:

(1) Air properties (ambient) at 25 °C
(2) Simple rectangular geometry (no beam pockets)
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant heat release rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) For concrete: 02.1_Temperature_N V_Sup1_SI.xls
(b) For gypsum board: 02.1_Temperature_NV_Sup1_SI.xls

FDT^s Input Parameters: (for both spreadsheets)
- Compartment Width (w_c) = 5 m
- Compartment Length (l_c) = 5 m
- Compartment Height (h_c) = 3 m
- Vent Width (w_v) = 1 m
- Vent Height (h_v) = 2 m
- Top of Vent from Floor (V_T) = 2 m
- Interior Lining Thickness (δ) = 30.48 cm (concrete) and 2.54 cm (gypsum board)
- Ambient Air Temperature (T_a) = 25 °C
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Concrete** and **Gypsum Board** on the respective FDT^s
- Fire Heat Release Rate ($\dot{Q}$) = 500 kW
- Time after Ignition (t) = 2 min

Results*

Interior Boundary Material	Hot Gas Layer Temperature (T_g) (Method of MQH) (°C)	Smoke Layer Height (z) (Method of Yamana and Tanaka) (m)
Concrete	144	2.0 (smoke exiting vent, $z < V_T$)
Gypsum Board	214	2.0 (compartment filled with smoke)

*see spreadsheet on next page at t = 2 min

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

Version 1805.1 (SI Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title:	**Example 2.16.1.-1a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	5.00	m
Compartment Length (l_c)	5.00	m
Compartment Height (h_c)	3.00	m
Vent Width (w_v)	1.00	m
Vent Height (h_v)	2.00	m
Top of Vent from Floor (V_T)	2.00	m
Interior Lining Thickness (δ)	30.50	cm

AMBIENT CONDITIONS

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

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Concrete

Scroll to desired material
Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 500.00 kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

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

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

Where,

ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

Where,

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

A_v = 2.00 m^2

Thermal Penetration Time Calculation

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

Where,

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 26163.28 sec

Heat Transfer Coefficient Calculation

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

Where,

h_k = heat transfer coefficient (kW/m²-K)

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

t = time after ignition (sec)

See table below for results (column 3)

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 = 108.00 m^2

COMPARTMENT HOT GAS LAYER TEMPERATURE WITH NATURAL

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

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Results	Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
	(min)	(sec)	(kW/m^2-K)	(°K)	(°K)	(°C)	(°F)
	0	0.00	-	-	298.00	25.00	77.00
	1	60	0.22	106.16	404.16	131.16	268.09
	2	120	0.16	119.16	417.16	144.16	291.50
	3	180	0.13	127.50	425.50	152.50	306.49
	4	240	0.11	133.76	431.76	158.76	317.76
	5	300	0.10	138.83	436.83	163.83	326.89
	10	600	0.07	155.83	453.83	180.83	357.49
	15	900	0.06	166.72	464.72	191.72	377.10
	20	1200	0.05	174.91	472.91	199.91	391.84
	25	1500	0.04	181.54	479.54	206.54	403.77
	30	1800	0.04	187.14	485.14	212.14	413.85
	35	2100	0.04	192.01	490.01	217.01	422.61
	40	2400	0.03	196.33	494.33	221.33	430.39
	45	2700	0.03	200.22	498.22	225.22	437.40
	50	3000	0.03	203.77	501.77	228.77	443.78
	55	3300	0.03	207.03	505.03	232.03	449.65
	60	3600	0.03	210.05	508.05	235.05	455.10

ESTIMATING SMOKE LAYER HEIGHT METHOD OF YAMANA AND TANAKA

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

Where,

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

Compartment Area Calculation

$$Ac = (w_c)\ (l_c)$$

Where,

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

A_c = 25.00 m^2

Hot Gas Layer Density Calculation

$$\rho_g = 353/T_g$$

Calculation for Constant K

$$k = 0.076/\rho_g$$

SMOKE GAS LAYER HEIGHT WITH NATURAL VENTILATION

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

Results

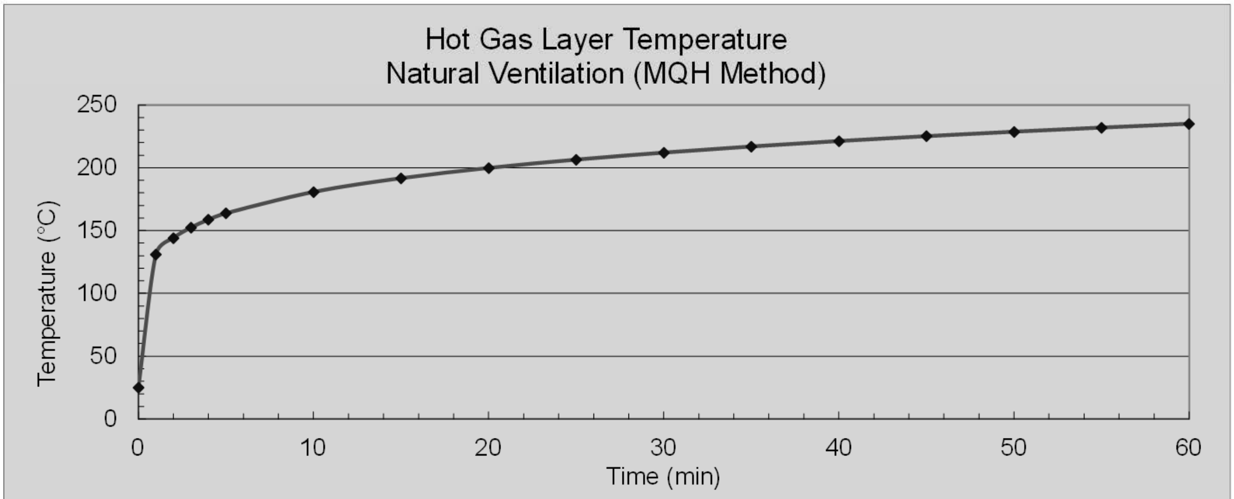
Caution! The smoke layer height is a conservative estimate and is only intended to provide an indication where the hot gas layer is located. Calculated smoke layer height below the vent height are not creditable since the calculation is not accounting for the smoke exiting the vent.

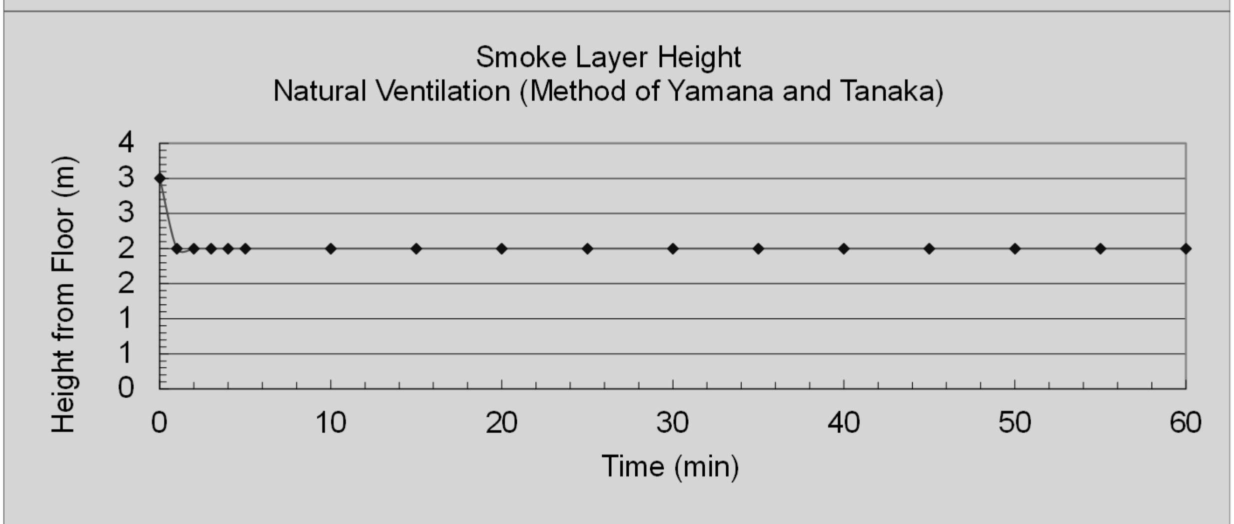
Time (min)	ρ_g (kg/m^3)	Constant (k) (kW/m-K)	Smoke Layer Height z (m)	Smoke Layer Height z (ft)	
0	1.18	0.064	3.00	9.84	
1	0.87	0.087	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
2	0.85	0.090	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
3	0.83	0.092	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
4	0.82	0.093	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
5	0.81	0.094	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
10	0.78	0.098	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
15	0.76	0.100	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
20	0.75	0.102	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
25	0.74	0.103	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
30	0.73	0.104	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
35	0.72	0.105	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
40	0.71	0.106	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
45	0.71	0.107	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
50	0.70	0.108	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
55	0.70	0.109	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
60	0.69	0.109	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT

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

Version 1805.1
(SI Units)

Summary of Results





NOTE:

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

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

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

Version 1805.1 (SI Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.1.-1b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	5.00	m
Compartment Length (l_c)	5.00	m
Compartment Height (h_c)	3.00	m
Vent Width (w_v)	1.00	m
Vent Height (h_v)	2.00	m
Top of Vent from Floor (V_T)	2.00	m
Interior Lining Thickness (δ)	2.54	cm

AMBIENT CONDITIONS

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

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Gypsum Board

Scroll to desired material
Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 500.00 kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

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

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

Where,

ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

Where,

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

A_v = 2.00 m^2

Thermal Penetration Time Calculation

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

Where,

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 1001.90 sec

Heat Transfer Coefficient Calculation

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

Where,

h_k = heat transfer coefficient (kW/m²-K)

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

t = time after ignition (sec)

See table below for results (column 3)

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 = 108.00 m^2

COMPARTMENT HOT GAS LAYER TEMPERATURE WITH NATURAL

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

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Results	Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
	(min)	(sec)	(kW/m^2-K)	(°K)	(°K)	(°C)	(°F)
	0	0.00	-	-	298.00	25.00	77.00
	1	60	0.05	168.72	466.72	193.72	380.69
	2	120	0.04	189.38	487.38	214.38	417.88
	3	180	0.03	202.62	500.62	227.62	441.71
	4	240	0.03	212.57	510.57	237.57	459.63
	5	300	0.02	220.63	518.63	245.63	474.13
	10	600	0.02	247.64	545.64	272.64	522.76
	15	900	0.01	264.96	562.96	289.96	553.92
	20	1200	0.01	340.00	638.00	365.00	689.00
	25	1500	0.01	340.00	638.00	365.00	689.00
	30	1800	0.01	340.00	638.00	365.00	689.00
	35	2100	0.01	340.00	638.00	365.00	689.00
	40	2400	0.01	340.00	638.00	365.00	689.00
	45	2700	0.01	340.00	638.00	365.00	689.00
	50	3000	0.01	340.00	638.00	365.00	689.00
	55	3300	0.01	340.00	638.00	365.00	689.00
	60	3600	0.01	340.00	638.00	365.00	689.00

ESTIMATING SMOKE LAYER HEIGHT
METHOD OF YAMANA AND TANAKA

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

Where,

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

Compartment Area Calculation

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

Where,

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

A_c = 25.00 m^2

Hot Gas Layer Density Calculation

$$\rho_g = 353/T_g$$

Calculation for Constant K

$$k = 0.076/\rho_g$$

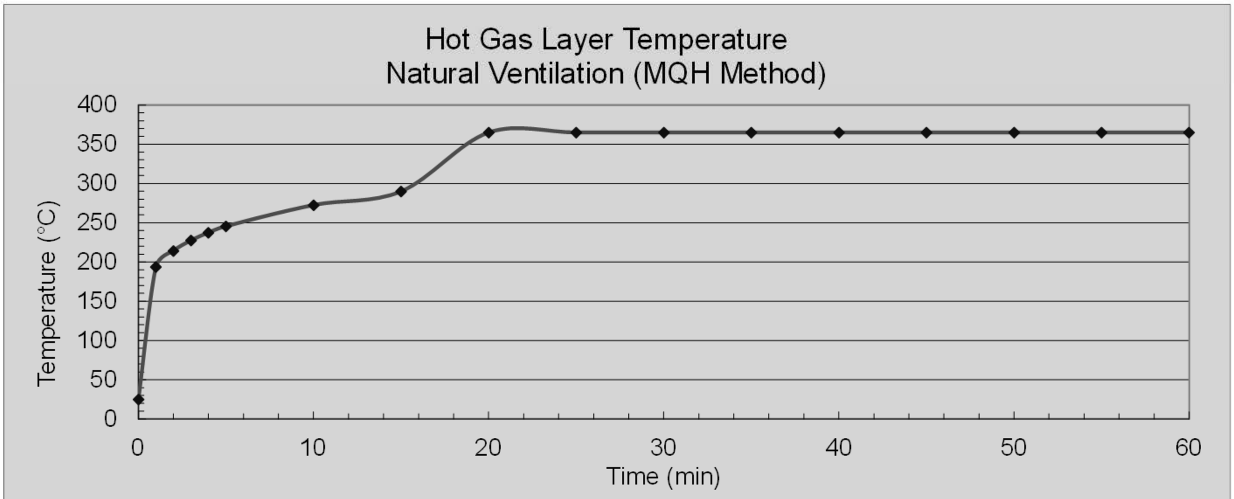
SMOKE GAS LAYER HEIGHT WITH NATURAL VENTILATION

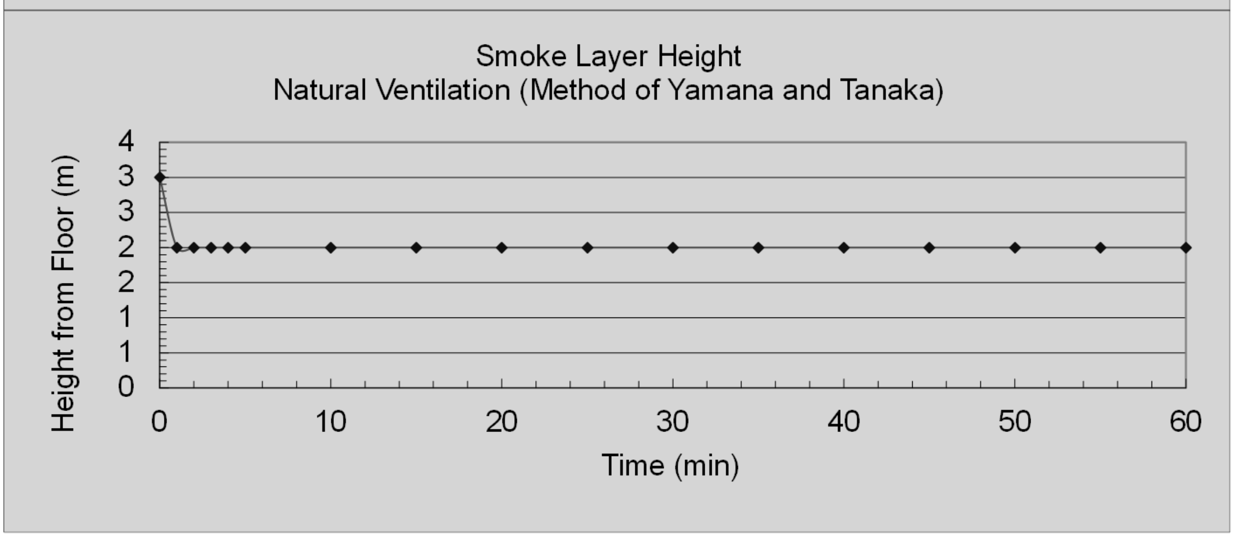
$$z = [(2kQ^{1/3}t/(3A_c)] + (1/h_c^{2/3})^{-3/2}$$

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

Time (min)	ρ_g (kg/m^3)	Constant (k) (kW/m-K)	Smoke Layer Height z (m)	Smoke Layer Height z (ft)	
0	1.18	0.064	3.00	9.84	
1	0.76	0.100	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
2	0.72	0.105	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
3	0.71	0.108	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
4	0.69	0.110	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
5	0.68	0.112	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
10	0.65	0.117	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
15	0.63	0.121	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
20	0.55	0.137	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
25	0.55	0.137	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
30	0.55	0.137	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
35	0.55	0.137	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
40	0.55	0.137	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
45	0.55	0.137	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
50	0.55	0.137	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
55	0.55	0.137	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT
60	0.55	0.137	2.00	6.56	CAUTION: SMOKE IS EXITING OUT VENT

Summary of Results





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

Prepared by: Date: Organization:

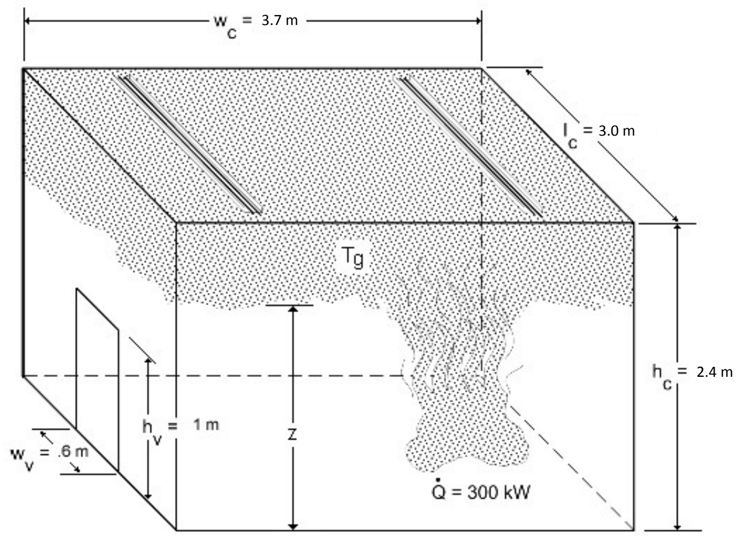
Checked by: Date: Organization:

Additional Information:

Example Problem 2.16.1-2

Problem Statement

Consider a compartment that is 3.7 m wide x 3.0 m long x 2.4 m high (w_c x l_c x h_c) with a simple vent 0.6 m wide x 1 m tall (w_v x h_v). The construction is essentially 0.1524 m thick gypsum board. The fire is constant with an HRR of 300 kW. Assume that the top of the vent is 1 m. Compute the hot gas temperature in the compartment, as well as the smoke layer height at 2 minutes.



Example Problem 2-2: Compartment with Natural Ventilation

Solution

Purpose:

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

Assumptions:

(1) Air properties (ambient) at 25 °C
(2) Simple rectangular geometry (no beam pockets)
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 02.1_Temperature_NV_Sup1_SI.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 3.7 m
- Compartment Length (l_c) = 3.0 m
- Compartment Height (h_c) = 2.4 m
- Vent Width (w_v) = 0.6 m
- Vent Height (h_v) = 1 m
- Top of Vent from Floor (V_T) = 1 m
- Interior Lining Thickness (δ) = 15.24 cm
- Ambient Air Temperature (T_a) = 25 °C
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Gypsum Board** on the FDT^s
- Fire Heat Release Rate ($\dot{Q}$) = 300 kW

Results*

Hot Gas Layer Temperature (T_g) (Method of MQH) (°C)	Smoke Layer Height (z) (Method of Yamana and Tanaka) (m)
310	1.0 (smoke exiting vent, $z < V_T$)

*see attached spreadsheet on next page at t = 2 min

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

Version 1805.1 (SI Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.1.-2**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	3.70	m
Compartment Length (l_c)	3.00	m
Compartment Height (h_c)	2.40	m
Vent Width (w_v)	0.60	m
Vent Height (h_v)	1.00	m
Top of Vent from Floor (V_T)	1.00	m
Interior Lining Thickness (δ)	15.24	cm

AMBIENT CONDITIONS

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

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Gypsum Board

Scroll to desired material
Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 300.00 kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

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

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

Where,

ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

Where,

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

A_v = 0.60 m^2

Thermal Penetration Time Calculation

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

Where,

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 36068.24 sec

Heat Transfer Coefficient Calculation

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

Where,

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec (a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)

See table below for results (column 3)

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 = 53.76 m^2

COMPARTMENT HOT GAS LAYER TEMPERATURE WITH NATURAL

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

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Results	Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
	(min)	(sec)	(kW/m^2-K)	(°K)	(°K)	(°C)	(°F)
	0	0.00	-	-	298.00	25.00	77.00
	1	60	0.05	253.93	551.93	278.93	534.07
	2	120	0.04	285.03	583.03	310.03	590.05
	3	180	0.03	304.95	602.95	329.95	625.92
	4	240	0.03	319.93	617.93	344.93	652.88
	5	300	0.02	332.05	630.05	357.05	674.70
	10	600	0.02	372.72	670.72	397.72	747.89
	15	900	0.01	398.78	696.78	423.78	794.80
	20	1200	0.01	418.36	716.36	443.36	830.05
	25	1500	0.01	434.21	732.21	459.21	858.59
	30	1800	0.01	447.61	745.61	472.61	882.70
	35	2100	0.01	459.26	757.26	484.26	903.67
	40	2400	0.01	469.60	767.60	494.60	922.27
	45	2700	0.01	478.91	776.91	503.91	939.03
	50	3000	0.01	487.39	785.39	512.39	954.30
	55	3300	0.01	495.19	793.19	520.19	968.35
	60	3600	0.01	502.43	800.43	527.43	981.37

ESTIMATING SMOKE LAYER HEIGHT METHOD OF YAMANA AND TANAKA

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

Where,

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

Compartment Area Calculation

$$Ac = (w_c)\ (l_c)$$

Where,

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

A_c = 11.10 m^2

Hot Gas Layer Density Calculation

$$\rho_g = 353/T_g$$

Calculation for Constant K

$$k = 0.076/\rho_g$$

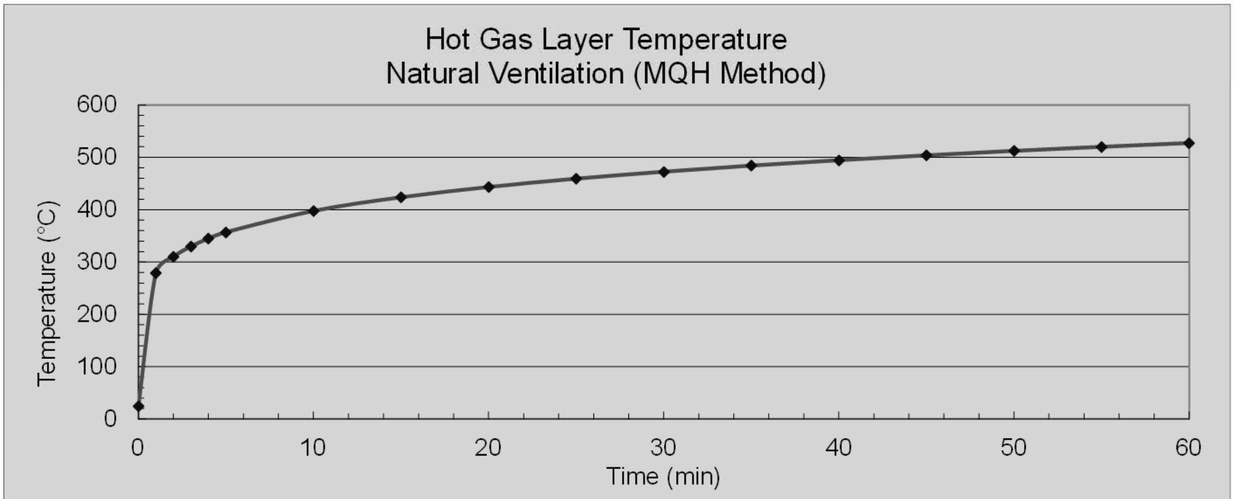
SMOKE GAS LAYER HEIGHT WITH NATURAL VENTILATION

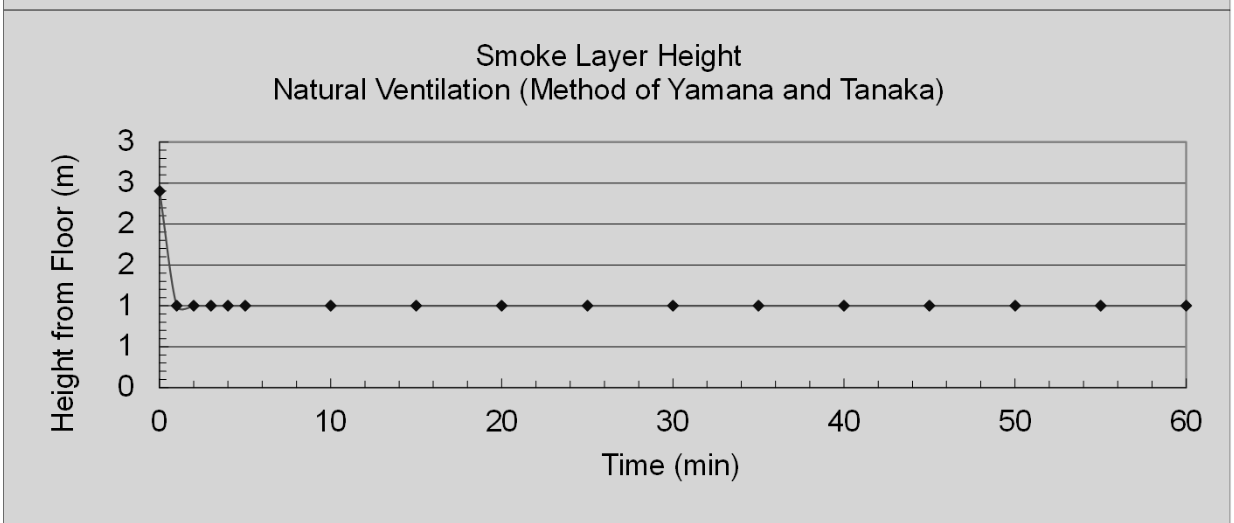
$$z = [(2kQ^{1/3}t/(3A_c)] + (1/h_c^{2/3})^{-3/2}$$

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

Time (min)	ρ_g (kg/m^3)	Constant (k) (kW/m-K)	Smoke Layer Height z (m)	Smoke Layer Height z (ft)	
0	1.18	0.064	2.40	7.87	
1	0.64	0.119	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
2	0.61	0.126	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
3	0.59	0.130	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
4	0.57	0.133	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
5	0.56	0.136	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
10	0.53	0.144	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
15	0.51	0.150	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
20	0.49	0.154	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
25	0.48	0.158	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
30	0.47	0.161	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
35	0.47	0.163	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
40	0.46	0.165	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
45	0.45	0.167	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
50	0.45	0.169	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
55	0.45	0.171	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
60	0.44	0.172	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT

Summary of Results





NOTE:

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

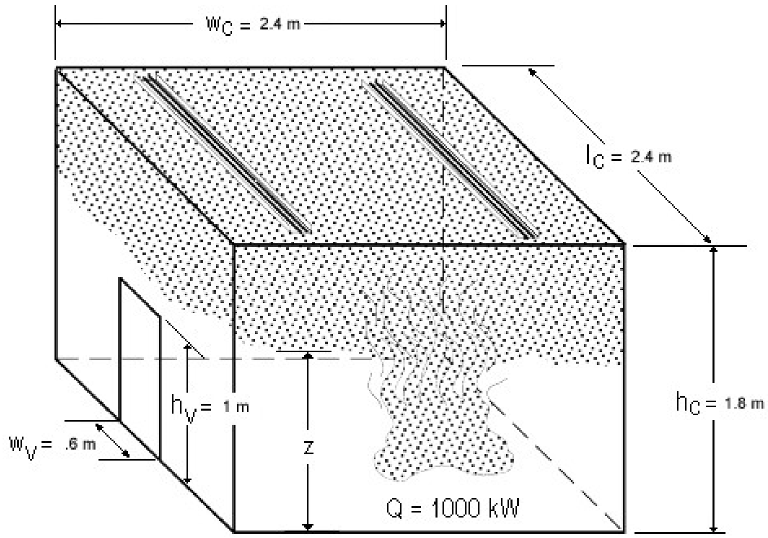
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 2.16.1-3

Problem Statement
Consider a compartment that is 2.4 m wide x 2.4 m long x 1.8 m high (w_c x l_c x h_c) with a simple vent that is 0.6 m wide x 1 m tall (w_v x h_v). The construction is essentially 0.2286 m thick concrete. The fire is constant with an HRR of 1,000 kW. Assume that the top of the vent is 1 m. Compute the hot gas temperature in the compartment, as well as the smoke layer height at 3 minutes.



Example Problem 2-3: Compartment with Natural Ventilation

Solution

Purpose:
(1) Determine the hot gas layer temperature in the compartment (T_g) at t = 3 min after ignition
(2) Determine the smoke layer height (z) at t = 3 min after ignition

Assumptions:
(1) Air properties (ambient) at 25 °C
(2) Simple rectangular geometry (no beam pockets)
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 02.1_Temperature_N V_Sup1_SI.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 2.4 m
- Compartment Length (l_c) = 2.4 m
- Compartment H eight (h_c) = 1.8 m
- Vent Width (w_v) = 0.6 m
- Vent Height (h_v) = 1 m
- Top of Vent from Floor (V_T) = 1 m
- Interior Lining Thickness (δ) = 22.86 cm
- Ambient Air Temperature (T_a) = 25 °C
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Concrete** on the FDT^s
- Fire Heat Release Rate ($\dot{Q}$) = 1,000 kW

Results*:

Hot Gas Layer Temperature (T_g) (Method of MQH) (°C)	Smoke Layer Height (z) (Method of Yamana and Tanaka) (m)
556	1.0 (compartment filled with smoke)

*see spreadsheet on next page at t = 3 min

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

Version 1805.1 (SI Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.1.-3**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	2.40	m
Compartment Length (l_c)	2.40	m
Compartment Height (h_c)	1.80	m
Vent Width (w_v)	0.60	m
Vent Height (h_v)	1.00	m
Top of Vent from Floor (V_T)	1.00	m
Interior Lining Thickness (δ)	22.86	cm

AMBIENT CONDITIONS

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

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

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

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

Select Material

Concrete

Scroll to desired material
Click the selection

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 1000.00 kW

Calculate

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

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

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

Where,

ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

Where,

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

A_v = 0.60 m^2

Thermal Penetration Time Calculation

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

Where,

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 14697.55 sec

Heat Transfer Coefficient Calculation

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

Where,

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia $(kW/m^2\text{-}K)^2$-sec (a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)

See table below for results (column 3)

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 = 28.20 m^2

COMPARTMENT HOT GAS LAYER TEMPERATURE WITH NATURAL

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

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Results	Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
	(min)	(sec)	(kW/m^2-K)	(°K)	(°K)	(°C)	(°F)
	0	0.00	-	-	298.00	25.00	77.00
	1	60	0.22	442.10	740.10	467.10	872.77
	2	120	0.16	496.24	794.24	521.24	970.22
	3	180	0.13	530.93	828.93	555.93	1032.67
	4	240	0.11	557.01	855.01	582.01	1079.61
	5	300	0.10	578.11	876.11	603.11	1117.60
	10	600	0.07	648.91	946.91	673.91	1245.03
	15	900	0.06	694.27	992.27	719.27	1326.69
	20	1200	0.05	728.37	1026.37	753.37	1388.07
	25	1500	0.04	755.97	1053.97	780.97	1437.75
	30	1800	0.04	779.30	1077.30	804.30	1479.73
	35	2100	0.04	799.58	1097.58	824.58	1516.24
	40	2400	0.03	817.57	1115.57	842.57	1548.63
	45	2700	0.03	833.78	1131.78	858.78	1577.80
	50	3000	0.03	848.55	1146.55	873.55	1604.39
	55	3300	0.03	862.14	1160.14	887.14	1628.85
	60	3600	0.03	874.73	1172.73	899.73	1651.52

ESTIMATING SMOKE LAYER HEIGHT METHOD OF YAMANA AND TANAKA

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

Where,

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

Compartment Area Calculation

$$Ac = (w_c)\ (l_c)$$

Where,

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

A_c = 5.76 m^2

Hot Gas Layer Density Calculation

$$\rho_g = 353/T_g$$

Calculation for Constant K

$$k = 0.076/\rho_g$$

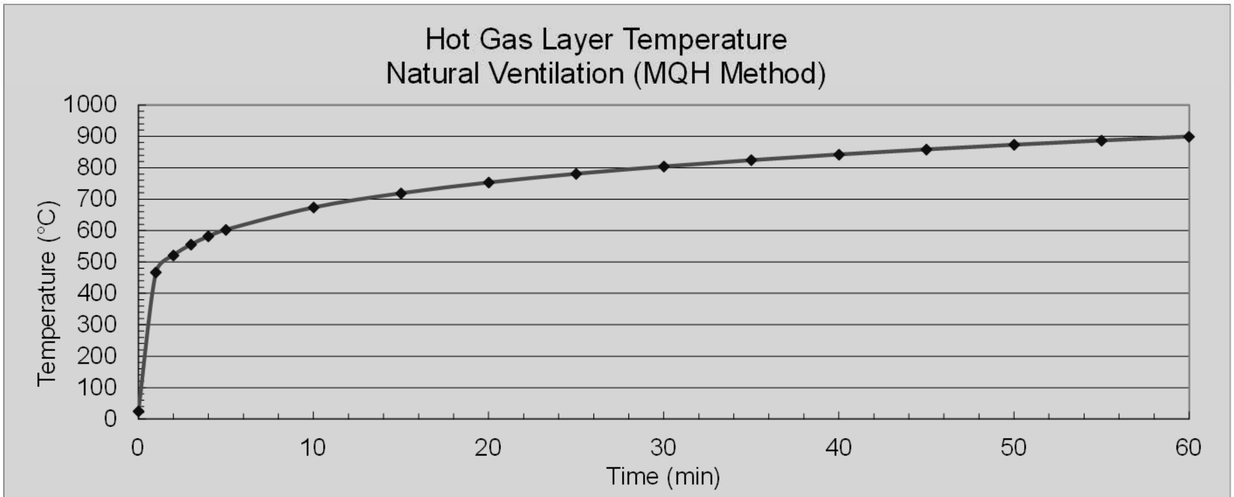
SMOKE GAS LAYER HEIGHT WITH NATURAL VENTILATION

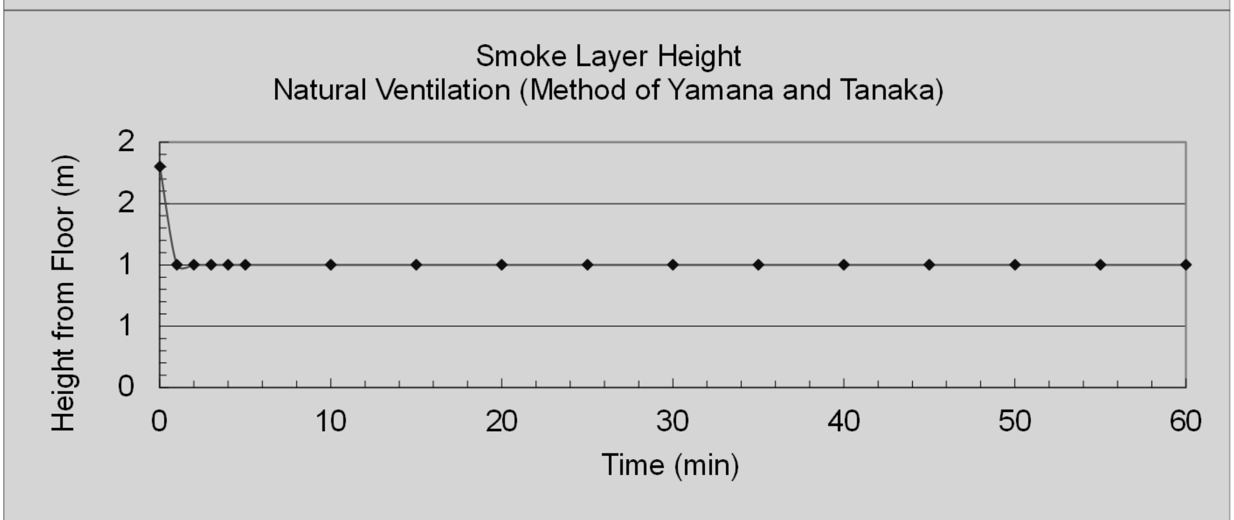
$$z = [(2kQ^{1/3}t/(3A_c)] + (1/h_c^{2/3})^{-3/2}$$

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

Time (min)	ρ_g (kg/m³)	Constant (k) (kW/m-K)	Smoke Layer Height z (m)	Smoke Layer Height z (ft)	
0	1.18	0.064	1.80	5.91	
1	0.48	0.159	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
2	0.44	0.171	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
3	0.43	0.178	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
4	0.41	0.184	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
5	0.40	0.189	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
10	0.37	0.204	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
15	0.36	0.214	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
20	0.34	0.221	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
25	0.33	0.227	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
30	0.33	0.232	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
35	0.32	0.236	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
40	0.32	0.240	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
45	0.31	0.244	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
50	0.31	0.247	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
55	0.30	0.250	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT
60	0.30	0.252	1.00	3.28	CAUTION: SMOKE IS EXITING OUT VENT

Summary of Results





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

Prepared by: ______ Date: ______ Organization: ______

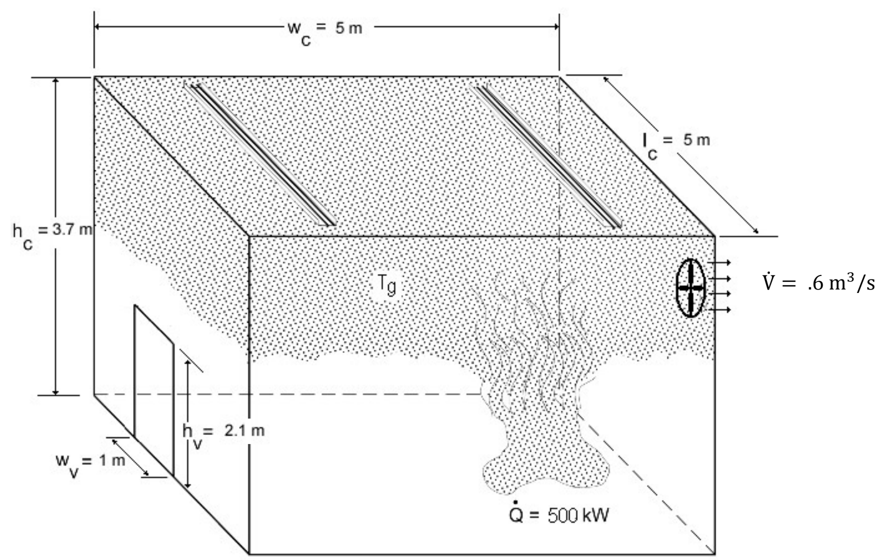
Checked by: ______ Date: ______ Organization: ______

Additional Information:

2.16.2 Forced Ventilation

Example Problem 2.16.2-1

Problem Statement
Consider a compartment that is 5 m wide x 5 m long x 3.7 m high (w_c x l_c x h_c), with a vent opening that is 1 m wide x 2.1 m tall (w_v x h_v). The forced ventilation rate is 0.6 m^3/sec (exhaust). Calculate the hot gas layer temperature for a fire size of 500 kW at 2 minutes after ignition. The compartment boundaries are made of (a) 30.48 cm thick concrete and (b) 1.778 cm thick gypsum board.



Example Problem 2-4: Compartment with Forced Ventilation

Solution

Purpose:
For two different interior lining materials determine the hot gas layer temperature in the compartment (T_g) at t = 2 min after ignition.

Assumptions:
(1) Air properties (ambient) at 25 °C
(2) Simple rectangular geom etry (no beam pockets)
(3) One-dimnsional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls
(6) The bottom of the vent is at the floor level
(7) The compartment is open to the outside at the inlet (pressure = 1 atm)

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) For Concrete:
02.2_Temperature_FV_Sup1_SI.xls

(b) For Gypsum Board:
02.2_Temperature_FV_Sup1_SI.xls

Note: The spreadsheet has two methods to calculate the hot gas layer temperature (T_g). We are going to use both methods to compare the results.

FDT^s Input Parameters: (for both spreadsheets)

- Compartment Width (w_c) = 5 m
- Compartment Length (l_c) = 5 m
- Compartment Height (h_c) = 3.7 m
- Interior Lining Thickness (δ) = 30.48 cm (concrete) and 1.778 cm (gypsum board)
- Ambient Air Temperature (T_a) = 25 °C
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Concrete** and **Gypsum Board** on the respective FDT^s
- Compartment Ventilation Rate ($\dot{V}$) = 0.6 m^3/sec
- Fire Heat Release Rate ($\dot{Q}$) = 500 kW
- Time after Iignition (t) = 2 min

Results*:

Boundary Material	Hot Layer Gas Temperature (T_g) (°C)	
	Method of Foote, Pagni & Alvares (FPA)	Method of Deal & Beyler
Concrete	131	84
Gypsum Board	200	215

*see spreadsheets on next page at t = 2 min.

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE
IN A ROOM FIRE
WITH FORCED VENTILATION

Version 1805.1
(SI Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection **Title:** **Example 2.16.2-1a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	5.00	m
Compartment Length (l_c)	5.00	m
Compartment Height (h_c)	3.70	m
Interior Lining Thickness (δ)	30.48	cm

AMBIENT CONDITIONS

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

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

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

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

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ $(kW/m^2\text{-}K)^2$-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: *Klote, J., J. Milke, Principles of Smoke Management, 2002 Page 270* .

Select Material

Concrete

Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m) 0.60 m^3/sec

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 500.00 kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 3-177.

$$\Delta T_g/T_a = 0.63(Q/(mc_aT_a))^{0.72}(h_kA_T/(mc_a))^{-0.36}$$

Where

ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_a = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Thermal Penetration Time Calculation

$$t_p = (\rho c_p/k)\ (\delta/2)^2$$

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 26128.98 sec

Heat Transfer Coefficient Calculation

$$h_k = \sqrt{(k\rho c/t)} \quad \text{for } t < t_p \quad \text{or} \quad (k/\delta) \quad \text{for } t > t_p$$

Where

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)
See table below for results

Area of Compartment Enclosing Surface Boundaries

$$A_T = 2\ (w_c \times l_c) + 2\ (h_c \times w_c) + 2\ (h_c \times l_c)$$

Where

A_T = total area of the compartment enclosing surface boundaries (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

A_T = 124.00 m^2

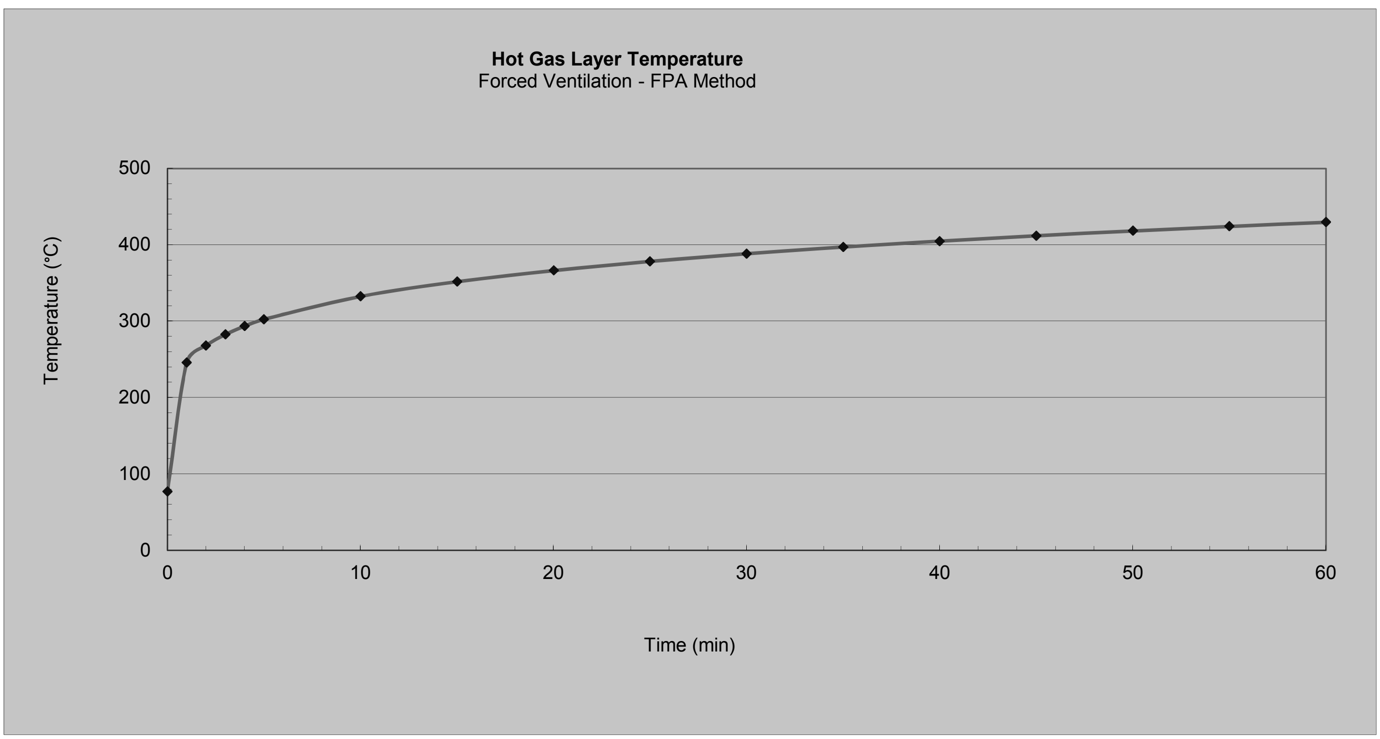
Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g/T_a = 0.63(Q/(mc_pT_a))^{0.72}(h_kA_T/(mc_p))^{-0.36}$$

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)		(K)	(K)	(°C)	(°F)
0	**0**	**-**	**-**	**-**	**298.00**	**25.00**	**77.00**
1	**60**	**0.22**	**0.31**	**93.75**	**391.75**	**118.75**	**245.75**
2	**120**	**0.16**	**0.36**	**106.21**	**404.21**	**131.21**	**268.17**
3	**180**	**0.13**	**0.38**	**114.25**	**412.25**	**139.25**	**282.65**
4	**240**	**0.11**	**0.40**	**120.32**	**418.32**	**145.32**	**293.58**
5	**300**	**0.10**	**0.42**	**125.25**	**423.25**	**150.25**	**302.45**
10	**600**	**0.07**	**0.48**	**141.90**	**439.90**	**166.90**	**332.41**
15	**900**	**0.06**	**0.51**	**152.64**	**450.64**	**177.64**	**351.75**
20	**1200**	**0.05**	**0.54**	**160.75**	**458.75**	**185.75**	**366.35**
25	**1500**	**0.04**	**0.56**	**167.34**	**465.34**	**192.34**	**378.21**
30	**1800**	**0.04**	**0.58**	**172.92**	**470.92**	**197.92**	**388.26**
35	**2100**	**0.04**	**0.60**	**177.79**	**475.79**	**202.79**	**397.02**
40	**2400**	**0.03**	**0.61**	**182.11**	**480.11**	**207.11**	**404.80**
45	**2700**	**0.03**	**0.62**	**186.01**	**484.01**	**211.01**	**411.83**
50	**3000**	**0.03**	**0.64**	**189.58**	**487.58**	**214.58**	**418.24**
55	**3300**	**0.03**	**0.65**	**192.86**	**490.86**	**217.86**	**424.14**
60	**3600**	**0.03**	**0.66**	**195.90**	**493.90**	**220.90**	**429.62**



METHOD OF DEAL AND BEYLER

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 3-178.

Thermal Penetration Time Calculation

$$t_p = (\rho c_p/k)\ (\delta/2)^2$$

Where
t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining heat capacity (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 26129 sec

Heat Transfer Coefficient Calculation

$$h_k = 0.4\ \sqrt{(k\rho c} \quad \text{for } t < t_p \qquad \text{or} \qquad 0.4(k/\delta\text{for } t > t_p$$

Where
h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)
See table below for results

Area of Compartment Enclosing Surface Boundaries

$$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$$

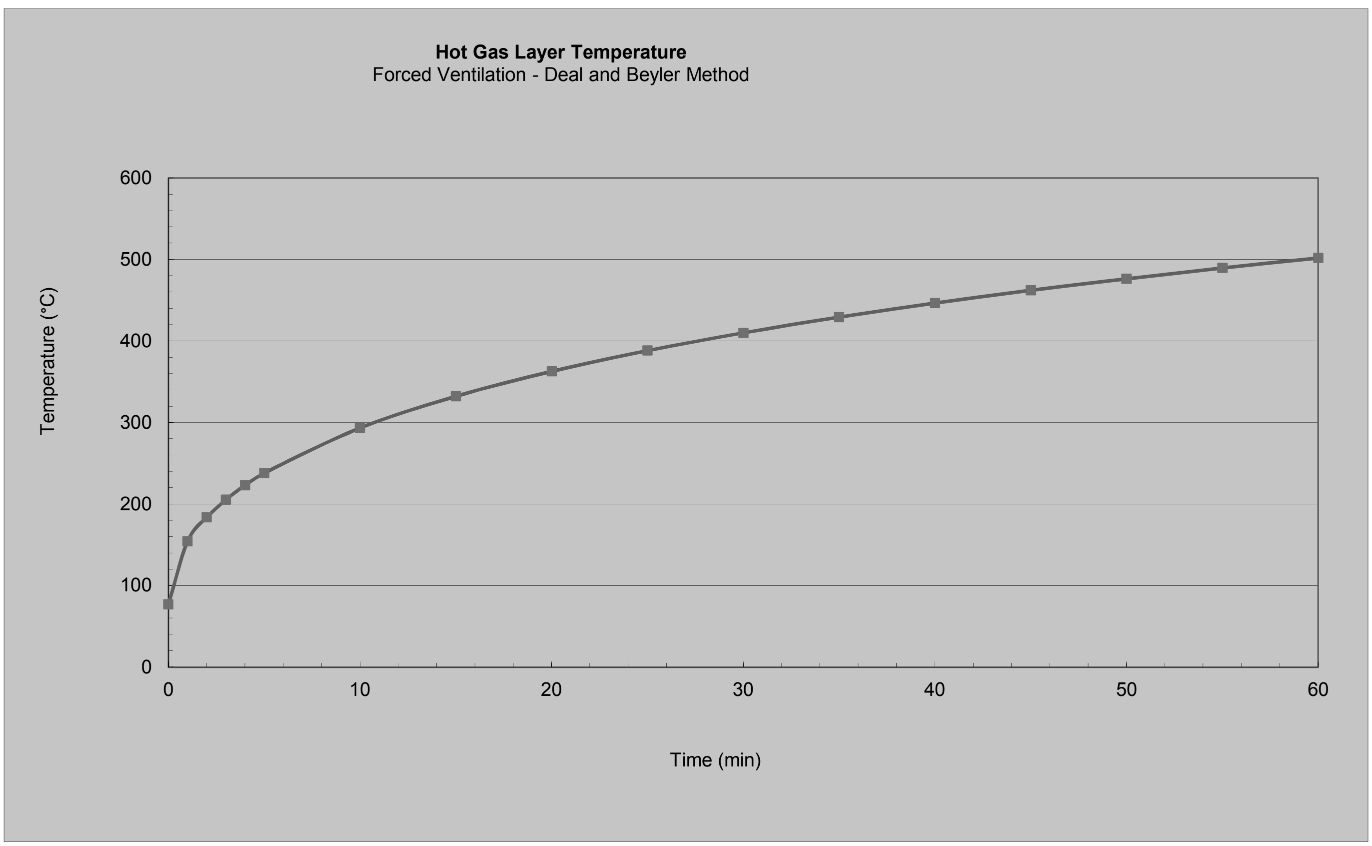
A_T = 124.00 m^2

Compartment Hot Gas Layer Temperature With Forced Ventilation

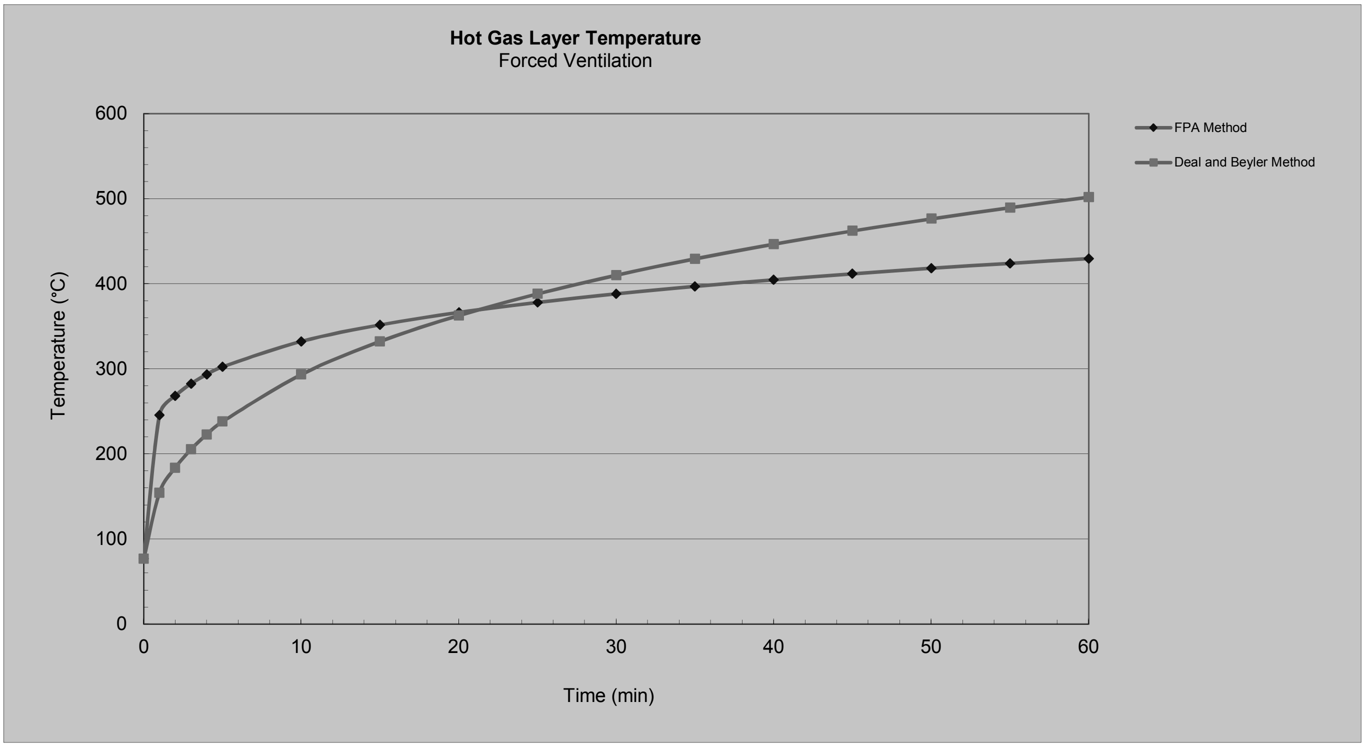
$$\Delta T_g = Q / (mc_a + h_k A_T)$$

Where
$\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_a = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.09	43.05	341.05	68.05	154.48
2	120	0.06	59.37	357.37	84.37	183.87
3	180	0.05	71.36	369.36	96.36	205.45
4	240	0.04	81.13	379.13	106.13	223.03
5	300	0.04	89.49	387.49	114.49	238.08
10	600	0.03	120.22	418.22	145.22	293.40
15	900	0.02	141.79	439.79	166.79	332.23
20	1200	0.02	158.78	456.78	183.78	362.80
25	1500	0.02	172.91	470.91	197.91	388.24
30	1800	0.02	185.07	483.07	210.07	410.13
35	2100	0.01	195.78	493.78	220.78	429.40
40	2400	0.01	205.35	503.35	230.35	446.63
45	2700	0.01	214.02	512.02	239.02	462.23
50	3000	0.01	221.94	519.94	246.94	476.49
55	3300	0.01	229.24	527.24	254.24	489.64
60	3600	0.01	236.02	534.02	261.02	501.83



Summary of Results



NOTE:
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Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION

Version 1805.1
(SI Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection **Title:** **Example 2.16.2-1b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	5.00	m
Compartment Length (l_c)	5.00	m
Compartment Height (h_c)	3.70	m
Interior Lining Thickness (δ)	1.78	cm

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	25.00	°C
Specific Heat of Air (c_a)	1.00	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia ($k\rho c$)	0.18	$(kW/m^2\text{-}K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K
Interior Lining Specific Heat (c_p)	1.10	kJ/kg-K
Interior Lining Density (ρ)	960	kg/m^3

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ $(kW/m^2\text{-}K)^2$-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: Klote, J., J. Milke, *Principles of Smoke Management, 2002 Page 270* .

Select Material

Gypsum Board

Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m)	0.60	m^3/sec

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	500.00	kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 3-177.

$$\Delta T_g/T_a = 0.63(Q/(mc_aT_a))^{0.72}(h_kA_T/(mc_a))^{-0.36}$$

Where

ΔT_g = $T_g - T_a$ = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_a = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Thermal Penetration Time Calculation

$$t_p = (\rho c_p/k)\,(\delta/2)^2$$

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 490.93 sec

Heat Transfer Coefficient Calculation

$$h_k = \sqrt{(k\rho c/t)} \quad \text{for } t < t_p \quad \text{or} \quad (k/\delta) \quad \text{for } t > t_p$$

Where

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)
See table below for results

Area of Compartment Enclosing Surface Boundaries

$$A_T = 2\,(w_c \times l_c) + 2\,(h_c \times w_c) + 2\,(h_c \times l_c)$$

Where

A_T = total area of the compartment enclosing surface boundaries (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

A_T = 124.00 m^2

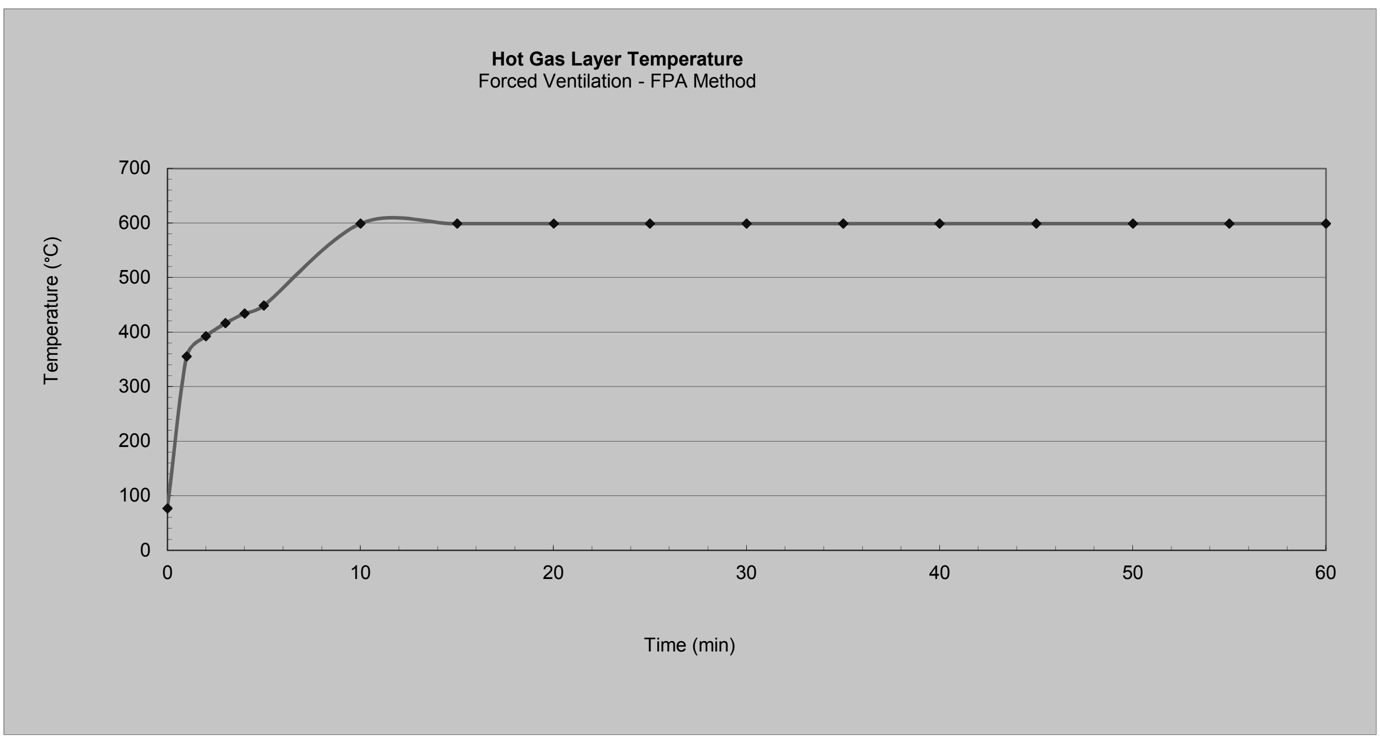
Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g/T_a = 0.63(Q/(mc_pT_a))^{0.72}(h_kA_T/(mc_p))^{-0.36}$$

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.05	0.52	154.61	452.61	179.61	355.31
2	120	0.04	0.59	175.16	473.16	200.16	392.29
3	180	0.03	0.63	188.42	486.42	213.42	416.16
4	240	0.03	0.67	198.44	496.44	223.44	434.19
5	300	0.02	0.69	206.57	504.57	231.57	448.82
10	600	0.01	0.97	289.83	587.83	314.83	598.70
15	900	0.01	0.97	289.83	587.83	314.83	598.70
20	1200	0.01	0.97	289.83	587.83	314.83	598.70
25	1500	0.01	0.97	289.83	587.83	314.83	598.70
30	1800	0.01	0.97	289.83	587.83	314.83	598.70
35	2100	0.01	0.97	289.83	587.83	314.83	598.70
40	2400	0.01	0.97	289.83	587.83	314.83	598.70
45	2700	0.01	0.97	289.83	587.83	314.83	598.70
50	3000	0.01	0.97	289.83	587.83	314.83	598.70
55	3300	0.01	0.97	289.83	587.83	314.83	598.70
60	3600	0.01	0.97	289.83	587.83	314.83	598.70



METHOD OF DEAL AND BEYLER

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 3-178.

Thermal Penetration Time Calculation

$$t_p = (\rho c_p/k)\,(\delta/2)^2$$

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining heat capacity (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = **490.929 sec**

Heat Transfer Coefficient Calculation

h_k = 0.4 $\sqrt{}$(kρc for $t < t_p$ or 0.4(k/δor $t > t_p$

Where

h_k = heat transfer coefficient (kW/m^2-K)
kρc = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)
See table below for results

Area of Compartment Enclosing Surface Boundaries

$$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$$

A_T = **124.00** m^2

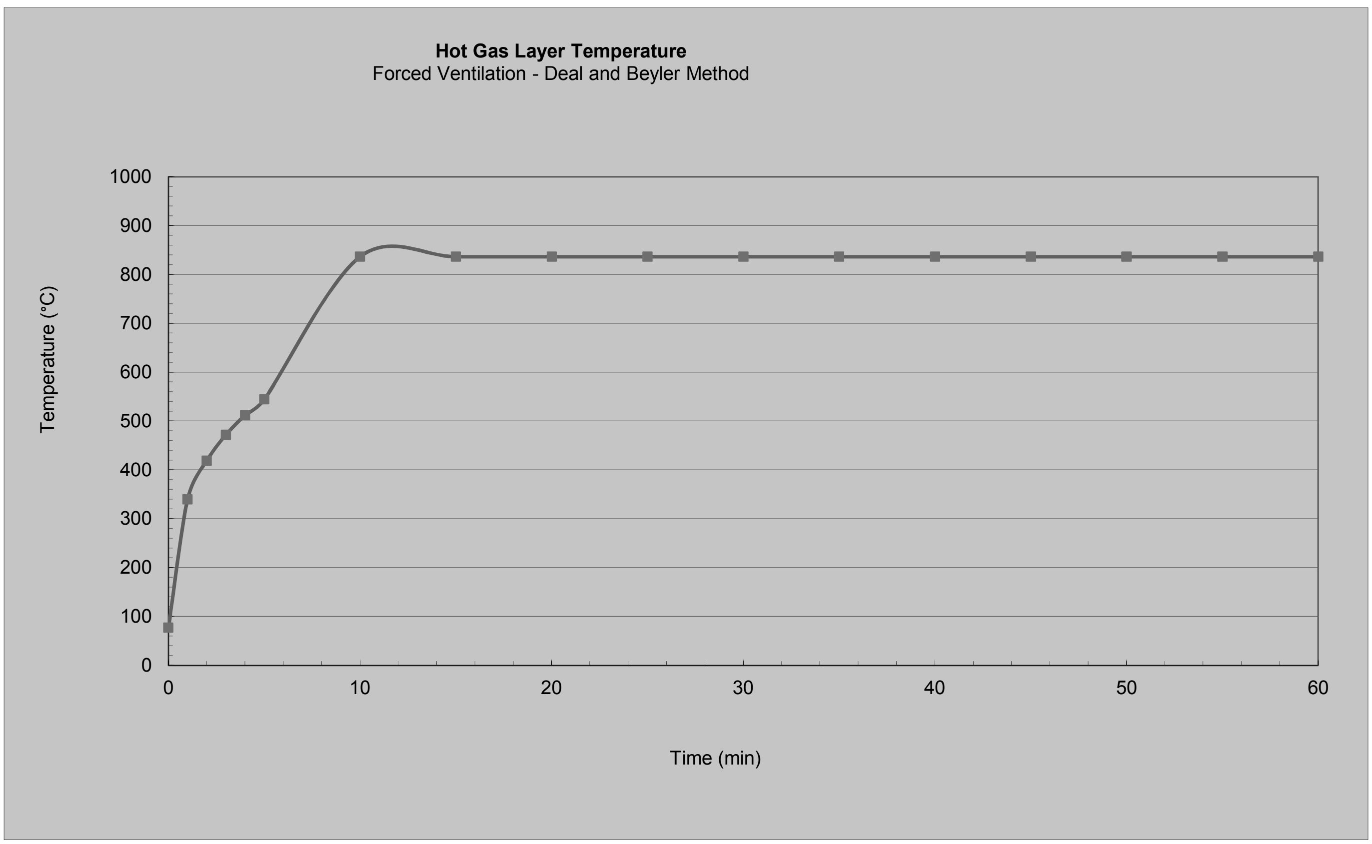
Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g = Q / (mc_a + h_k A_T)$$

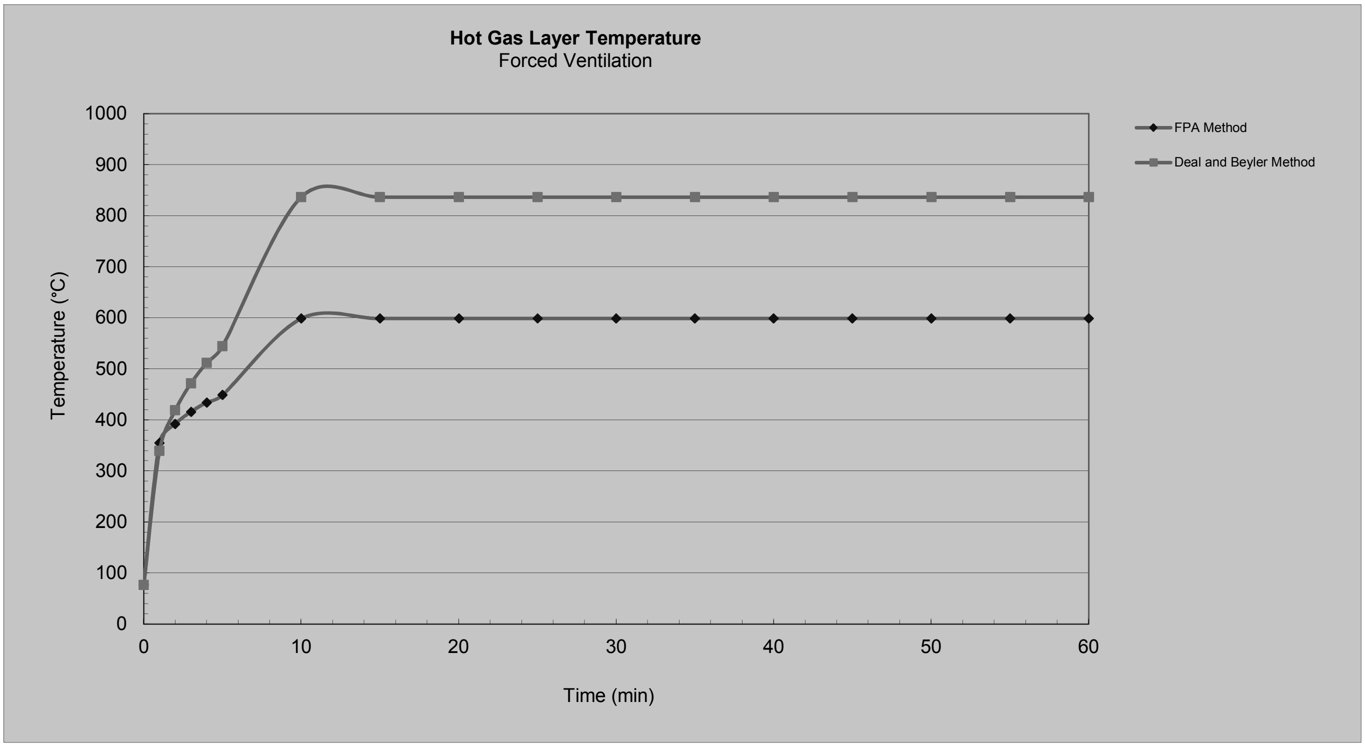
Where

$\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_a = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.02	145.88	443.88	170.88	339.59
2	120	0.02	189.99	487.99	214.99	418.98
3	180	0.01	219.37	517.37	244.37	471.87
4	240	0.01	241.65	539.65	266.65	511.97
5	300	0.01	259.65	557.65	284.65	544.37
10	600	0.00	421.95	719.95	446.95	836.51
15	900	0.00	421.95	719.95	446.95	836.51
20	1200	0.00	421.95	719.95	446.95	836.51
25	1500	0.00	421.95	719.95	446.95	836.51
30	1800	0.00	421.95	719.95	446.95	836.51
35	2100	0.00	421.95	719.95	446.95	836.51
40	2400	0.00	421.95	719.95	446.95	836.51
45	2700	0.00	421.95	719.95	446.95	836.51
50	3000	0.00	421.95	719.95	446.95	836.51
55	3300	0.00	421.95	719.95	446.95	836.51
60	3600	0.00	421.95	719.95	446.95	836.51



Summary of Results



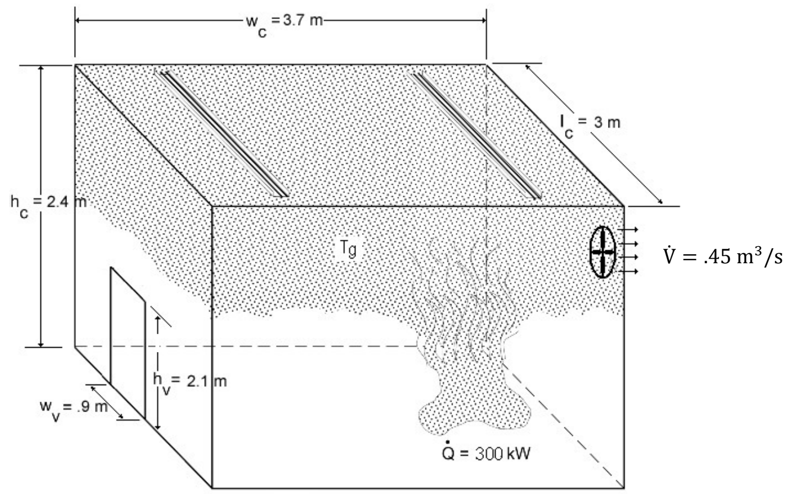
NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Example Problem 2.16.2-2

Problem Statement
Consider a compartment that is 3.7 m wide x 3.0 m long x 2.44 m high (w_c x l_c x h_c) with a vent opening that is 0.9 m wide x 2.1 m tall (w_v x h_v). The compartmentboundaries are made of 0.1524 m thick gypsum board. The forced ventilation rate is 0.45 m^3/sec (exhaust). Calculate the hot gas layer temperaturein the compartment for a fire size of 300 kW at 2 minutes.



Example Problem 2-5: Compartment with Forced Ventilation

Solution

Purpose:
(1) Determine the hot gas layer temperature in the compartment (T_g) at t = 2 min after ignition.

Assumptions:
(1) Air properties (ambient) at 25 °C
(2) Simple rectangular geometry no beam pockets
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls
(6) The bottom of the vent is at the floor level
(7) The compartment is open to the outside at the inlet (pressure = 1 atm)

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 02.2_Temperature_FV_Sup1_SI.xls

Note: The spreadsheet has two different methods for calculating the hot gas layer temperature. Both methods are presented for comparison.

FDT^s Input Parameters:

- Compartment Width (w_c) = 3.7 m
- Compartment Length (l_c) = 3.0 m
- Compartment Height (h_c) = 2.4 m
- Interior Lining Thickness (δ) = 15.24 cm
- Ambient Air Temperature (T_a) = 25 °C
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Gypsum Board** on the FDT^s
- Compartment Ventilation Rate ($\dot{V}$) = 0.45 m^3/sec
- Fire Heat Release Rate ($\dot{Q}$) = 300 kW

Results*

Boundary Material	Hot Layer Gas Temperature (T_g) (°C)	
	Method of Foote, Pagni & Alvares (FPA)	Method of Deal & Beyler
Gypsum Board	206	243

*see spreadsheet on next page at t = 2 min

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION

Version 1805.1
(SI Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection **Title:** **Example 2.16.2-2**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	3.70	m
Compartment Length (l_c)	3.00	m
Compartment Height (h_c)	2.40	m
Interior Lining Thickness (δ)	15.24	cm

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	25.00	°C
Specific Heat of Air (c_a)	1.00	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia ($k\rho c$)	0.18	$(kW/m^2\text{-}K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K
Interior Lining Specific Heat (c_p)	1.10	kJ/kg-K
Interior Lining Density (ρ)	960	kg/m^3

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ $(kW/m^2\text{-}K)^2$-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: *Klote, J., J. Milke, Principles of Smoke Management, 2002 Page 270* .

Select Material
Gypsum Board
Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m)	0.45	m^3/sec

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	300.00	kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 3-177.

$$\Delta T_g/T_a = 0.63(Q/(mc_aT_a))^{0.72}(h_kA_T/(mc_a))^{-0.36}$$

Where

ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_a = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Thermal Penetration Time Calculation

$$t_p = (\rho c_p/k)\ (\delta/2)^2$$

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 36068.24 sec

Heat Transfer Coefficient Calculation

$$h_k = \sqrt{(k\rho c/t)} \quad \text{for } t < t_p \quad \text{or} \quad (k/\delta) \quad \text{for } t > t_p$$

Where

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)
See table below for results

Area of Compartment Enclosing Surface Boundaries

$$A_T = 2\ (w_c \times l_c) + 2\ (h_c \times w_c) + 2\ (h_c \times l_c)$$

Where

A_T = total area of the compartment enclosing surface boundaries (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

A_T = 54.36 m^2

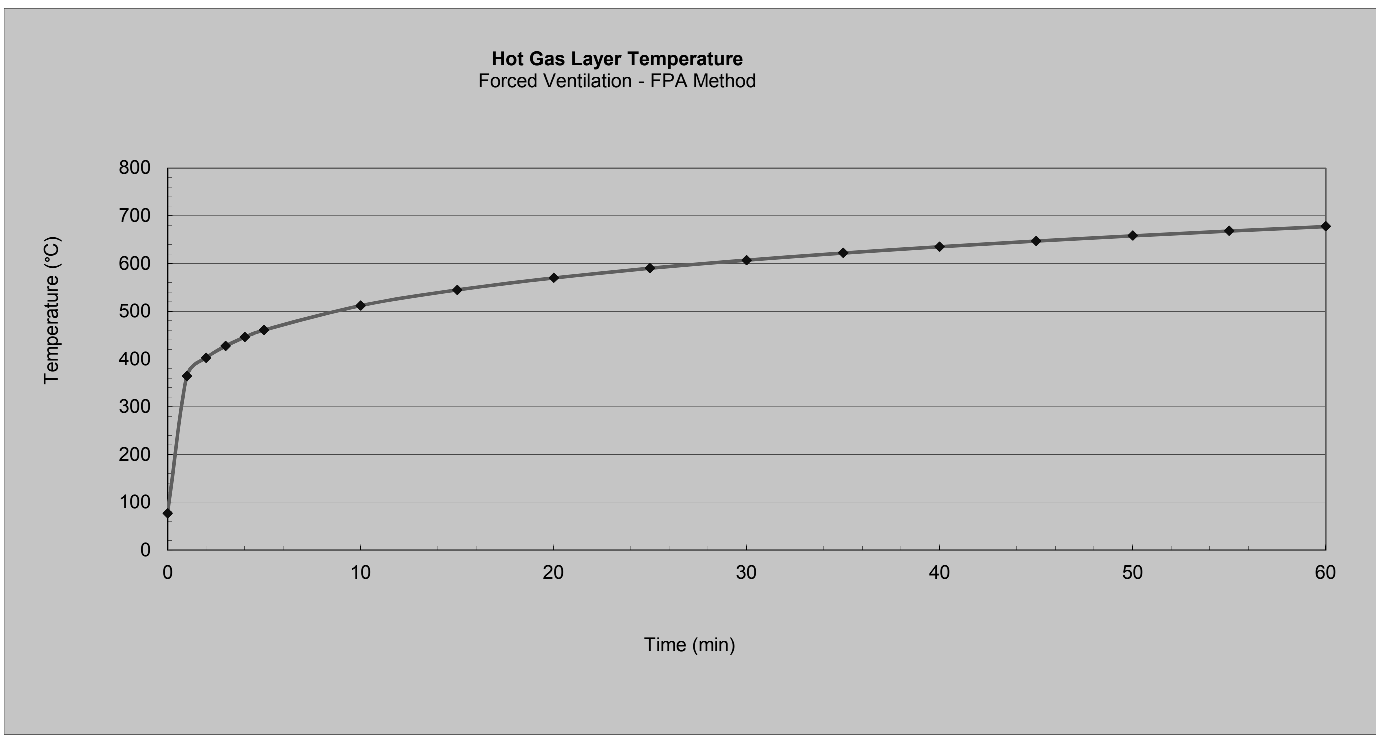
Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g/T_a = 0.63(Q/(mc_pT_a))^{0.72}(h_kA_T/(mc_p))^{-0.36}$$

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m²-K)		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.05	0.54	159.75	457.75	184.75	364.54
2	120	0.04	0.61	180.97	478.97	205.97	402.75
3	180	0.03	0.65	194.68	492.68	219.68	427.42
4	240	0.03	0.69	205.02	503.02	230.02	446.04
5	300	0.02	0.72	213.42	511.42	238.42	461.16
10	600	0.02	0.81	241.78	539.78	266.78	512.21
15	900	0.01	0.87	260.09	558.09	285.09	545.16
20	1200	0.01	0.92	273.91	571.91	298.91	570.04
25	1500	0.01	0.96	285.14	583.14	310.14	590.25
30	1800	0.01	0.99	294.65	592.65	319.65	607.37
35	2100	0.01	1.02	302.94	600.94	327.94	622.30
40	2400	0.01	1.04	310.31	608.31	335.31	635.56
45	2700	0.01	1.06	316.96	614.96	341.96	647.53
50	3000	0.01	1.08	323.03	621.03	348.03	658.45
55	3300	0.01	1.10	328.62	626.62	353.62	668.52
60	3600	0.01	1.12	333.81	631.81	358.81	677.85



METHOD OF DEAL AND BEYLER

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 3-178.

Thermal Penetration Time Calculation

$$t_p = (\rho c_p/k)\ (\delta/2)^2$$

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining heat capacity (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = **36068.2 sec**

Heat Transfer Coefficient Calculation

$$h_k = 0.4\ \sqrt{(k\rho c}\ \text{ for } t < t_p \quad \text{or} \quad 0.4(k/\delta \text{ for } t > t_p$$

Where

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)
See table below for results

Area of Compartment Enclosing Surface Boundaries

$$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$$

A_T = **54.36 m^2**

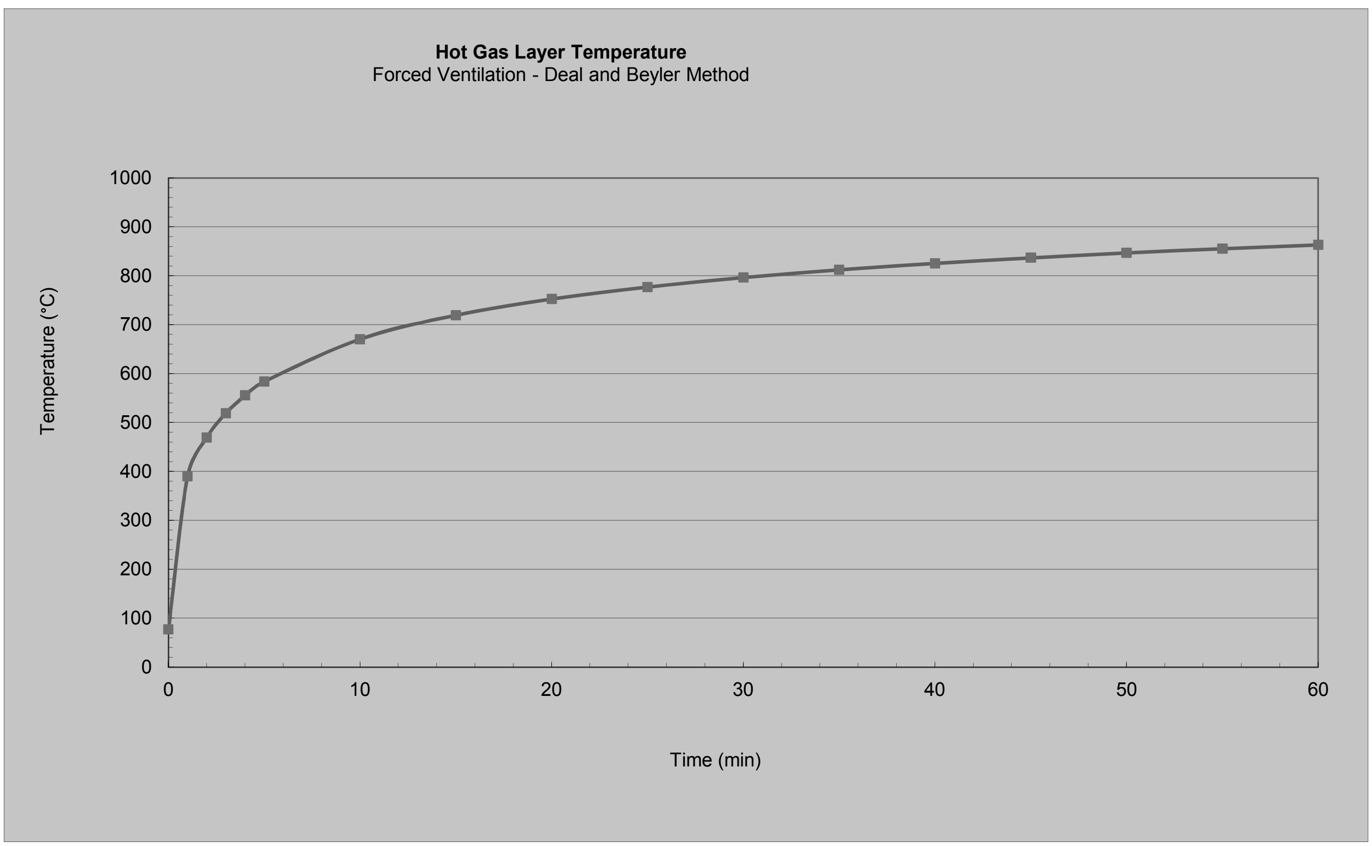
Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g = Q / (mc_a + h_k A_T)$$

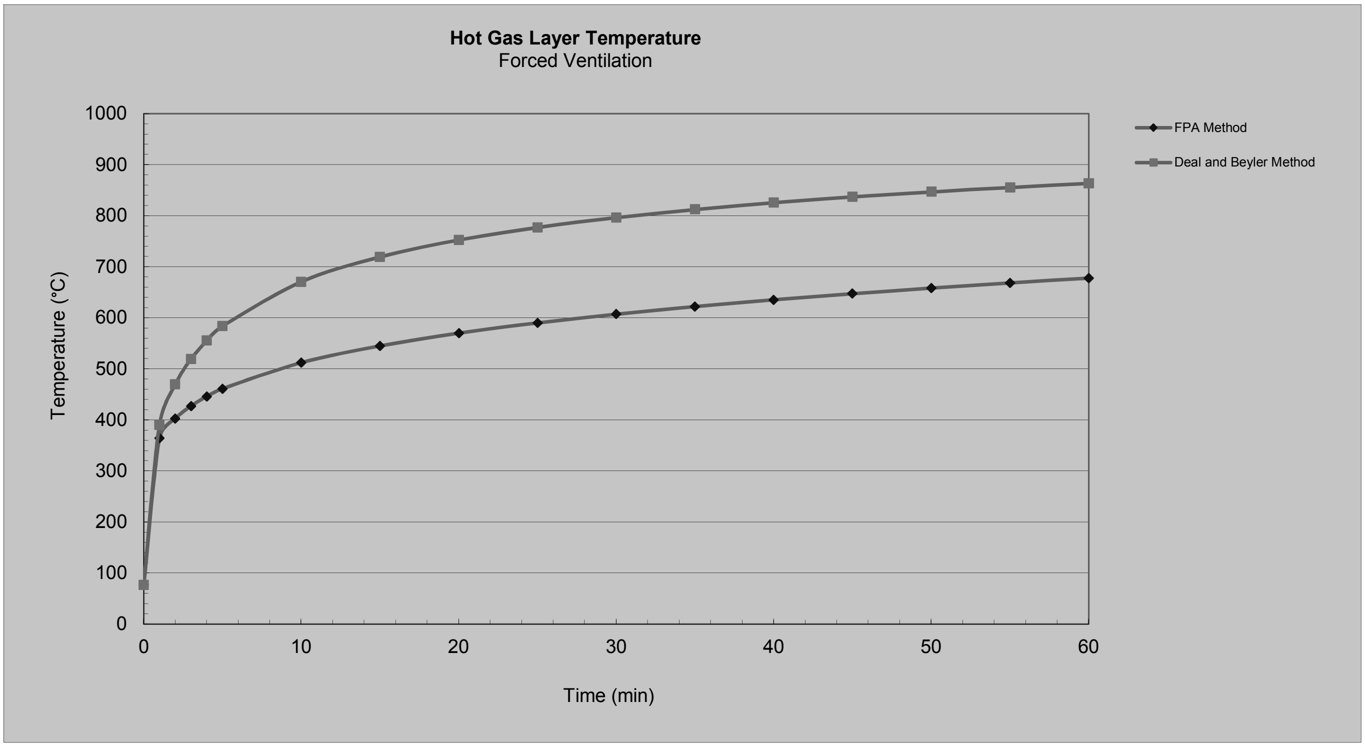
Where

$\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_a = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.02	174.01	472.01	199.01	390.22
2	120	0.02	218.15	516.15	243.15	469.67
3	180	0.01	245.77	543.77	270.77	519.38
4	240	0.01	265.83	563.83	290.83	555.50
5	300	0.01	281.51	579.51	306.51	583.72
10	600	0.01	329.79	627.79	354.79	670.62
15	900	0.01	356.90	654.90	381.90	719.43
20	1200	0.00	375.30	673.30	400.30	752.54
25	1500	0.00	388.98	686.98	413.98	777.16
30	1800	0.00	399.74	697.74	424.74	796.53
35	2100	0.00	408.52	706.52	433.52	812.33
40	2400	0.00	415.88	713.88	440.88	825.58
45	2700	0.00	422.18	720.18	447.18	836.93
50	3000	0.00	427.67	725.67	452.67	846.80
55	3300	0.00	432.50	730.50	457.50	855.50
60	3600	0.00	436.80	734.80	461.80	863.25



Summary of Results



NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

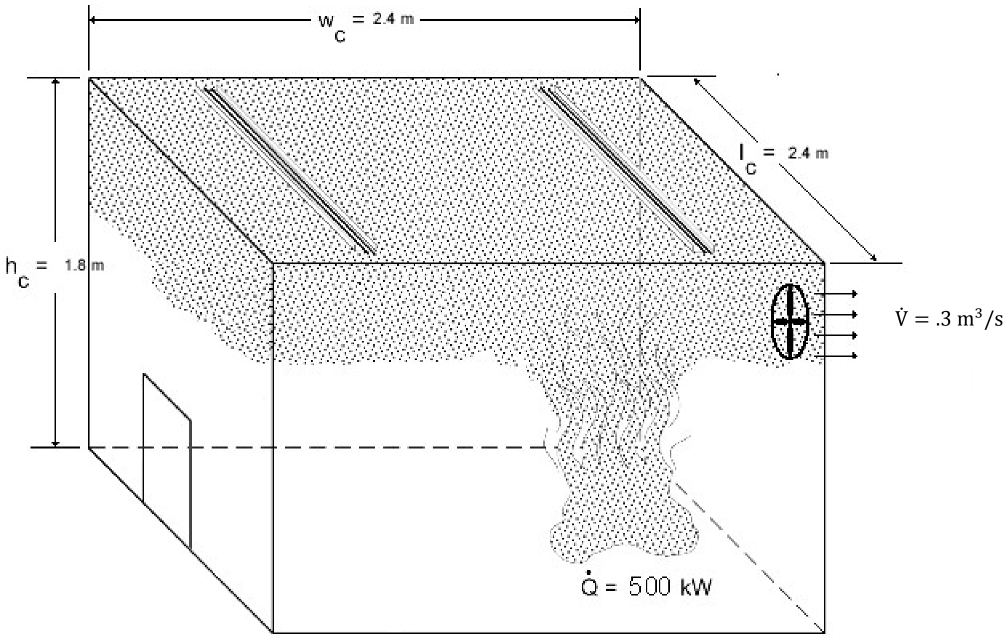
Checked by: ______ Date: ______ Organization: ______

Additional Information:

Problem 2.16.2-3

Problem Statement

Consider a compartment that is 2.4 m wide x 2.4 m long x 1.8 m high (w_c x l_c x h_c). The compartment boundaries are made of 0.2286 m thick brick. The forced ventilation rate is 0.3 m^3/sec (exhaust). Calculate the hot gas layer temperature in the compartment for a fire size of 500 kW at 2 minutes.



Example Problem 2-6: Compartment with Forced Ventilation

Solution

Purpose:

(1) Determine the hot gas layer temperature in the compartment (T_g) at t = 2 min after ignition.

Assumptions:

(1) Air properties (ambient) at 25 °C
(2) Simple rectangular geometry (no beam pockets)
(3) One-dimensional heat flow through the compartment boundaries
(4) Constant Heat Release Rate (HRR)
(5) The fire is located at the center of the compartment or away from the walls
(6) The bottom of the vent is at the floor level
(7) The compartment is open to the outside at the inlet (pressure = 1 atm

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 02.2_Temperature_FV_Sup1_SI.xls

Note: The spreadsheet has two different methods for calculating the hot gas layer temperature. We are going to use both methods to compare values.

FDT^s Input Parameters:
- Compartment Width (w_c) = 2.4 m
- Compartment Length (l_c) = 2.4 m
- Compartment Height (h_c) = 1.8 m
- Interior Lining Thickness (δ) = 22.86 cm
- Ambient Air Temperature (T_a) = 25 °C
- Specific Heat of Air (c_p) = 1 kJ/kg-K
- Material: Select **Brick** on the FDT^s
- Compartment Ventilation Rate ($\dot{V}$) = 0.3 m^3/sec
- Fire Heat Release Rate ($\dot{Q}$) = 500 kW

Results*

Boundary Material	Hot Layer Gas Temperature (T_g) (°C)	
	Method of Foote, Pagni & Alvares (FPA)	Method of Deal & Beyler
Brick	279	315

*see spreadsheet on next page at t = 2 min.

CHAPTER 2. PREDICTING HOT GAS LAYER TEMPERATURE IN A ROOM FIRE WITH FORCED VENTILATION

Version 1805.1 (SI Units)

COMPARTMENT WITH THERMALLY THICK/THIN BOUNDARIES

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.

Project / Inspection Title: **Example 2.16.2-3**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	2.40	m
Compartment Length (l_c)	2.40	m
Compartment Height (h_c)	1.80	m
Interior Lining Thickness (δ)	22.86	cm

AMBIENT CONDITIONS

Ambient Air Temperature (T_a)	25.00	°C
Specific Heat of Air (c_a)	1.00	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES

Interior Lining Thermal Inertia ($k\rho c$)	1.7	$(kW/m^2\text{-}K)^2$-sec
Interior Lining Thermal Conductivity (k)	0.0008	kW/m-K
Interior Lining Specific Heat (c_p)	0.80	kJ/kg-K
Interior Lining Density (ρ)	2600	kg/m^3

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES FOR COMMON INTERIOR LINING MATERIALS

Material	$k\rho c$ $(kW/m^2\text{-}K)^2$-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m^3)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	0.000037	0.8	60
Expanded Polystyrene	0.001	0.000034	1.5	20
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: *Klote, J., J. Milke, Principles of Smoke Management, 2002 Page 270* .

Select Material

Brick

Scroll to desired material then Click on selection

COMPARTMENT MASS VENTILATION FLOW RATE

Forced Ventilation Flow Rate (m)	0.30	m^3/sec

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q)	500.00	kW

Calculate

METHOD OF FOOTE, PAGNI, AND ALVARES (FPA)

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 3-177.

$$\Delta T_g/T_a = 0.63(Q/(mc_aT_a))^{0.72}(h_kA_T/(mc_a))^{-0.36}$$

Where

ΔT_g = T_g - T_a = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_a = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Thermal Penetration Time Calculation

$$t_p = (\rho c_p/k)\ (\delta/2)^2$$

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining specific heat (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 33967.67 sec

Heat Transfer Coefficient Calculation

$$h_k = \sqrt{(k\rho c/t)} \quad \text{for } t < t_p \quad \text{or} \quad (k/\delta) \quad \text{for } t > t_p$$

Where

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
t = time after ignition (sec)
See table below for results

Area of Compartment Enclosing Surface Boundaries

$$A_T = 2\ (w_c \times l_c) + 2\ (h_c \times w_c) + 2\ (h_c \times l_c)$$

Where

A_T = total area of the compartment enclosing surface boundaries (m^2)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

A_T = 28.80 m^2

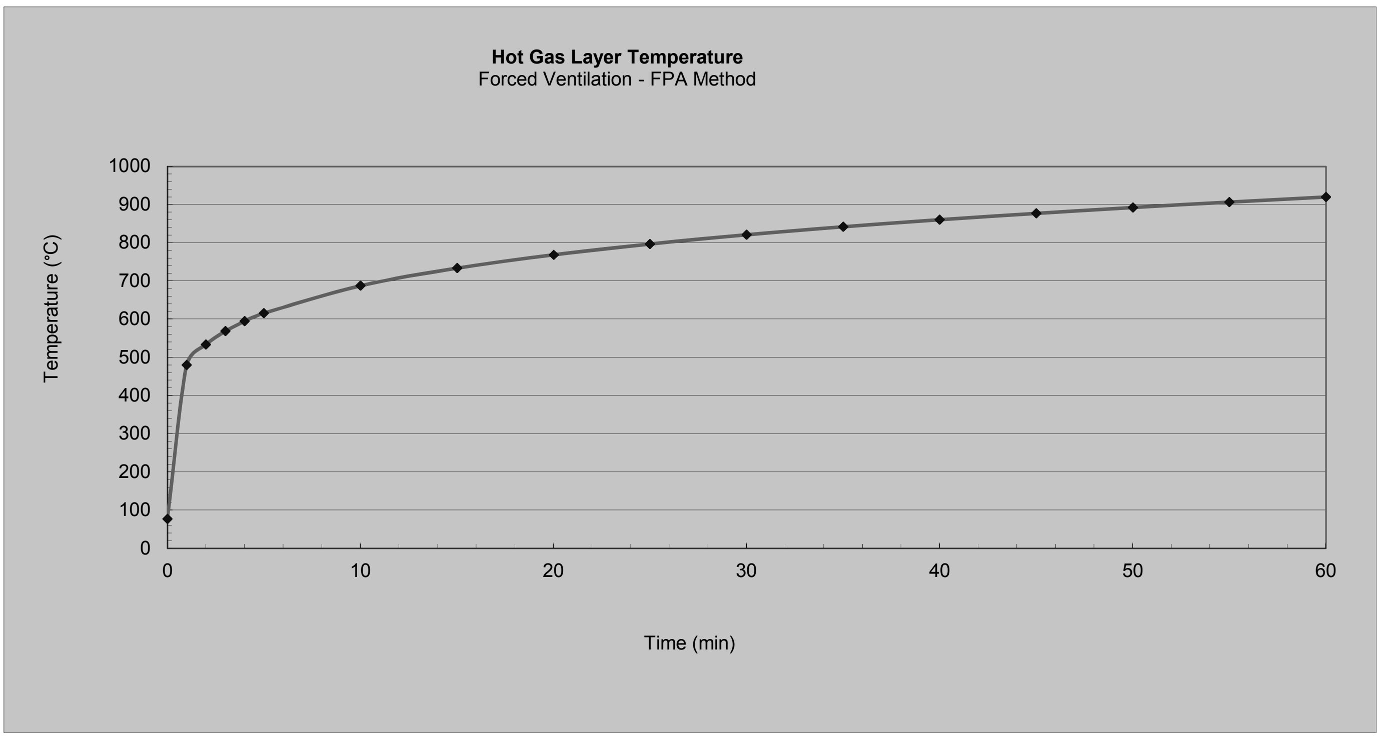
Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g/T_a = 0.63(Q/(mc_pT_a))^{0.72}(h_kA_T/(mc_p))^{-0.36}$$

$$\Delta T_g = T_g - T_a$$

$$T_g = \Delta T_g + T_a$$

Time After Ignition (t)		h_k	$\Delta T_g/T_a$	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)		(K)	(K)	(°C)	(°F)
0	0	-	-	-	298.00	25.00	77.00
1	60	0.17	0.75	224.05	522.05	249.05	480.29
2	120	0.12	0.85	253.82	551.82	278.82	533.88
3	180	0.10	0.92	273.04	571.04	298.04	568.47
4	240	0.08	0.96	287.55	585.55	312.55	594.59
5	300	0.08	1.00	299.33	597.33	324.33	615.80
10	600	0.05	1.14	339.11	637.11	364.11	687.40
15	900	0.04	1.22	364.78	662.78	389.78	733.61
20	1200	0.04	1.29	384.17	682.17	409.17	768.51
25	1500	0.03	1.34	399.92	697.92	424.92	796.85
30	1800	0.03	1.39	413.26	711.26	438.26	820.87
35	2100	0.03	1.43	424.89	722.89	449.89	841.79
40	2400	0.03	1.46	435.22	733.22	460.22	860.40
45	2700	0.03	1.49	444.55	742.55	469.55	877.19
50	3000	0.02	1.52	453.06	751.06	478.06	892.51
55	3300	0.02	1.55	460.90	758.90	485.90	906.62
60	3600	0.02	1.57	468.17	766.17	493.17	919.71



METHOD OF DEAL AND BEYLER

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 3-178.

Thermal Penetration Time Calculation

$$t_p = (\rho c_p/k)\ (\delta/2)^2$$

Where

t_p = thermal penetration time (sec)
ρ = interior lining density (kg/m^3)
c_p = interior lining heat capacity (kJ/kg-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

t_p = 33967.7 sec

Heat Transfer Coefficient Calculation

$h_k = 0.4\ \sqrt{}(k\rho c$ for $t < t_p$ or $0.4(k/\delta$ for $t > t_p$

Where

h_k = heat transfer coefficient (kW/m^2-K)
$k\rho c$ = interior construction thermal inertia (kW/m^2-K)^2-sec
(a thermal property of material responsible for the rate of temperature rise)
δ = thickness of interior lining (m)
See table below for results

Area of Compartment Enclosing Surface Boundaries

$$A_T = 2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)$$

A_T = 28.80 m^2

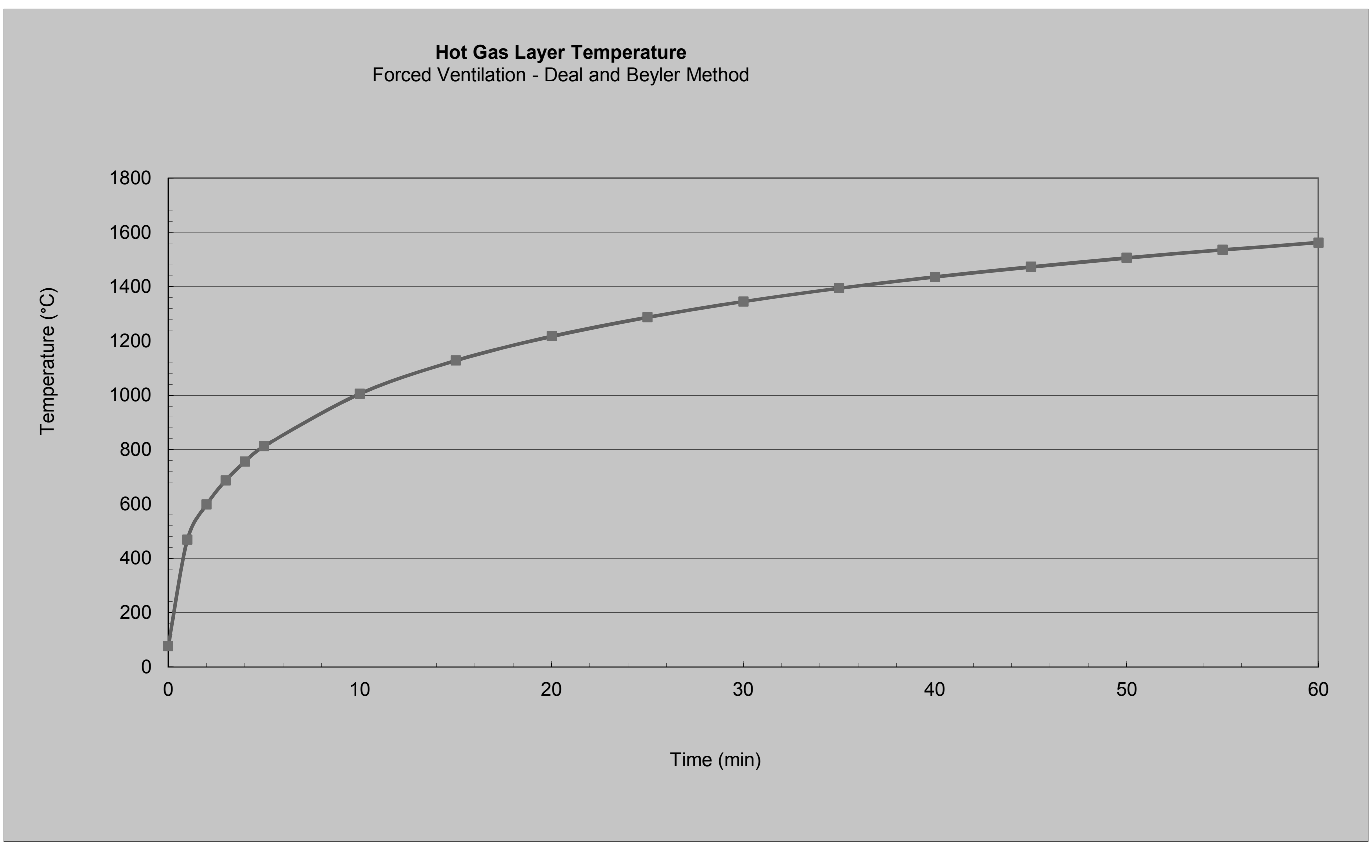
Compartment Hot Gas Layer Temperature With Forced Ventilation

$$\Delta T_g = Q / (mc_a + h_k A_T)$$

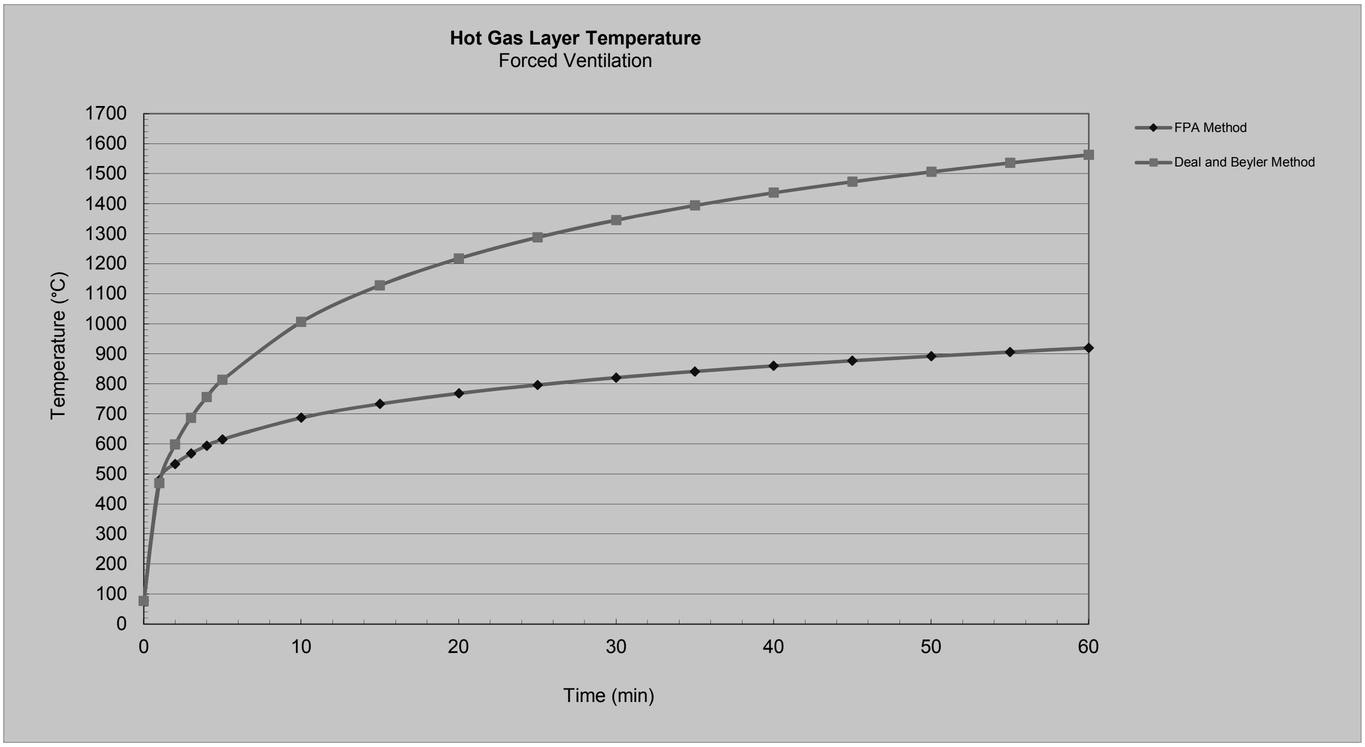
Where

$\Delta T_g = T_g - T_a$ = upper layer gas temperature rise above ambient (K)
T_a = ambient air temperature (K)
Q = heat release rate of the fire (kW)
m = compartment mass ventilation flow rate (kg/sec)
c_a = specific heat of air (kJ/kg-K)
h_k = convective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries (m^2)

Time After Ignition (t)		h_k	ΔT_g	T_g	T_g	T_g
(min)	(sec)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
0	0	-	-	298.00	25.00	77.00
1	60	0.07	217.91	515.91	242.91	469.25
2	120	0.05	289.60	587.60	314.60	598.28
3	180	0.04	339.00	637.00	364.00	687.21
4	240	0.03	377.38	675.38	402.38	756.29
5	300	0.03	408.98	706.98	433.98	813.16
10	600	0.02	516.23	814.23	541.23	1006.21
15	900	0.02	584.08	882.08	609.08	1128.35
20	1200	0.02	633.74	931.74	658.74	1217.73
25	1500	0.01	672.78	970.78	697.78	1288.00
30	1800	0.01	704.82	1002.82	729.82	1345.68
35	2100	0.01	731.92	1029.92	756.92	1394.45
40	2400	0.01	755.32	1053.32	780.32	1436.58
45	2700	0.01	775.87	1073.87	800.87	1473.57
50	3000	0.01	794.16	1092.16	819.16	1506.48
55	3300	0.01	810.59	1108.59	835.59	1536.05
60	3600	0.01	825.48	1123.48	850.48	1562.87



Summary of Results



NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

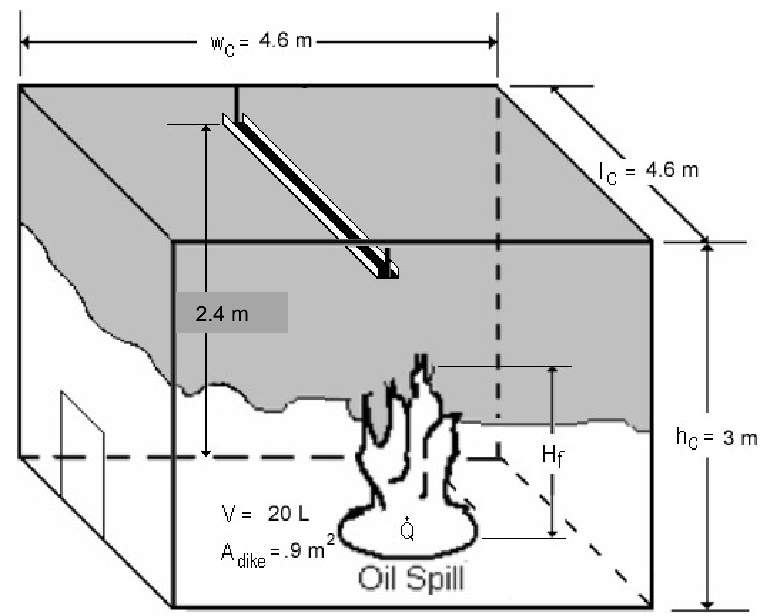
Checked by: Date: Organization:

Additional Information:

3.11 Problems

Example Problem 3.11-1

Problem Statement
A pool fire scenario arises from a breach (leak or rupture) in an auxiliary cooling water pump oil tank. This event allows the fuel contents of the pump to spill and spread over the compartment floor. A 20 liter, 0.9 m^2 surface area, spill of flammable liquid (lubricating oil) leads to consideration of a pool fire in a compartment with a concrete floor. The fuel 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 4.6 m wide x 4.6 m deep x 3.0 m high. The cable tray is located 2.4 m above the pool fire. Determine whether the flame will impinge upon the cable tray. Assume instantaneous and complete involvement of the liquid pool with no fire growth and no intervention by the plant fire department or automatic suppression systems.



Example Problem 3-1: Compartment with Pool Fire

Solution

Purpose:
1. Determine the Heat Release Rate (HRR) of the fire source.
2. Determine the burning duration of the pool fire.
3. Determine the flame height of the pool fire.
4. Determine whether the flame will impinge upon the cable tray.

Assumptions:
1. Instantaneous and complete involvement of the liquid in the pool fire
2. The pool fire is burning in the open
3. No fire growth period (instantaneous HRR_{max})
4. The pool is circular or nearly circular and contains a fixed mass of liquid volume
5. The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 03_HRR_Flame_H eight_Burning_Duration_Calculations_Sup1_SI.xls

FDT^s Input Parameter:
- Fuel Spill Volume (V) =20 liters
- Fuel Spill Area or Dike Area (A_{dike}) = 0.9 m^2
- Select Fuel Type: **Lube Oil**

Results*

Heat Release Rate (HRR) ($\dot{Q}$) (kW)	Burning Duration (t_b) (min.)	Pool Fire Flame Height (H_f) (m)	
		Method of Heskestad	Method of Thomas
851	7.22	2.4	2.7

*see spreadsheet on next page

Both methods for pool fire flame height estimation show that the pool fire flame will impinge upon the cable tray.

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.

Project / Inspection Title: **Example 3.11-1**

INPUT PARAMETERS

Fuel Spill Volume (V)	20.00	liters
Fuel Spill Area or Dike Area (A_{dike})	0.90	m^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Fuel Density (ρ)	760	kg/m^3
Empirical Constant ($k\beta$)	0.7	m^{-1}
Ambient Air Temperature (T_a)	25.00	°C
Gravitational Acceleration (g)	9.81	m/sec^2
Ambient Air Density (ρ_a)	1.18	kg/m^3

Calculate

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Density ρ (kg/m^3)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	796	100
Ethanol	0.015	26,800	794	100
Butane	0.078	45,700	573	2.7
Benzene	0.085	40,100	874	2.7
Hexane	0.074	44,700	650	1.9
Heptane	0.101	44,600	675	1.1
Xylene	0.09	40,800	870	1.4
Acetone	0.041	25,800	791	1.9
Dioxane	0.018	26,200	1035	5.4
Diethy Ether	0.085	34,200	714	0.7
Benzine	0.048	44,700	740	3.6
Gasoline	0.055	43,700	740	2.1
Kerosine	0.039	43,200	820	3.5
Diesel	0.045	44,400	918	2.1
JP-4	0.051	43,500	760	3.6
JP-5	0.054	43,000	810	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	760	0.7
561 Silicon Transformer Fluid	0.005	28,100	960	100
Fuel Oil, Heavy	0.035	39,700	970	1.7
Crude Oil	0.0335	42,600	855	2.8
Lube Oil	0.039	46,000	760	0.7
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type
Lube Oil
Scroll to desired fuel type
Click on selection

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-25.*

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\ D})\ A_{dike}$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
$DH_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)
kb = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$

Where
Adike = surface area of pool fire (m^2)
D = pool fire diamter (m)

$$D = \sqrt{(4A_{dike}/\pi)}$$

D = 1.070 m

Heat Release Rate Calculation

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

$$Q = m''\Delta H_{c,eff}\,(1-e^{-k\beta\ D})\ A_{dike}$$

Q = 851.41 kW 806.98 Btu/sec

ESTIMATING POOL FIRE BURNING DURATION

Reference: *SFPE Handbook of Fire Protection Engineering* , 2nd Edition, 1995, Page 3-197.

$$t_b = 4V / \pi D^2 \nu$$

Where
t_b = burning duration of pool fire (sec)
V = volume of liquid (m^3)
D = pool diameter (m)
ν = regression rate (m/sec)

Calculation for Regression Rate

$$\nu = m''/\rho$$

Where
ν = regression rate (m/sec)
m" = mass burning rate of fuel (kg/m^2-sec)
ρ = liquid fuel density (kg/m^3)

ν = 0.000051 m/sec

Burning Duration Calculation

$$t_b = 4V/\pi D^2 \nu$$

t_b = 433.05 sec 7.22 minutes

Note that a liquid pool fire with a given amount of fuel can burn for long periods of time over small area or for short periods of time over a large area.

ESTIMATING POOL FIRE FLAME HEIGHT

METHOD OF HESKESTAD

Reference: *SFPE Handbook of Fire Protection Engineering* , 2nd Edition, 1995, Page 2-10.

$$H_f = 0.235\ Q^{2/5} - 1.02\ D$$

Where
H_f = pool fire flame height (m)
Q = pool fire heat release rate (kW)
D = pool fire diameter (m)

Pool Fire Flame Height Calculation

$$H_f = 0.235\ Q^{2/5} - 1.02\ D$$

H_f = 2.40 m 7.88 ft

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering* , 2nd Edition, 1995, Page 3-204.

$$H_f = 42\ D\ (m''/\rho_a \sqrt{(g\ D)})^{0.61}$$

Where
H_f = pool fire flame height (m)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ρ_a = ambient air density (kg/m^3)
D = pool fire diameter (m)
g = gravitational acceleration (m/sec^2)

Pool Fire Flame Height Calculation

$$H_f = 42\ D\ (m''/(\rho_a \sqrt{(g\ D)}))^{0.61}$$

H_f = 2.74 m 8.97 ft

CHAPTER 3: ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE, HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT

Version 1805.1
(SI Units)

Summary of Results

Heat Release Rate Calculation

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

$$Q = m''\Delta H_{c,eff}\,(1-e^{-k\beta\,D})\,A_{dike}$$

Answer	Q=	851.41 kW	806.98 Btu/sec

Burning Duration Calculation

$$t_b = 4V/\pi D^2 \nu$$

Answer	t_b=	433.05 sec	7.22 minutes

Flame Height Calculation

Method of Heskestad
$$H_f = 0.235\,Q^{2/5} - 1.02\,D$$

Method of Thomas
$$H_f = 42\,D\,(m''/(\rho_a\,\sqrt{(g\,D)}))^{0.61}$$

Answer		
	METHOD OF HESKESTAD	2.40 m
	METHOD OF THOMAS	2.74 m

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (m) (Heskestad)	H_f (m) (Thomas)
1	0.09	0.34	35.66	4195.17	0.63	1.24
2	0.19	0.49	96.19	2097.58	0.96	1.58
3	0.28	0.60	170.49	1398.39	1.23	1.82
4	0.37	0.69	254.77	1048.79	1.45	2.01
5	0.46	0.77	346.90	839.03	1.65	2.17
6	0.56	0.84	445.52	699.19	1.84	2.32
7	0.65	0.91	549.63	599.31	2.00	2.44
8	0.74	0.97	658.49	524.40	2.16	2.56
9	0.84	1.03	771.52	466.13	2.31	2.67
10	0.93	1.09	888.26	419.52	2.44	2.77
11	1.02	1.14	1008.32	381.38	2.57	2.86
12	1.11	1.19	1131.38	349.60	2.70	2.95
13	1.21	1.24	1257.17	322.71	2.82	3.03
14	1.30	1.29	1385.45	299.65	2.93	3.11
15	1.39	1.33	1516.02	279.68	3.04	3.18
20	1.86	1.54	2197.59	209.76	3.53	3.52
25	2.32	1.72	2916.42	167.81	3.96	3.80
50	4.65	2.43	6814.63	83.90	5.54	4.84
75	6.97	2.98	10946.20	55.94	6.66	5.57
100	9.29	3.44	15166.14	41.95	7.54	6.16

Caution! The purpose of this random spill size chart is to aid the user in evaluating the hazard of random sized spills. Please note that the calculation does not take into account the viscosity or volatility of the liquid, or the absorptivity of the surface. The results generated for small volume spills over large

NOTE:
The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

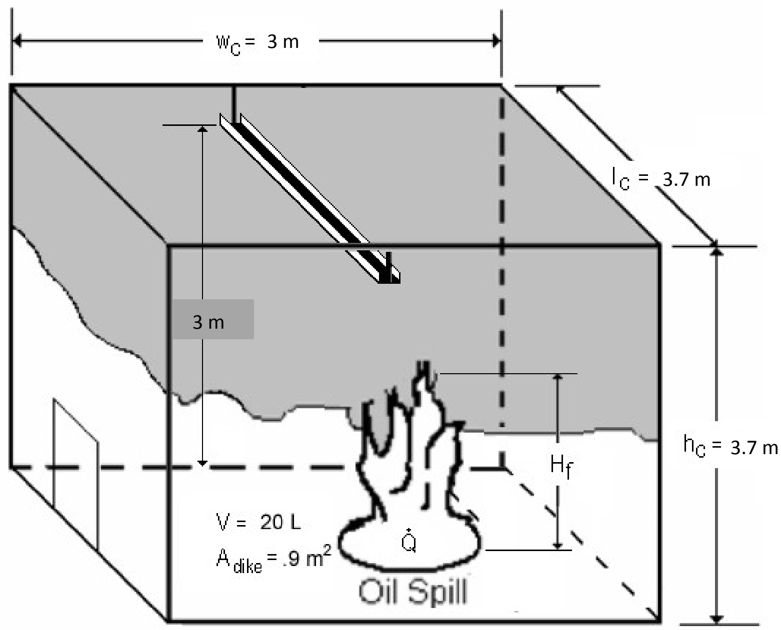
Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 3.11-2

Problem Statement
A standby diesel generator (SBDG) room in a power plant has a 10 liter spill of diesel fuel over a 0.1 m^2 diked area. This event allows the diesel fuel to form a pool. The diesel is ignited and fire 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 3.0 m wide x 3.7 m deep x 3.7 m high. The cable tray is located 3.0 m above the pool fire. Determine whether flame will impinge upon the cable tray. Also, determine the minimum area of the pool fire required for the flame to impinge upon the cable tray. Assume instantaneous, complete involvement of the liquid pool with no fire growth and no intervention by plant fire department or automatic suppression.



Example Problem 3-2: Compartment with Pool Fire

Solution

Purpose:

(1) Determine the Heat Release Rate (HRR) of the fire source.
(2) Determine the burning duration of the pool fire.
(3) Determine the flame height of the pool fire.
(4) Determine whether the flame will impinge upon the cable tray.
(5) Determine the minimum dike area required for the flame to impinge upon the cable tray.

Assumptions:

(1) Instantaneous and complete involvement of the liquid in the pool fire
(2) The pool fire is burning in the open
(3) No fire growth period (instantaneous HRR_{max})
(4) The pool is circular or nearly circular and contains a fixed mass of liquid volume
(5) The fire is located at the center of the compartment or away from the walls

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations_Sup1_SI.xls

FDT^s Input Parameter:
- Fuel Spill Volume (V) = 10 liters
- Fuel Spill Area or Dike Area (A_{dike}) = 0.1 m^2
- Select Fuel Type: **Diesel**

Results*

Heat Release Rate (HRR) ($\dot{Q}$) (kW)	Burning Duration (t_b) (min.)	Pool Fire Flame Height (H_f) (m)	
		Method of Heskestad	Method of Thomas
105	34	1.2	1.4

*see spreadsheet on next page

Both methods for pool fire flame height estimation show that pool fire flame will not impinge the cable tray.

To determine the minimum dike area required for the flame to impinge upon the cable tray, the user must substitute different values for the area in the spreadsheet until we obtain a flame height value of 3 m (cable tray height). The user must keep the input values used for the previous results, and change only the area value. This trial and error procedure is shown in the following table.

Trial	A_{dike} (m^2)	Pool Fire Flame Height (H_f) (m)	
		Method of Heskestad	Method of Thomas
1	7	2.9	2.7
2	8	3.1	2.8
3	9	3.3	2.9

To be conservative, we are going to consider the method that gets the 3 m flame height first. The method of Heskestad tells that the pool fire flame will impinge upon the cable tray if the dike area is 7.2 m^2. For practical purposes, we could say that a spill pool area around 7 to 8 m^2 would be a risk for the cable tray integrity.

CHAPTER 3: ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE, HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT

Version 1805.1 (SI Units)

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.

Project / Inspection Title: **Example 3.11-2**

INPUT PARAMETERS

Fuel Spill Volume (V)	10.00	liters
Fuel Spill Area or Dike Area (A_{dike})	0.10	m^2
Mass Burning Rate of Fuel (m")	0.045	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	44400	kJ/kg
Fuel Density (ρ)	918	kg/m^3
Empirical Constant ($k\beta$)	2.1	m^{-1}
Ambient Air Temperature (T_a)	25.00	°C
Gravitational Acceleration (g)	9.81	m/sec^2
Ambient Air Density (ρ_a)	1.18	kg/m^3

Calculate

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Density ρ (kg/m^3)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	796	100
Ethanol	0.015	26,800	794	100
Butane	0.078	45,700	573	2.7
Benzene	0.085	40,100	874	2.7
Hexane	0.074	44,700	650	1.9
Heptane	0.101	44,600	675	1.1
Xylene	0.09	40,800	870	1.4
Acetone	0.041	25,800	791	1.9
Dioxane	0.018	26,200	1035	5.4
Diethy Ether	0.085	34,200	714	0.7
Benzine	0.048	44,700	740	3.6
Gasoline	0.055	43,700	740	2.1
Kerosine	0.039	43,200	820	3.5
Diesel	0.045	44,400	918	2.1
JP-4	0.051	43,500	760	3.6
JP-5	0.054	43,000	810	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	760	0.7
561 Silicon Transformer Fluid	0.005	28,100	960	100
Fuel Oil, Heavy	0.035	39,700	970	1.7
Crude Oil	0.0335	42,600	855	2.8
Lube Oil	0.039	46,000	760	0.7
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type
Diesel
Scroll to desired fuel type
Click on selection

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-25.*

$$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta\, D})\, A_{dike}$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
$DH_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)
kb = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$

Where
Adike = surface area of pool fire (m^2)
D = pool fire diamter (m)

$$D = \sqrt{(4A_{dike}/\pi)}$$

D = 0.357 m

Heat Release Rate Calculation

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

$$Q = m''\Delta H_{c,eff} (1-e^{-k\beta\, D})\, A_{dike}$$

Q = 105.36 kW 99.86 Btu/sec

ESTIMATING POOL FIRE BURNING DURATION

Reference: *SFPE Handbook of Fire Protection Engineering* , 2nd Edition, 1995, Page 3-197.

$$t_b = 4V / \pi D^2 \nu$$

Where
t_b = burning duration of pool fire (sec)
V = volume of liquid (m^3)
D = pool diameter (m)
ν = regression rate (m/sec)

Calculation for Regression Rate

$$\nu = m''/\rho$$

Where
ν = regression rate (m/sec)
m" = mass burning rate of fuel (kg/m^2-sec)
ρ = liquid fuel density (kg/m^3)

ν = 0.000049 m/sec

Burning Duration Calculation

$$t_b = 4V/\pi D^2 \nu$$

t_b = 2040.00 sec 34.00 minutes

Note that a liquid pool fire with a given amount of fuel can burn for long periods of time over small area or for short periods of time over a large area.

ESTIMATING POOL FIRE FLAME HEIGHT

METHOD OF HESKESTAD

Reference: *SFPE Handbook of Fire Protection Engineering* , 2nd Edition, 1995, Page 2-10.

$$H_f = 0.235\ Q^{2/5} - 1.02\ D$$

Where
H_f = pool fire flame height (m)
Q = pool fire heat release rate (kW)
D = pool fire diameter (m)

Pool Fire Flame Height Calculation

$H_f = 0.235\ Q^{2/5} - 1.02\ D$

H_f = 1.15 m 3.77 ft

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering* , 2nd Edition, 1995, Page 3-204.

$$H_f = 42\ D\ (m''/\rho_a \sqrt{(g\ D)})^{0.61}$$

Where
H_f = pool fire flame height (m)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ρ_a = ambient air density (kg/m^3)
D = pool fire diameter (m)
g = gravitational acceleration (m/sec^2)

Pool Fire Flame Height Calculation

$H_f = 42\ D\ (m''/(\rho_a \sqrt{(g\ D)}))^{0.61}$

H_f = 1.39 m 4.56 ft

Version 1805.1
(SI Units)

Summary of Results

Heat Release Rate Calculation

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

$$Q = m''\Delta H_{c,eff}\,(1-e^{-k\beta D})\,A_{dike}$$

Answer	Q=	105.36 kW	99.86 Btu/sec

Burning Duration Calculation

$$t_b = 4V/\pi D^2 \nu$$

Answer	t_b=	2040.00 sec	34.00 minutes

Flame Height Calculation

Method of Heskestad

$$H_f = 0.235\,Q^{2/5} - 1.02\,D$$

Method of Thomas

$$H_f = 42\,D\,(m''/(\rho_a\,\sqrt{(g\,D)}))^{0.61}$$

Answer		
	METHOD OF HESKESTAD	1.15 m
	METHOD OF THOMAS	1.39 m

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (m) (Heskestad)	H_f (m) (Thomas)
1	0.09	0.34	95.47	2195.84	1.10	1.36
2	0.19	0.49	237.56	1097.92	1.60	1.73
3	0.28	0.60	397.47	731.95	1.97	1.99
4	0.37	0.69	567.36	548.96	2.27	2.20
5	0.46	0.77	743.51	439.17	2.52	2.37
6	0.56	0.84	923.86	365.97	2.75	2.53
7	0.65	0.91	1107.11	313.69	2.95	2.67
8	0.74	0.97	1292.42	274.48	3.13	2.79
9	0.84	1.03	1479.22	243.98	3.30	2.91
10	0.93	1.09	1667.09	219.58	3.46	3.02
11	1.02	1.14	1855.75	199.62	3.61	3.12
12	1.11	1.19	2044.96	182.99	3.74	3.22
13	1.21	1.24	2234.57	168.91	3.87	3.31
14	1.30	1.29	2424.46	156.85	4.00	3.39
15	1.39	1.33	2614.53	146.39	4.11	3.47
20	1.86	1.54	3565.55	109.79	4.62	3.84
25	2.32	1.72	4515.13	87.83	5.05	4.15
50	4.65	2.43	9224.83	43.92	6.58	5.28
75	6.97	2.98	13894.78	29.28	7.63	6.08
100	9.29	3.44	18548.48	21.96	8.47	6.72

Caution! The purpose of this random spill size chart is to aid the user in evaluating the hazard of random sized spills. Please note that the calculation does not take into account the viscosity or volatility of the liquid, or the absorptivity of the surface. The results generated for small volume spills over large

NOTE:
The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

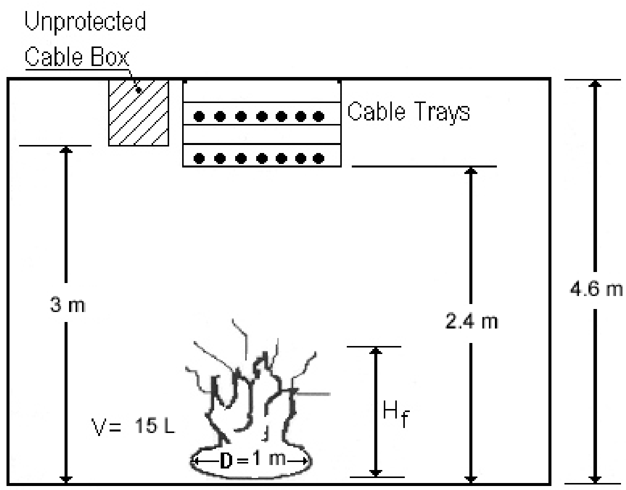
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 3.11-3

Problem Statement
In one NPP, it was important to determine whether a fire involving a 15 liter spill of lubricating oil from an auxiliary feedwater (AFW) pump could cause damage to an unprotected electrical cable pull box and cable trays. The unprotected pull box and cable trays were located 3.0 m and 2.4 m above the AFW pump, respectively. The pump room had a floor area of 6 m x 6 m and a ceiling height of 4.6 m with a vent opening of 1.5 m x 4.6 m. Compute the HRR, burning duration, and flame height of the poolfire with a diameter of 1 m. The lowest cable tray is located 2.4 m above the pool. Determine whether flame will impinge upon the cable tray or cable pull box. Assume instantaneous, complete involvement of the liquid pool with no fire growth and no intervention by the plant fire department or automatic suppression systems.



Example 3-3: Compartment with Pool Fire

Solution

Purpose:
(1) Determine the Heat Release Rate (HRR) of the fire source.
(2) Determine the burning duration of the pool fire.
(3) Determine the flame height of the pool fire.
(4) Determine whether the flame will impinge upon the cable tray or cable pull box.

Assumptions:
(1) Instantaneous and complete involvement of the liquid in the pool fire
(2) The pool fire is burning in the open
(3) No fire growth period (instantaneous HRR_{max})
(4) The pool is circular or nearly circular and contains a fixed mass of liquid volume
(5) The fire is located at the center of the compartment or away from the walls

Pre FDT^s Calculations:
The input parameters of the FDT^s assigned for this problem are the fuel spill volume, dike area and fuel material. As we can see, the problem statement does not give the dike area but the pool diameter is given. The dike area can be obtained from the formula of the area of a circle, since we assume that the pool has circular shape.

$$A_{dike} = \frac{\pi}{4} D^2 = \frac{\pi}{4}(1\ m)^2 = 0.8\ m^2$$

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 03_HRR_Flame_Height_Burning_Duration_Calculations_Sup1_SI.xls

FDT^s Inputs: (for both spreadsheets)
- Fuel Spill Volume (V) = 15 liters
- Fuel Spill Area or Dike Area (A_{dike}) = 0.8 m^2
- Select Fuel Type: **Lube Oil**

Results*

Heat Release Rate (HRR) ($\dot{Q}$) (kW)	Burning Duration (t_b) (min.)	Pool Fire Flame Height (H_f) (m)	
		Method of Heskestad	Method of Thomas
727	6.1	2.3	2.6

*see spreadsheet on next page

Both methods for pool fire flame height estimation show that pool fire flame will impinge upon the cable tray and cable pull box.

CHAPTER 3: ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE, HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT

Version 1805.1
(SI Units)

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.

Project / Inspection Title: **Example 3.11-3**

INPUT PARAMETERS

Fuel Spill Volume (V)	15.00	liters
Fuel Spill Area or Dike Area (A_{dike})	0.80	m^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Fuel Density (ρ)	760	kg/m^3
Empirical Constant ($k\beta$)	0.7	m^{-1}
Ambient Air Temperature (T_a)	25.00	°C
Gravitational Acceleration (g)	9.81	m/sec^2
Ambient Air Density (ρ_a)	1.18	kg/m^3

Calculate

Note: Air density will automatically correct with Ambient Air Temperature (T_a) Input

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Density ρ (kg/m^3)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	796	100
Ethanol	0.015	26,800	794	100
Butane	0.078	45,700	573	2.7
Benzene	0.085	40,100	874	2.7
Hexane	0.074	44,700	650	1.9
Heptane	0.101	44,600	675	1.1
Xylene	0.09	40,800	870	1.4
Acetone	0.041	25,800	791	1.9
Dioxane	0.018	26,200	1035	5.4
Diethy Ether	0.085	34,200	714	0.7
Benzine	0.048	44,700	740	3.6
Gasoline	0.055	43,700	740	2.1
Kerosine	0.039	43,200	820	3.5
Diesel	0.045	44,400	918	2.1
JP-4	0.051	43,500	760	3.6
JP-5	0.054	43,000	810	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	760	0.7
561 Silicon Transformer Fluid	0.005	28,100	960	100
Fuel Oil, Heavy	0.035	39,700	970	1.7
Crude Oil	0.0335	42,600	855	2.8
Lube Oil	0.039	46,000	760	0.7
User Specified Value	Enter Value	Enter Value	Enter Value	Enter Value

Select Fuel Type
Lube Oil
Scroll to desired fuel type
Click on selection

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-25.*

$$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_{dike}$$

Where

Q = pool fire heat release rate (kW)

m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)

$DH_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)

$A_f = A_{dike}$ = surface area of pool fire (area involved in vaporization) (m^2)

kb = empirical constant (m^{-1})

D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$

Where

Adike = surface area of pool fire (m^2)

D = pool fire diamter (m)

$$D = \sqrt{(4A_{dike}/\pi)}$$

D = 1.009 m

Heat Release Rate Calculation

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

$$Q = m''\Delta H_{c,eff} (1-e^{-k\beta D}) A_{dike}$$

Q = 727.10 kW 689.16 Btu/sec

ESTIMATING POOL FIRE BURNING DURATION

Reference: *SFPE Handbook of Fire Protection Engineering* , 2nd Edition, 1995, Page 3-197.

$$t_b = 4V / \pi D^2 \nu$$

Where
t_b = burning duration of pool fire (sec)
V = volume of liquid (m^3)
D = pool diameter (m)
ν = regression rate (m/sec)

Calculation for Regression Rate

$$\nu = m''/\rho$$

Where
ν = regression rate (m/sec)
m'' = mass burning rate of fuel (kg/m^2-sec)
ρ = liquid fuel density (kg/m^3)

ν = 0.000051 m/sec

Burning Duration Calculation

$$t_b = 4V/\pi D^2 \nu$$

t_b = 365.38 sec 6.09 minutes

Note that a liquid pool fire with a given amount of fuel can burn for long periods of time over small area or for short periods of time over a large area.

ESTIMATING POOL FIRE FLAME HEIGHT

METHOD OF HESKESTAD

Reference: *SFPE Handbook of Fire Protection Engineering* , 2nd Edition, 1995, Page 2-10.

$$H_f = 0.235\ Q^{2/5} - 1.02\ D$$

Where
H_f = pool fire flame height (m)
Q = pool fire heat release rate (kW)
D = pool fire diameter (m)

Pool Fire Flame Height Calculation

$H_f = 0.235\ Q^{2/5} - 1.02\ D$

H_f = 2.25 m 7.38 ft

METHOD OF THOMAS

Reference: *SFPE Handbook of Fire Protection Engineering* , 2nd Edition, 1995, Page 3-204.

$$H_f = 42\ D\ (m''/\rho_a\ \sqrt{(g\ D)})^{0.61}$$

Where
H_f = pool fire flame height (m)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ρ_a = ambient air density (kg/m^3)
D = pool fire diameter (m)
g = gravitational acceleration (m/sec^2)

Pool Fire Flame Height Calculation

$H_f = 42\ D\ (m''/(\rho_a\ \sqrt{(g\ D)}))^{0.61}$

H_f = 2.63 m 8.61 ft

Summary of Results

Heat Release Rate Calculation

(Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition)

$$Q = m''\Delta H_{c,eff}\,(1-e^{-k\beta\,D})\,A_{dike}$$

Answer	Q=	727.10 kW	689.16 Btu/sec

Burning Duration Calculation

$$t_b = 4V/\pi D^2 \nu$$

Answer	t_b=	365.38 sec	6.09 minutes

Flame Height Calculation

Method of Heskestad
$$H_f = 0.235\,Q^{2/5} - 1.02\,D$$

Method of Thomas
$$H_f = 42\,D\,(m''/(\rho_a\,\sqrt{(g\,D)}))^{0.61}$$

Answer		
	METHOD OF HESKESTAD	2.25 m
	METHOD OF THOMAS	2.63 m

ESTIMATING POOL FIRE RESULTS FOR RANDOM SIZE SPILLS USING INPUT PARAMETERS

Area (ft^2)	Area (m^2)	Diameter (m)	Q (kW)	t_b (sec)	H_f (m) (Heskestad)	H_f (m) (Thomas)
1	0.09	0.34	35.66	3146.37	0.63	1.24
2	0.19	0.49	96.19	1573.19	0.96	1.58
3	0.28	0.60	170.49	1048.79	1.23	1.82
4	0.37	0.69	254.77	786.59	1.45	2.01
5	0.46	0.77	346.90	629.27	1.65	2.17
6	0.56	0.84	445.52	524.40	1.84	2.32
7	0.65	0.91	549.63	449.48	2.00	2.44
8	0.74	0.97	658.49	393.30	2.16	2.56
9	0.84	1.03	771.52	349.60	2.31	2.67
10	0.93	1.09	888.26	314.64	2.44	2.77
11	1.02	1.14	1008.32	286.03	2.57	2.86
12	1.11	1.19	1131.38	262.20	2.70	2.95
13	1.21	1.24	1257.17	242.03	2.82	3.03
14	1.30	1.29	1385.45	224.74	2.93	3.11
15	1.39	1.33	1516.02	209.76	3.04	3.18
20	1.86	1.54	2197.59	157.32	3.53	3.52
25	2.32	1.72	2916.42	125.85	3.96	3.80
50	4.65	2.43	6814.63	62.93	5.54	4.84
75	6.97	2.98	10946.20	41.95	6.66	5.57
100	9.29	3.44	15166.14	31.46	7.54	6.16

Caution! The purpose of this random spill size chart is to aid the user in evaluating the hazard of random sized spills. Please note that the calculation does not take into account the viscosity or volatility of the liquid, or the absorptivity of the surface. The results generated for small volume spills over large

NOTE:
The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

4.9 Problems

Example Problem 4.9-1

Problem Statement
A pool fire scenario arises from a breach (leak or rupture) in an oil-filled transformer. This event allows the fuel contents of the transformer to spill 8 liters along a wall with an area of 0.8 m^2. A cable tray is located 2.4 m above the fire. Calculate the wall flame height of the fire and determine whether the flame will impinge upon the cable tray.

Solution

Purpose:
(1) Calculate the wall flame height.
(2) Determine whether the flame will impinge upon the cable tray.

Assumptions:
(1) Air is entrained only from one side during the combustion process.
(2) The fire is located at or near a wall configuration of a compartment that affects the spread of the fire.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 04_Flame_Height_Calculations_Sup1_SI.xls (click on *Wall_Flame_Height*)

FDT^s Input Parameters:
- Fuel spill volum e (V) = 8 liters
- Fuel Spill Area or Dike Area (A_{dike}) = 0.8 m^2
- Select Fuel Type: **Transformer Oil, Hydrocarbon**

Results*

Fuel	Wall Fire Flame Height ($H_{f(Wall)}$) (m)	Cable Tray Impingement
Transformer Oil, Hydrocarbon	3.0	Yes

*see spreadsheet on next page

CHAPTER 4
ESTIMATING WALL FIRE
FLAME HEIGHT

Version 1805.1
(SI Units)

The following calculations estimate the wall fire flame height.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 4.9-1**

INPUT PARAMETERS

Fuel Spill Volume (V)	8.00	liters
Fuel Spill Area or Dike Area (A_{dike})	0.80	m^2
Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Empirical Constant ($k\beta$)	0.7	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Acetone	0.041	25,800	1.9
Benzene	0.085	40,100	2.7
Benzene	0.048	44,700	3.6
Butane	0.078	45,700	2.7
Crude Oil	0.034	42,600	2.8
Diesel	0.045	44,400	2.1
Diethy Ether	0.085	34,200	0.7
Dioxane	0.018	26,200	5.4
Ethanol	0.015	26,800	100
Fuel Oil, Heavy	0.035	39,700	1.7
Gasoline	0.055	43,700	2.1
Heptane	0.101	44,600	1.1
Hexane	0.074	44,700	1.9
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Kerosene	0.039	43,200	3.5
Lube Oil	0.039	46,000	0.7
Methanol	0.017	20,000	100
Silicon Transformer Fluid (561)	0.005	28,100	100
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
Xylene	0.09	40,800	1.4
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.

Select Fuel Type

Transformer Oil, Hydrocarbon

Scroll to desired fuel type **then Click** on selection

Heat Release Rate Calculation

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-25.

$$Q = m''\Delta H_{c,eff}(1 - e^{-k\beta D})\, A_{dike}$$

Where,
Q = pool fire heat release rate (kW)
m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where,
A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.009 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff}(1 - e^{-k\beta D})\, A_{dike}$$

Q = 727.10 kW 689.16 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

Where,
Q' = heat release rate per unit length (kW/m)
Q = fire heat release rate of the fire (kW)
L = length of the fire source (m)

Fire Source Length Calculation

$$L \times W = A_{dike}$$

$L \times W =$ 0.800 m^2

$L =$ 0.894 m

Heat Release Rate Per Unit Length of Fire Calculation

$$Q' = Q/L$$

$Q' =$ 812.92 kW/m

ESTIMATING WALL FIRE FLAME HEIGHT

Reference: NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.

$$H_{f(wall)} = 0.034\ Q'^{\ 2/3}$$

Where,
$H_{f(wall)}$ = wall fire flame height (m)
Q' = rate of heat release per unit length of the fire (kW/m)

$$H_{f(wall)} = 0.034\ Q'^{\ 2/3}$$

Answer	$H_{f(wall)}$ =	**2.96 m**	**9.72 ft**

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and NFPA Fire Protection Handbook, 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Example Problem 4.9-2

Problem Statement
A pool fire scenario arises from a transient combustible liquid spill. This event allows the fuel contents of a 57 liter can to form along a wall with an area of 2.8 m^2. A cable tray is located 3.7 m above the fire. Determine the line wall fire flame height and whether the flame will impinge upon the cable tray if the spilled liquids are (a) diesel, (b) acetone, and (c) methanol.

Solution

Purpose:
(1) Calculate the line wall fire flame height using three transient combustibles.
(2) Determine whether the flame will impinge upon the cable tray in each case.

Assumptions:
(1) Air is entrained only from one side during the combustion process.
(2) The fire is located at or near a wall configuration of a compartment that affects the spread of the fire.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 04_Flame_Height_Calculations_Sup1_SI.xls (click on *Wall_Line_Flame_Height*)

FDT^s Input Parameters:
- Fuel spill volume (V) = 57 liters
- Fuel Spill Area or Dike Area (A_{dike}) = 2.8 m^2
- Select Fuel Type: **Diesel**, **Acetone**, and **Methanol**

Results*

Fuel	Wall Line Fire Height ($H_{f(Wall Line)}$) (m)	Cable Tray Impingement
Diesel	3.8	Yes
Acetone	2.4	No
Methanol	1.2	No

*See spreadsheets on next page

CHAPTER 4
ESTIMATING LINE FIRE
FLAME HEIGHT AGAINST THE WALL

Version 1805.1
(SI Units)

The following calculations estimate the line fire flame height against the wall.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 4.9-2a**

INPUT PARAMETERS

Fuel Spill Volume (V)	57.00	liters
Fuel Spill Area or Dike Area (A_{dike})	2.80	m^2
Mass Burning Rate of Fuel (m")	0.045	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	44400	kJ/kg
Empirical Constant (kβ)	2.1	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Acetone	0.041	25,800	1.9
Benzene	0.085	40,100	2.7
Benzene	0.048	44,700	3.6
Butane	0.078	45,700	2.7
Crude Oil	0.034	42,600	2.8
Diesel	0.045	44,400	2.1
Diethy Ether	0.085	34,200	0.7
Dioxane	0.018	26,200	5.4
Ethanol	0.015	26,800	100
Fuel Oil, Heavy	0.035	39,700	1.7
Gasoline	0.055	43,700	2.1
Heptane	0.101	44,600	1.1
Hexane	0.074	44,700	1.9
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Kerosene	0.039	43,200	3.5
Lube Oil	0.039	46,000	0.7
Methanol	0.017	20,000	100
Silicon Transformer Fluid (561)	0.005	28,100	100
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
Xylene	0.09	40,800	1.4
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.

Select Fuel Type

Diesel

Scroll to desired fuel type **then Click** on selection

Heat Release Rate Calculation

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-25.

$$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_{dike}$$

Where,
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where,
A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.888 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_{dike}$$

Q = 5488.30 kW 5201.92 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

Q' = Q/L

Where,
Q' = heat release rate per unit length (kW/m)
Q = fire heat release rate of the fire (kW)
L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

L x W = 2.800 m^2

L = 1.673 m

Heat Release Rate Per Unit Length of Fire Calculation

Q' = Q/L

Q' = 3279.88 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

Reference: NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.

$$H_{f(wall\ line)} = 0.017\ Q'^{\ 2/3}$$

Where,
$H_{f(wall\ line)}$ = wall fire flame height (m)
Q' = rate of heat release per unit length of the fire (kW/m)

$$H_{f(wall\ line)} = 0.017\ Q'^{\ 2/3}$$

Answer	$H_{f(wall\ line)}$ =	3.75 m	12.31 ft

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and NFPA Fire Protection Handbook, 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions, or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ____ Date: ____ Organization: ____

Checked by: ____ Date: ____ Organization: ____

Additional Information:

CHAPTER 4
ESTIMATING LINE FIRE FLAME HEIGHT AGAINST THE WALL

Version 1805.1
(SI Units)

The following calculations estimate the line fire flame height against the wall.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 4.9-2b**

INPUT PARAMETERS

Fuel Spill Volume (V)	57.00	liters
Fuel Spill Area or Dike Area (A_{dike})	2.80	m^2
Mass Burning Rate of Fuel (m")	0.041	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	25800	kJ/kg
Empirical Constant (kβ)	1.9	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Acetone	0.041	25,800	1.9
Benzene	0.085	40,100	2.7
Benzene	0.048	44,700	3.6
Butane	0.078	45,700	2.7
Crude Oil	0.034	42,600	2.8
Diesel	0.045	44,400	2.1
Diethy Ether	0.085	34,200	0.7
Dioxane	0.018	26,200	5.4
Ethanol	0.015	26,800	100
Fuel Oil, Heavy	0.035	39,700	1.7
Gasoline	0.055	43,700	2.1
Heptane	0.101	44,600	1.1
Hexane	0.074	44,700	1.9
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Kerosene	0.039	43,200	3.5
Lube Oil	0.039	46,000	0.7
Methanol	0.017	20,000	100
Silicon Transformer Fluid (561)	0.005	28,100	100
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
Xylene	0.09	40,800	1.4
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.

Select Fuel Type

Acetone

Scroll to desired fuel type **then Click** on selection

Heat Release Rate Calculation

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-25.

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\,D})\,A_{dike}$$

Where,
Q = pool fire heat release rate (kW)
m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where,
A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.888 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\,D})\,A_{dike}$$

Q = 2879.89 kW   2729.62 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

$Q' = Q/L$

Where,
Q' = heat release rate per unit length (kW/m)
Q = fire heat release rate of the fire (kW)
L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

$L \times W =$ 2.800 m^2

L = 1.673 m

Heat Release Rate Per Unit Length of Fire Calculation

$Q' = Q/L$

Q' = 1721.06 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

Reference: NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.

$$H_{f(wall\ line)} = 0.017\ Q'^{\ 2/3}$$

Where,
$H_{f(wall\ line)}$ = wall fire flame height (m)
Q' = rate of heat release per unit length of the fire (kW/m)

$$H_{f(wall\ line)} = 0.017\ Q'^{\ 2/3}$$

Answer	$H_{f(wall\ line)}$ =	**2.44 m**	**8.01 ft**

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and NFPA Fire Protection Handbook, 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions, or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ____________ Date: ________ Organization: ____________

Checked by: ____________ Date: ________ Organization: ____________

Additional Information:

CHAPTER 4
ESTIMATING LINE FIRE
FLAME HEIGHT AGAINST THE WALL

Version 1805.1
(SI Units)

The following calculations estimate the line fire flame height against the wall.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 4.9-2c**

INPUT PARAMETERS

Fuel Spill Volume (V)	57.00	liters
Fuel Spill Area or Dike Area (A_{dike})	2.80	m^2
Mass Burning Rate of Fuel (m")	0.017	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	20000	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Acetone	0.041	25,800	1.9
Benzene	0.085	40,100	2.7
Benzene	0.048	44,700	3.6
Butane	0.078	45,700	2.7
Crude Oil	0.034	42,600	2.8
Diesel	0.045	44,400	2.1
Diethy Ether	0.085	34,200	0.7
Dioxane	0.018	26,200	5.4
Ethanol	0.015	26,800	100
Fuel Oil, Heavy	0.035	39,700	1.7
Gasoline	0.055	43,700	2.1
Heptane	0.101	44,600	1.1
Hexane	0.074	44,700	1.9
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Kerosene	0.039	43,200	3.5
Lube Oil	0.039	46,000	0.7
Methanol	0.017	20,000	100
Silicon Transformer Fluid (561)	0.005	28,100	100
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
Xylene	0.09	40,800	1.4
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.

Select Fuel Type

Methanol

Scroll to desired fuel type **then**
Click on selection

Heat Release Rate Calculation

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-25.

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\, D})\, A_{dike}$$

Where,

Q = pool fire heat release rate (kW)
m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where,

A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.888 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\, D})\, A_{dike}$$

Q = 952.00 kW 902.32 Btu/sec

Heat Release Rate Per Unit Length of Fire Calculation

Q' = Q/L

Where,
Q' = heat release rate per unit length (kW/m)
Q = fire heat release rate of the fire (kW)
L = length of the fire source (m)

Fire Source Length Calculation

$L \times W = A_{dike}$

$L \times W =$ 2.800 m^2

L = 1.673 m

Heat Release Rate Per Unit Length of Fire Calculation

Q' = Q/L

Q' = 568.93 kW/m

ESTIMATING LINE WALL FIRE FLAME HEIGHT

Reference: NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-134.

$$H_{f(wall\ line)} = 0.017\ Q'^{\,2/3}$$

Where,
$H_{f(wall\ line)}$ = wall fire flame height (m)
Q' = rate of heat release per unit length of the fire (kW/m)

$$H_{f(wall\ line)} = 0.017\ Q'^{\,2/3}$$

Answer	$H_{f(wall\ line)}$ =	1.17 m	3.83 ft

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and NFPA Fire Protection Handbook, 19th Edition, 2003. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions, or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Example Problem 4.9-3

Problem Statement
A pool fire scenario arises from a rupture in a diesel generator fuel line. This event allows diesel fuel to spill 5.7 liters along the corner of walls with an area of 0.9 m^2. An unprotected junction box is located 3.7 m above the fire. Determine whether the flame will impinge upon the junction box.

Solution

Purpose:
(1) Calculate the line wall fire flame height.
(2) Determine whether the flame will impinge upon the junction box.

Assumptions:
(1) Air is entrained only from one side during the combustion process.
(2) The fire is located at or near a wall configuration of a compartment that affects the spread of the fire.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 04_Flame_Height_Calculations_Sup1_SI.xls (click on *Corner_Flame_Height*)

FDTs Input Parameters:
- Fuel spill volume (V) = 5.7 liters
- Fuel Spill Area or Dike Area (A_{dike}) = 0.9 m^2
- Select Fuel Type: **Diesel**

Results*

Fuel	Corner Fire Flame Height ($H_{f(Corner)}$) (m)	Junction Box Impingement
Diesel	6.3	Yes

*see spreadsheet on next page

CHAPTER 4
ESTIMATING CORNER FIRE FLAME HEIGHT

Version 1805.1
(SI Units)

The following calculations estimate the corner fire flame height.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 4.9-3**

INPUT PARAMETERS

Fuel Spill Volume (V)	5.70	liters
Fuel Spill Area or Dike Area (A_{dike})	0.90	m^2
Mass Burning Rate of Fuel (m")	0.045	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	44400	kJ/kg
Empirical Constant (kβ)	2.1	m^{-1}

Calculate

THERMAL PROPERTIES FOR

BURNING RATE DATA FOR LIQUID HYDROCARBON FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Acetone	0.041	25,800	1.9
Benzene	0.085	40,100	2.7
Benzene	0.048	44,700	3.6
Butane	0.078	45,700	2.7
Crude Oil	0.034	42,600	2.8
Diesel	0.045	44,400	2.1
Diethy Ether	0.085	34,200	0.7
Dioxane	0.018	26,200	5.4
Ethanol	0.015	26,800	100
Fuel Oil, Heavy	0.035	39,700	1.7
Gasoline	0.055	43,700	2.1
Heptane	0.101	44,600	1.1
Hexane	0.074	44,700	1.9
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Kerosene	0.039	43,200	3.5
Lube Oil	0.039	46,000	0.7
Methanol	0.017	20,000	100
Silicon Transformer Fluid (561)	0.005	28,100	100
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
Xylene	0.09	40,800	1.4
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, Page 3-26.

Select Fuel Type

Diesel

Scroll to desired fuel type **then Click** on selection

Heat Release Rate Calculation

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-25.

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta D})\,A_{dike}$$

Where,
Q = pool fire heat release rate (kW)
m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
$\Delta H_{c,eff}$ = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

NOTE: Liquids with relatively high flash point, like transformer oil, require localized heating to achieve ignition.

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where,
A_{dike} = surface area of pool fire (m^2)
D = pool fire diameter (m)

D = 1.070 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta D})\,A_{dike}$$

Q = 1608.29 kW 1524.37 Btu/sec

ESTIMATING CORNER FIRE FLAME HEIGHT

Reference: Hesemi and Tokunaga, "Modeling of Turbulent Diffusion Flames and Fire Plumes for the Analysis of Fire Growth," Proceeding of the 21th National Heat Transfer Conference, American Society of Mechanical Engineers (ASME), 1983.

$$H_{f(corner)} = 0.075\ Q^{3/5}$$

Where,
Q = heat release rate of the fire (kW)

$$H_{f(corner)} = 0.075\ Q^{3/5}$$

Answer	$H_{f(corner)}$ =	6.29 m	20.65 ft

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, and Hesemi and Tokunage, 1983. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

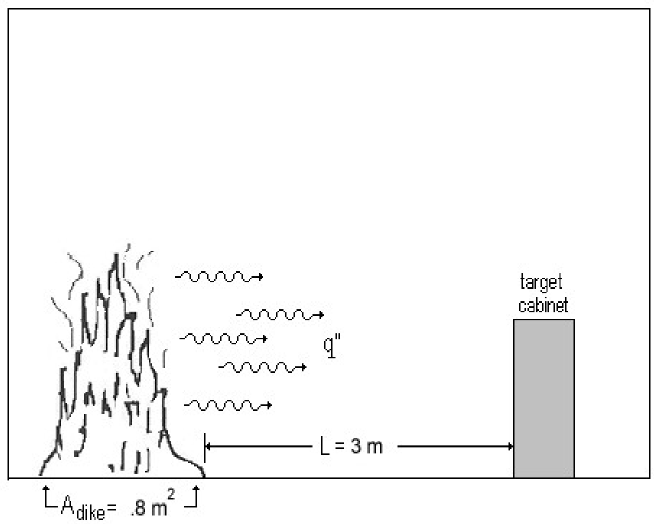
Checked by: Date: Organization:

Additional Information:

5.11 Problems

Example Problem 5.11-1

Problem Statement
A pool fire scenario arises from a breach (leak or rupture) in a transformer. This event allows the fuel contents of the transformer to spill and spread over the compartment floor. The compartment is very large and has a high ceiling (e.g., typical reactor building elevation of a BWR, turbine building open area). A pool fire ensues with a spill area of 0.8 m^2 on the concrete floor. Calculate the flame radiant heat flux to a target (cabinet) at ground level with no wind using: a) point source radiation model and b) solid flame radiation model. The distance between the fire source and the target edge is assumed to be 3.0 m.



Example Problem 5-1: Radiant Heat Flux from a Pool Fire to a Target Fuel

Solution

Purpose:
(1) Calculate the radiant heat flux from the pool fire to the target cabinet using the point source and solid flame radiation models.

Assumptions:
(1) The pool is circular or nearly circular.
(2) Radiation to the surroundings can be approximated as being isotropic or emanating from a point source (valid for point source radiation model only).
(3) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1_SI.xls
(click on *Point Source* and *Solid Flame 1* for point source and solid flame analysis, respectively)

FDT^s Input Parameters: (For both spreadsheets)
- Fuel Spill Area or Curb Area (A_{curb}) = 0.8 m^2
- Distance between Fire Source and Target (L) = 3.0 m
- Select Fuel Type: **Transformer Oil, Hydrocarbon**

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)
Point Source	1.4
Solid Flame	3.0

* see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS POINT SOURCE RADIATION MODEL

Version 1805.1 (SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-1a**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Empirical Constant ($k\beta$)	0.7	m^{-1}
Heat Release Rate (Q)	727.10	kW
Fuel Area or Dike Area (A_{dike})	0.80	m^2
Distance between Fire and Target (L)	3.00	m
Radiative Fraction (χ_r)	0.30	

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ____ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type
Transformer Oil, Hydrocarbon
Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-272.*

POINT SOURCE RADIATION MODEL

$$q'' = Q \chi_r / 4 \pi R^2$$

Where
q" = incident radiative heat flux on the target (kW/m^2)
Q = pool fire heat release rate (kW)
χr = radiative fraction
R = distance from center of the pool fire to edge of the target (m)

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where
A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.01 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_f$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A_f = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 727.1 kW

Distance from Center of the Fire to Edge of the Target Calculation

$$R = L+D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = 3.50 m

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
POINT SOURCE RADIATION MODEL

Version 1805.1
(SI Units)

RADIATIVE HEAT FLUX CALCULATION

$$q'' = Q \chi_r / 4 \pi R^2$$

Answer	q'' =	1.41	kW/m^2	0.12	Btu/ft^2-sec

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-1b**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Empirical Constant (kβ)	0.7	m^{-1}
Heat Release Rate (Q)	727.10	kW
Fuel Area or Dike Area (A_{dike})	0.80	m^2
Distance between Fire and Target (L)	3.00	m

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Constant kβ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type

Transformer Oil, Hydrocarbon

Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\to 2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\to 2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$

$$D = \sqrt{(4A_{dike}/\pi)}$$

Where
A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.01 m

Emissive Power Calculation

$$E = 58\ (10^{-0.00823\ D})$$

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.90 kW/m^2

View Factor Calculation

$$F_{1\to 2,H} = (B-1/S)/\pi(B^2-1)^{1/2} \tan^{-1} ((B+1)(S-1)/(B-1)(S+1))^{1/2} - (A-1/S)/(\pi(A^2-1)^{1/2}) \tan^{-1} ((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$F_{1\to 2,V} = 1/(\pi S) \tan^{-1}(h/(S^2-1)^{1/2}) - (h/\pi S) \tan^{-1} ((S-1)/(S+1))^{1/2} + Ah/\pi S(A^2-1)^{1/2} \tan^{-1} ((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$A = (h^2+S^2+1)/2S$$

$$B = (1+S^2)/2S$$

$$S = 2R/D$$

$$h = 2H_f/D$$

$$F_{1\to 2,max} = \sqrt{(F^2_{1\to 2,H} + F^2_{1\to 2,V})}$$

Where
$F_{1\to 2,H}$ = horizontal view factor
$F_{1\to 2,V}$ = vertical view factor
$F_{1\to 2,max}$ = maximum view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

Distance from Center of the Pool Fire to Edge of the Target Calculation

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 3.505 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\,D})\,A_{dike}$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 727.10 kW

Pool Fire Flame Height Calculation

$$H_f = 0.235\,Q^{2/5} - 1.02\,D$$

Where
Hf = flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

H_f = 2.249 m

$S = 2R/D =$	6.945
$h = 2H_f/D =$	4.457
$A = (h^2+S^2+1)/2S =$	4.975
$B = (1+S^2)/2S =$	3.544
$F_{1\to 2,H} =$	0.016
$F_{1\to 2,V} =$	0.051
$F_{1\to 2,\,max} = \sqrt{(F^2_{1\to 2,H} + F^2_{1\to 2,V})} =$	0.053

F_{H1}	F_{H2}	F_{H3}	F_{H4}	$F_{1\to 2,H}$
0.318	0.858	0.316	0.815	0.016

F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\to 2,V}$
0.026	0.146	0.209	0.815	0.051

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

RADIATIVE HEAT FLUX CALCULATION

$q'' = EF_{1\text{->}2}$

Answer	q'' =	3.02 kW/m^2	0.27 Btu/ft^2-sec

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

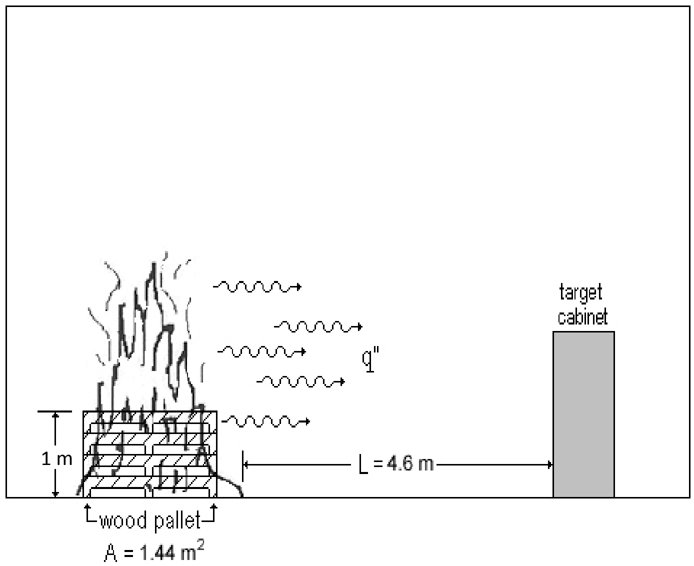
Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 5.11-2

Problem Statement
A transient combustible fire scenario may arise from burning wood pallets 1.2 m x 1.2 m = 1.44 m^2, stacked 1 m high on the floor of a compartment with a very high ceiling. Calculate the flame radiant heat flux to a target (safety-related cabinet) at ground level with no wind, using the point source radiation model and the solid flame radiation model. The distance between the fire source and the target edge (L) is assumed to be 4.6 m.



Example Problem 5-2: Radiant Heat Flux from a Burning Pallet to a Target Fuel

Solution

Purpose:
(1) Calculate the radiant heat flux from the fire source to the target cabinet using the point source and solid flame radiation models.

Assumptions:
(1) The fire source will be nearly circular.
(2) Radiation to the surroundings can be approximated as being isotropic or emanating from a point source (valid for point source radiation model only).
(3) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1_SI.xls
(click on *Point Source* and *Solid Flame 1* for point source and solid flame analysis respectively)

FDT^s Inputs: (For both spreadsheets)
-Fuel Spill Area or Curb Area (A_{curb}) = 1.44 m^2
-Distance between Fire Source and Target (L) = 4.6 m
-Select Fuel Type: **Douglas Fir Plywood**

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)
Point Source	0.15
Solid Flame	0.44

* see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS POINT SOURCE RADIATION MODEL

Version 1805.1 (SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-2a**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.01082	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	10900	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}
Heat Release Rate (Q)	169.83	kW
Fuel Area or Dike Area (A_{dike})	1.44	m^2
Distance between Fire and Target (L)	4.60	m
Radiative Fraction (χ_r)	0.30	

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type
Douglas Fir Plywood
Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-272.*

POINT SOURCE RADIATION MODEL

$$q'' = Q \chi_r / 4 \pi R^2$$

Where
q" = incident radiative heat flux on the target (kW/m^2)
Q = pool fire heat release rate (kW)
χr = radiative fraction
R = distance from center of the pool fire to edge of the target (m)

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where
A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.35 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_f$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A_f = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 169.8 kW

Distance from Center of the Fire to Edge of the Target Calculation

$$R = L+D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = 5.28 m

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
POINT SOURCE RADIATION MODEL

Version 1805.1
(SI Units)

RADIATIVE HEAT FLUX CALCULATION

$$q'' = Q\,\chi_r / 4\,\pi\,R^2$$

Answer	$q'' =$	0.15	kW/m^2	0.01	Btu/ft^2-sec

NOTE:
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Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-2b**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.01082	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	10900	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}
Heat Release Rate (Q)	169.83	kW
Fuel Area or Dike Area (A_{dike})	1.44	m^2
Distance between Fire and Target (L)	4.60	m

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type
Douglas Fir Plywood
Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\to2}$$

Where
q" = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\to2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$

$$D = \sqrt{(4A_{dike}/\pi)}$$

Where
A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.35 m

Emissive Power Calculation

$$E = 58\ (10^{-0.00823\ D})$$

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.53 kW/m^2

View Factor Calculation

$$F_{1\to2,H} = (B-1/S)/\pi(B^2-1)^{1/2}\ \tan^{-1}((B+1)(S-1)/(B-1)(S+1))^{1/2} - (A-1/S)/(\pi(A^2-1)^{1/2})\ \tan^{-1}((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$F_{1\to2,V} = 1/(\pi S)\ \tan^{-1}(h/(S^2-1)^{1/2}) - (h/\pi S)\ \tan^{-1}((S-1)/(S+1))^{1/2} + Ah/\pi S(A^2-1)^{1/2}\ \tan^{-1}((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$A = (h^2+S^2+1)/2S$$

$$B = (1+S^2)/2S$$

$$S = 2R/D$$

$$h = 2H_f/D$$

$$F_{1\to2,max} = \sqrt{(F^2_{1\to2,H} + F^2_{1\to2,V})}$$

Where
$F_{1\to2,H}$ = horizontal view factor
$F_{1\to2,V}$ = vertical view factor
$F_{1\to2,max}$ = maximum view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1 (SI Units)

Distance from Center of the Pool Fire to Edge of the Target Calculation

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 5.277 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\, D})\, A_{dike}$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 169.83 kW

Pool Fire Flame Height Calculation

$$H_f = 0.235\, Q^{2/5} - 1.02\, D$$

Where
Hf = flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

H_f = 0.451 m

S = 2R/D =	7.794
$h = 2H_f/D$ =	0.667
$A = (h^2+S^2+1)/2S$ =	3.990
$B = (1+S^2)/2S$ =	3.961
$F_{1\text{->}2,H}$ =	0.000
$F_{1\text{->}2,V}$ =	0.008
$F_{1\text{->}2,\,max} = \sqrt{(F^2_{1\text{->}2,H} + F^2_{1\text{->}2,V})}$ =	0.008

F_{H1}	F_{H2}	F_{H3}	F_{H4}	$F_{1\text{->}2,H}$
0.318	0.850	0.318	0.849	0.000

F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V}$
0.004	0.020	0.028	0.849	0.008

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

RADIATIVE HEAT FLUX CALCULATION

$$q'' = EF_{1->2}$$

Answer	q" =	0.44 kW/m^2	0.04 Btu/ft^2-sec

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

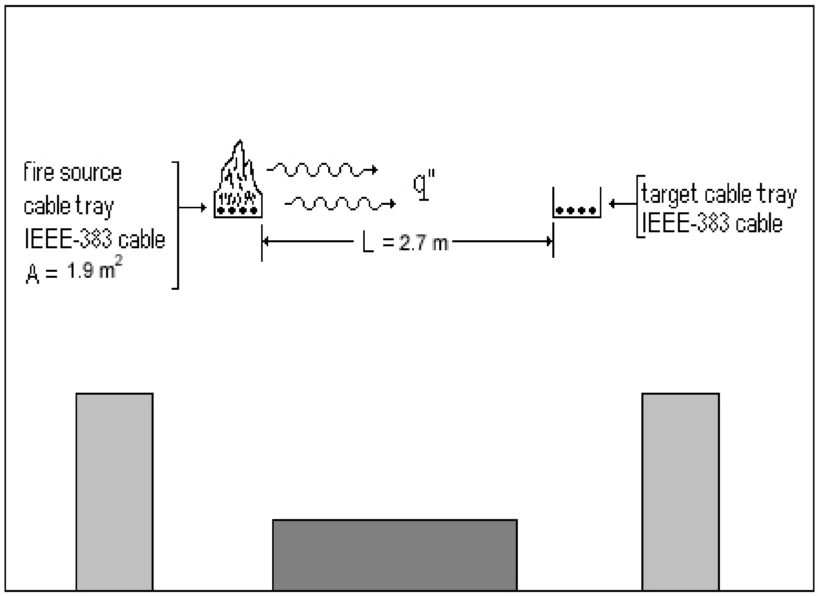
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 5.11-3

Problem Statement
A fire scenario may arise from a horizontal cable tray burning in a very large compartment. The cables in the tray are IEEE-383 unqualified and made of PE/PVC insulation material (assume that the exposed area of the cable is 1.9 m^2). Another safety-related cable tray also filled with IEEE-383 unqualified made of PE/PVC insulation material is located at a radial distance (L) of 2.7 m from the fire source. Calculate the flame radiant heat flux to a target (safety-related cable tray) using the point source radiation model and solid flame radiation model. Is this heat flux sufficient to ignite the cable tray?



Example Problem 5-3: Radiant Heat Flux from a Burning Cable Tray to a Target Fuel

Solution

Purpose:
(1) Calculate the radiant heat flux from the burning cable tray to the target cable tray using the point source and solid flame radiation models.
(2) Determine if the heat flux is sufficient to ignite the cable tray.

Assumptions:
(1) The fire source will be nearly circular.
(2) Radiation to the surroundings can be approximated as being isotropic or emanating from a point source (point source radiation model only).
(3) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1_SI.xls
(click on *Point Source* and *Solid Flame 1* for point source and solid flame analysis, respectively).

FDT^s Inputs: (For both spreadsheets)

- Mass Burning Rate of Fuel ($\dot{m}''$) = 0.0044 kg/m^2-sec
- Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$) = 25,100 kJ/kg
- Empirical Constant (kβ) = 100 m^{-1} (use this if actual value is unknown)
- Fuel Spill Area or Curb Area (A_{curb}) = 1.9 m^2
- Distance between Fire Source and Target (L) = 2.7 m

Note: Since the insulation material (PE /PVC) is not available in the thermal properties data of the spreadsheet, we have to input the mass burning rate and effective heat of combustion in the spreadsheet. Values of cable materials properties are available in Table 3-4. Select **User-Specified Value**, and enter the respective values.

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)
Point Source	0.4
Solid Flame	1.1

* see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS POINT SOURCE RADIATION MODEL

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-3a**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.0044	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	25100	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}
Heat Release Rate (Q)	209.84	kW
Fuel Area or Dike Area (A_{dike})	1.90	m^2
Distance between Fire and Target (L)	2.70	m
Radiative Fraction (χ_r)	0.30	

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type
User Specified Value
Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-272.*

POINT SOURCE RADIATION MODEL

$$q'' = Q \chi_r / 4 \pi R^2$$

Where
q" = incident radiative heat flux on the target (kW/m^2)
Q = pool fire heat release rate (kW)
χr = radiative fraction
R = distance from center of the pool fire to edge of the target (m)

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where
A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.56 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_f$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A_f = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 209.8 kW

Distance from Center of the Fire to Edge of the Target Calculation

$$R = L+D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = 3.48 m

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
POINT SOURCE RADIATION MODEL

Version 1805.1
(SI Units)

RADIATIVE HEAT FLUX CALCULATION

$$q'' = Q\,\chi_r / 4\,\pi\,R^2$$

Answer	q'' =	0.41	kW/m^2	0.04	Btu/ft^2-sec

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ________ Date: ________ Organization: ________

Checked by: ________ Date: ________ Organization: ________

Additional Information:

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-3b**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.0044	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	25100	kJ/kg
Empirical Constant ($k\beta$)	100	m^{-1}
Heat Release Rate (Q)	209.84	kW
Fuel Area or Dike Area (A_{dike})	1.90	m^2
Distance between Fire and Target (L)	2.70	m

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type

User Specified Value

Scroll to desired fuel type then Click on selection

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\text{->}2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\text{->}2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$

$$D = \sqrt{(4A_{dike}/\pi)}$$

Where
A_{dike} = surface area of pool fire (m^2)
D = pool fire diamter (m)

D = 1.56 m

Emissive Power Calculation

$$E = 58\ (10^{-0.00823\ D})$$

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.32 kW/m^2

View Factor Calculation

$$F_{1\text{->}2,H} = (B-1/S)/\pi(B^2-1)^{1/2}\tan^{-1}((B+1)(S-1)/(B-1)(S+1))^{1/2}-(A-1/S)/(\pi(A^2-1)^{1/2})\tan^{-1}((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$F_{1\text{->}2,V} = 1/(\pi S)\tan^{-1}(h/(S^2-1)^{1/2})-(h/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2} + Ah/\pi S(A^2-1)^{1/2}\tan^{-1}((A+1)(S-1)/(A-1)(S+1))^{1/2}$$

$$A = (h^2+S^2+1)/2S$$

$$B = (1+S^2)/2S$$

$$S = 2R/D$$

$$h = 2H_f/D$$

$$F_{1\text{->}2,max} = \sqrt{(F^2_{1\text{->}2,H} + F^2_{1\text{->}2,V})}$$

Where
$F_{1\text{->}2,H}$ = horizontal view factor
$F_{1\text{->}2,V}$ = vertical view factor
$F_{1\text{->}2,max}$ = maximum view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

Distance from Center of the Pool Fire to Edge of the Target Calculation

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 3.478 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff} (1 - e^{-k\beta D}) A_{dike}$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 209.84 kW

Pool Fire Flame Height Calculation

$$H_f = 0.235\, Q^{2/5} - 1.02\, D$$

Where
Hf = flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

H_f = 0.408 m

$S = 2R/D =$	4.472
$h = 2H_f/D =$	0.525
$A = (h^2+S^2+1)/2S =$	2.379
$B = (1+S^2)/2S =$	2.348
$F_{1\text{->}2,H} =$	0.001
$F_{1\text{->}2,V} =$	0.020
$F_{1\text{->}2,\,max} = \sqrt{(F^2_{1\text{->}2,H} + F^2_{1\text{->}2,V})} =$	0.020

F_{H1}	F_{H2}	F_{H3}	F_{H4}	$F_{1\text{->}2,H}$
0.318	0.898	0.318	0.895	0.001
F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V}$
0.009	0.025	0.041	0.895	0.020

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

RADIATIVE HEAT FLUX CALCULATION

$q'' = EF_{1->2}$

Answer	q'' =	1.14	kW/m^2	0.10	Btu/ft^2-sec

NOTE:
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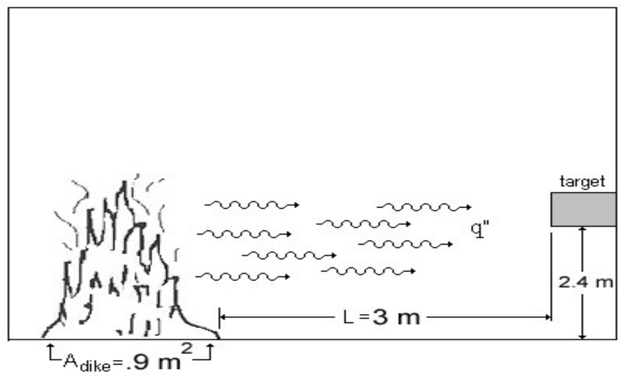
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 5.11-4

Problem Statement
A pool fire scenario may arise from a leak in a pump. This event allows the lubricating oil to spill and spread over the compartment floor. A pool fire ensues with a spill of 0.9 m^2 in a compartment with a concrete floor. The distance (L) between the pool fire and the target edge is assumed to be 3 m. Calculate the flame radiant heat flux to a vertical target (safety-related) 2.4 m high above the floor with no wind, using the solid flame radiation model. If the vertical target contains IEEE-383 unqualified cables ($\dot{q}''_{critical} = 5 \text{ kW/m}^2$), could there be cable failure in this fire scenario?



Example Problem 5-4: Radiant Heat Flux from a Pool Fire to a Vertical Target Fuel

Solution

Purpose:
(1) Calculate the radiant heat flux from the pool fire to the vertical target using the solid flame radiation model.
(2) Determine if the IEEE-383 unqualified cables are damaged.

Assumptions:
(1) The fire source will be nearly circular.
(2) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1_SI.xls (click on *Solid Flame 2*)

FDT^s Inputs:
- Fuel Spill Area or Curb Area (A_{curb}) = 0.9 m^2
- Distance between Fire Source and Target (L) = 3 m
- Vertical Distance of Target from Ground ($H_1 = H_{f1}$) = 2.4 m
- Select Fuel Type: **Lube Oil**

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}''$) (kW/m^2)	Cable Failure
Solid Flame	3.1	No, $\dot{q}''_r < \dot{q}''_{critical}$

* see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-4**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.039	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	46000	kJ/kg
Empirical Constant ($k\beta$)	0.7	m^{-1}
Heat Release Rate (Q)	851.41	kW
Fuel Area or Dike Area (A_{dike})	0.90	m^2
Distance between Fire and Target (L)	3.00	m
Vertical Distance of Target from Ground ($H_t = H_{f1}$)	2.40	m

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant $k\beta$ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type
Lube Oil
Scroll to desired fuel type then Click on selection

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\to 2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\to 2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where
A_{dike} = surface area of pool fire (m^2)
D = pool fire diameter (m)

D = 1.07 m

Emissive Power Calculation

$$E = 58\ (10^{-0.00823\ D})$$

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.84 (kW/m^2)

View Factor Calculation

$F_{1\to 2,V1}$ = $1/(\pi S)\tan^{-1}(h_1/(S^2-1)^{1/2})-(h_1/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_1h_1/\pi S(A_1^2-1)^{1/2}\tan^{-1}((A_1+1)(S-1)/(A_1-1)(S+1))^{1/2}$
$F_{1\to 2,V2}$ = $1/(\pi S)\tan^{-1}(h_2/(S^2-1)^{1/2})-(h_2/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_2h_2/\pi S(A_2^2-1)^{1/2}\tan^{-1}((A_2+1)(S-1)/(A_2-1)(S+1))^{1/2}$
A_1 = $(h_1^2+S^2+1)/2S$
A_2 = $(h_2^2+S^2+1)/2S$
B = $(1+S^2)/2S$
S = $2R/D$
h_1 = $2H_{f1}/D$
h_2 = $2H_{f2}/D$
$F_{1\to 2,V}$ = $F_{1\to 2,V1} + F_{1\to 2,V2}$

Where
$F_{1\to 2,V}$ = total vertical view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

Distance from Center of the Pool Fire to Edge of the Target Calculation

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 3.535 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\ D})\ A_{dike}$$

Where
Q = pool fire heat release rate (kW)
m'' = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 851.41 kW

Pool Fire Flame Height Calculation

$$H_f = 0.235\ Q^{2/5} - 1.02\ D$$

Where
H_f = flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

H_f = 2.401 m

$S = 2R/D =$		6.605
$h_1 = 2H_{f1}/D =$		4.484
$h_2 = 2H_{f2}/D =$	$2(H_f-H_{f1})/D =$	0.001
$A_1 = (h_1^2+S^2+1)/2S =$		4.900
$A_2 = (h_2^2+S^2+1)/2S =$		3.378
$B = (1+S^2)/2S =$		3.378

		F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V1}$
$F_{1\text{->}2,V1} =$	0.055	0.029	0.153	0.221	0.813	0.055
		F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\text{->}2,V2}$
$F_{1\text{->}2,V2} =$	0.000					
$F_{1\text{->}2,V} = F_{1\text{->}2,V1} + F_{1\text{->}2,V2} =$	0.055	0.000	0.000	0.000	0.861	0.000

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

RADIATIVE HEAT FLUX CALCULATION

$q'' = EF_{1->2}$

Answer	q" =	3.13	kW/m^2	0.28	Btu/ft^2-sec

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accurac of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

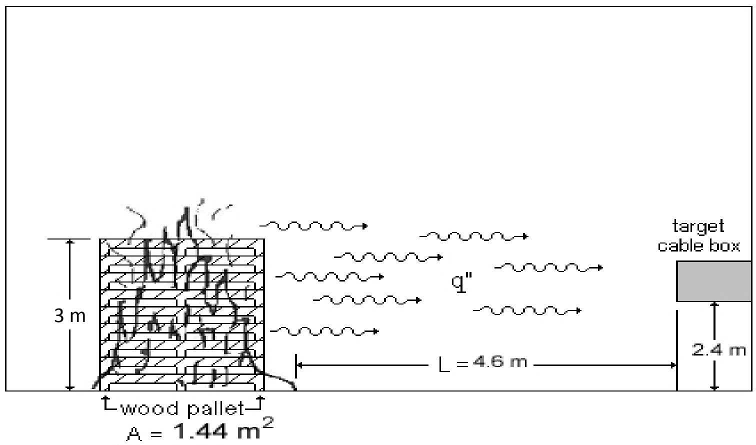
Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 5.11-5

Problem Statement
A transient combustible fire scenario may arise from burning wood pallets 1.2 m x 1.2 m = 1.44 m^2 stacked 3 m high on the floor of a compartment. Calculate the flame radiant heat flux from exposure fire to a vertical target (safety-related electrical junction box) located 2.4 m high above the floor, with no wind, using the solid flame radiation model. The distance (L) between the transient fire and the target edge is assumed to be 4.6 m.



Example Problem 5-5: Radiant Heat Flux from a Burning Pallet to a Vertical Target Fuel

Solution

Purpose:
(1) Calculate the radiant heat flux from the burning pallet to the vertical target fuel using the solid flame radiation model.

Assumptions:
(1) The fire source will be nearly circular.
(2) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1_SI.xls (click on *Solid Flame 2*)

FDT^s Inputs:
- Fuel Spill Area or Curb Area (A_{curb}) = 1.44 m^2
- Distance between Fire Source and Target (L) = 4.6 m
- Vertical Distance of Target from Ground ($H_1 = H_{f1}$) = 2.4 m
- Select Fuel Type: **Douglas Fir Plywood**

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}$") (kW/m^2)
Solid Flame	0.30

* see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-5**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.01082	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	10900	kJ/kg
Empirical Constant (kβ)	100	m^{-1}
Heat Release Rate (Q)	169.83	kW
Fuel Area or Dike Area (A_{dike})	1.44	m^2
Distance between Fire and Target (L)	4.60	m
Vertical Distance of Target from Ground ($H_t = H_{f1}$)	2.40	m

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type
Douglas Fir Plywood
Scroll to desired fuel type then Click on selection

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
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SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\to 2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\to 2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$
$$D = \sqrt{(4A_{dike}/\pi)}$$

Where
A_{dike} = surface area of pool fire (m^2)
D = pool fire diameter (m)

D = 1.35 m

Emissive Power Calculation

$$E = 58\,(10^{-0.00823\,D})$$

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.53 (kW/m^2)

View Factor Calculation

$F_{1\to 2,V1}$ = $1/(\pi S)\tan^{-1}(h_1/(S^2-1)^{1/2})-(h_1/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_1h_1/\pi S(A_1^2-1)^{1/2}\tan^{-1}((A_1+1)(S-1)/(A_1-1)(S+1))^{1/2}$
$F_{1\to 2,V2}$ = $1/(\pi S)\tan^{-1}(h_2/(S^2-1)^{1/2})-(h_2/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_2h_2/\pi S(A_2^2-1)^{1/2}\tan^{-1}((A_2+1)(S-1)/(A_2-1)(S+1))^{1/2}$
A_1 = $(h_1^2+S^2+1)/2S$
A_2 = $(h_2^2+S^2+1)/2S$
B = $(1+S^2)/2S$
S = $2R/D$
h_1 = $2H_{f1}/D$
h_2 = $2H_{f2}/D$
$F_{1\to 2,V}$ = $F_{1\to 2,V1} + F_{1\to 2,V2}$

Where
$F_{1\to 2,V}$ = total vertical view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

Distance from Center of the Pool Fire to Edge of the Target Calculation

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 5.277 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\,D})\,A_{dike}$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 169.83 kW

Pool Fire Flame Height Calculation

$$H_f = 0.235\,Q^{2/5} - 1.02\,D$$

Where
H_f = flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

H_f = 0.451 m

$S = 2R/D =$		7.794
$h_1 = 2H_{f1}/D =$		3.545
$h_2 = 2H_{f2}/D =$	$2(H_f - H_{f1})/D =$	-2.878
$A_1 = (h_1^2+S^2+1)/2S =$		4.767
$A_2 = (h_2^2+S^2+1)/2S =$		4.493
$B = (1+S^2)/2S =$		3.961

		F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\to 2,V1}$
$F_{1\to 2,V1} =$	0.036	0.018	0.104	0.148	0.827	0.036
		F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\to 2,V2}$
$F_{1\to 2,V2} =$	-0.030					
$F_{1\to 2,V} = F_{1\to 2,V1} + F_{1\to 2,V2} =$	0.005	-0.015	-0.085	-0.121	0.834	-0.030

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE TO A TARGET FUEL AT GROUND LEVEL UNDER WIND-FREE CONDITIONS SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

RADIATIVE HEAT FLUX CALCULATION

$$q'' = EF_{1\text{->}2}$$

Answer	q" =	0.30	kW/m^2	0.03	Btu/ft^2-sec

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accurac of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

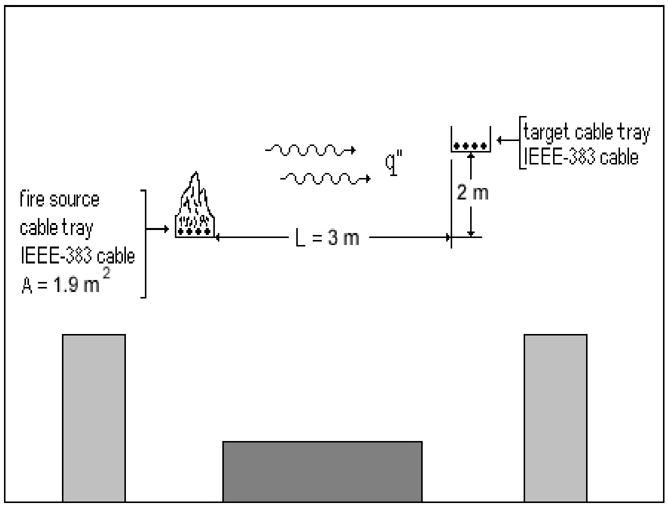
Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 5.11-6

Problem Statement

A fire scenario may arise from a horizontal cable tray burning in a very large compartment. The cables in the tray are IEEE-383 unqualified ($\dot{q}''_{critical} = 5\ \mathrm{kW/m^2}$) and made of XPE/FRXPE insulation material (assume that the exposed area of the cable is 1.9 m^2. A safety-related cable tray is also filled with IEEE-383 qualified ($\dot{q}''_{critical} = 10\ \mathrm{kW/m^2}$) made of XLPE insulation material located at a radial distance (L) of 3 m from the fire source and 2 m above the fire source. Calculate the flame radiant heat flux to a target (safety-related cable tray) using the solid flame radiation model. Is the IEEE-383 qualified cable tray damaged?



Example Problem 5-6: Radiant Heat Flux from a Burning Cable Tray to a Vertical Target Fuel

Solution

Purpose:

(1) Calculate the radiant heat flux from the burning cable tray to the vertical target cable tray using the solid flame radiation model.
(2) Determine if the IEEE-383 cable tray (target) is damaged.

Assumptions:

(1) The fire source will be nearly circular.
(2) The correlation for solid flame radiation model is suitable for most fuels.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 05.1_Heat_Flux_Calculations_Wind_Free_Sup1_SI.xls (click on *Solid Flame 2*)

FDT^s Inputs:

- Mass Burning Rate of Fuel ($\dot{m}$") = 0.0037 kg/m^2-sec
- Effective Heat of Com bustion of Fuel ($\Delta H_{c,eff}$) = 28,300 kJ/kg
- Fuel Spill Area or Curb Area (A_{curb}) = 1.9 m^2
- Distance between Fire Source and Target (L) = 3 m
- Vertical Distance of Target from Ground ($H_1 = H_{f1}$) = 2 m

Note: Since the insulation material (XPE /FRXPE) is not available in the thermal properties data of the spreadsheet, we have to input the mass burning rate and effective heat of combustion in the spreadsheet. Values of cable materials properties are available in Table 3-4. Select **User-Specified Value**, and enter the $\dot{m}$" and Fuel $\Delta H_{c,eff}$ values from Table 3-4.

Results*

Radiation Model	Radiant Heat Flux ($\dot{q}$") (kW/m^2)	Cable Failure
Solid Flame	0.60	No, $\dot{q}_r'' << \dot{q}_{critical}''$

* see spreadsheet on next page

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 5.11-6**

INPUT PARAMETERS

Mass Burning Rate of Fuel (m")	0.0037	kg/m^2-sec
Effective Heat of Combustion of Fuel ($\Delta H_{c,eff}$)	28300	kJ/kg
Empirical Constant (kβ)	100	m^{-1}
Heat Release Rate (Q)	198.95	kW
Fuel Area or Dike Area (A_{dike})	1.90	m^2
Distance between Fire and Target (L)	2.70	m
Vertical Distance of Target from Ground ($H_1 = H_{f1}$)	1.80	m

OPTIONAL CALCULATION FOR GIVEN HEAT RELEASE RATE

Select "User Specified Value" from Fuel Type Menu and Enter Your HRR here → ______ kW

Calculate

THERMAL PROPERTIES DATA

BURNING RATE DATA FOR FUELS

Fuel	Mass Burning Rate m" (kg/m^2-sec)	Heat of Combustion $\Delta H_{c,eff}$ (kJ/kg)	Empirical Constant kβ (m^{-1})
Methanol	0.017	20,000	100
Ethanol	0.015	26,800	100
Butane	0.078	45,700	2.7
Benzene	0.085	40,100	2.7
Hexane	0.074	44,700	1.9
Heptane	0.101	44,600	1.1
Xylene	0.09	40,800	1.4
Acetone	0.041	25,800	1.9
Dioxane	0.018	26,200	5.4
Diethy Ether	0.085	34,200	0.7
Benzine	0.048	44,700	3.6
Gasoline	0.055	43,700	2.1
Kerosine	0.039	43,200	3.5
Diesel	0.045	44,400	2.1
JP-4	0.051	43,500	3.6
JP-5	0.054	43,000	1.6
Transformer Oil, Hydrocarbon	0.039	46,000	0.7
561 Silicon Transformer Fluid	0.005	28,100	100
Fuel Oil, Heavy	0.035	39,700	1.7
Crude Oil	0.0335	42,600	2.8
Lube Oil	0.039	46,000	0.7
Douglas Fir Plywood	0.01082	10,900	100
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-26.*

Select Fuel Type
User Specified Value
Scroll to desired fuel type then Click on selection

ESTIMATING RADIATIVE HEAT FLUX TO A TARGET FUEL

Reference: *SFPE Handbook of Fire Protection Engineering*, 3rd Edition, 2002, *Page 3-276.*

SOLID FLAME RADIATION MODEL

$$q'' = EF_{1\text{->}2}$$

Where
q'' = incident radiative heat flux on the target (kW/m^2)
E = emissive power of the pool fire flame (kW/m^2)
$F_{1\text{->}2}$ = view factor between target and the flame

Pool Fire Diameter Calculation

$$A_{dike} = \pi D^2/4$$

$$D = \sqrt{(4A_{dike}/\pi)}$$

Where
A_{dike} = surface area of pool fire (m^2)
D = pool fire diameter (m)

D = 1.56 m

Emissive Power Calculation

$$E = 58\ (10^{-0.00823\ D})$$

Where
E = emissive power of the pool fire flame (kW/m^2)
D = diameter of the pool fire (m)

E = 56.32 (kW/m^2)

View Factor Calculation

$F_{1\text{->}2,V1}$ = $1/(\pi S)\tan^{-1}(h_1/(S^2-1)^{1/2})-(h_1/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_1h_1/\pi S(A_1^2-1)^{1/2}\tan^{-1}((A_1+1)(S-1)/(A_1-1)(S+1))^{1/2}$

$F_{1\text{->}2,V2}$ = $1/(\pi S)\tan^{-1}(h_2/(S^2-1)^{1/2})-(h_2/\pi S)\tan^{-1}((S-1)/(S+1))^{1/2}+A_2h_2/\pi S(A_2^2-1)^{1/2}\tan^{-1}((A_2+1)(S-1)/(A_2-1)(S+1))^{1/2}$

A_1 = $(h_1^2+S^2+1)/2S$

A_2 = $(h_2^2+S^2+1)/2S$

B = $(1+S^2)/2S$

S = $2R/D$

h_1 = $2H_{f1}/D$

h_2 = $2H_{f2}/D$

$F_{1\text{->}2,V}$ = $F_{1\text{->}2,V1} + F_{1\text{->}2,V2}$

Where
$F_{1\text{->}2,V}$ = total vertical view factor
R = distance from center of the pool fire to edge of the target (m)
H_f = height of the pool fire flame (m)
D = pool fire diameter (m)

Distance from Center of the Pool Fire to Edge of the Target Calculation

$$R = L + D/2$$

Where
R = distance from center of the pool fire to edge of the target (m)
L = distance between pool fire and target (m)
D = pool fire diameter (m)

R = L+D/2 = 3.478 m

Heat Release Rate Calculation

$$Q = m''\Delta H_{c,eff}\,(1 - e^{-k\beta\, D})\,A_{dike}$$

Where
Q = pool fire heat release rate (kW)
m" = mass burning rate of fuel per unit surface area (kg/m^2-sec)
ΔH_c = effective heat of combustion of fuel (kJ/kg)
A_{dike} = surface area of pool fire (area involved in vaporization) (m^2)
$k\beta$ = empirical constant (m^{-1})
D = diameter of pool fire (diameter involved in vaporization, circular pool is assumed) (m)

Q = 198.95 kW

Pool Fire Flame Height Calculation

$$H_f = 0.235\, Q^{2/5} - 1.02\, D$$

Where
H_f = flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

H_f = 0.366 m

$S = 2R/D$ =			4.472					
$h_1 = 2H_{f1}/D$ =			2.315					
$h_2 = 2H_{f2}/D$ =	$2(H_f-H_{f1})/D$ =		-1.844					
$A_1 = (h_1^2+S^2+1)/2S$ =			2.947					
$A_2 = (h_2^2+S^2+1)/2S$ =			2.728					
$B = (1+S^2)/2S$ =			2.348					
				F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\to2,V1}$
$F_{1\to2,V1}$ =		0.072		0.035	0.111	0.175	0.848	0.072
$F_{1\to2,V2}$ =		-0.062		F_{V1}	F_{V2}	F_{V3}	F_{V4}	$F_{1\to2,V2}$
$F_{1\to2,V} = F_{1\to2,V1} + F_{1\to2,V2}$ =		0.010		-0.028	-0.088	-0.141	0.864	-0.062

CHAPTER 5
ESTIMATING RADIANT HEAT FLUX FROM FIRE
TO A TARGET FUEL AT GROUND LEVEL
UNDER WIND-FREE CONDITIONS
SOLID FLAME RADIATION MODEL

Version 1805.1
(SI Units)

RADIATIVE HEAT FLUX CALCULATION

$q'' = EF_{1->2}$

Answer	q'' =	0.59 kW/m^2	0.05 Btu/ft^2-sec

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accurac of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

6.11 Problems

Example Problem 6.11-1

Problem Statement
Calculate the ignition time for a PVC/PE power cable, assuming that a 2 m diameter pool fire produces a 25 kW /m^2 heat flux.

Solution

Purpose:
(1) Calculate the ignition time for a PVC/PE power cable.

Assumptions:
(1) The material is infinitely thick.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 06_Ignition_Time_Calculations_Sup1_SI.xls (click on *Ignition_Time _Calculations3*)

FDT^s Input Parameters:
- Exposure or External Radiative Heat Flux to Target Fuel ($\dot{q}_e''$) = 25 kW/m^2
- Click on the option button for Electrical Cables - Power
- Select Material: **PVC/PE**

Results*

Material	Ignition Time (t_{ig}) Method of Tewarson (min.)
PVC/PE	9.1

*see spreadsheet on next page

CHAPTER 6
ESTIMATING THE IGNITION TIME OF A TARGET FUEL EXPOSED TO A CONSTANT RADIATIVE HEAT

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 6.11-1**

INPUT PARAMETERS

Exposure or External Radiative Heat Flux to Target Fuel (q''_e)	25.00	kW/m^2
Target Critical Heat Flux for Ignition (CHF)	15.00	kW/m^2
Target Thermal Response Parameter (TRP)	263	$kW\text{-}sec^{1/2}/m^2$

Calculate

CRITICAL HEAT FLUX AND THERMAL RESPONSE PARAMETER FOR MATERIALS

Materials	Critical Heat Flux for Ignition CHF (kW/m^2)	Thermal Response Parameter (TRP) ($kW\text{-}sec^{1/2}/m^2$)
Electrical Cables - Power		
PVC/PVC	19.00	248.5
PE/PVC	15.00	232.5
PVC/PE	15.00	263
Silicone/PVC	19.00	212
Silicone/crosslinked polyolefin (XLPO)	27.50	446
EPR (ethylene-propylene rubber/EPR)	21.50	517
XLPE/XLPE	22.50	329.5
XLPE/EVA (ethyl-vinyl acetate)	17.00	472.5
XLPE/Neoprene	15.00	291
XLPO/XLPO	20.50	498
XLPO, PVF (polyvinylidine fluoride)/XLPO	15.50	526
EPR/Chlorosulfonated PE	16.50	349.5
EPR, FR	21.00	368.5
User Specified Value	Enter Value	Enter Value
Electrical Cables - Communications		
PVC/PVC	15.00	131
PE/PVC	20.00	183
XLPE/XLOP	20.00	498
Si/XLOP	20.00	457
EPR-FR	19.00	295
Chlorinated PE	12.00	217
ETFE/EVA	22.00	454
PVC/PVF	30.00	264
FEP/FEP	36.00	645
User Specified Value	Enter Value	Enter Value
Synthetic Materials		
Polypropylene	15.00	193
Nylon	15.00	270
Polymethylmethacrylate (PMMA)	11.00	274
Polycarbonate	15.00	331
Polycarbonate panel	16.00	420
User Specified Value	Enter Value	Enter Value
Natural Materials		
Wood (red oak)	10.00	134
Wood (douglas fir)	10.00	138
Wood (douglas fir/fire retardant, FR)	10.00	251
Corrugated paper (light)	10.00	152
User Specified Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-58.*

Select Material
PVC/PE
Scroll to desired material then Click on selection

Select Material
Scroll to desired material then Click on selection

Select Material
Scroll to desired material then Click on selection

Select Material
Scroll to desired material then Click on selection

Version 1805.1
(SI Units)

ESTIMATING IGNITION TIME FOR COMBUSTIBLES
METHOD OF TEWARSON
THERMALLY THICK MATERIALS

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-83.*

$$\sqrt{(1/t_{ig})} = (\sqrt{(4/\pi)}\,(q''_e - CHF))/TRP$$

$$t_{ig} = (\pi/4)\,(TRP)^2/(q''_e - CHF)^2$$

Where
t_{ig} = target ignition time (sec)
q''_e = external radiative heat flux to target (kW/m^2)
CHF = target critical heat flux for ignition (kW/m^2)
TRP = thermal response parameter of target material (kW-sec^2/m^2)

$$t_{ig} = (\pi/4)\,(TRP)^2/(q''_e - CHF)^2$$

Answer	t_{ig} =	543.25 sec	9.05 minutes

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Or ______

Checked by: ______ Date: ______ Or ______

Additional Information:

Example Problem 6.11-2

Problem Statement
Determine the time for 5.08 cm thick Douglas fir plywood to ignite when it is subjected to a flame heat flux of 25 kW /m^2, assuming the surface of the plywood is initially at 20 °C.

Solution

Purpose:
(1) Calculate the ignition time of Douglas fir plywood.

Assumptions:
(1) The material is infinitely thick.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 06_Ignition_Time_Calculations_Sup1_SI.xls (click on *Ignition_Time_Calculations3*)

FDT^s Input Parameters:
- Exposure or External Radiative Heat Flux to Target Fuel ($\dot{q}_e''$) = 25 kW /m^2
- Cick on the option button for Natural Materials
- Select Material: **Wood (Douglas fir)**

Note: The ignition time calculation method (Tewarson) provided in the spreadsheet *Ignition_Time_Calculations3* does not require the material thickness or initial surface temperature; therefore, material thickness and temperature are additional information only. However, if the initial temperature of the material is relatively high (compare with ambient temperature range), the ignition time value definitely will not be realistic based on this method. Also, we are assuming the material as infinitely thick to use the method; thus, we do not have to consider the thickness for this problem.

Results*

Material	Ignition Time (t_{ig}) Method of Tewarson (min.)
Wood (Douglas fir)	1.11

*see spreadsheet on next page

CHAPTER 6
ESTIMATING THE IGNITION TIME
OF A TARGET FUEL
EXPOSED TO A CONSTANT RADIATIVE HEAT

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 6.11-2**

INPUT PARAMETERS

Exposure or External Radiative Heat Flux to Target Fuel (q''_e)	25.00	kW/m^2
Target Critical Heat Flux for Ignition (CHF)	10.00	kW/m^2
Target Thermal Response Parameter (TRP)	138	$kW\text{-}sec^{1/2}/m^2$

Calculate

CRITICAL HEAT FLUX AND THERMAL RESPONSE PARAMETER FOR MATERIALS

Materials	Critical Heat Flux for Ignition CHF (kW/m^2)	Thermal Response Parameter (TRP) ($kW\text{-}sec^{1/2}/m^2$)
Electrical Cables - Power		
PVC/PVC	19.00	248.5
PE/PVC	15.00	232.5
PVC/PE	15.00	263
Silicone/PVC	19.00	212
Silicone/crosslinked polyolefin (XLPO)	27.50	446
EPR (ethylene-propylene rubber/EPR)	21.50	517
XLPE/XLPE	22.50	329.5
XLPE/EVA (ethyl-vinyl acetate)	17.00	472.5
XLPE/Neoprene	15.00	291
XLPO/XLPO	20.50	498
XLPO, PVF (polyvinylidine fluoride)/XLPO	15.50	526
EPR/Chlorosulfonated PE	16.50	349.5
EPR, FR	21.00	368.5
User Specified Value	Enter Value	Enter Value
Electrical Cables - Communications		
PVC/PVC	15.00	131
PE/PVC	20.00	183
XLPE/XLOP	20.00	498
Si/XLOP	20.00	457
EPR-FR	19.00	295
Chlorinated PE	12.00	217
ETFE/EVA	22.00	454
PVC/PVF	30.00	264
FEP/FEP	36.00	645
User Specified Value	Enter Value	Enter Value
Synthetic Materials		
Polypropylene	15.00	193
Nylon	15.00	270
Polymethylmethacrylate (PMMA)	11.00	274
Polycarbonate	15.00	331
Polycarbonate panel	16.00	420
User Specified Value	Enter Value	Enter Value
Natural Materials		
Wood (red oak)	10.00	134
Wood (douglas fir)	10.00	138
Wood (douglas fir/fire retardant, FR)	10.00	251
Corrugated paper (light)	10.00	152
User Specified Value	Enter Value	Enter Value

Reference: *SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-58.*

Select Material

Scroll to desired material then Click on selection

Select Material

Scroll to desired material then Click on selection

Select Material

Scroll to desired material then Click on selection

Select Material

Wood (douglas fir)

Scroll to desired material then Click on selection

CHAPTER 6
ESTIMATING THE IGNITION TIME
OF A TARGET FUEL
EXPOSED TO A CONSTANT RADIATIVE HEAT

Version 1805.1
(SI Units)

ESTIMATING IGNITION TIME FOR COMBUSTIBLES
METHOD OF TEWARSON
THERMALLY THICK MATERIALS

Reference: *SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-83.*

$$\sqrt{(1/t_{ig})} = (\sqrt{(4/\pi)}\,(q''_e - CHF))/TRP$$

$$t_{ig} = (\pi/4)\,(TRP)^2/(q''_e - CHF)^2$$

Where

t_{ig} = target ignition time (sec)

q''_e = external radiative heat flux to target (kW/m^2)

CHF = target critical heat flux for ignition (kW/m^2)

TRP = thermal response parameter of target material ($kW\text{-}sec^2/m^2$)

$$t_{ig} = (\pi/4)\,(TRP)^2/(q''_e - CHF)^2$$

Answer	t_{ig} =	66.48 sec	1.11 minutes

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Or

Checked by: Date: Or

Additional Information:

7.12 Problems

Example Problem 7.12-1

Problem Statement
A 120 liter trash can exposure fire source is located 2 m beneath a horizontal cable tray. It is assumed that the trash fire ignites an area of approximately 2 m^2 of the cable tray. The cables in the tray are IEEE-383 unqualified and made of PE/PVC insulation material. Compute the full-scale HRR of the PE/PVC cable insulation. The bench-scale HRR of PE/PVC is 589 kW/m^2.

Solution

Purpose:
(1) Calculate the full-scale HRR of the PE/PVC insulation material.

Assumptions:
(1) Lee's correlation is valid for this fire scenario.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 07_Cable_HRRCalculations_Sup1_SI.xls

FDTs Input Parameters:
- Exposed Floor Area of Burning Cable Tray (A_f) = 2 m^2
- Select Material: **PE/PVC** (the one with a bench-scale HRR of 589 kW/m^2)

Results*

Cable Insulation	Full Scale HRR ($\dot{Q}_{fs}$) (kW)
PE/PVC	530

*see spreadsheet on next page

CHAPTER 7
ESTIMATING THE FULL-SCALE
HEAT RELEASE RATE OF A
CABLE TRAY FIRE

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 7.12-1**

INPUT PARAMETERS

Cable Bench-Scale HRR (Q_{bs}'')	589	kW/m^2
Exposed Floor Area (Length x Width) of Burning Cable Tray (A_f)	2.00	m^2

Calculate

HEAT RELEASE RATE DATA FOR CABLE TRAY FIRE

BENCH-SCALE HRR OF CABLE TRAY FIRE

Cable Type	Bench-Scale HRR per Unit Floor Area (L x W) Q''_{bs} (kW/m^2)
FRXPE/Cl.S.PE	258
Id PE	1071
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218
PE, PP/Cl.S.PE	345
PE, PP/Cl.S.PE	299
PE, PP/Cl.S.PE	271
PE, PP/Cl.S.PE	177
PE/PVC	589
PE/PVC	395
PE/PVC	359
PE/PVC	312
Silicone, glass braid	128
Silicone, glass braid, asbestos	182
Teflon	98
XPE/Cl.S.PE	204
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
User Specified Value	Enter Value

Reference: "Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters," EPRI Research Project 1165-1, NP-1200, Part 1.

Select Cable Type

PE/PVC

Scroll to desired cable type **then Click** on selection

ESTIMATING FULL-SCALE CABLE TRAY HEAT RELEASE RATE

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition 2002, Page 3-16.

$$Q_{fs} = 0.45\ Q_{bs}''\ A_f$$

Where,

Q_{fs} = cable tray full-scale HRR (kW)

Q_{bs}'' = cable tray bench-scale HRR (kW/m^2)

A_f = exposed floor area (length x width) of burning cable tray (m^2)

Heat Release Rate Calculation

$$Q_{fs} = 0.45\ Q_{bs}\ A_f$$

Answer	Q_{fs} =	530.10 kW	502.44 Btu/sec

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 7.12-2

Problem Statement
A 0.5 m high stack of untreated wood pallets (exposure fire source) from a recent plant modification ignites and is located 1.5 m beneath a horizontal cable tray. It is assumed that the wood pallets ignite an area of approximately 4 m^2 of the cable tray. The cables in the tray are IEEE-383 qualified and made of PE insulation material. Compute the full-scale HRR of PE cable insulation. The bench-scale HRR of PE material is 1,071 kW/m^2.

Solution

Purpose:
(1) Calculate the full-scale HRR of the PE insulation material.

Assumptions:
(1) Lee's correlation is valid for this fire scenario.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 07_Cable_HRRCalculations_Sup1_SI.xls

FDTs Input Parameters:
- Exposed Floor Area of Burning Cable Tray (A_f) = 4 m^2
- Select Material: **Id PE**

Results*

Cable Insulation	Full Scale HRR ($\dot{Q}_{fs}$) (kW)
Id PE	1,925

*see spreadsheet on next page

CHAPTER 7
ESTIMATING THE FULL-SCALE HEAT RELEASE RATE OF A CABLE TRAY FIRE

Version 1805.1 (SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 7.12-2**

INPUT PARAMETERS

Cable Bench-Scale HRR (Q_{bs}")	1071	kW/m^2
Exposed Floor Area (Length x Width) of Burning Cable Tray (A_f)	4.00	m^2

Calculate

HEAT RELEASE RATE DATA FOR CABLE TRAY FIRE

BENCH-SCALE HRR OF CABLE TRAY FIRE

Cable Type	Bench-Scale HRR per Unit Floor Area (L x W) Q''_{bs} (kW/m^2)
FRXPE/Cl.S.PE	258
Id PE	1071
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218
PE, PP/Cl.S.PE	345
PE, PP/Cl.S.PE	299
PE, PP/Cl.S.PE	271
PE, PP/Cl.S.PE	177
PE/PVC	589
PE/PVC	395
PE/PVC	359
PE/PVC	312
Silicone, glass braid	128
Silicone, glass braid, asbestos	182
Teflon	98
XPE/Cl.S.PE	204
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
User Specified Value	Enter Value

Reference: "Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters," EPRI Research Project 1165-1, NP-1200, Part 1.

Select Cable Type

Id PE

Scroll to desired cable type **then Click** on selection

ESTIMATING FULL-SCALE CABLE TRAY HEAT RELEASE RATE

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition 2002, Page 3-16.

$$Q_{fs} = 0.45\ Q_{bs}''\ A_f$$

Where,

Q_{fs} = cable tray full-scale HRR (kW)
Q_{bs}'' = cable tray bench-scale HRR (kW/m^2)
A_f = exposed floor area (length x width) of burning cable tray (m^2)

Heat Release Rate Calculation

$$Q_{fs} = 0.45\ Q_{bs}\ A_f$$

Answer	Q_{fs} =	1925.39 kW	1824.92 Btu/sec

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 7.12-3

Problem Statement
A 1.1 m diameter flammable liquid (lubricating oil) pool fire arises from a breach in an auxiliary cooling water pump oil tank. The pool fire is located on the floor, 3 m beneath a horizontal cable tray. It is assumed that the pool fire ignites an area of approximately 1 m^2 of the cable tray. The cables in the tray are IEEE-383 unqualified and made of XPE /FRXPE insulation material. Compute the full scale HRR of XPE/FRXPE cable insulation. The bench-scale HRR of XPE/FRXPE is 475 kW/m^2.

Solution

Purpose:
(1) Calculate the full-scale HRR of the XPE/FRXPE insulation material.

Assumptions:
(1) Lee's correlation is valid for this fire scenario.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 07_Cable_HRCalculations_Sup1_SI.xls

FDT^s Input Parameters:
- Exposure Cable Tray Burning Area (A_f) = 1 m^2
- Select Material: **XPE/FRXPE**

Results*

Cable Insulation	Full Scale HRR ($\dot{Q}_{fs}$) (kW)
XPE/FRXPE	214

*see spreadsheet on next page

CHAPTER 7
ESTIMATING THE FULL-SCALE HEAT RELEASE RATE OF A CABLE TRAY FIRE

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 7.12-3**

INPUT PARAMETERS

Cable Bench-Scale HRR (Q_{bs}")	475	kW/m^2
Exposed Floor Area (Length x Width) of Burning Cable Tray (A_f)	1.00	m^2

Calculate

HEAT RELEASE RATE DATA FOR CABLE TRAY FIRE

BENCH-SCALE HRR OF CABLE TRAY FIRE

Cable Type	Bench-Scale HRR per Unit Floor Area (L x W) Q''_{bs} (kW/m^2)
FRXPE/Cl.S.PE	258
Id PE	1071
PE, Nylon/PVC, Nylon	231
PE, Nylon/PVC, Nylon	218
PE, PP/Cl.S.PE	345
PE, PP/Cl.S.PE	299
PE, PP/Cl.S.PE	271
PE, PP/Cl.S.PE	177
PE/PVC	589
PE/PVC	395
PE/PVC	359
PE/PVC	312
Silicone, glass braid	128
Silicone, glass braid, asbestos	182
Teflon	98
XPE/Cl.S.PE	204
XPE/FRXPE	475
XPE/Neoprene	354
XPE/Neoprene	302
XPE/XPE	178
User Specified Value	Enter Value

Reference: "Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters," EPRI Research Project 1165-1, NP-1200, Part 1.

Select Cable Type

XPE/FRXPE

Scroll to desired cable type **then Click** on selection

ESTIMATING FULL-SCALE CABLE TRAY HEAT RELEASE RATE

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition 2002, Page 3-16.

$$Q_{fs} = 0.45\ Q_{bs}''\ A_f$$

Where,

Q_{fs} = cable tray full-scale HRR (kW)

Q_{bs}'' = cable tray bench-scale HRR (kW/m^2)

A_f = exposed floor area (length x width) of burning cable tray (m^2)

Heat Release Rate Calculation

$$Q_{fs} = 0.45\ Q_{bs}\ A_f$$

Answer	Q_{fs} =	213.75 kW	202.60 Btu/sec

NOTE:

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: | Date: | Organization:

Checked by: | Date: | Organization:

Additional Information:

8.9 Problems

Example Problem 8.9-1

Problem Statement
A horizontal power cable fails as a result of self-initiated fire and burn in a compartment. Compute the burning duration of a cable tray with an exposed surface area of 0.1 m^2 filled with 4.54 kg of non-IEEE-383 qualified PE/PVC cables. The heat release per unit floor area of PE/PVC is 589 kW/m^2, and the heat of combustion is 24,000 kJ/kg.

Solution

Purpose:
(1) Calculate the burning duration of the cable material (PE/PVC).

Assumptions:
(1) Combustion is incomplete and takes place entirely within the confines of the compartment.
(2) Virtually all of the potential energy in the fuel is released in the involved compartment.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 08_Burning_DurationSolid_Sup1_SI.xls

FDTs Input Parameters:
- Mass of Solid Fuel (m_{solid}) = 4.54 kg
- Exposure Fuel Surface Area (A_{fuel}) = 0.1 m^2
- Select Material: **PE/PVC**

Results*

Material	Burning Duration (t_{solid}) (min.)
PE/PVC	31

*see spreadsheet on next page

CHAPTER 8
ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.1 (SI Units)

The following calculations provides an approximation of the burning duration of solid combustibles based on free burning rate with a given surface area.

Parameters in YELLOW CELLS are Entered by the User.

Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.

All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: Example 8.9-1

INPUT PARAMETERS

COMPARTMENT INFORMATION

Mass of Solid Fuel (msolid)	4.54	kg
Exposed Floor Area (Length x Width) of Fuel (Afuel)	0.10	m^2
Heat Release Rate (HRR) per Unit Floor Area (Q")	589	kW/m^2
Effective Heat of Combustion ($\Delta H_{c,eff}$)	24000	kJ/kg

Calculate

THERMAL PROPERTIES OF SOLID COMBUSTIBLE MATERIALS

Material	HRR per Unit Floor Area Q" (kW/m^2)	Heat of Combustion ΔH_c (kJ/kg)
Douglas Fir Plywood	221	17600
Empty Cartons 15 ft high	1700	12700
Ethylene Propylene Dien Rubber (EPDM)	956	28800
Fire Retardant Treated Plywood	81	13500
Nylon 6/6	1313	32000
Particle Board, 19 mm thick	1900	17500
PE, Nylon/PVC, Nylon	231	9200
PE/PVC	589	24000
Polycarbonate	420	24400
Polyethylene (PE)	1408	46500
Polymethlmethacrylate (PMMA)	665	26000
Polypropylene (PP)	1509	43200
Polystyrene (PS)	1101	42000
Polyurethane	710	45000
Polyvinyl Chloride (PVC) Flexible	237	15700
Strene-Butadiene Copolymers (SBR)	163	44000
Teflon	98	3200
Wood Pallets, stacked 1.5 ft high	1420	14000
Wood Pallets, stacked 5 ft high	3970	14000
Wood Pallets, stacked 10 ft high	6800	14000
XPE/FRXPE	475	28300
XPE/Neoprene	354	10300
User Specified Value	Enter Value	Enter Value

Select Material

PE/PVC

Scroll to desired material **then Click** on selection

CHAPTER 8
ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.1
(SI Units)

References:

"Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters," EPRI Research Project 1165-1, NP-1200, Part 1.

Karlsson and Quantiere, Enclosure Fire Dynamics, Chapter 3: Energy Release Rate," CRC Press, 1999.

Johnson, D. G., "Combustion Properties of Plastics," Journal of Applied Fire Science, Volume 4, No. 3, 1994-95, pp. 185-201.

Hirschler, M. M., "Heat Release from Plastic Materials," Heat Release in Fires, Babrauskas and Grayson, Editors, Elsevier Applied Science, 1992.

BURNING DURATION OF SOLID COMBUSTIBLES

Reference: Buchanan, A. H., "Structural Design for Fire Safety," 2001, Page 38.

The burning duration of a solid fuel can be calculated if the total energy contained in the fuel and HRR are known.
The burning duration is given by:

$$Q = E / tsolid \quad \text{or} \quad t_{solid} = (E) / (Q'' \, AFuel)$$

Where,

t_{solid} = burning duration of solid combustible (sec)
E = mFuel DHc = total energy contained in the fuel (kJ)
Q = heat release rate of fire (kW)
Q" = heat release rate per unit floor area of fuel (kW/m^2)
A_{Fuel} = exposed floor area (length x width) of fuel (m^2)

$$t_{solid} = (m_{Fuel} \, \Delta H_c) / (Q'' \, A_{Fuel})$$

Where,

m_{Fuel} = mass of solid fuel (kg)
ΔH_c = fuel effective heat of combustion (kJ/kg)

$$t_{solid} = (msolid \, DHc) / (Q'' \, Asolid)$$

Answer	t_{solid} =	1849.92 sec	30.83 min

NOTE:
The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 8.9-2

Problem Statement

A horizontal cable tray filled with non-IEEE-383 qualified XPE/FRXPE cables are ignited as a result of overhead welding and burn in a compartment 6.1 m wide x 6.1 m deep x 3 m high. The cable tray has a nominal width of 0.6 m and a linear length of 7.3 m (i.e., exposed surface area of 4.4 m^2). Compute the burning duration of XPE/FRXPE cables assuming the mass of cables is 22.7 kg. The heat release per unit area of XPE/FRXPE is 475 kW/m^2 and heat of combustion is 28,300 kJ/kg.

Solution

Purpose:

(1) Calculate the burning duration of the cable material (XPE/FRXPE).

Assumptions:

(1) Combustion is incomplete and takes place entirely within the confines of the compartment.
(2) Virtually all of the heat energy in the fuel is released in the involved compartment.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 08_Burning_Duration Solid_Sup1_SI.xls

FDTs Input Parameters:

- Mass of Solid Fuel (m_{solid}) = 22.7 kg
- Exposure Fuel Surface Area (A_{fuel}) = 4.4 m^2
- Select Material: **XPE/FRXPE**

Results*

Material	Burning Duration (t_{solid}) (min.)
XPE/FRXPE	5

*see spreadsheet on next page

CHAPTER 8
ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.1 (SI Units)

The following calculations provides an approximation of the burning duration of solid combustibles based on free burning rate with a given surface area.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: Example 8.9-2

INPUT PARAMETERS

COMPARTMENT INFORMATION

Mass of Solid Fuel (msolid)	22.70	kg
Exposed Floor Area (Length x Width) of Fuel (Afuel)	4.40	m^2
Heat Release Rate (HRR) per Unit Floor Area (Q")	475	kW/m^2
Effective Heat of Combustion ($\Delta H_{c,eff}$)	28300	kJ/kg

Calculate

THERMAL PROPERTIES OF SOLID COMBUSTIBLE MATERIALS

Material	HRR per Unit Floor Area Q" (kW/m^2)	Heat of Combustion ΔH_c (kJ/kg)
Douglas Fir Plywood	221	17600
Empty Cartons 15 ft high	1700	12700
Ethylene Propylene Dien Rubber (EPDM)	956	28800
Fire Retardant Treated Plywood	81	13500
Nylon 6/6	1313	32000
Particle Board, 19 mm thick	1900	17500
PE, Nylon/PVC, Nylon	231	9200
PE/PVC	589	24000
Polycarbonate	420	24400
Polyethylene (PE)	1408	46500
Polymethlmethacrylate (PMMA)	665	26000
Polypropylene (PP)	1509	43200
Polystyrene (PS)	1101	42000
Polyurethane	710	45000
Polyvinyl Chloride (PVC) Flexible	237	15700
Strene-Butadiene Copolymers (SBR)	163	44000
Teflon	98	3200
Wood Pallets, stacked 1.5 ft high	1420	14000
Wood Pallets, stacked 5 ft high	3970	14000
Wood Pallets, stacked 10 ft high	6800	14000
XPE/FRXPE	475	28300
XPE/Neoprene	354	10300
User Specified Value	Enter Value	Enter Value

Select Material

XPE/FRXPE

Scroll to desired material **then Click** on selection

CHAPTER 8
ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.1 (SI Units)

References:

"Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters," EPRI Research Project 1165-1, NP-1200, Part 1.

Karlsson and Quantiere, Enclosure Fire Dynamics, Chapter 3: Energy Release Rate," CRC Press, 1999.

Johnson, D. G., "Combustion Properties of Plastics," Journal of Applied Fire Science, Volume 4, No. 3, 1994-95, pp. 185-201.

Hirschler, M. M., "Heat Release from Plastic Materials," Heat Release in Fires, Babrauskas and Grayson, Editors, Elsevier Applied Science, 1992.

BURNING DURATION OF SOLID COMBUSTIBLES

Reference: Buchanan, A. H., "Structural Design for Fire Safety," 2001, Page 38.

The burning duration of a solid fuel can be calculated if the total energy contained in the fuel and HRR are known. The burning duration is given by:

Q = E / tsolid or t_{solid} = (E) / (Q" AFuel)

Where,

t_{solid} = burning duration of solid combustible (sec)
E = mFuel DHc = total energy contained in the fuel (kJ)
Q = heat release rate of fire (kW)
Q" = heat release rate per unit floor area of fuel (kW/m^2)
A_{Fuel} = exposed floor area (length x width) of fuel (m^2)

$$t_{solid} = (m_{Fuel}\ \Delta H_c) / (Q''\ A_{Fuel})$$

Where,

m_{Fuel} = mass of solid fuel (kg)
ΔH_c = fuel effective heat of combustion (kJ/kg)

t_{solid} = (msolid DHc) / (Q" Asolid)

Answer	t_{solid} =	307.37 sec	5.12 min

NOTE:
The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 8.9-3

Problem Statement

A fire involving a 0.5 m high stack of wood pallets is located in a compartment 12 m wide x 12 m long x 3 m high. The mass of the wood pallets is 14 kg. Compute the burning duration of the wood pallet fire in the compartment. The exposed surface area of the wood pallets is 1.2 m x 1.2 m or 1.44 m^2.

Solution

Purpose:

(1) Calculate the burning duration of the stack of wood pallets.

Assumptions:

(1) Combustion is incomplete and takes place entirely within the confines of the compartment.
(2) Virtually all of the heat energy in the fuel is released in the involved compartment.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:

(a) 08_Burning_Duration Solid_Sup1_SI.xls

FDT^s Input Parameters:

- Mass of Solid Fuel (m_{solid}) = 14 kg
- Exposure Fuel Surface Area (A_{fuel}) = 1.44 m^2
- Select Material: **Wood pallet, stacked 1.5 ft high**

Results*

Material	Burning Duration (t_{solid}) (min.)
Wood pallet, stacked 1.5 ft high	1.6

*see spreadsheet on next page

CHAPTER 8
ESTIMATING BURNING DURATION
OF
SOLID COMBUSTIBLES

Version 1805.1
(SI Units)

The following calculations provides an approximation of the burning duration of solid combustibles based on free burning rate with a given surface area.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Material Selected.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 8.9-3**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Mass of Solid Fuel (msolid)	14.00	kg
Exposed Floor Area (Length x Width) of Fuel (Afuel)	1.44	m^2
Heat Release Rate (HRR) per Unit Floor Area (Q")	1420	kW/m^2
Effective Heat of Combustion ($\Delta H_{c,eff}$)	14000	kJ/kg

Calculate

THERMAL PROPERTIES OF SOLID COMBUSTIBLE MATERIALS

Material	HRR per Unit Floor Area Q" (kW/m^2)	Heat of Combustion ΔH_c (kJ/kg)
Douglas Fir Plywood	221	17600
Empty Cartons 15 ft high	1700	12700
Ethylene Propylene Dien Rubber (EPDM)	956	28800
Fire Retardant Treated Plywood	81	13500
Nylon 6/6	1313	32000
Particle Board, 19 mm thick	1900	17500
PE, Nylon/PVC, Nylon	231	9200
PE/PVC	589	24000
Polycarbonate	420	24400
Polyethylene (PE)	1408	46500
Polymethlmethacrylate (PMMA)	665	26000
Polypropylene (PP)	1509	43200
Polystyrene (PS)	1101	42000
Polyurethane	710	45000
Polyvinyl Chloride (PVC) Flexible	237	15700
Strene-Butadiene Copolymers (SBR)	163	44000
Teflon	98	3200
Wood Pallets, stacked 1.5 ft high	1420	14000
Wood Pallets, stacked 5 ft high	3970	14000
Wood Pallets, stacked 10 ft high	6800	14000
XPE/FRXPE	475	28300
XPE/Neoprene	354	10300
User Specified Value	Enter Value	Enter Value

Select Material

Wood Pallets, stacked 1.5 ft high

Scroll to desired material **then**
Click on selection

CHAPTER 8
ESTIMATING BURNING DURATION OF SOLID COMBUSTIBLES

Version 1805.1
(SI Units)

References:
"Categorization of Cable Flammability, Part 1: Laboratory Evaluation of Cable Flammability Parameters," EPRI Research Project 1165-1, NP-1200, Part 1.
Karlsson and Quantiere, Enclosure Fire Dynamics, Chapter 3: Energy Release Rate," CRC Press, 1999.
Johnson, D. G., "Combustion Properties of Plastics," Journal of Applied Fire Science, Volume 4, No. 3, 1994-95, pp. 185-201.
Hirschler, M. M., "Heat Release from Plastic Materials," Heat Release in Fires, Babrauskas and Grayson, Editors, Elsevier Applied Science, 1992.

BURNING DURATION OF SOLID COMBUSTIBLES

Reference: Buchanan, A. H., "Structural Design for Fire Safety," 2001, Page 38.

The burning duration of a solid fuel can be calculated if the total energy contained in the fuel and HRR are known.
The burning duration is given by:

$$Q = E / tsolid \quad \text{or} \quad t_{solid} = (E) / (Q'' \, AFuel)$$

Where,
t_{solid} = burning duration of solid combustible (sec)
E = mFuel DHc = total energy contained in the fuel (kJ)
Q = heat release rate of fire (kW)
Q" = heat release rate per unit floor area of fuel (kW/m^2)
A_{Fuel} = exposed floor area (length x width) of fuel (m^2)

$$t_{solid} = (m_{Fuel} \, \Delta H_c) / (Q'' \, A_{Fuel})$$

Where,
m_{Fuel} = mass of solid fuel (kg)
ΔH_c = fuel effective heat of combustion (kJ/kg)

$$t_{solid} = (msolid \, DHc) / (Q'' \, Asolid)$$

Answer	t_{solid} =	**95.85 sec**	**1.60 min**

NOTE:
The above calculations are based on principles developed in the Structural Design for Fire Safety, 2001. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

9.11 Problems

Example Problem 9.11-1

Problem Statement
A steel beam is located 7.6 m above the floor. Calculate the temperature of the beam exposed from a 3.2 m^2 lube oil pool fire. Assume the HRR of the fire is 5,000 kW.

Solution

Purpose:
(1) Determine the plume centerline temperature for the pool fire scenario.

Assumptions:
(1) All heat is released at a point.
(2) Buoyant forces are more significant than momentum forces.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 09_Plume_Temperature_Calculations_Sup1_SI.xls

FDT^s Input Parameters:
- Heat Release Rate ($\dot{Q}$) = 5,000 kW
- Distance from the Top of the Fuel to the Ceiling (z) = 7.6 m
- Area of Combustible Fuel (A_c) = 3.2 m^2

Results*

Heat Release Rate ($\dot{Q}$) (kW)	Plume Centerline Temperature ($T_{p(centerline)}$) (°C)
5,000	245

*see spreadsheet on next page

CHAPTER 9
ESTIMATING CENTERLINE TEMPERATURE OF A BUOYANT FIRE PLUME

Version 1805.1 (SI Units)

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.

Project / Inspection Title: **Example 9.11-1**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q)	5000.00	kW
Elevation Above the Fire Source (z)	7.60	m
Area of Combustible Fuel (A_c)	3.20	m^2
Ambient Air Temperature (T_a)	25.00	°C

Calculate

AMBIENT CONDITIONS

Specific Heat of Air (c_a)	1.00	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3
Acceleration of Gravity (g)	9.81	m/sec^2
Convective Heat Release Fraction (χ_c)	0.70	

NOTE: **Ambient Air Density (ρ_a) 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.

$$T_{p(centerline)} - T_a = 9.1\ (T_a/g\ c_a^2\ \rho_a^2)^{1/3}\ Q_c^{2/3}\ (z - z_0)^{-5/3}$$

Where,
$T_{p(centerline)}$ = plume centerline temperature (°C)
Q_c = convective portion of the heat release rate (kW)
T_a = ambient air temperature (K)
g = acceleration of gravity (m/sec^2)
c_a = specific heat of air (kJ/kg-K)
ρ_a = ambient air density (kg/m^3)
z = distance from the top of the fuel package to the ceiling (m)
z_0 = hypothetical virtual origin of the fire (m)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where,
Q_c = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χ_c = convective heat release fraction

Q_c = 3500 kW

Fire Diameter Calculation

$$A_c = \pi D^2/4$$
$$D = \sqrt{(4\ A_c/\pi)}$$

Where,
A_c = area of combustible fuel (m^2)
D = fire diameter (m)

D = 2.02 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 = 0.22

z_0 = 0.45 m

Mean Flame Height Calculation

$$L = -1.02D + 0.235\,(Q^{2/5})$$

Where,
L = mean flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

L = 5.03 m

ESTIMATING PLUME CENTERLINE TEMPERATURE

$$T_{p(centerline)} - T_a = 9.1\,(T_a/g\,c_a^2\,\rho_a^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$$

$$T_{p(centerline)} - T_a = 220.08 \quad °K$$

$$T_{p(centerline)} = 9.1\,(T_a/g\,c_a^2\,\rho_a^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3} + Ta$$

$$T_{p(centerline)} = 518.08 \quad °K$$

ESTIMATED PLUME CENTERLINE TEMPERATURE

Answer	$T_{p(centerline)}$ =	245.08 °C	473.14 °F

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 9.11-2

Problem Statement
Estimate the maximum plume temperature at the ceiling of a 2.4 m high room above a 1,000 kW trash fire with an area of 1 m^2. Assume that the ambient air temperature is 25 °C.

Solution

Purpose:
(1) Determine the maximum plume centerline temperature for the transient combustible fire scenario.

Assumptions:
(1) All heat is released at a point.
(2) Buoyant forces are more significant than momentum forces.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 09_Plume_Temperature_Calculations_Sup1_SI.xls

FDTs Input Parameters:
- Heat Release Rate ($\dot{Q}$) = 1000 kW
- Distance from the Top of the Fuel to the Ceiling (z) = 2.4 m
- Area of Combustible Fuel (A_c) = 1 m^2

Results*

Heat Release Rate ($\dot{Q}$) (kW)	Plume Centerline Temperature ($T_{p(centerline)}$) (°C)
1,000	548

*see spreadsheet on next page

CHAPTER 9
ESTIMATING CENTERLINE TEMPERATURE OF A BUOYANT FIRE PLUME

Version 1805.1
(SI Units)

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.

Project / Inspection Title: **Example 9.11-2**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q)	1000.00	kW
Elevation Above the Fire Source (z)	2.40	m
Area of Combustible Fuel (A_c)	1.00	m^2
Ambient Air Temperature (T_a)	25.00	°C

Calculate

AMBIENT CONDITIONS

Specific Heat of Air (c_a)	1.00	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3
Acceleration of Gravity (g)	9.81	m/sec^2
Convective Heat Release Fraction (χ_c)	0.70	

NOTE: **Ambient Air Density (ρ_a) will automatically correct with Ambient Air Temperature (T_a) Input**

CHAPTER 9
ESTIMATING CENTERLINE TEMPERATURE
OF A
BUOYANT FIRE PLUME

Version 1805.1
(SI Units)

ESTIMATING PLUME CENTERLINE TEMPERATURE

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 2-6.

$$T_{p(centerline)} - T_a = 9.1\,(T_a/g\,c_a^2\,\rho_a^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$$

Where,
$T_{p(centerline)}$ = plume centerline temperature (°C)
Q_c = convective portion of the heat release rate (kW)
T_a = ambient air temperature (K)
g = acceleration of gravity (m/sec^2)
c_a = specific heat of air (kJ/kg-K)
ρ_a = ambient air density (kg/m^3)
z = distance from the top of the fuel package to the ceiling (m)
z_0 = hypothetical virtual origin of the fire (m)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\,Q$$

Where,
Q_c = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χ_c = convective heat release fraction

Q_c = 700 kW

Fire Diameter Calculation

$$A_c = \pi D^2/4$$
$$D = \sqrt{(4\,A_c/\pi)}$$

Where,
A_c = area of combustible fuel (m^2)
D = fire diameter (m)

D = 1.13 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 = 0.15

z_0 = 0.16 m

Mean Flame Height Calculation

$$L = -1.02D + 0.235\ (Q^{2/5})$$

Where,
L = mean flame height (m)
Q = heat release rate of fire (kW)
D = fire diameter (m)

L = 2.57 m

ESTIMATING PLUME CENTERLINE TEMPERATURE

$$T_{p(centerline)} - T_a = 9.1\ (T_a/g\ c_a^2\ \rho_a^2)^{1/3}\ Q_c^{2/3}\ (z - z_0)^{-5/3}$$

$T_{p(centerline)} - T_a =$ 523.16 °K

$$T_{p(centerline)} = 9.1\ (T_a/g\ c_a^2\ \rho_a^2)^{1/3}\ Q_c^{2/3}\ (z - z_0)^{-5/3} + Ta$$

$T_{p(centerline)} =$ 821.16 °K

ESTIMATED PLUME CENTERLINE TEMPERATURE

Answer	$T_{p(centerline)} =$	548.16 °C	1018.68 °F

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

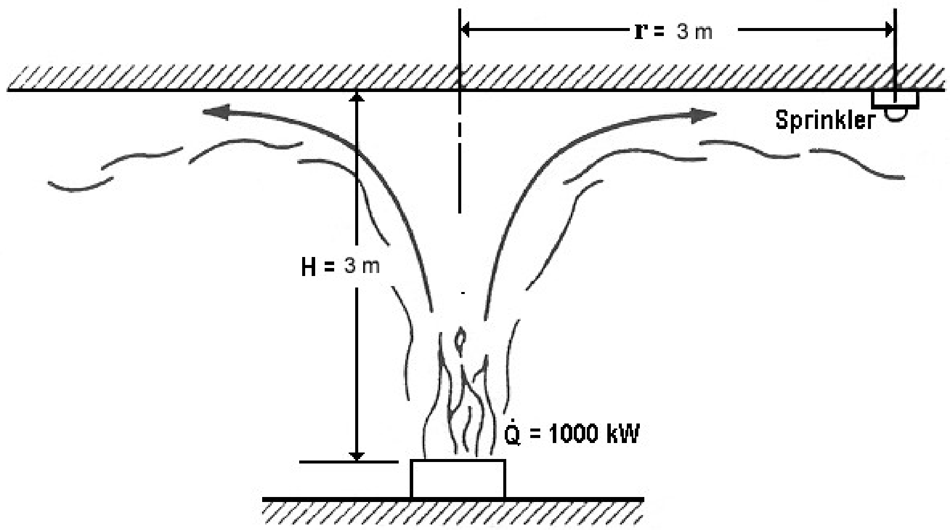
Additional Information:

10.10 Problems

Example Problem 10.10-1

Problem Statement

A fire with $\dot{Q}$ = 1,000 kW occurs in a space that is protected with sprinklers. Sprinklers are rated at 74 °C [standard response link with RTI = 130 (m-sec^{½})] and located 3 m on center. The ceiling is 3.0 m above the fire. The ambient temperature is 25 °C. Would the sprinklers activate, and if so, how long would it take for them to activate?



Example Problem 10-1: Fire Scenario with Sprinkler

Solution

Purpose:

(1) Determine if the sprinklers will be activated for the fire scenario.
(2) If the sprinkles are activated, how long would it take for them to activate?

Assumptions:

(1) The fire is located away from walls and corners.
(2) The fire is steady state.
(3) The ceiling is unconfined.
(4) Only convective heat transfer from the hot fire gases is considered.
(5) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1_SI.xls (click on *Sprinkler*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 1,000 kW
- Distance from the Top of the Fuel Package to the Ceiling (H) = 3 m
- Radial Distance from the Plume Centerline to the Sprinkler (r) = 3 m
- Ambient Air Temperature (T_a) = 25 °C
- Select Type of Sprinkler = Standard response link
- Select Sprinkler Classification = Ordinary

Note: Ordinary classification has been selected because the rated value for the sprinklers in this problem (74 °C) is within the range of temperature ratings for ordinary sprinklers (57 °C – 77 °C).

Results*

Sprinkler Type	Sprinkler Activation Time ($t_{activation}$) (min.)
Standard Response Link	1.6

*see spreadsheet on next page

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 10.10-1**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW
Sprinkler Response Time Index (RTI)	130	$(m\text{-}sec)^{1/2}$
Activation Temperature of the Sprinkler ($T_{activation}$)	165	°F
Height of Ceiling above Top of Fuel (H)	3.00	m
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	3.00	m
Ambient Air Temperature (T_a)	25.00	°C
Convective Heat Release Rate Fraction (χ_c)	0.70	

r/H = **1.00**

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, 1 st Proceeding, March 15-16, 1995, Kowloon, Hong Kong, pp. 211-218.*

***Note: The actual RTI should be used when the value is available.**

GENERIC SPRINKLER TEMPERATURE RATING ($T_{activation}$)*

Temperature Classification	Range of Temperature Ratings (°F)	Generic Temperature Ratings (°F)
Ordinary	135 to 170	165
Intermediate	175 to 225	212
High	250 to 300	275
Extra high	325 to 375	350
Very extra high	400 to 475	450
Ultra high	500 to 575	550
Ultra high	650	550
User Specified Value	–	Enter Value

Select Sprinkler Classification
Ordinary
Scroll to desired sprinkler class then Click on selection

Reference: *Automatic Sprinkler Systems Handbook, 6 th Edition, National Fire Protection Association, Quincy, Massachusetts, 1994, Page 67.*

***Note: The actual temperature rating should be used when the value is available.**

ESTIMATING SPRINKLER RESPONSE TIME

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-140.*

$$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln((T_{jet} - T_a)/(T_{jet} - T_{activation})))$$

Where
$t_{activation}$ = sprinkler activation response time (sec)
RTI = sprinkler response time index $(m\text{-}sec)^{1/2}$
u_{jet} = ceiling jet velocity (m/sec)
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
$T_{activation}$ = activation temperature of sprinkler (°C)

Ceiling Jet Temperature Calculation

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \quad \text{for } r/H \leq 0.18$$
$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \quad \text{for } r/H > 0.18$$

Where
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where
Qc = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release rate fraction

Q_c = 700 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.00 r/H > 0.18

>0.18	86.21	<0.18	270.82

$T_{jet} - T_a =$ {5.38 (Q/r)^2/3}/H

$T_{jet} - T_a =$ 86.21

$T_{jet} =$ 111.21 (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\,(Q/H)^{1/3}$ for $r/H \leq 0.15$

$u_{jet} = (0.195\,Q^{1/3}\,H^{1/2})/r^{5/6}$ for $r/H > 0.15$

Where
ujet = 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 = 1.00 r/H > 0.15

>0.15	1.35	<0.15	6.656268234

$u_{jet} =$ (0.195 Q^1/3 H^1/2)/r^5/6

$u_{jet} =$ 1.352 m/sec

SPRINKLER ACTIVATION TIME CALCULATION

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation}$ 93.60 sec

Answer	The sprinkler will respond in approximately	1.56 minutes

NOTE: If $t_{activation}$ = "NUM" Sprinkler does not activate

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 10.10-2

Problem Statement
If the sprinklers in Problem 10-1 are replaced by sprinklers with a response time index (RTI) of 235 (m-sec)^{½}, how long would it take for them to activate?

Solution

Purpose:
(1) Determine the activation time for the specified sprinklers under the fire scenario of Problem 10-1.

Assumptions:
(1) The fire is located away from walls and corners.
(2) The fire is steady state.
(3) The ceiling is unconfined.
(4) Only convective heat transfer from the hot fire gases is considered.
(5) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1_SI.xls (click on *Sprinkler*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 1000 kW
- Distance from the Top of the Fuel Package to the Ceiling (H) = 3 m
- Radial Distance from the Plume Centerline to the Sprinkler (r) = 3 m
- Ambient Air Temperature (T_a) = 25 °C
- Select Type of Sprinkler = Standard response bulb
- Select Sprinkler Classification = Ordinary

Note: The RTI value of 235 (m-sec)^{½} corresponds to a standard response bulb sprinkler. Ordinary classification has been selected because the rated value for the sprinklers in this problem (74 °C, same as Problem 10-1) is within the range of temperature ratings for ordinary sprinklers (57 °C – 77 °C).

Results*

Sprinkler Type	Sprinkler Activation Time ($t_{activation}$) (min.)
Standard Response Bulb	2.8

*see spreadsheet on next page

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 10.10-2**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW
Sprinkler Response Time Index (RTI)	235	$(m\text{-}sec)^{1/2}$
Activation Temperature of the Sprinkler ($T_{activation}$)	165	°F
Height of Ceiling above Top of Fuel (H)	3.00	m
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	3.00	m
Ambient Air Temperature (T_a)	25.00	°C
Convective Heat Release Rate Fraction (χ_c)	0.70	

r/H = 1.00

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 bulb
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, 1 st Proceeding, March 15-16, 1995, Kowloon, Hong Kong, pp. 211-218.*

***Note: The actual RTI should be used when the value is available.**

GENERIC SPRINKLER TEMPERATURE RATING ($T_{activation}$)*

Temperature Classification	Range of Temperature Ratings (°F)	Generic Temperature Ratings (°F)
Ordinary	135 to 170	165
Intermediate	175 to 225	212
High	250 to 300	275
Extra high	325 to 375	350
Very extra high	400 to 475	450
Ultra high	500 to 575	550
Ultra high	650	550
User Specified Value	–	Enter Value

Select Sprinkler Classification
Ordinary
Scroll to desired sprinkler class then Click on selection

Reference: *Automatic Sprinkler Systems Handbook, 6 th Edition, National Fire Protection Association, Quincy, Massachusetts, 1994, Page 67.*

***Note: The actual temperature rating should be used when the value is available.**

ESTIMATING SPRINKLER RESPONSE TIME

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-140.*

$$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln((T_{jet} - T_a)/(T_{jet} - T_{activation})))$$

Where

$t_{activation}$ = sprinkler activation response time (sec)
RTI = sprinkler response time index $(m\text{-}sec)^{1/2}$
u_{jet} = ceiling jet velocity (m/sec)
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
$T_{activation}$ = activation temperature of sprinkler (°C)

Ceiling Jet Temperature Calculation

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \leq 0.18$$
$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

Where

T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where

Qc = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release rate fraction

Q_c = 700 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 1.00 r/H > 0.18

>0.18	86.21	<0.18	270.82

$T_{jet} - T_a =$ {5.38 (Q/r)^2/3}/H

$T_{jet} - T_a =$ 86.21

$T_{jet} =$ 111.21 (°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
ujet = 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 = 1.00 r/H > 0.15

>0.15	1.35	<0.15	6.656268234

$u_{jet} =$ (0.195 Q^1/3 H^1/2)/r^5/6

$u_{jet} =$ 1.352 m/sec

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SPRINKLER ACTIVATION TIME CALCULATION

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation}$ **169.19 sec**

Answer	The sprinkler will respond in approximately	2.82 minutes

NOTE: If $t_{activation}$ = "NUM" Sprinkler does not activate

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

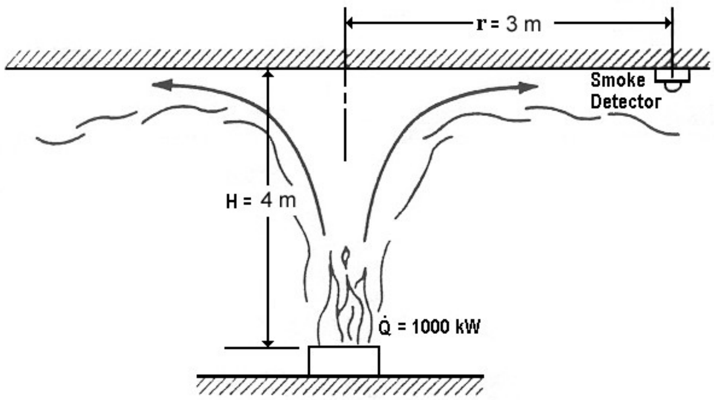
Checked by: Date: Organization:

Additional Information:

11.12 Problems

Example Problem 11.12-1

Problem Statement
Estimate the response time of a smoke detector that is located 3 m radially from the centerline of a 1,000 kW pool fire in a 4 m tall compartment.



Example Problem 11-1: Fire Scenario with Smoke Detector

Solution

Purpose:
(1) Determine the response time of the smoke detector for the fire scenario.

Assumptions:
(1) The fire is steady state
(2) The forced ventilation system is off
(3) There is no heavily obstructed overhead

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1_SI.xls (click on *Smoke_Detector*)

FDTs Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 1,000 kW
- Ceiling Height (H) = 4 m
- Radial Distance from the Plume Centerline to the Smoke Detector (r) = 3 m

Results*

Heat Release Rate (kW)	Smoke Detector Activation Time (t_R) (sec)		
	Method of Alpert	Method of Mowrer	Method of Milke
1,000	0.32	0.74	0.22

*see spreadsheet on next page

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 11.12-1**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	3.00	m
Height of Ceiling above Top of Fuel (H)	4.00	m
Activation Temperature of the Smoke Detector ($T_{activation}$)	30.00	°C
Smoke Detector Response Time Index (RTI)	5.00	$(m\text{-}sec)^{1/2}$
Ambient Air Temperature (T_a)	25.00	°C
Convective Heat Release Rate Fraction (χ_c)	0.70	
Plume Leg 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	10.00	°C

r/H = 0.75

Calculate

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(SI Units)

ESTIMATING SMOKE DETECTOR RESPONSE TIME
METHOD OF ALPERT

Reference: *NFPA Fire Protection Handbook, 19 th Edition, 2003, Page 3-140.*

$$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (ln\ ((T_{jet} - T_a)/(T_{jet} - T_{activation})))$$

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

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \leq 0.18$$

$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

Where
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where
Qc = 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 = 700 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.75 **r/H > 0.18**

>0.18 64.66 **<0.18 167.67**

$T_{jet} - T_a$ = 5.38 ((Q/r)^2/3)/H
$T_{jet} - T_a$ = 64.66
T_{jet} = 89.66 (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\ (Q/H)^{1/3}$ **for r/H ≤ 0.15**
$u_{jet} = (0.195\ Q^{1/3}\ H^{1/2})/r^{5/6}$ **for r/H > 0.15**

Where
u_{jet} = ceiling jet velocity (m/sec)
Q = heat release rate of the fire (kW)
H = height of ceiling above top of fuel (m)
r = radial distance from the plume centerline to the detector (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.75 r/H > 0.15

>0.15 1.56 **<0.15 6.05**

u_{jet} = (0.195 Q^1/3 H^1/2)/r^(5/6)
u_{jet} = 1.561 m/sec

Smoke Detector Response Time Calculation

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln\ (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation}$ = 0.32 sec
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

tpl = t_{pl} = transport lag time of plume (sec)
Cpl = C_{pl} = plume lag time constant
H = H = height of ceiling above top of fuel (m)
Q = Q = heat release rate of the fire (kW)

t_{pl} = 0.43 sec

Transport Lag Time of Ceiling Jet Calculation

$$t_{cj} = (r)^{11/6}/(C_{cj})\,(Q)^{1/3}\,(H)^{1/2}$$

Where

tcj = t_{cj} = transport lag time of ceiling jet (sec)
Ccj = C_{cj} = ceiling jet lag time constant
r = r = radial distance from the plume centerline to the detector (m)
H = H = height of ceiling above top of fuel (m)
Q = Q = heat release rate of the fire (kW)

t_{cj} = 0.31 sec

Smoke Detector Response Time Calculation

$$t_{activation} = t_{pl} + t_{cj}$$

$t_{activation}$ = 0.74 sec

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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 Mall, Atria, and Large Areas," 2000 Edition, Section A.3.4.

$$t_{activation} = X\ H^{4/3}/Q^{1/3}$$

Where
tactivation = 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 = $\Delta T_c\ H^{5/3} / Q^{2/3}$
ΔTc = temperature rise of gases under the ceiling for smoke detector to activate (°C)

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.

$$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f\text{->}c}^{3/5}$$

Where
Hmax = the maximum ceiling clearance to which a plume can rise (ft)
Qc = convective portion of the heat release rate (Btu/sec)
$\Delta T_{f\text{->}c}$ = 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 (kW)
Q = heat release rate of the fire (kW)
χ_c = convective heat release rate fraction

Q_c = 700.00 kW 663.097 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
$\Delta T_{f->c}$ = 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)

$\Delta T_{f->c}$ = **734.39 °C** **1353.90 °F**

Smoke Stratification Effects

$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f->c}^{3/5}$

H_{max} = **4.01 m** **13.15 ft**

In this case the highest point of smoke rise is estimated to be **4.01** m
Thus, the smoke would be expected to reach the ceiling mounted smoke detector.

$Y = \Delta T_c\ H^{5/3} / Q^{2/3}$

Y = **12.68**

$X = 4.6\ 10^{-4}\ Y^2 + 2.7\ 10^{-15}\ Y^6$

X = **0.07**

Smoke Detector Response Time Calculation

$t_{activation} = X\ H^{4/3}/Q^{1/3}$

$t_{activation}$ = **0.22 sec**

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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	Calculation Method	Smoke Detector Response Time (sec)
Summary of Results	**METHOD OF ALPERT**	**0.32**
	METHOD OF MOWRER	**0.74**
	METHOD OF MILKE	**0.22**

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 11.12-2

Problem Statement
During a routine inspection, an NRC resident inspector finds a 1.2 m high stack of wood pallets left in the NPP after a recent MOV modification. When the inspector questions the licensee about this transient combustible, the licensee assures the inspector that if the transient ignited, the smoke detection system would alarm in less than 1 minute.

The SFPE Handbook provides test data for a stack of 4 ft high wood pallets, from which the HRR can be estimated at 3.5 MW.

The compartment has a 7.6 m ceiling with the smoke detectors spaced 9 m (30 ft) on center. The pallets are located in the worst position (i.e., in the center of four smoke detectors).

How long does it take the smoke detector to alarm?

Solution

Purpose:
(1) Determine the response time of the smoke detector for the fire scenario.

Assumptions:
(1) The fire is steady-state.
(2) The forced ventilation system is off.
(3) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1_SI.xls (click on *Smoke_Detector*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 3,500 kW
- Ceiling Height (H) = 7.6 m
- Radial Distance from the Plume Centerline to the Smoke Detector (r) = 6.46 m

Results*

Heat Release Rate ($\dot{Q}$) (kW)	Smoke Detector Activation Time (t_R) (sec)		
	Method of Alpert	Method of Mowrer	Method of Milke
3,500	0.43	1.27	0.56

*see spreadsheets on next page

Therefore, it can be assumed that the smoke detectors would alarm within 1 minute.

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 11.12-2**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	3500.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	6.46	m
Height of Ceiling above Top of Fuel (H)	7.60	m
Activation Temperature of the Smoke Detector ($T_{activation}$)	30.00	°C
Smoke Detector Response Time Index (RTI)	5.00	$(m\text{-}sec)^{1/2}$
Ambient Air Temperature (T_a)	25.00	°C
Convective Heat Release Rate Fraction (χ_c)	0.70	
Plume Leg 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	10.00	°C

r/H = 0.85

Calculate

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ESTIMATING SMOKE DETECTOR RESPONSE TIME
METHOD OF ALPERT

Reference: *NFPA Fire Protection Handbook, 19 th Edition, 2003, Page 3-140.*

$$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln((T_{jet} - T_a)/(T_{jet} - T_{activation})))$$

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

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \leq 0.18$$
$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

Where
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where
Qc = 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 = 2450 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.85 r/H > 0.18

>0.18 47.05 <0.18 132.61

$T_{jet} - T_a =$ 5.38 ((Q/r)^2/3)/H
$T_{jet} - T_a =$ 47.05
$T_{jet} =$ 72.05 (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\ (Q/H)^{1/3}$ for r/H ≤ 0.15
$u_{jet} = (0.195\ Q^{1/3}\ H^{1/2})/r^{5/6}$ for r/H > 0.15

Where
u_{jet} = ceiling jet velocity (m/sec)
Q = heat release rate of the fire (kW)
H = height of ceiling above top of fuel (m)
r = radial distance from the plume centerline to the detector (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.85 r/H > 0.15

>0.15 1.72 <0.15 7.41

$u_{jet} =$ (0.195 Q^1/3 H^1/2)/r^(5/6)
$u_{jet} =$ 1.724 m/sec

Smoke Detector Response Time Calculation

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln\ (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation} =$ **0.43 sec**
NOTE: If $t_{activation}$ = "NUM" Detector does not activate

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(SI Units)

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

tpl = t_{pl} = transport lag time of plume (sec)
Cpl = C_{pl} = plume lag time constant
H = H = height of ceiling above top of fuel (m)
Q = Q = heat release rate of the fire (kW)

t_{pl} = 0.66 sec

Transport Lag Time of Ceiling Jet Calculation

$$t_{cj} = (r)^{11/6}/(C_{cj})\,(Q)^{1/3}\,(H)^{1/2}$$

Where

tcj = t_{cj} = transport lag time of ceiling jet (sec)
Ccj = C_{cj} = ceiling jet lag time constant
r = r = radial distance from the plume centerline to the detector (m)
H = H = height of ceiling above top of fuel (m)
Q = Q = heat release rate of the fire (kW)

t_{cj} = 0.61 sec

Smoke Detector Response Time Calculation

$$t_{activation} = t_{pl} + t_{cj}$$

$t_{activation}$ = 1.27 sec

Version 1805.1
(SI Units)

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 Mall, Atria, and Large Areas," 2000 Edition, Section A.3.4.

$$t_{activation} = X\ H^{4/3}/Q^{1/3}$$

Where
tactivation = 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
$Y = \Delta T_c\ H^{5/3} / Q^{2/3}$
ΔTc = temperature rise of gases under the ceiling for smoke detector to activate (°C)

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.

$$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f\text{->}c}^{3/5}$$

Where
Hmax = the maximum ceiling clearance to which a plume can rise (ft)
Qc = convective portion of the heat release rate (Btu/sec)
$\Delta T_{f\text{->}c}$ = 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 (kW)
Q = heat release rate of the fire (kW)
χ_c = convective heat release rate fraction

Q_c =	**2450.00 kW**	**2320.84 Btu/sec**

Difference in Temperature Due to Fire Between the Fuel Location and Ceiling Level

$$\Delta T_{f\text{->}c} = 1300\ Q_c^{2/3} / H^{5/3}$$

Where
$\Delta T_{f\text{->}c}$ = 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)

$\Delta T_{f\text{->}c}$ = **577.11 °C** **1070.80 °F**

Smoke Stratification Effects

$$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f\text{->}c}^{3/5}$$

H_{max} = **7.62 m** **24.98 ft**

In this case the highest point of smoke rise is estimated to be **7.62** m
Thus, the smoke would be expected to reach the ceiling mounted smoke detector.

$$Y = \Delta T_c\ H^{5/3} / Q^{2/3}$$

Y = **16.03**

$$X = 4.6\ 10^{-4}\ Y^2 + 2.7\ 10^{-15}\ Y^6$$

X = **0.12**

Smoke Detector Response Time Calculation

$$t_{activation} = X\ H^{4/3}/Q^{1/3}$$

$t_{activation}$ = **0.56 sec**

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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(SI Units)

	Calculation Method	Smoke Detector Response Time (sec)
Summary of Results	**METHOD OF ALPERT**	**0.43**
	METHOD OF MOWRER	**1.27**
	METHOD OF MILKE	**0.56**

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 11.12-3

Problem Statement
During a triennial inspection, an NRC inspector discovers that every other smoke detector has inadvertently been painted and is not functional. The detection system in the compartment is single-zoned to arm a pre-action sprinkler system. The detectors are 6.1 m on center. The ceiling is 7 m. The sprinkler system uses 74 °C sprinklers, 3 m on center, and 10.2 cm from the ceiling. The licensee states that even with half the smoke detectors inoperable, a smoke detector would alarm and charge the pre-action system before a quick-response link-type sprinkler head fuses. The expected fire in the compartment is approximately 750 kW. Is the licensee's statement true?

Solution

Purpose:
(1) Determine the response time of the smoke detector for the fire scenario.
(2) Determine the response time of the sprinkler system.

Assumptions:
(1) The fire is steady-state.
(2) The forced ventilation system is off.
(3) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1_SI.xls (click on *Smoke-Detector*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 750 kW
- Ceiling Height (H) = 7 m
- Radial Distance from the Plume Centerline to the Smoke Detector (r) = 6.1 m

(b) 10_Detector_Activation_Time_Sup1_SI.xls (click on *Sprinkler*)

FDT^s Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 750 kW
- Select Quick Response Link
- Select Ordinary
- Ceiling Height (H) = 7 m
- Radial Distance from the Plume Centerline to the Sprinkler (r) = 4.3 m

Results*

Heat Release Rate ($\dot{Q}$) (kW)	Smoke Detector Activation Time (t_R) (sec)		
	Method of Alpert	Method of Mowrer	Method of Milke
750	1.5	1.9	4.9

*see spreadsheet on next page

The sprinkler heads do not activate. Therefore, the licensee's statement is true; however, the non-activation of the sprinkler heads should be of great concern.

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

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(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 11.12-3a**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	750.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	6.10	m
Height of Ceiling above Top of Fuel (H)	7.00	m
Activation Temperature of the Smoke Detector ($T_{activation}$)	30.00	°C
Smoke Detector Response Time Index (RTI)	5.00	$(m\text{-}sec)^{1/2}$
Ambient Air Temperature (T_a)	25.00	°C
Convective Heat Release Rate Fraction (χ_c)	0.70	
Plume Leg 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	10.00	°C

r/H = 0.87

Calculate

Version 1805.1
(SI Units)

ESTIMATING SMOKE DETECTOR RESPONSE TIME
METHOD OF ALPERT

Reference: *NFPA Fire Protection Handbook, 19 th Edition, 2003, Page 3-140.*

$$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln ((T_{jet} - T_a)/(T_{jet} - T_{activation})))$$

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

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \le 0.18$$
$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

Where
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where
Qc = 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 = **525 kW**

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.87 r/H > 0.18

>0.18 19.00 <0.18 54.46

$T_{jet} - T_a =$ 5.38 ((Q/r)^2/3)/H
$T_{jet} - T_a =$ 19.00
$T_{jet} =$ 44.00 (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\ (Q/H)^{1/3}$ for r/H ≤ 0.15
$u_{jet} = (0.195\ Q^{1/3}\ H^{1/2})/r^{5/6}$ for r/H > 0.15

Where
u_{jet} = ceiling jet velocity (m/sec)
Q = heat release rate of the fire (kW)
H = height of ceiling above top of fuel (m)
r = radial distance from the plume centerline to the detector (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.87 r/H > 0.15

>0.15 1.04 <0.15 4.56

$u_{jet} =$ (0.195 Q^1/3 H^1/2)/r^(5/6)
$u_{jet} =$ 1.039 m/sec

Smoke Detector Response Time Calculation

$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln\ (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation} =$ 1.50 sec
NOTE: If $t_{activation}$ = "NUM" Detector does not activate

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(SI Units)

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

tpl = t_{pl} = transport lag time of plume (sec)
Cpl = C_{pl} = plume lag time constant
H = H = height of ceiling above top of fuel (m)
Q = Q = heat release rate of the fire (kW)

t_{pl} = 0.99 sec

Transport Lag Time of Ceiling Jet Calculation

$$t_{cj} = (r)^{11/6}/(C_{cj})\,(Q)^{1/3}\,(H)^{1/2}$$

Where

tcj = t_{cj} = transport lag time of ceiling jet (sec)
Ccj = C_{cj} = ceiling jet lag time constant
r = r = radial distance from the plume centerline to the detector (m)
H = H = height of ceiling above top of fuel (m)
Q = Q = heat release rate of the fire (kW)

t_{cj} = 0.95 sec

Smoke Detector Response Time Calculation

$$t_{activation} = t_{pl} + t_{cj}$$

$t_{activation}$ = 1.94 sec

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(SI Units)

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 Mall, Atria, and Large Areas," 2000 Edition, Section A.3.4.

$$t_{activation} = X\ H^{4/3}/Q^{1/3}$$

Where
tactivation = 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
$Y = \Delta T_c\ H^{5/3} / Q^{2/3}$
ΔTc = temperature rise of gases under the ceiling for smoke detector to activate (°C)

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.

$$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f\text{->}c}^{3/5}$$

Where
Hmax = the maximum ceiling clearance to which a plume can rise (ft)
Qc = convective portion of the heat release rate (Btu/sec)
$\Delta T_{f\text{->}c}$ = 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 (kW)
Q = heat release rate of the fire (kW)
χ_c = convective heat release rate fraction

Q_c = 525.00 kW 497.323 Btu/sec

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Difference in Temperature Due to Fire Between the Fuel Location and Ceiling Level

$$\Delta T_{f\text{->}c} = 1300\ Q_c^{2/3} / H^{5/3}$$

Where
$\Delta T_{f\text{->}c}$ = 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)

$\Delta T_{f\text{->}c}$ =	**226.54 °C**	**439.78 °F**

Smoke Stratification Effects

$$H_{max} = 74\ Q_c^{2/5} / \Delta T_{f\text{->}c}^{3/5}$$

H_{max} =	**7.01 m**	**23.01 ft**

In this case the highest point of smoke rise is estimated to be **7.01** m
Thus, the smoke would be expected to reach the ceiling mounted smoke detector.

$$Y = \Delta T_c\ H^{5/3} / Q^{2/3}$$

Y = **39.03**

$$X = 4.6\ 10^{-4}\ Y^2 + 2.7\ 10^{-15}\ Y^6$$

X = **0.70**

Smoke Detector Response Time Calculation

$$t_{activation} = X\ H^{4/3}/Q^{1/3}$$

$t_{activation}$ = **4.94 sec**

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.1
(SI Units)

	Calculation Method	Smoke Detector Response Time (sec)
Summary of Results	METHOD OF ALPERT	1.50
	METHOD OF MOWRER	1.94
	METHOD OF MILKE	4.94

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 11.12-3b**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	750.00	kW
Sprinkler Response Time Index (RTI)	34	$(m\text{-}sec)^{1/2}$
Activation Temperature of the Sprinkler ($T_{activation}$)	165	°F
Height of Ceiling above Top of Fuel (H)	7.00	m
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	4.30	m
Ambient Air Temperature (T_a)	25.00	°C
Convective Heat Release Rate Fraction (χ_c)	0.70	

r/H = 0.61

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
Quick 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.*

$$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln ((T_{jet} - T_a)/(T_{jet} - T_{activation})))$$

Where

$t_{activation}$ = sprinkler activation response time (sec)
RTI = sprinkler response time index $(m\text{-}sec)^{1/2}$
u_{jet} = ceiling jet velocity (m/sec)
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
$T_{activation}$ = activation temperature of sprinkler (°C)

Ceiling Jet Temperature Calculation

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \le 0.18$$
$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

Where

T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where

Qc = convective portion of the heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release rate fraction

Q_c = 525 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.61 r/H > 0.18

>0.18 23.99 <0.18 54.46

$T_{jet} - T_a =$ {5.38 (Q/r)^2/3}/H

$T_{jet} - T_a =$ 23.99

$T_{jet} =$ 48.99 (°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
ujet = ceiling jet velocity (m/sec)
Q = heat release rate of the fire (kW)
H = height of ceiling above top of fuel (m)
r = radial distance from the plume centerline to the sprinkler (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H = 0.61 r/H > 0.15

>0.15 1.39 <0.15 4.559588408

$u_{jet} =$ (0.195 Q^1/3 H^1/2)/r^5/6

$u_{jet} =$ 1.390 m/sec

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(SI Units)

SPRINKLER ACTIVATION TIME CALCULATION

$t_{activation} = (RTI/(\sqrt{u_{jet}})) (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation}$ #NUM! sec

Answer	The sprinkler will respond in approximately	#NUM!	minutes

NOTE: If $t_{activation}$ = "NUM" Sprinkler does not activate

NOTE:

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

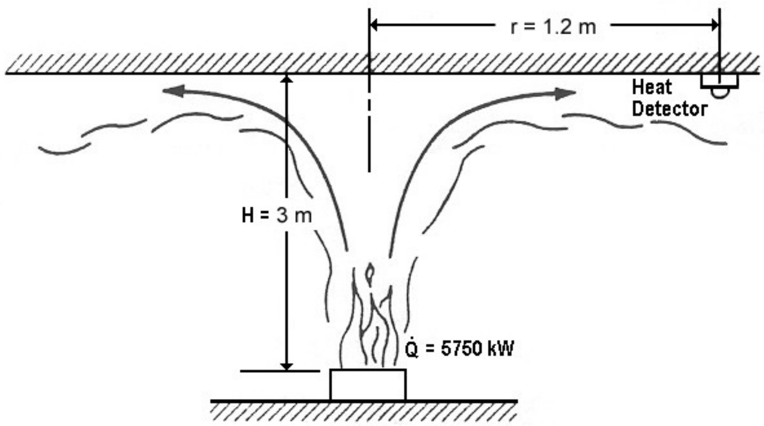
Additional Information:

12.12 Problems

Example Problem 12.12-1

Problem Statement

A 3.2 m^2 lube oil pool fire with $\dot{Q}$ = 5,750 kW occurs in a space protected with fixed- temperature heat detectors. Calculate the activation time for the fixed-temperature heat detectors, using 3 m spacing, in an area with a ceiling height of 3 m. The detector activation temperature is 53 °C, the radial distance to the detector is 1.2 m, and the ambient temperature is 25 °C.



Example Problem 12-1: Fire Scenario with Heat Detectors

Solution

Purpose:

(1) Determine the response time of the fixed-temperature heat detectors for the fire scenario.

Assumptions:

(1) The fire is located away from walls and corners.
(2) The fire is steady state and plume is under unconfined ceiling.
(3) Only convective heat transfer from the hot fire gases is considered.
(4) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 10_Detector_Activation_Time_Sup1_SI.xls (click on *FTHDetector*)

FDTs Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 5,750 kW
- Radial Distance to the Detector (r) = 1.2 m
- Activation Temperature of the Fixed-Temperature Heat Detector ($T_{activation}$) = 53 °C
- Distance from the Top of the Fuel Package to the Ceiling (H) = 3 m
- Ambient Air Temperature (T_a) = 25 °C
- Click on the option button for FTH Detectors with $T_{activation}$ = 128 °F
- Select Detector Spacing: 10

Results*

Detector Type	Heat Detector Activation Time ($t_{activation}$) (min.)
Fixed-Temperature	0.2

*see spreadsheet on next page

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 12.12-1**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	5750.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	1.20	m
Activation Temperature of the Fixed Temperature Heat Detector ($T_{activation}$)	128	°F
Detector Response Time Index (RTI)	490.00	$(m\text{-}sec)^{1/2}$
Height of Ceiling above Top of Fuel (H)	3.00	m
Ambient Air Temperature (T_a)	25.00	°C
Convective Heat Release Fraction (χ_c)	0.70	

r/H = **0.40**

Calculate

INPUT DATA FOR ESTIMATING HEAT DETECTOR RESPONSE TIME

Activation Temperature $T_{activation}$

T= 128 F

UL Listed Spacing r (ft)	Response Time Index RTI $(m\text{-}sec)^{1/2}$	Activation Temperature (°F)
10	490	128
15	306	128
20	325	128
25	152	128
30	116	128
40	87	128
50	72	128
70	44	128
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

10

Scroll to desired spacing then Click on selection

T= 135 F

UL Listed Spacing r (ft)	Response Time Index RTI $(m\text{-}sec)^{1/2}$	Activation Temperature (°F)
10	404	135
15	233	135
20	165	135
25	123	135
30	98	135
40	70	135
50	54	135
70	20	135
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 145 F

UL Listed Spacing r (ft)	Response Time Index RTI $(m\text{-}sec)^{1/2}$	Activation Temperature (°F)
10	321	145
15	191	145
20	129	145
25	96	145
30	75	145
40	50	145
50	37	145
70	11	145
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 160 F

UL Listed Spacing r (ft)	Response Time Index RTI $(m\text{-}sec)^{1/2}$	Activation Temperature (°F)
10	239	160
15	135	160
20	86	160
25	59	160
30	44	160
40	22	160
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 170 F

UL Listed Spacing r (ft)	Response Time Index RTI $(m\text{-}sec)^{1/2}$	Activation Temperature (°F)
10	196	170
15	109	170
20	64	170
25	39	170
30	27	170
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 196 F

UL Listed Spacing r (ft)	Response Time Index RTI $(m\text{-}sec)^{1/2}$	Activation Temperature (°F)
10	119	196
15	55	196
20	21	196
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then

Click on selection

Reference: *NFPA Standard 72, National Fire Alarm Code, Appendix B, Table B-3.2.5.1, 1999, Edition*.

ESTIMATING FIXED TEMPERATURE HEAT DETECTOR RESPONSE TIME

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-140.*

$$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln ((T_{jet} - T_a)/(T_{jet} - T_{activation})))$$

Where

$t_{activation}$ = detector activation time (sec)
RTI = detector response time index $(m\text{-}sec)^{1/2}$
u_{jet} = ceiling jet velocity (m/sec)
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
$T_{activation}$ = activation temperature of detector (°C)

Ceiling Jet Temperature Calculation

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \le 0.18$$
$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

Where

T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where

Qc = convective heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release fraction

Q_c = 4025 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H =		0.40	r/H > 0.18	
>0.18	509.70		<0.18	869.22

$T_{jet} - T_a =$ 5.38 ((Q/r)^2/3)/H

$T_{jet} - T_a =$ 509.70

$T_{jet} =$ 534.70 (°C)

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\ (Q/H)^{1/3}$ for $r/H \leq 0.15$

$u_{jet} = (0.195\ Q^{1/3}\ H^{1/2})/r^{5/6}$ for $r/H > 0.15$

Where
u_{jet} = ceiling jet velocity (m/sec)
Q = heat release rate of the fire (kW)
H = height of ceiling above top of fuel (m)
r = radial distance from the plume centerline to the detector (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H =		0.40	r/H > 0.15	
>0.15	5.20		<0.15	11.925

$u_{jet} =$ (0.195 Q^1/3 H^1/2)/r^(5/6)

$u_{jet} =$ 5.198 m/sec

DETECTOR ACTIVATION TIME CALCULATION

$t_{activation} = (RTI/(\sqrt{u_{jet}})) (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$

$t_{activation} =$ 12.29 sec

Answer	The detector will respond in approximately	0.20 minutes

NOTE: If $t_{activation}$ = "NUM" Detector does not activate

NOTE:

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

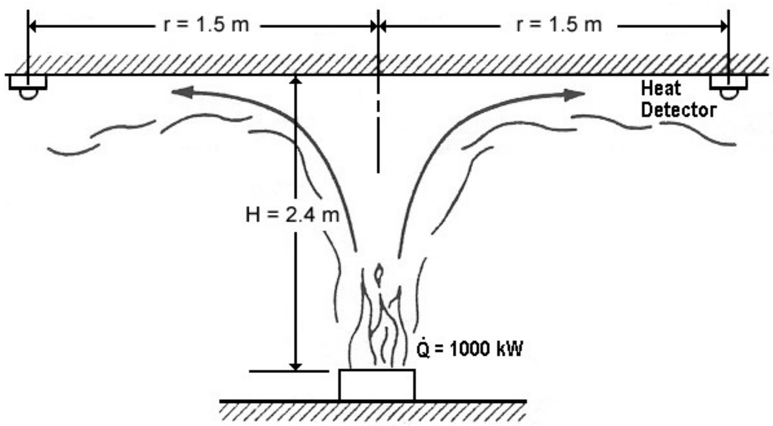
Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 12.12-2

Problem Statement
A trash fire with $\dot{Q}$ = 1,000 kW occurs in a space protected with fixed-temperature heat detectors. Calculate the activation time for the fixed-temperature heat detectors, using 3 m spacing, in an area with a ceiling height of 2.4 m. The fire is located directly between heat detectors. The detector activation temperature is 71 °C, and the ambient temperature is 20 °C.



Example Problem 12-2: Fire Scenario with heat detectors equidistant from the fire source

Solution

Purpose:
(1) Determine the response time of the fixed-temperature heat detectors for the fire scenario.

Assumptions:
(1) The fire is located away from walls and corners.
(2) The fire is steady state and plume is under unconfined ceiling.
(3) Only convective heat transfer from the hot fire gases is considered.
(4) There is no heavily obstructed overhead.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(1) 10_Detector_Activation_Time_Sup1_SI.xls (click on *FTHDetector*)

FDTs Input Parameters:
- Heat Release Rate of the Fire ($\dot{Q}$) = 1,000 kW
- Radial Distance to the Detector (r) = 1.5 m
- Activation Temperature of the Fixed-Temperature Heat Detector ($T_{activation}$) = 71 °C
- Distance from the Top of the Fuel Package to the Ceiling (H) = 2.4 m
- Ambient Air Temperature (T_a) = 20 °C
- Click on the option button for FTH detectors with $T_{activation}$ = 160 °F
- Select Detector Spacing: 10

Results*

Detector Type	Heat Detector Activation Time ($t_{activation}$) (min.)
Fixed-Temperature	0.9

*see spreadsheet on next page

CHAPTER 10
ESTIMATING SPRINKLER RESPONSE TIME

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 12.12-2**

INPUT PARAMETERS

Heat Release Rate of the Fire (Q) (Steady State)	1000.00	kW
Radial Distance to the Detector (r) **never more than 0.707 or 1/2√2 of the listed spacing**	1.50	m
Activation Temperature of the Fixed Temperature Heat Detector ($T_{activation}$)	160	°F
Detector Response Time Index (RTI)	239.00	$(m\text{-}sec)^{1/2}$
Height of Ceiling above Top of Fuel (H)	2.40	m
Ambient Air Temperature (T_a)	25.00	°C
Convective Heat Release Fraction (χ_c)	0.70	

r/H = **0.63**

Calculate

INPUT DATA FOR ESTIMATING HEAT DETECTOR RESPONSE TIME

Activation Temperature $T_{activation}$

T= 128 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	490	128
15	306	128
20	325	128
25	152	128
30	116	128
40	87	128
50	72	128
70	44	128
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 135 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	404	135
15	233	135
20	165	135
25	123	135
30	98	135
40	70	135
50	54	135
70	20	135
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 145 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	321	145
15	191	145
20	129	145
25	96	145
30	75	145
40	50	145
50	37	145
70	11	145
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 160 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	239	160
15	135	160
20	86	160
25	59	160
30	44	160
40	22	160
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

10

Scroll to desired spacing then Click on selection

T= 170 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	196	170
15	109	170
20	64	170
25	39	170
30	27	170
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then Click on selection

T= 196 F

UL Listed Spacing r (ft)	Response Time Index RTI (m-sec)$^{1/2}$	Activation Temperature (°F)
10	119	196
15	55	196
20	21	196
User Specified Value	Enter Value	Enter Value

Select Detector Spacing

Scroll to desired spacing then

Click on selection

Reference: *NFPA Standard 72, National Fire Alarm Code, Appendix B, Table B-3.2.5.1, 1999, Edition*.

ESTIMATING FIXED TEMPERATURE HEAT DETECTOR RESPONSE TIME

Reference: *NFPA Fire Protection Handbook, 19th Edition, 2003, Page 3-140.*

$$t_{activation} = (RTI/(\sqrt{u_{jet}}))\ (\ln ((T_{jet} - T_a)/(T_{jet} - T_{activation})))$$

Where

$t_{activation}$ = detector activation time (sec)
RTI = detector response time index $(m\text{-}sec)^{1/2}$
u_{jet} = ceiling jet velocity (m/sec)
T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
$T_{activation}$ = activation temperature of detector (°C)

Ceiling Jet Temperature Calculation

$$T_{jet} - T_a = 16.9\ (Q)^{2/3}/H^{5/3} \qquad \text{for } r/H \le 0.18$$

$$T_{jet} - T_a = 5.38\ (Q/r)^{2/3}/H \qquad \text{for } r/H > 0.18$$

Where

T_{jet} = ceiling jet temperature (°C)
T_a = ambient air temperature (°C)
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)

Convective Heat Release Rate Calculation

$$Q_c = \chi_c\ Q$$

Where

Qc = convective heat release rate (kW)
Q = heat release rate of the fire (kW)
χc = convective heat release fraction

Q_c = 700 kW

Radial Distance to Ceiling Height Ratio Calculation

r/H =		**0.63**	**r/H > 0.18**	
>0.18		**171.07**	**<0.18**	**392.83**

T_{jet} - T_a = **5.38 ((Q/r)^2/3)/H**

T_{jet} - T_a = **171.07**

T_{jet} = **196.07 (°C)**

Ceiling Jet Velocity Calculation

$u_{jet} = 0.96\ (Q/H)^{1/3}$ **for r/H ≤ 0.15**

$u_{jet} = (0.195\ Q^{1/3}\ H^{1/2})/r^{5/6}$ **for r/H > 0.15**

Where
u_{jet} = ceiling jet velocity (m/sec)
Q = heat release rate of the fire (kW)
H = height of ceiling above top of fuel (m)
r = radial distance from the plume centerline to the detector (m)

Radial Distance to Ceiling Height Ratio Calculation

r/H =		**0.63**	**r/H > 0.15**	
>0.15	**2.15**		**<0.15**	**7.1702**

u_{jet} = **(0.195 Q^1/3 H^1/2)/r^(5/6)**

u_{jet} = **2.155** **m/sec**

DETECTOR ACTIVATION TIME CALCULATION

$$t_{activation} = (RTI/(\sqrt{u_{jet}})) (\ln (T_{jet} - T_a)/(T_{jet} - T_{activation}))$$

$t_{activation} =$ **51.14 sec**

Answer	**The detector will respond in approximately**	**0.85 minutes**

NOTE: If $t_{activation}$ = "NUM" Detector does not activate

NOTE:

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

13.10 Problems

Example Problem 13.10-1

Problem Statement
Consider a compartment 6.0 m wide x 8.0 m long x 4.0 m high (w_c x l_c x h_c), with an opening 1.0 m wide and 2.5 m high (w_v x h_v). The interior lining material of the compartment is 15.24 cm concrete. Calculate the HRR necessary for flashover, $\dot{Q}_{FO}$, and the post-flashover compartment temperature, T_{PFO}.

Solution

Purpose:
(1) Determine the heat release rate for flashover for the given compartment.

Assumptions:
(1) Natural Ventilation

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 13_Compartment_Flashover_Calculations_Sup1_SI.xls
(click on *Post_Flashover_Temperature* to calculate the post-flashover temperature)
(click on *Flashover-HRR* to calculate the HRR for flashover)

FDTs Input Parameters:
- Compartment Width (w_c) = 6.0 m
- Compartment Length (l_c) = 8.0 m
- Compartment Height (h_c) = 4.0 m
- Vent Width (w_v) = 1.0 m
- Vent Height (h_v) = 2.5 m
- Interior Lining Thickness (δ) = 15.24 cm (*Flashover-HRR only*)
- Select Material: **Concrete** (*Flashover-HRR only*)

Results*

Post-Flashover Compartment Temperature (T_{PFO}) (°C)	HRR for Flashover ($\dot{Q}_{FO}$) (kW)		
Method of Law	Method of MQH	Method of Babrauskas	Method of Thomas
832	1,781	2,965	3097

*see spreadsheet on next page

CHAPTER 13
PREDICTING COMPARTMENT
POST-FLASHOVER TEMPERATURE

Version 1805.1
(SI Units)

The following calculations estimate the compartment post-flashover temperature.

Parameters in YELLOW CELLS are Entered by the User.

All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 13.10-1a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	6.00	m
Compartment Length (l_c)	8.00	m
Compartment Height (h_c)	4.00	m
Vent Width (w_v)	1.00	m
Vent Height (h_v)	2.50	m

Calculate

METHOD OF MARGARET LAW

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-183.

$$T_{PFO\ (max)} = 6000\ (1 - e^{-0.1\Omega}) / (\sqrt{\Omega})$$

Where,
$T_{PFO\ (max)}$ = maximum compartment post-flashover temperature (°C)
Ω = ventilation factor

Ventilation Factor

$$\Omega = (A_T - A_v) / A_v (\sqrt{h_v})$$

Where,
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\ (h_v)$$

Where,
A_v = area of ventilation opening (m^2)
w_v = vent width (m)
h_v = vent height (m)

A_v = 2.50 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 = 205.50 m^2

Ventilation Factor Calculation

$$\Omega = (A_T - A_v) / A_v (\sqrt{h_v})$$

Where,

Ω = ventilation factor
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = vent height (m)

Ω = 51.36 $m^{-1/2}$

COMPARTMENT POST-FLASHOVER TEMPERATURE

$$T_{PFO\ (max)} = 6000\ (1 - e^{-0.1\Omega}) / (\sqrt{\Omega})$$

Answer	$T_{PFO\ (max)}$ =	832.33 °C	1530.19 °F

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions, or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

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.

Project / Inspection Title: Example 13.10-1b

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	6.00	m
Compartment Length (l_c)	8.00	m
Compartment Height (h_c)	4.00	m
Vent Width (w_v)	1.00	m
Vent Height (h_v)	2.50	m
Interior Lining Thickness (δ)	15.24	cm
Interior Lining Thermal Conductivity (k)	0.0016	kW/m-K

Calculate

THERMAL PROPERTIES DATA

MATERIAL	THERMAL CONDUCTIVITY k (kW/m-K)
Aerated Concrete	0.00026
Alumina Silicate Block	0.00014
Aluminum (pure)	0.206
Brick	0.0008
Brick/Concrete Block	0.00073
Calcium Silicate Board	0.00013
Chipboard	0.00015
Concrete	0.0016
Expended Polystyrene	0.000034
Fiber Insulation Board	0.00053
Glass Fiber Insulation	0.000037
Glass Plate	0.00076
Gypsum Board	0.00017
Plasterboard	0.00016
Plywood	0.00012
Steel (0.5% Carbon)	0.054
User Specified Value	Enter Value

Reference: Klote, J., J. Milke, Principles of Smoke Management, 2002, Page 270.

Select Material

Concrete

Scroll to desired material
Click on selection

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.

$$Q_{FO} = 610 \sqrt{(h_k\, A_T\, A_v\, (\sqrt{h_v}))}$$

Where,
Q_{FO} = heat release rate necessary for flashover (kW)
h_k = effective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Heat Transfer Coefficient Calculation

$$h_k = k/\delta$$

Assuming that compartment has been heated thoroughly before flashover, i.e., t > tp.

Where,
h_k = effective heat transfer coefficient (kW/m^2-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

h_k = 0.010 kW/m^2-K

Area of Ventilation Opening Calculation

$$A_v = (w_v)\,(h_v)$$

Where,
A_v = area of ventilation opening (m^2)
w_v = vent width (m)
h_v = vent height (m)

A_v = 2.50 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 = 205.50 m^2

MINIMUM HEAT RELEASE RATE FOR FLASHOVER

$$Q_{FO} = 610 \sqrt{(h_k A_T A_v (\sqrt{h_v}))}$$

Q_{FO} = 1781.39 kW

PREDICTING FLASHOVER HEAT RELEASE RATE METHOD OF BABRAUSKAS

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.

$$Q_{FO} = 750 A_v (\sqrt{h_v})$$

Where,
Q_{FO} = heat release rate necessary for flashover (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover

$$Q_{FO} = 750 A_v (\sqrt{h_v})$$

Q_{FO} = 2964.64 kW

PREDICTING FLASHOVER HEAT RELEASE RATE METHOD OF THOMAS

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.

$$Q_{FO} = 7.8 A_T + 378 A_v (\sqrt{h_v})$$

Where,
Q_{FO} = heat release rate necessary for flashover (kW)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover

$$Q_{FO} = 7.8 A_T + 378 A_v (\sqrt{h_v})$$

Q_{FO} = 3097.08 kW

Summary of Results

CALCULATION METHOD	FLASHOVER HRR (kW)
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)	1781
METHOD OF BABRAUSKAS	2965
METHOD OF THOMAS	3097

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions, or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 13.10-2

Problem Statement
Consider a compartment 6.0 m wide x 8.0 m long x 4.0 m high (w_c x l_c x h_c), with an opening 1.0 m wide and 2.5 m high (w_v x h_v). The interior lining material of the compartment is 1.6 cm gypsum. Calculate the HRR necessary for flashover, $\dot{Q}_{FO}$, and the post- flashover compartment temperature, T_{PFO}.

Solution

Purpose:
(1) Determine the heat release rate for flashover for the given compartment.

Assumptions:
(1) Natural Ventilation

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 13_Compartment_Flashover_Calculations_Sup1_SI.xls
(click on *Post_Flashover_Temperature* to calculate the post-flashover temperature)
(click on *Flashover-HRR* to calculate the HRR for flashover)

FDT^s Input Parameters:
- Compartment Width (w_c) = 6.0 m
- Compartment Length (l_c) = 8.0 m
- Com partment Height (h_c) = 4.0 m
- Vent Width (w_v) = 1.0 m
- Vent Height (h_v) = 2.5 m
- Interior Lining Thickness (δ) = 1.6 cm (Flashover-HRR only)
- Select Material: **Gypsum Board** (Flashover-HRR only)

Results*

Post-Flashover Compartment Temperature (T_{PFO}) (°C)	HRR for Flashover ($\dot{Q}_{FO}$) (kW)		
Method of Law	Method of MQH	Method of Babrauskas	Method of Thomas
832	1,792	2,965	3,097

*see spreadsheet on next page

CHAPTER 13
PREDICTING COMPARTMENT
POST-FLASHOVER TEMPERATURE

Version 1805.1
(SI Units)

The following calculations estimate the compartment post-flashover temperature.

Parameters in YELLOW CELLS are Entered by the User.

All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 13.10-2a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	6.00	m
Compartment Length (l_c)	8.00	m
Compartment Height (h_c)	4.00	m
Vent Width (w_v)	1.00	m
Vent Height (h_v)	2.50	m

Calculate

METHOD OF MARGARET LAW

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-183.

$$T_{PFO\,(max)} = 6000\,(1 - e^{-0.1\Omega}) / (\sqrt{\Omega})$$

Where,
$T_{PFO\,(max)}$ = maximum compartment post-flashover temperature (°C)
Ω = ventilation factor

Ventilation Factor

$$\Omega = (A_T - A_v) / A_v\,(\sqrt{h_v})$$

Where,
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\,(h_v)$$

Where,
A_v = area of ventilation opening (m^2)
w_v = vent width (m)
h_v = vent height (m)

A_v = 2.50 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 = 205.50 m^2

Ventilation Factor Calculation

$$\Omega = (A_T - A_v) / A_v (\sqrt{h_v})$$

Where,

Ω = ventilation factor
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = vent height (m)

Ω = 51.36 $m^{-1/2}$

COMPARTMENT POST-FLASHOVER TEMPERATURE

$$T_{PFO\,(max)} = 6000\,(1 - e^{-0.1\Omega}) / (\sqrt{\Omega})$$

Answer	$T_{PFO\,(max)}$ =	832.33 °C	1530.19 °F

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions, or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

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.

Project / Inspection Title: **Example 13.10-2b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	6.00	m
Compartment Length (l_c)	8.00	m
Compartment Height (h_c)	4.00	m
Vent Width (w_v)	1.00	m
Vent Height (h_v)	2.50	m
Interior Lining Thickness (δ)	1.60	cm
Interior Lining Thermal Conductivity (k)	0.00017	kW/m-K

Calculate

THERMAL PROPERTIES DATA

MATERIAL	THERMAL CONDUCTIVITY k (kW/m-K)
Aerated Concrete	0.00026
Alumina Silicate Block	0.00014
Aluminum (pure)	0.206
Brick	0.0008
Brick/Concrete Block	0.00073
Calcium Silicate Board	0.00013
Chipboard	0.00015
Concrete	0.0016
Expended Polystyrene	0.000034
Fiber Insulation Board	0.00053
Glass Fiber Insulation	0.000037
Glass Plate	0.00076
Gypsum Board	0.00017
Plasterboard	0.00016
Plywood	0.00012
Steel (0.5% Carbon)	0.054
User Specified Value	Enter Value

Reference: Klote, J., J. Milke, Principles of Smoke Management, 2002, Page 270.

Select Material

Gypsum Board

Scroll to desired material
Click on selection

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.

$$Q_{FO} = 610 \sqrt{(h_k A_T A_v (\sqrt{h_v}))}$$

Where,
Q_{FO} = heat release rate necessary for flashover (kW)
h_k = effective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Heat Transfer Coefficient Calculation

$$h_k = k/\delta$$

Assuming that compartment has been heated thoroughly before flashover, i.e., t > tp.

Where,
h_k = effective heat transfer coefficient (kW/m^2-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

h_k = 0.011 kW/m^2-K

Area of Ventilation Opening Calculation

$$A_v = (w_v)(h_v)$$

Where,
A_v = area of ventilation opening (m^2)
w_v = vent width (m)
h_v = vent height (m)

A_v = 2.50 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 = 205.50 m^2

MINIMUM HEAT RELEASE RATE FOR FLASHOVER

$$Q_{FO} = 610 \sqrt{(h_k A_T A_v (\sqrt{h_v}))}$$

Q_{FO} = 1792.07 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF BABRAUSKAS

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.

$$Q_{FO} = 750 A_v (\sqrt{h_v})$$

Where,
Q_{FO} = heat release rate necessary for flashover (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover

$$Q_{FO} = 750 A_v (\sqrt{h_v})$$

Q_{FO} = 2964.64 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF THOMAS

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.

$$Q_{FO} = 7.8 A_T + 378 A_v (\sqrt{h_v})$$

Where,
Q_{FO} = heat release rate necessary for flashover (kW)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover

$$Q_{FO} = 7.8 A_T + 378 A_v (\sqrt{h_v})$$

Q_{FO} = 3097.08 kW

CHAPTER 13
PREDICTING COMPARTMENT FLASHOVER
HEAT RELEASE RATE

Version 1805.1
(SI Units)

Summary of Results

CALCULATION METHOD	FLASHOVER HRR (kW)
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)	1792
METHOD OF BABRAUSKAS	2965
METHOD OF THOMAS	3097

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions, or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 13.10-3

Problem Statement
Consider a compartment 6.0 m wide x 8.0 m long x 4.0 m high (w_c x l_c x h_c), with an opening 2.0 m wide and 2.5 m high (w_v x h_v). The interior lining material of the compartment is 15.24 cm concrete. Calculate the HRR necessary for flashover, $\dot{Q}_{FO}$, and the post-flashover compartment temperature, T_{PFO}.

Solution

Purpose:
(1) Determine the heat release rate for flashover for the given compartment.

Assumptions:
(1) Natural Ventilation

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 13.1_Compartment_Flashover_Calculations_Sup1_SI.xls
(click on *Post_Flashover_Temperature* to calculate the post-flashover temperature)
(click on *Flashover-HRR* to calculate the HRR for flashover)

FDTs Input Parameters:
- Compartment Width (w_c) = 6.0 m
- Compartment Length (l_c) = 8.0 m
- Compartment Height (h_c) = 4.0 m
- Vent Width (w_v) = 2.0 m
- Vent Height (h_v) = 2.5 m
- Interior Lining Thickness (δ) = 15.24 cm (*Flashover-HRR only*)
- Select Material: **Concrete** (*Flashover-HRR only*)

Results*

Post-Flashover Compartment Temperature (T_{PFO}) (°C)	HRR for Flashover ($\dot{Q}_{FO}$) (kW)		
Method of Law	Method of MQH	Method of Babrauskas	Method of Thomas
1,100	2,504	5,929	4,572

*see spreadsheet on next page

CHAPTER 13
PREDICTING COMPARTMENT
POST-FLASHOVER TEMPERATURE

Version 1805.1
(SI Units)

The following calculations estimate the compartment post-flashover temperature.
Parameters in YELLOW CELLS are Entered by the User.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 13.10-3a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	6.00	m
Compartment Length (l_c)	8.00	m
Compartment Height (h_c)	4.00	m
Vent Width (w_v)	2.00	m
Vent Height (h_v)	2.50	m

Calculate

METHOD OF MARGARET LAW

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-183.

$$T_{PFO\,(max)} = 6000\,(1 - e^{-0.1\Omega}) / (\sqrt{\Omega})$$

Where,
$T_{PFO\,(max)}$ = maximum compartment post-flashover temperature (°C)
Ω = ventilation factor

Ventilation Factor

$$\Omega = (A_T - A_v) / A_v\,(\sqrt{h_v})$$

Where,
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Area of Ventilation Opening Calculation

$$A_v = (w_v)\,(h_v)$$

Where,
A_v = area of ventilation opening (m^2)
w_v = vent width (m)
h_v = vent height (m)

A_v = 5.00 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 = 203.00 m^2

Ventilation Factor Calculation

$$\Omega = (A_T - A_v) / A_v (\sqrt{h_v})$$

Where,
Ω = ventilation factor
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = vent height (m)

Ω = 25.05 $m^{-1/2}$

COMPARTMENT POST-FLASHOVER TEMPERATURE

$$T_{PFO\ (max)} = 6000\ (1 - e^{-0.1\Omega}) / (\sqrt{\Omega})$$

Answer	$T_{PFO\ (max)}$ =	1100.95 °C	2013.70 °F

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions, or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

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.

Project / Inspection Title: **Example 13.10-3b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	6.00	m
Compartment Length (l_c)	8.00	m
Compartment Height (h_c)	4.00	m
Vent Width (w_v)	2.00	m
Vent Height (h_v)	2.50	m
Interior Lining Thickness (δ)	15.24	cm
Interior Lining Thermal Conductivity (k)	0.0016	kW/m-K

Calculate

THERMAL PROPERTIES DATA

MATERIAL	THERMAL CONDUCTIVITY k (kW/m-K)
Aerated Concrete	0.00026
Alumina Silicate Block	0.00014
Aluminum (pure)	0.206
Brick	0.0008
Brick/Concrete Block	0.00073
Calcium Silicate Board	0.00013
Chipboard	0.00015
Concrete	0.0016
Expended Polystyrene	0.000034
Fiber Insulation Board	0.00053
Glass Fiber Insulation	0.000037
Glass Plate	0.00076
Gypsum Board	0.00017
Plasterboard	0.00016
Plywood	0.00012
Steel (0.5% Carbon)	0.054
User Specified Value	Enter Value

Reference: Klote, J., J. Milke, Principles of Smoke Management, 2002, Page 270.

Select Material

Concrete

Scroll to desired material
Click on selection

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.

$$Q_{FO} = 610 \sqrt{(h_k\, A_T\, A_v\, (\sqrt{h_v}))}$$

Where,
Q_{FO} = heat release rate necessary for flashover (kW)
h_k = effective heat transfer coefficient (kW/m^2-K)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Heat Transfer Coefficient Calculation

$$h_k = k/\delta$$

Assuming that compartment has been heated thoroughly before flashover, i.e., t > tp.

Where,
h_k = effective heat transfer coefficient (kW/m^2-K)
k = interior lining thermal conductivity (kW/m-K)
δ = interior lining thickness (m)

h_k = 0.010 kW/m^2-K

Area of Ventilation Opening Calculation

$$A_v = (w_v)\,(h_v)$$

Where,
A_v = area of ventilation opening (m^2)
w_v = vent width (m)
h_v = vent height (m)

A_v = 5.00 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 = 203.00 m^2

MINIMUM HEAT RELEASE RATE FOR FLASHOVER

$$Q_{FO} = 610 \sqrt{(h_k A_T A_v (\sqrt{h_v}))}$$

Q_{FO} = 2503.89 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF BABRAUSKAS

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.

$$Q_{FO} = 750 A_v (\sqrt{h_v})$$

Where,
Q_{FO} = heat release rate necessary for flashover (kW)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover

$$Q_{FO} = 750 A_v (\sqrt{h_v})$$

Q_{FO} = 5929.27 kW

PREDICTING FLASHOVER HEAT RELEASE RATE
METHOD OF THOMAS

Reference: SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 3-184.

$$Q_{FO} = 7.8 A_T + 378 A_v (\sqrt{h_v})$$

Where,
Q_{FO} = heat release rate necessary for flashover (kW)
A_T = total area of the compartment enclosing surface boundaries excluding area of vent openings (m^2)
A_v = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)

Minimum Heat Release Rate for Flashover

$$Q_{FO} = 7.8 A_T + 378 A_v (\sqrt{h_v})$$

Q_{FO} = 4571.75 kW

Summary of Results

CALCULATION METHOD	FLASHOVER HRR (kW)
METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)	2504
METHOD OF BABRAUSKAS	5929
METHOD OF THOMAS	4572

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions, or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

14.10 Problems

Example Problem 14.10-1

Problem Statement

A closed compartment in a facility pump room has dimensions 3.0 m wide x 3.7 m long x 3.0 m high (w_c x l_c x h_c). A fire starts with a constant HRR of $\dot{Q}$ = 100 kW. Estimate the pressure rise attributable to the expansion of gases after 10 seconds.

Solution

Purpose:

(1) Estimate the pressure rise in the compartment 10 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) Information:

Use the following FDT^s:

(a) 14_Compartment_Over_Pressure_Calculations_Sup1_SI.xls

FDT^s Input Parameters:

- Compartment Width (w_c) = 3.0 m
- Compartment Length (l_c) = 3.7 m
- Compartment Height (h_c) = 3.0 m
- Fire Heat Release Rate ($\dot{Q}$) = 100 kW
- Time After Ignition (t) = 10 sec

Results*

Pressure Rise	12.14 kPa

*see spreadsheet on next page

CHAPTER 14
ESTIMATING PRESSURE RISE DUE TO A FIRE IN A CLOSED COMPARTMENT

Version 1805.1 (SI Units)

The following calculations estimate the pressure rise in a compartment due to fire and combustion.
Parameters in YELLOW CELLS are Entered by the User.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 14.10-1**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	3.00	m
Compartment Length (l_c)	3.70	m
Compartment Height (h_c)	3.00	m
Fire Heat Release Rate (Q)	100.00	kW
Time after Ignition (t)	10.00	sec
Ambient Air Temperature (T_a)	25.00	°C

Calculate

AMBIENT CONDITIONS

Initial Atmospheric Pressure (P_a)	101.35	kPa
Specific Heat of Air at Constant Volume (c_v)	0.71	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3

NOTE:

Values of Specific Heat of Air at Constant Volume (c_v) range from 0.71 to 0.85 kJ/kg-k

Ambient Air Density (ρ_a) will automatically correct with Ambient Air Temperature (T_a) Input

METHOD OF KARLSSON AND QUINTIERE

Reference: Karlsson and Quintiere, Enclosure Fire Dynamics, 1999, Page 192.

$$(P - P_a) / P_a = Q\ t / (V\ \rho_a\ c_v\ T_a)$$

Where,
P = compartment pressure due to fire and combustion (kPa)
P_a = initial atmospheric pressure (kPa)
Q = heat release rate of the fire (kW)
t = time after ignition (sec)
V = compartment volume (m^3)
ρ_a = ambient density (kg/m^3)
c_v = specific heat of air at constant volume (kJ/kg-K)
T_a = ambient air temperature (K)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

Where,
V = volume of the compartment (m^3)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

V = 33.30 m^3 1175.978402 ft^3

Pressure Rise in Compartment

$$(P - P_a) / P_a = Q\, t / (V\, \rho_a\, c_v\, T_a)$$

$(P-P_a)/P_a =$ **0.120 atm**

Multiplying by the atmospheric pressure (P_a) = 101 kPa
Gives a pressure difference equal to:

Answer	12.14 kPa	1.76 psi

This example shows that in a very short time the pressure in a closed compartment rises to quite a large value.

Most buildings have leaks of some sort. The above example indicates that even though a fire compartment may be closed, the pressure rise is very rapid and would presumably lead to sufficient leaks to prevent any further pressure rise from occurring. We will use this conclusion when dealing with pressure rises in enclosures with small leaks.

NOTE:
The above calculations are based on principles developed in the Enclosure Fire Dynamics. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Example Problem 14.10-2

Problem Statement
A facility has a sealed compartment (assume zero leakage) with a blowout panel that is designed to fail at two atmospheres. The compartment is 6.1 m long x 7.6 m wide x 3.0 m high. A fire is assumed with a constant heat release rate of 255 kW.

At what time (sec) does the blow out panel fail?

Solution

Purpose:
(1) Estimate the time after ignition the pressure reaches 2 atm (202.5 kPa).

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) Information:

Use the following FDT^s:
(a) 14_Compartment_Over_Pressure_Calculations_Sup1_SI.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 6.1 m
- Compartment Length (l_c) = 7.6 m
- Compartment Height (h_c) = 3.0 m
- Fire Heat Release Rate ($\dot{Q}$) = 255 kW
- Time After Ignition (t) = varies until output is 202.5 kPa

Results*

Time After Ignition	274 sec

*see spreadsheet on next page

CHAPTER 14
ESTIMATING PRESSURE RISE DUE TO A FIRE IN A CLOSED COMPARTMENT

Version 1805.1 (SI Units)

The following calculations estimate the pressure rise in a compartment due to fire and combustion.
Parameters in YELLOW CELLS are Entered by the User.
All subsequent output values are calculated by the spreadsheet and based on values specified in the input parameters. This spreadsheet is protected and secure to avoid errors due to a wrong entry in a cell(s). The chapter in the NUREG should be read before an analysis is made.

Project / Inspection Title: **Example 14.10-2**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	6.10	m
Compartment Length (l_c)	7.60	m
Compartment Height (h_c)	3.00	m
Fire Heat Release Rate (Q)	255.00	kW
Time after Ignition (t)	274.00	sec
Ambient Air Temperature (T_a)	25.00	°C

Calculate

AMBIENT CONDITIONS

Initial Atmospheric Pressure (P_a)	101.35	kPa
Specific Heat of Air at Constant Volume (c_v)	0.71	kJ/kg-K
Ambient Air Density (ρ_a)	1.18	kg/m^3

NOTE:

Values of Specific Heat of Air at Constant Volume (c_v) range from 0.71 to 0.85 kJ/kg-k

Ambient Air Density (ρ_a) will automatically correct with Ambient Air Temperature (T_a) Input

METHOD OF KARLSSON AND QUINTIERE

Reference: Karlsson and Quintiere, Enclosure Fire Dynamics, 1999, Page 192.

$$(P - P_a) / P_a = Q\ t / (V\ \rho_a\ c_v\ T_a)$$

Where,
P = compartment pressure due to fire and combustion (kPa)
P_a = initial atmospheric pressure (kPa)
Q = heat release rate of the fire (kW)
t = time after ignition (sec)
V = compartment volume (m^3)
ρ_a = ambient density (kg/m^3)
c_v = specific heat of air at constant volume (kJ/kg-K)
T_a = ambient air temperature (K)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

Where,
V = volume of the compartment (m^3)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

V = 139.08 m^3 4911.563848 ft^3

Pressure Rise in Compartment

$$(P - P_a) / P_a = Q\, t / (V\, \rho_a\, c_v\, T_a)$$

$(P-P_a)/P_a =$ **2.004 atm**

Multiplying by the atmospheric pressure (P_a) = 101 kPa
Gives a pressure difference equal to:

Answer	203.15 kPa	29.46 psi

This example shows that in a very short time the pressure in a closed compartment rises to quite a large value.

Most buildings have leaks of some sort. The above example indicates that even though a fire compartment may be closed, the pressure rise is very rapid and would presumably lead to sufficient leaks to prevent any further pressure rise from occurring. We will use this conclusion when dealing with pressure rises in enclosures with small leaks.

NOTE:
The above calculations are based on principles developed in the Enclosure Fire Dynamics. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ____ Date: ____ Organization: ____

Checked by: ____ Date: ____ Organization: ____

Additional Information:

15.18 Problems

Example Problem 15.18-1

Problem Statement
In an NPP, a liquid propane gas (LPG) driven forklift is used to unload materials from an upcoming outage. Mechanical failure could result in the release of LPG in the area. The maximum fuel capacity of the forklift is 38 liters. Calculate pressure rise, energy released by expanding LPG, and equivalent TNT charge weight. Assume that the mass of the vapor released is 22 kg.

Solution

Purpose:
(1) Estimate pressure rise, energy released, and TNT equivalent.

Assumptions:
(1) The atmospheric pressure is 101.35 kPa.
(2) Ambient air temperature is 25 °C.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 15_Explosion_Calculations_Sup1_SI.xls

FDT^s Input Parameters:
- Select Fuel Type = **Propane**
- Percent yield = 100%
- Mass of flammable vapor release = 22 kg

Results*

Pressure Rise	529 kPa
Energy Released	1,019,920 kJ
Equivalent TNT	227 kg

*see spreadsheet on next page

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(SI Units)

The following calculations estimate the pressure and energy due to an explosion in a confined space.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 15.18-1**

INPUT PARAMETERS

EXPLOSIVE FUEL INFORMATION

Adiabatic Flame Temperature of the Fuel ((T_{ad})	1281	°C
Heat of Combustion of the Fuel (ΔH_c)	46360	kJ/kg
Yield (α) See Note	100.00	%
Mass of Flammable Vapor Release (m_F)	22.00	kg
Ambient Air Temperature (T_a)	25.00	°C
Initial Atmospheric Pressure (P_a)	101.35	kPa

Note: The fraction of available combustion is 1% for unconfined mass release and 100% for confined vapor release energy participating in blast wave generation.

Calculate

THERMAL PROPERTIES FOR FUEL

FUEL FLAMMABILITY DATA

Fuel	Adiabatic Flame Temperature T_{ad} (°C)	Heat of Combustion ΔH_c (kJ/kg)
Acetylene	2637	48,220
Carbon Monoxide	2387	10,100
Ethane	1229	47,490
Ethylene	2289	47,170
Hydrogen	2252	130,800
Methane	1173	50,030
n-Butane	1339	45,720
n-Heptane	1419	44,560
n-Octane	1359	44,440
n-Pentane	1291	44,980
Propane	1281	46,360
Propylene	2232	45,790
User Specified Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 1-86.

Select Fuel Type

Propane

Scroll to desired Fuel Type **then Click** on selection

METHOD OF ZALOSH

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-312.

Pressure Rise from a Confined Explosion

$$(P_{max})/P_a = (T_{ad}/T_a)$$

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Where,
P_{max} = maximum pressure developed at completion of combustion (kPa)
P_a = initial atmospheric pressure (kPa)
T_{ad} = adiabatic flame temperature (K)
T_a = ambient temperature (K)

P_{max} = 528.52 kPa 76.65 psi

Blast Wave Energy Calculation

$$E = \alpha\ \Delta H_c\ m_F$$

Where,
E = blast wave energy (kJ) [E is the Trinitrotoluene (TNT) equivalent energy]
α = yield (a is the fraction of available combustion energy participating in blast wave generation)
ΔH_c = heat of combustion (kJ/kg)
m_F = mass of flammable vapor release (kg)

E = 1019920.00 kJ 965966.23 Btu

TNT Mass Equivalent Calculation

$$W_{TNT} = E/4500$$

Where,
W_{TNT} = weight of TNT (kg)
E = explosive energy release (kJ)

W_{TNT} = 226.65 kg 499.68 lb

Results Summary

Pressure Rise from a Confined Explosion

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Answer	P_{max} =	528.52 kPa	76.65 psi

Blast Wave Energy

$$E = \alpha\ \Delta H_c\ m_F$$

Answer	E =	1019920.00 kJ	965966.23 Btu

TNT Mass Equivalent

$$W_{TNT} = E/4500$$

Answer	W_{TNT} =	226.65 kg	499.68 lb

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 15.18-2

Problem Statement
An investigator is performing a review of an accident at a facility. The report states that a pipe fitter accidently left his acetylene “B” tank on which leaked its contents and caused the explosion. Assuming the tank was full (1.133 m^3 of gas at atmospheric pressure), how large could the explosion have been?

Solution

Purpose:
(1) Estimate energy released, and TNT equivalent.

Assum ptions:
(1) The atmospheric pressure is 101.35 kPa
(2) Ambient air temperature is 25 °C.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 15_Explosion_Calculations_Sup1_SI.xls

FDT^s Input Parameters:
- Select Fuel Type = **Acetylene**
- Percent yield = 100%
- Mass of vapor release = volume x density (from manufacture’s Web site)
  1.133 m^3 x 1.087 kg/m^3 = 1.23 kg

Results*

Energy Released	59,310 kJ
Equivalent TNT	13.2 kg

*see spreadsheet on next page

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(SI Units)

The following calculations estimate the pressure and energy due to an explosion in a confined space.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: Example 15.18-2

INPUT PARAMETERS

EXPLOSIVE FUEL INFORMATION

Adiabatic Flame Temperature of the Fuel ((T_{ad})	2637	°C
Heat of Combustion of the Fuel (ΔH_c)	48220	kJ/kg
Yield (α) See Note	100.00	%
Mass of Flammable Vapor Release (m_F)	1.23	kg
Ambient Air Temperature (T_a)	25.00	°C
Initial Atmospheric Pressure (P_a)	101.35	kPa

Note: The fraction of available combustion is 1% for unconfined mass release and 100% for confined vapor release energy participating in blast wave generation.

Calculate

THERMAL PROPERTIES FOR FUEL

FUEL FLAMMABILITY DATA

Fuel	Adiabatic Flame Temperature T_{ad} (°C)	Heat of Combustion ΔH_c (kJ/kg)
Acetylene	2637	48,220
Carbon Monoxide	2387	10,100
Ethane	1229	47,490
Ethylene	2289	47,170
Hydrogen	2252	130,800
Methane	1173	50,030
n-Butane	1339	45,720
n-Heptane	1419	44,560
n-Octane	1359	44,440
n-Pentane	1291	44,980
Propane	1281	46,360
Propylene	2232	45,790
User Specified Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 1-86.

Select Fuel Type

Acetylene

Scroll to desired Fuel Type **then Click** on selection

METHOD OF ZALOSH

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-312.

Pressure Rise from a Confined Explosion

$$(P_{max})/P_a = (T_{ad}/T_a)$$

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Where,
P_{max} = maximum pressure developed at completion of combustion (kPa)
P_a = initial atmospheric pressure (kPa)
T_{ad} = adiabatic flame temperature (K)
T_a = ambient temperature (K)

P_{max} = 989.69 kPa 143.54 psi

Blast Wave Energy Calculation

$$E = \alpha\ \Delta H_c\ m_F$$

Where,
E = blast wave energy (kJ) [E is the Trinitrotoluene (TNT) equivalent energy]
α = yield (a is the fraction of available combustion energy participating in blast wave generation)
ΔH_c = heat of combustion (kJ/kg)
m_F = mass of flammable vapor release (kg)

E = 59310.60 kJ 56173.07 Btu

TNT Mass Equivalent Calculation

$$W_{TNT} = E/4500$$

Where,
W_{TNT} = weight of TNT (kg)
E = explosive energy release (kJ)

W_{TNT} = 13.18 kg 29.06 lb

Results Summary

Pressure Rise from a Confined Explosion

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Answer	P_{max} =	989.69 kPa	143.54 psi

Blast Wave Energy

$$E = \alpha\ \Delta H_c\ m_F$$

Answer	E =	59310.60 kJ	56173.07 Btu

TNT Mass Equivalent

$$W_{TNT} = E/4500$$

Answer	W_{TNT} =	13.18 kg	29.06 lb

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 15.18-3

Problem Statement
Which has a larger TNT mass equivalent: 5 kg (mass vapor) of acetylene or 2.5 kg (mass vapor) of hydrogen?

Solution

Purpose:
(1) Estimate TNT equivalent.

Assumptions:
(1) The atmospheric pressure is 101.35 kPa
(2) Ambient air temperature is 25 °C.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 15_Explosion_Calculations_Sup1_SI.xls

FDT^s Input Parameters:
- Select Fuel Type = **Acetylene**
- Percent yield = 100%
- Mass of flammable vapor release = 5 kg
- Select Fuel Type = **Hydrogen**
- Percent yield = 100%
- Mass of flammable vapor release = 2.5 kg

Results*

	Acetylene	Hydrogen
Equivalent TNT	54 kg	73 kg

*see spreadsheet on next page

Therefore, 2.5 kg of hydrogen produces more explosive force than 5 kg of acetylene.

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(SI Units)

The following calculations estimate the pressure and energy due to an explosion in a confined space.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: **Example 15.18-3a**

INPUT PARAMETERS

EXPLOSIVE FUEL INFORMATION

Adiabatic Flame Temperature of the Fuel ((T_{ad})	2637	°C
Heat of Combustion of the Fuel (ΔH_c)	48220	kJ/kg
Yield (α) See Note	100.00	%
Mass of Flammable Vapor Release (m_F)	5.00	kg
Ambient Air Temperature (T_a)	25.00	°C
Initial Atmospheric Pressure (P_a)	101.35	kPa

Note: The fraction of available combustion is 1% for unconfined mass release and 100% for confined vapor release energy participating in blast wave generation.

Calculate

THERMAL PROPERTIES FOR FUEL

FUEL FLAMMABILITY DATA

Fuel	Adiabatic Flame Temperature T_{ad} (°C)	Heat of Combustion ΔH_c (kJ/kg)
Acetylene	2637	48,220
Carbon Monoxide	2387	10,100
Ethane	1229	47,490
Ethylene	2289	47,170
Hydrogen	2252	130,800
Methane	1173	50,030
n-Butane	1339	45,720
n-Heptane	1419	44,560
n-Octane	1359	44,440
n-Pentane	1291	44,980
Propane	1281	46,360
Propylene	2232	45,790
User Specified Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 1-86.

Select Fuel Type

Acetylene

Scroll to desired Fuel Type **then Click** on selection

METHOD OF ZALOSH

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-312.

Pressure Rise from a Confined Explosion

$$(P_{max})/P_a = (T_{ad}/T_a)$$

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Where,
P_{max} = maximum pressure developed at completion of combustion (kPa)
P_a = initial atmospheric pressure (kPa)
T_{ad} = adiabatic flame temperature (K)
T_a = ambient temperature (K)

P_{max} = 989.69 kPa 143.54 psi

Blast Wave Energy Calculation

$$E = \alpha\ \Delta H_c\ m_F$$

Where,
E = blast wave energy (kJ) [E is the Trinitrotoluene (TNT) equivalent energy]
α = yield (a is the fraction of available combustion energy participating in blast wave generation)
ΔH_c = heat of combustion (kJ/kg)
m_F = mass of flammable vapor release (kg)

E = 241100.00 kJ 228345.81 Btu

TNT Mass Equivalent Calculation

$$W_{TNT} = E/4500$$

Where,
W_{TNT} = weight of TNT (kg)
E = explosive energy release (kJ)

W_{TNT} = 53.58 kg 118.12 lb

Results Summary

Pressure Rise from a Confined Explosion

$$P_{max} = (T_{ad}/T_a)\, P_a$$

Answer	P_{max} =	989.69 kPa	143.54 psi

Blast Wave Energy

$$E = \alpha\, \Delta H_c\, m_F$$

Answer	E =	241100.00 kJ	228345.81 Btu

TNT Mass Equivalent

$$W_{TNT} = E/4500$$

Answer	W_{TNT} =	53.58 kg	118.12 lb

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

CHAPTER 15
ESTIMATING PRESSURE INCREASE AND EXPLOSIVE ENERGY RELEASE ASSOCIATED WITH EXPLOSIONS

Version 1805.1
(SI Units)

The following calculations estimate the pressure and energy due to an explosion in a confined space.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Fuel Type 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.

Project / Inspection Title: Example 15.18-3b

INPUT PARAMETERS

EXPLOSIVE FUEL INFORMATION

Adiabatic Flame Temperature of the Fuel ((T_{ad})	2252	°C
Heat of Combustion of the Fuel (ΔH_c)	130800	kJ/kg
Yield (α) See Note	100.00	%
Mass of Flammable Vapor Release (m_F)	2.50	kg
Ambient Air Temperature (T_a)	25.00	°C
Initial Atmospheric Pressure (P_a)	101.35	kPa

Note: The fraction of available combustion is 1% for unconfined mass release and 100% for confined vapor release energy participating in blast wave generation.

Calculate

THERMAL PROPERTIES FOR FUEL

FUEL FLAMMABILITY DATA

Fuel	Adiabatic Flame Temperature T_{ad} (°C)	Heat of Combustion ΔH_c (kJ/kg)
Acetylene	2637	48,220
Carbon Monoxide	2387	10,100
Ethane	1229	47,490
Ethylene	2289	47,170
Hydrogen	2252	130,800
Methane	1173	50,030
n-Butane	1339	45,720
n-Heptane	1419	44,560
n-Octane	1359	44,440
n-Pentane	1291	44,980
Propane	1281	46,360
Propylene	2232	45,790
User Specified Value	Enter Value	Enter Value

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 1-86.

Select Fuel Type

Hydrogen

Scroll to desired Fuel Type **then Click** on selection

METHOD OF ZALOSH

Reference: SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995, Page 3-312.

Pressure Rise from a Confined Explosion

$$(P_{max})/P_a = (T_{ad}/T_a)$$

$$P_{max} = (T_{ad}/T_a)\ P_a$$

Where,

P_{max} = maximum pressure developed at completion of combustion (kPa)
P_a = initial atmospheric pressure (kPa)
T_{ad} = adiabatic flame temperature (K)
T_a = ambient temperature (K)

P_{max} = 858.75 kPa 124.55 psi

Blast Wave Energy Calculation

$$E = \alpha\ \Delta H_c\ m_F$$

Where,

E = blast wave energy (kJ) [E is the Trinitrotoluene (TNT) equivalent energy]
α = yield (a is the fraction of available combustion energy participating in blast wave generation)
ΔH_c = heat of combustion (kJ/kg)
m_F = mass of flammable vapor release (kg)

E = 327000.00 kJ 309701.70 Btu

TNT Mass Equivalent Calculation

$$W_{TNT} = E/4500$$

Where,

W_{TNT} = weight of TNT (kg)
E = explosive energy release (kJ)

W_{TNT} = 72.67 kg 160.20 lb

Results Summary

Pressure Rise from a Confined Explosion

$$P_{max} = (T_{ad}/T_a)\, P_a$$

Answer	P_{max} =	858.75 kPa	124.55 psi

Blast Wave Energy

$$E = \alpha\, \Delta H_c\, m_F$$

Answer	E =	327000.00 kJ	309701.70 Btu

TNT Mass Equivalent

$$W_{TNT} = E/4500$$

Answer	W_{TNT} =	72.67 kg	160.20 lb

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 2nd Edition, 1995. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheet, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

16.14 Problems

Example Problem 16.14-1

Problem Statement
Assume a 60-cell GT-41 (3,730 Ampere-hour) battery near the end of its life, on equalize at 2.33 VPC at an electrolyte temperature of 33 °C. Estimate the rate of hydrogen generation (in cubic meters per minute).

Solution

Purpose:
(1) Estimate the rate of hydrogen generation.

Assumptions:
(1) Old Antimony-type battery

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 16_Battery_Room_Flammable_Gas_Conc_Sup1_SI.xls
(click on *Battery_Room_Hydrogen*)

FDTs Input Parameters:
- Ampere Hours = 3730 Ah
- Number of Cells = 60
- Click on **Old Antimony type** and Select 2.33 VPC

Results*

Generation Rate	0.0152 m^3/min

*see spreadsheet on next page

CHAPTER 16
CALCULATING THE RATE OF HYDROGEN GAS GENERATION IN BATTERY ROOMS

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 16.14-1**

INPUT PARAMETERS

BATTERY INFORMATION

Float Current (F_C)	450	mA per 100 A_H @ 8-hr. rate
Ampere Hours (A_H)	3730.00	Ampere hours
Number of Cells (N)	60.00	
Constant (K)	0.00000756	m^3

COMPARTMENT INFORMATION

Compartment Width (w_c)	7.93	m
Compartment Length (l_c)	15.24	m
Compartment Height (h_c)	3.66	m

FLAMMABLE GAS INFORMATION

Lower Flammability Limit of Hydrogen (FL)	4.00	%

Calculate

Float Current Demand of Fully Charged Stationary Lead-Acid Cells

Reference: *Yuasa, Inc., Safety Storage, Installation, Operation, and Maintenance Manual, Section 58.00, Heritage Series, Flooded Lead-Acid Batteries, 2000.*

New Antimony	F_C*
Charge Voltage (VPC)	Antimony New
2.15	15
2.17	19
2.20	26
2.23	37
2.25	45
2.27	60
2.33	120
2.37	195
2.41	300
User Specified Value	Enter Value

*(milliamperes per 100 AH @ 8-hr. rate)

Select Charge Current Value

Scroll to desired value then Click on selection

Old Antimony	F_C*
Charge Voltage (VPC)	Antimony Old
2.15	60
2.17	80
2.20	105
2.23	150
2.25	185
2.27	230
2.33	450
2.37	700
2.41	1100
User Specified Value	Enter Value

*(milliamperes per 100 AH @ 8-hr. rate)

Select Charge Current Value

2.33

Scroll to desired value then Click on selection

Calcium	F_C*
Charge Voltage (VPC)	Antimony Calcium
2.15	
2.17	4
2.20	6
2.23	8
2.25	11
2.27	12
2.33	24
2.37	38
2.41	58
User Specified Value	Enter Value

*(milliamperes per 100 AH @ 8-hr. rate)

Select Charge Current Value

Scroll to desired value then Click on selection

METHOD OF YUASA, INC.

Reference: *Yuasa, Inc., Safety Storage, Installation, Operation, and Maintenance Manual, Section 58.00, Heritage Series, Flooded Lead-Acid Batteries, 2000.*

Estimating Hydrogen Gas Generation Rate

$$H_{2(gen)} = F_C/1000 \times A_H/100 \times K \times N$$

This equation is based on when electrolyte temperature is 77 °F (25 °C)
For every 15 °F (8 °C) electrolyte temperature rise the equation will multiply by 2

Where
$H_{2(gen)}$ = hydrogen gas generation rate (m^3/min)
F_C = float current (mA per 100 A_H @ 8-hr. rate)
A_H = ampere hours (normal 8 hour)
K = constant - 1 A_H = 7.5606×10^{-6} m^3
N = number of cells

$$H_{2(gen)} = F_C/1000 \times A_H / 100 \times K \times N \times 2$$

Since electrolyte temperature is 92 °F (33 °C) the equation is multiplied by 2

$H_{2(gen)}$ = **0.0152 m^3/min** **0.5377 ft^3/min**

Estimating Hydrogen Gas in Compartment Based on Given Flammability Limit

$$H_{2(comp)} = V \times FL$$

Where
$H_{2(comp)}$ = hydrogen gas in compartment (m^3)
V = volume of compartment (m^3)
FL = hydrogen gas flammability limit

$H_{2(comp)}$ = **17.67209064 m^3**

Volume of Compartment

$$V = w_c \times l_c \times h_c$$

Where
V = compartment volume (m^3)
w_c = compartment width (m)
lc = compartment length (m)
hc = compartment height (m)

V = **441.802266 m^3**

Estimating Time Required to Reach Hydrogen Concentration on Given Flammability Limit

$$t_{H2} = H_{2(comp)} / H_{2(gen)}$$

Where
t_{H2} = time require to reach on given flammability limit (min)
$H_{2(comp)}$ = hydrogen gas in compartment (m^3)
$H_{2(gen)}$ = hydrogen gas generation rate (m^3/min)

t_{H2} = **1160.46 min. or approx. 19 hours**

Summary of Results

ESTIMATING HYDROGEN GAS GENERATION RATE

$$H_{2(gen)} = F_C/1000 \times A_H / 100 \times K \times N \times 2$$

Answer	$H_{2(gen)}$ =	0.01523 m^3/min	0.53773 ft^3/min

ESTIMATING TIME REQUIRED TO REACH HYDROGEN CONCENTRATION ON GIVEN FLAMMABILITY LIMIT

$$t_{H2} = H_{2(comp)} / H_{2(gen)}$$

Answer	t_{H2}=	1160.46 min. or approx.	19 hours

NOTE:

The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

Additional Information:

Example Problem 16.14-2

Problem Statement
Consider an enclosure 3.0 m wide x 3.0 m long x 3.0 m high or 27 m^3 in the turbine generator area of a nuclear facility in which hydrogen gas is accumulated. Calculate the concentration of hydrogen gas by volume reaching its LFL of 4 percent.

Solution

Purpose:
(1) Estimate the concentration of hydrogen gas in the compartment at LFL.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 16_Battery_Room_Flammable _Gas_Conc_Sup1_SI.xls
(click on *Flammable_Gas_Buildup*)

FDT^s Input Parameters:
- Compartment Width (w_c) = 3.0 m
- Compartment Length (l_c) = 3.0 m
- Compartment Height (h_c) = 3.0 m
- Select **Hydrogen**

Results*

Volume	1.08 m^3

*see spreadsheet on next page

Therefore, the concentration of hydrogen gas in the 27 m^3 compartment is 4% (1.08/27).

CHAPTER 16
CALCULATING THE RATE OF HYDROGEN GENERATION IN BATTERY ROOMS

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 16.14-2**

INPUT PARAMETERS

Lower Flammability Limit of Flammable Gas or Vapor (LFL)	4.00	%
Compartment Width (w_c)	3.00	m
Compartment Length (l_c)	3.00	m
Compartment Height (h_c)	3.00	m

Calculate

LOWER FLAMMABILITY DATA FOR GASES AND VAPORS

Gases and Vapors	LFL Volume-Percent
Hydrogen	4.00
Carbon Monoxide	12.50
Methane	5.00
Ethane	3.00
Propane	2.10
n-Butane	1.80
n-Pentane	1.40
n-Hexane	1.20
n-Heptane	1.05
n-Octane	0.95
n-Nonane	0.85
n-Decane	0.75
Ethene	2.70
Propane	2.40
Butene-1	1.70
Acetylene	2.50
Methanol	6.70
Ethanol	3.30
n-Propanol	2.20
Acetone	2.60
Methyl Ethyl Ketone	1.90
Diethyl Ketone	1.60
Benzene	1.30
User Specified Value	Enter Value

Select Gas or Vapor
Hydrogen
Scroll to desired gas or vapor then Click on selection

Reference: *SFPE Handbook of Fire Protection Engineering* , 3rd Edition, 2002, Page 2-175.

CHAPTER 16
CALCULATING THE RATE OF HYDROGEN GENERATION IN BATTERY ROOMS

Version 1805.1
(SI Units)

ESTIMATING FLAMMABLE CONCENTRATION OF GASES USING LIMITS OF FLAMMABILITY

Volume of Gas or Vapor for Deflagration = V x LFL

Where
V = volume of enclosure (m^3)
LFL= lower flammability of a gas or vapor (percent-volume)

Volume of Compartment

$$V = w_c \times l_c \times h_c$$

Where
V = compartment volume (m^3)
wc = compartment width (m)
lc = compartment length (m)
hc = compartment height (m)

V = 27.00 m^3

Volume of Gas or Vapor for Deflagration = V x LFL

Answer	Volume of Gas or Vapor for Deflagration =	1.08 m^3	38.1 ft^3

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 16.14-3

Problem Statement

Assume a leak of 3 m^3/min of a 15 percent hydrogen gas/air mixture in a compartment that is 9.0 m wide x 4.6 m long x 3.7 m high (w_c x l_c x h_c). How long would it take to reach a hydrogen concentration of 2 percent throughout the enclosure, assuming infiltration through multiple compartment cracks?

Solution

Purpose:

(1) Estimate the time until the room reaches 2% hydrogen concentration.

Assumptions:

(1) Infiltration through compartment leaks.
(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) Information:

Use the following FDT^s:

(a) 16_Battery_Room_Flammable_Gas_Conc_Sup1_SI.xls (click on *Flammable_Gas_Buildup_Time*)

FDT^s Input Parameters:

- Compartment Width (w_c) = 9.0 m
- Compartment Length (l_c) = 4.6 m
- Compartment Height (h_c) = 3.7 m
- Enter 3 m^3/min as the Leakage Rate
- Enter 15% as Percent of Combustible Gas/Air M ixture
- Enter 2% as Combustible Gas Concentration (C)
- Click on **Infiltration Through Cracks** and select 0.3 from the drop-down menu

Results*

Time	20.5 minutes

*see spreadsheet on next page

CHAPTER 16
CALCULATING THE RATE OF HYDROGEN GENERATION IN BETTERY ROOMS

Version 1805.1 (SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 16.14-3**

INPUT PARAMETERS

COMPARTMENT INFORMATION HYDROGEN LEAK INFORMATION

Compartment Width (w_c)	9.00	m
Compartment Length (l_c)	4.60	m
Compartment Height (h_c)	3.70	m
Leakage Rate	3.00	m^3/min
Percent of Combustible Gas/Air Mixture	15.00	percent
Combustible Gas Concentration (C)	2.00	percent
Mixing Efficiency Factor (K)	0.3	

Calculate

Mixing Efficiency (K Values) for Various Ventilation Arrangements

Reference: *NFPA 69, "Standard on Explosion Prevention Systems," 1997 Edition.*

Infiltration Through Cracks	K
Single Exhaust Opening	0.2
Multiple Exhaust Openings	0.3

Select Ventilation Arrangement
0.3
Scroll to desired arrangement then **Click** on selection

Open Door, or Windows	K
Single Exhaust Opening	0.2
Multiple Exhaust Openings	0.4

Select Ventilation Arrangement
Scroll to desired arrangement then **Click** on selection

Grill and Registers	K
Single Exhaust Opening	0.3
Multiple Exhaust Openings	0.5

Select Ventilation Arrangement
Scroll to desired arrangement then **Click** on selection

Diffusers	K
Single Exhaust Opening	0.5
Multiple Exhaust Openings	0.7

Select Ventilation Arrangement
Scroll to desired arrangement then **Click** on selection

Perforated Ceiling	K
Single Exhaust Opening	0.8
Multiple Exhaust Openings	0.9

Select Ventilation Arrangement
Scroll to desired arrangement then **Click** on selection

User Specified Value	K
Single Exhaust Opening	Enter Value
Multiple Exhaust Openings	Enter Value

Select Ventilation Arrangement
Enter Value
Scroll to desired arrangement then **Click** on selection

METHOD OF NFPA 69, STANDARD ON EXPLOSION PREVENTION SYSTEMS

Reference: *NFPA 69, "Standard on Explosion Prevention Systems, 1997 Edition, Appendix D.*

Estimating Number of Theoretical Air Changes

ln [1 - (CQ / G)] = - K N

Where
C = combustible gas concentration
Q = air flow rate (fresh air) in enclosure (m^3/min)
G = combustible gas leakage rate (m^3/min)
K = mixing efficiency factor (constant)
N = number of theoretical air changes

Q = air flow rate (fresh air) in enclosure

Q = 2.55 m^3/min

G = combustible gas leakage rate

G = 0.45 (m^3/min)

N = number of theoretical air changes

ln [1 - (CQ / G)] = - K N
or
N = - [ln(1 - (CQ/G))]/ K

N = 0.40

Estimating Combustible Gas Concentration Buildup Time

t = (V / leakage rate) * N

Where
t = buildup time (min)
V = compartment volume (m^3)
leakage rate (m^3/min)
N = number of theoretical air changes

Volume of Compartment

$V = w_c \times l_c \times h_c$

Where
V = compartment volume (m^3)
wc = compartment width (m)
lc = compartment length (m)
hc = compartment height (m)

V = 153.18 m^3

COMBUSTIBLE GAS CONCENTRATION BUILDUP TIME

$$t = (V / \text{leakage rate}) * N$$

Answer	t =	20.47 minutes

NOTE:
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Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

17.14 Problems

Example Problem 17.14-1

Problem Statement
Calculate the thickness of spray-on fire protection required to provide a 2-hour fire resistance for a W12 x 16 beam to be substituted for a W8 x 18 beam requiring 3.66 cm of protection for the same rating.

Solution

Purpose:
(1) Estimate the spray-on thickness required for the beam substitution.

Assumptions:
(1) The 3.66 cm. of spray-on provides the W8 x 18 beam 2 hours of fire resistance.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 17.1_FR_Beams_Columns_Substitution_Correlation_Sup1_SI.xls
(click on *Beam*)

FDT^s Input Parameters:
- Known beam insulation thickness
- Select W8 x 18 for Rated Beam
- Select W12 x 16 for Substitute Beam

Results*

Substitute Beam Spray on Thickness	4.1 cm

*see spreadsheet on next page

CHAPTER 17
ESTIMATING THE THICKNESS OF FIRE PROTECTION
SPRAY-APPLIED COATING
FOR STRUCTURAL STEEL BEAMS
(SUBSTITUTION CORRELATION)

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: Example 17.14-1

INPUT PARAMETERS

Rated Design Thickness of Beam Insulation (T_2)	3.66	cm
Known Insulation Rating		
Weight of the Beam (W_2)	18	lb/ft
Heated Perimeter of Beam (D_2)	31.57	in
Unknown Insulation Rating		
Weight of the Beam (W_1)	16.00	lb/ft
Heated Perimeter of Beam (D_1)	35.51	in

SECTIONAL FACTORS FOR STEEL BEAMS

Select the Beam with known rating for insulation thickness
W8 x 18
Subscript 2
(Rated Beam)

Calculate

Select the Beam with unknown rating for insulation thickness
W12 x 16
Subscript 1
(Substitute Beam)

CHAPTER 17
ESTIMATING THE THICKNESS OF FIRE PROTECTION SPRAY-APPLIED COATING FOR STRUCTURAL STEEL BEAMS (SUBSTITUTION CORRELATION)

Version 1805.1
(SI Units)

ESTIMATING THICKNESS OF FIRE PROTECTION INSULATION ON UNRATED BEAM

Reference: *UL Fire Resistance Directory, Volume 1, 1995, Page 19.*

$$T_1 = ((W_2/D_2 + 0.6)T_2)/(W1/D_1 + 0.6)$$

Where

T_1 = calculated thickness of fire protection insulation on unrated beam (in)
T_2 = design thickness of insulation on rated beam (in)
W_1 = weight of beam with unknown insulation rating (lb/ft)
W_2 = weight of design rated beam (lb/ft)
D_1 = heated perimeter of unrated beam (in)
D_2 = heated perimeter of the rated beam (in)

REQUIRED EQUIVALENT THICKNESS OF FIRE PROTECTION INSULATION ON UNRATED BEAM

$$T_1 = ((W_2/D_2 + 0.6)T_2)/(W1/D1 + 0.6)$$

Answer	T_1 =	**4.1 cm**	**1.60 in**

Beams with a larger W/D ratio can always be substituted for the structural member listed with a specific fire resistive covering without changing the thickness of the covering.

NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ____ Date: ____ Organization: ____

Checked by: ____ Date: ____ Organization: ____

Additional Information:

Example Problem 17.14-2

Problem Statement
Use the quasi-steady-state heat transfer approach to determine the fire resistance of a W24 x 76 steel beam protected with 1.27 cm of spray-on mineral fiber material. Sprayed-on mineral fiber has the follow ing thermal properties:

- Thermal Conductivity, k_i = 0.06936 Btu/ft-hr-°F
- Specific Heat, c_i = 0.2868 Btu/lb-°F
- Density, ρ_i =19.0 lb/ft^3

Solution

Purpose:
(1) Estimate the fire resistance of the beam.

Assumptions:
(1) The heat transfer is quasi-steady-state.

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 17.2_FR_Beams_Columns_Quasi_Steady_State_Spray_Insulated_Sup1_SI.xls (click on *Beam*)

FDT^s Input Parameters:
- Select W24 x 76 beam
- Enter 1.27 cm spray-on thickness
- Select **Sprayed Mineral Fiber** from Insulation Type drop-down menu

Results*

Fire Resistance	42.5 min

*see spreadsheet on next page

ESTIMATING FIRE RESISTANCE TIME OF STEEL BEAMS PROTECTED BY FIRE PROTECTION INSULATION (QUASI-STEADY-STATE APPROACH)

Version 1805.1
(SI Units)

The following calculations estimate the full-scale cable tray heat release rate.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from the DROP DOWN MENU for the Cable Type 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.

Project / Inspection Title: **Example 17.14-2**

INPUT PARAMETERS

Ratio of Weight of Steel Section per Linear Foot and Heated Perimeter (W/D)		12.34	lb/ft^2
Thickness of Spray-Applied Protection on Steel Beam (h)	**h ≥ 1/6 cm**	1.27	cm
Density of Spray-Applied Material (ρ_i)		19.00	lb/ft^3
Thermal Conductivity of Spray-Applied Material (k_i)		0.06936	Btu/ft-hr-°F
Specific Heat of Spray-Applied Material (c_i)		0.2868	Btu/lb-°F
Ambient Air Temperature (T_a)		25	°C
Specific Heat of Steel (c_s)		0.132	Btu/lb-°F

Calculate

SECTIONAL FACTORS FOR STEEL BEAMS

Select Beam

24x76

Scroll to desired beam size then Click on selection

THERMAL PROPERTIES OF SPRAY-APPLIED INSULATION MATERIALS

Insulation Material Spray-Applied	Density ρ_i (lb/ft^3)	Thermal Conductivity k_i (Btu/ft-hr-°F)	Specific Heat c_i (Btu/lb-°F)
Sprayed mineral fiber	19	0.06936	0.2868
Perlite or vermiculite	22	0.06936	0.2868
High density perlite or vermiculite	35	0.06936	0.2868
User Specified Value	Enter Value	Enter Value	Enter Value

Reference: *Buchanan, A. H., Structural Design for Fire Safety, 2001, Page 179.*

Select Insulation Type

Sprayed mineral fiber

Scroll to desired material then Click on selection

ESTIMATING FIRE RESISTANCE TIME USING QUASI-STEADY-STATE APPROACH

Reference: *"Analytical Methods for Determining Fire Resistance of Steel Members,"*
"SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002, Page 4-209.

Temperature Rise in Steel Beam

$$\Delta T_s = (k_i /(c_s\ h\ W/D + 1/2\ c_i\ \rho_i\ h^2))\ (T_f - T_s)\ \Delta t$$

Where

ΔT_s = temperature rise in steel (°F)
k_i = thermal conductivity of spray-applied material (Btu/ft-sec-°F)
ρ_i = density of spray-applied material (lb/ft^3)
c_i = specific heat of spray-applied material (Btu/lb-°F)
c_s = specific heat of steel (Btu/lb-°F)
h = thickness of spray-applied protection on steel beam (in)
W/D = ratio of weight of steel section per linear foot and heated perimeter (lb/ft^2)
T_f = fire exposure temperature (°F)
T_s = steel temperature (°F)
Δt = time step (sec)

$$c_s\ W/D > 2\ c_i\ \rho_i\ h$$

Where

c_s = specific heat of steel (Btu/lb-°F)
W/D = ratio of weight of steel section per linear foot and heated perimeter (lb/ft^2)
ρ_i = density of spray-applied material (lb/ft^3)
c_i = specific heat of spray-applied material (BTU/lb-°F)
h = thickness of spray-applied protection on steel beam (in)

1.63 > 0.45

The Maximum Allowable Time Step

$$\Delta t = 15.9\ W/D$$

Δt = 196 sec
Δt = 3.27 minutes

For ASTM-E-119 exposure, T_f at any time, t, is given by the following expression

$$T_f = C_1\ LOG\ (0.133\ t + 1) + T_a$$

Where

T_f = fire exposure temperature (°F)
C_1 = constant = 620
t = time step (sec)
T_a = ambient air temperature (°F)

$$\Delta T_{s1} = (k_i /(c_s\ h\ W/D + 1/2\ c_i\ \rho_i\ h^2))\ ((C_1\ LOG\ (0.133\ t_1 + 1)+T_a) - T_{s0})\ \Delta t$$

Where

$t_1 = \Delta t/2$
T_{s0} = initial steel temperature (°F)

Caution! This equation is only valid up to 1000 °F (538 °C) where carbon steel structural members begin to fail. Predicted temperatures above 1000 °F (538 °C) are not accurate or valid.

$$\Delta T_{s2} = (k_i /(c_s\ h\ W/D + 1/2\ c_i\ \rho_i\ h^2))\ ((C_1\ LOG\ (0.133\ t_2 + 1)+T_a) - T_s)\ \Delta t$$

Where

$t_2 = t_1 + \Delta t/2$
$T_s = T_{s0} + \Delta T_s$ from previous row

ESTIMATING FIRE RESISTANCE TIME OF STEEL BEAMS PROTECTED BY FIRE PROTECTION INSULATION (QUASI-STEADY-STATE APPROACH)

Version 1805.1 (SI Units)

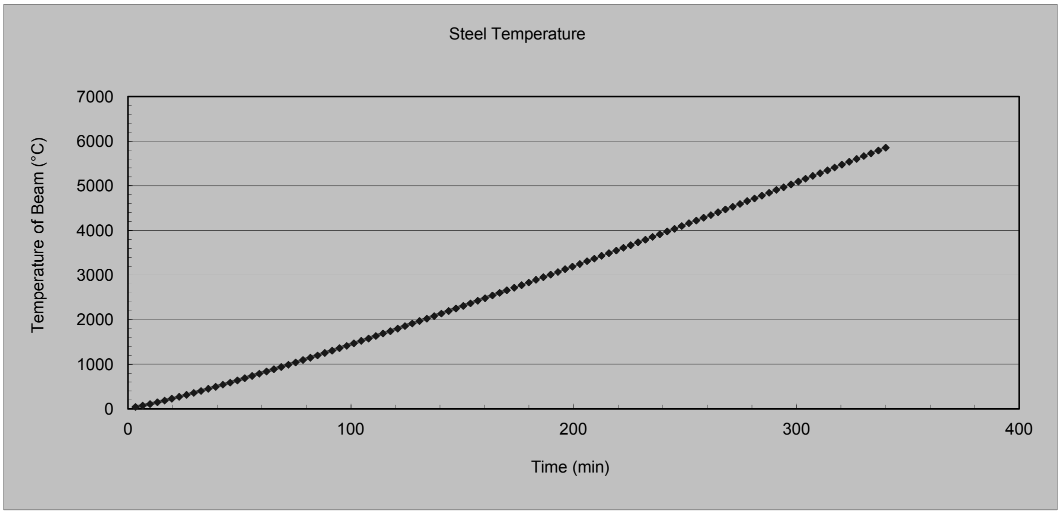
Answer

Time (min)	Time (sec)	ΔT_s (°F)	T_s (°C)	
3.3	196	43	49	
6.5	392	56	80	
9.8	588	63	114	
13.1	785	67	152	
16.3	981	71	191	
19.6	1177	74	232	
22.9	1373	76	274	
26.2	1569	78	317	
29.4	1765	80	362	
32.7	1961	81	407	
36.0	2158	83	453	
39.2	2354	84	499	
42.5	2550	85	547	Failure of Beam
45.8	2746	86	594	Failure of Beam
49.0	2942	87	643	Failure of Beam
52.3	3138	88	692	Failure of Beam
55.6	3334	89	741	Failure of Beam
58.8	3531	90	791	Failure of Beam
62.1	3727	91	841	Failure of Beam
65.4	3923	91	892	Failure of Beam
68.6	4119	92	943	Failure of Beam
71.9	4315	93	995	Failure of Beam
75.2	4511	93	1047	Failure of Beam
78.5	4707	94	1099	Failure of Beam
81.7	4904	95	1151	Failure of Beam
85.0	5100	95	1204	Failure of Beam
88.3	5296	96	1257	Failure of Beam
91.5	5492	96	1311	Failure of Beam
94.8	5688	97	1365	Failure of Beam
98.1	5884	97	1419	Failure of Beam
101.3	6080	98	1473	Failure of Beam
104.6	6277	98	1527	Failure of Beam
107.9	6473	99	1582	Failure of Beam
111.1	6669	99	1637	Failure of Beam
114.4	6865	99	1692	Failure of Beam
117.7	7061	100	1748	Failure of Beam
121.0	7257	100	1804	Failure of Beam
124.2	7453	101	1859	Failure of Beam
127.5	7650	101	1916	Failure of Beam
130.8	7846	101	1972	Failure of Beam
134.0	8042	102	2028	Failure of Beam
137.3	8238	102	2085	Failure of Beam
140.6	8434	102	2142	Failure of Beam
143.8	8630	103	2199	Failure of Beam
147.1	8826	103	2256	Failure of Beam
150.4	9023	103	2314	Failure of Beam
153.6	9219	104	2371	Failure of Beam
156.9	9415	104	2429	Failure of Beam
160.2	9611	104	2487	Failure of Beam
163.5	9807	105	2545	Failure of Beam
166.7	10003	105	2603	Failure of Beam
170.0	10199	105	2662	Failure of Beam

Time (min)	Time (sec)	ΔT_s (°F)	T_s (°C)	
173.3	10396	105	2720	Failure of Beam
176.5	10592	106	2779	Failure of Beam
179.8	10788	106	2838	Failure of Beam
183.1	10984	106	2897	Failure of Beam
186.3	11180	106	2956	Failure of Beam
189.6	11376	107	3015	Failure of Beam
192.9	11572	107	3074	Failure of Beam
196.1	11769	107	3134	Failure of Beam
199.4	11965	107	3193	Failure of Beam
202.7	12161	108	3253	Failure of Beam
205.9	12357	108	3313	Failure of Beam
209.2	12553	108	3373	Failure of Beam
212.5	12749	108	3433	Failure of Beam
215.8	12945	109	3494	Failure of Beam
219.0	13142	109	3554	Failure of Beam
222.3	13338	109	3615	Failure of Beam
225.6	13534	109	3675	Failure of Beam
228.8	13730	109	3736	Failure of Beam
232.1	13926	110	3797	Failure of Beam
235.4	14122	110	3858	Failure of Beam
238.6	14318	110	3919	Failure of Beam
241.9	14515	110	3980	Failure of Beam
245.2	14711	110	4041	Failure of Beam
248.4	14907	111	4103	Failure of Beam
251.7	15103	111	4164	Failure of Beam
255.0	15299	111	4226	Failure of Beam
258.3	15495	111	4288	Failure of Beam
261.5	15691	111	4349	Failure of Beam
264.8	15888	111	4411	Failure of Beam
268.1	16084	112	4473	Failure of Beam
271.3	16280	112	4535	Failure of Beam
274.6	16476	112	4598	Failure of Beam
277.9	16672	112	4660	Failure of Beam
281.1	16868	112	4722	Failure of Beam
284.4	17064	112	4785	Failure of Beam
287.7	17261	113	4847	Failure of Beam
290.9	17457	113	4910	Failure of Beam
294.2	17653	113	4973	Failure of Beam
297.5	17849	113	5036	Failure of Beam
300.8	18045	113	5098	Failure of Beam
304.0	18241	113	5161	Failure of Beam
307.3	18437	114	5225	Failure of Beam
310.6	18634	114	5288	Failure of Beam
313.8	18830	114	5351	Failure of Beam
317.1	19026	114	5414	Failure of Beam
320.4	19222	114	5478	Failure of Beam
323.6	19418	114	5541	Failure of Beam
326.9	19614	114	5605	Failure of Beam
330.2	19810	115	5668	Failure of Beam
333.4	20007	115	5732	Failure of Beam
336.7	20203	115	5796	Failure of Beam
340.0	20399	115	5860	Failure of Beam

ESTIMATING FIRE RESISTANCE TIME OF STEEL BEAMS PROTECTED BY FIRE PROTECTION INSULATION (QUASI-STEADY-STATE APPROACH)

Version 1805.1
(SI Units)



NOTE:
The above calculations are based on principles developed in the SFPE Handbook of Fire Protection Engineering, 3rd Edition, 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

18.11 Problems

Example Problem 18.11-1

Problem Statement
A compartment is 9.0 m wide x 6.1 m long x 4.6 m high (w_c x l_c x h_c). In the center of the compartment, 0.5 kg of polypropylene is involved in flaming combustion:

(a) From the center of the compartment, can you see the "Reflecting Exit Sign" at either end of the compartment?

(b) What if you increase the mass of burned fuel (polypropylene) to 1 kg?

Solution

Purpose:
(1) Determine the visibility of the exit sign.

Assumptions:
(1) Complete burning within the method specified

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 18_Visibility_Through_Smoke_Sup1_SI.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 9.0 m
- Compartment Length (l_c) = 6.1 m
- Compartment Height (h_c) = 4.6 m
- Mass of fuel burn = 0.5 kg
- Select **Reflecting Signs**
- Select **Flaming Combustion**
- Select **Polypropylene**

Results*

	0.5 kg of Material	1 kg of Material
Visible Distance	3.39 m	1.69 m

*see spreadsheet on next page

Therefore, the signs placed at either end of the room (3.0 m away) are visible with 0.5 kg of material burning, but would not be visible if 1 kg of material was burned.

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

The following calculations estimate the smoke obscuration during a fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: **Example 18.11-1a**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	9.00	m
Compartment Length (l_c)	6.10	m
Compartment Height (h_c)	4.60	m
Mass of Fuel Burn (M_f)	0.50	kg
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	7578.2	m^2/kg
Material / Particulate Yield (y_p)	0.059	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (m^2/kg)
Flaming Combustion	7578.2
Smoldering Combustion	4301.1
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Flaming Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel™)	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon™)	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon™)	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas™)	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.

Select Material / Particulate Yield (y_p)

Polypropylene

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m\, m_p$$

Where,
S = visibility through smoke (m)
K = proportionality constant
α_m = specific extinction coefficient (m^2/kg)
m_p = mass concentration of particulate (kg/m^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

Where,
V = volume of the compartment (m^3)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

V = 252.54 m^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p\, M_f$$

Where,
M_p = mass of particulates produced (kg)
y_p = particulates yield
M_f = mass of fuel consumed (kg)

M_p = 0.02950 kg

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
m_p = mass concentration of the particulates (kg/m^3)
M_p = mass of particulates produced (kg)
V = volume of the compartment (m^3)

m_p = 1.16813E-04 kg/m^3

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

Results Summary

Visibility Through Smoke Calculation

$$S = K / \alpha_m m_p$$

Answer	S =	3.39 m	11.12 ft

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

The following calculations estimate the smoke obscuration during a fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: Example 18.11-1b

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	9.00	m
Compartment Length (l_c)	6.10	m
Compartment Height (h_c)	4.60	m
Mass of Fuel Burn (M_f)	1.00	kg
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	7578.2	m^2/kg
Material / Particulate Yield (y_p)	0.059	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (m^2/kg)
Flaming Combustion	7578.2
Smoldering Combustion	4301.1
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Flaming Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel™)	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon™)	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon™)	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas™)	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.

Select Material / Particulate Yield (y_p)

Polypropylene

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m m_p$$

Where,
S = visibility through smoke (m)
K = proportionality constant
α_m = specific extinction coefficient (m^2/kg)
m_p = mass concentration of particulate (kg/m^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

Where,
V = volume of the compartment (m^3)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

V = 252.54 m^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p M_f$$

Where,
M_p = mass of particulates produced (kg)
y_p = particulates yield
M_f = mass of fuel consumed (kg)

M_p = 0.05900 kg

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
m_p = mass concentration of the particulates (kg/m^3)
M_p = mass of particulates produced (kg)
V = volume of the compartment (m^3)

m_p = 2.33626E-04 kg/m^3

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

Results Summary

Visibility Through Smoke Calculation

$$S = K / \alpha_m m_p$$

Answer	S =	1.69 m	5.56 ft

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by:		Date:		Organization:	
Checked by:		Date:		Organization:	

Additional Information:

Example Problem 18.11-2

Problem Statement
A compartment is 3.0 m wide x 9.0 m long x 3.7 m high (w_c x l_c x h_c). What is the minimum amount (kg) of rigid polyurethane foam involved in smoldering combustion necessary to obstruct the visibility for the length of the compartment to a building compartment in reflective light?

Solution

Purpose:
(1) Determine the minimum mass of burning fuel that will obscure the sign.

Assumptions:
(1) Complete burning within the method specified

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 18_Visibility_Through_Smoke_Sup1_SI.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 3.0 m
- Compartment Length (l_c) = 9.0 m
- Compartment Height (h_c) = 3.7 m
- Mass of fuel burn = variable
- Select **Reflecting Signs**
- Select **Smoldering Combustion**
- Select **Polyurethane Foam (Rigid)**

Results*

Visible Distance	Mass of Fuel Burn
8.95 m	0.066 kg

*see spreadsheet on next page

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

The following calculations estimate the smoke obscuration during a fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: **Example 18.11-2**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	3.00	m
Compartment Length (l_c)	9.00	m
Compartment Height (h_c)	3.70	m
Mass of Fuel Burn (M_f)	0.07	kg
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	4301.1	m^2/kg
Material / Particulate Yield (y_p)	0.118	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (m^2/kg)
Flaming Combustion	7578.2
Smoldering Combustion	4301.1
User Specified Value	Enter Value
Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.	

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Smoldering Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel^{TM})	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon^{TM})	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon^{TM})	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas^{TM})	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value
Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.	

Select Material / Particulate Yield (y_p)

Polyurethane Foam (Rigid)

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m m_p$$

Where,
S = visibility through smoke (m)
K = proportionality constant
α_m = specific extinction coefficient (m^2/kg)
m_p = mass concentration of particulate (kg/m^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

Where,
V = volume of the compartment (m^3)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

V = 99.90 m^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p M_f$$

Where,
M_p = mass of particulates produced (kg)
y_p = particulates yield
M_f = mass of fuel consumed (kg)

M_p = 0.00779 kg

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
m_p = mass concentration of the particulates (kg/m^3)
M_p = mass of particulates produced (kg)
V = volume of the compartment (m^3)

m_p = 7.79580E-05 kg/m^3

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

Results Summary

Visibility Through Smoke Calculation

$$S = K / \alpha_m m_p$$

Answer	S =	8.95 m	29.35 ft

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

Example Problem 18.11-3

Problem Statement
An inspector finds 3 kg of PVC pipe in a compartment 3.0 m wide x 9.14 m long x 3.7 m high (w_c x l_c x h_c):

(a) What is the visibility to a reflecting sign given flaming combustion?

(b) What is the visibility to a reflecting sign given smoldering combustion?

Solution

Purpose:
(1) Determine the visibility under the different burning methods.

Assumptions:
(1) Complete burning within the method specified

Spreadsheet (FDT^s) Information:

Use the following FDT^s:
(a) 18_Visibility_Through_Smoke_Sup1_SI.xls

FDT^s Input Parameters:
- Compartment Width (w_c) = 3.0 m
- Compartment Length (l_c) = 9.0 m
- Compartment Height (h_c) = 3.7 m
- Mass of fuel burn = 3 kg
- Select **Reflecting Signs**
- Select **Flaming Combustion** (get result)
- Select **Smoldering Combustion** (get result)
- Select **PVC**

Results*

Burning Method	Visibility
Flaming	0.08 m
Smoldering	0.14 m

*see spreadsheet on next page

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

The following calculations estimate the smoke obscuration during a fire.
Parameters in YELLOW CELLS are Entered by the User.
Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: Example 18.11-3a

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	3.00	m
Compartment Length (l_c)	9.00	m
Compartment Height (h_c)	3.70	m
Mass of Fuel Burn (M_f)	3.00	kg
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	7578.2	m^2/kg
Material / Particulate Yield (y_p)	0.172	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (m^2/kg)
Flaming Combustion	7578.2
Smoldering Combustion	4301.1
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Flaming Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel™)	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon™)	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon™)	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas™)	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.

Select Material / Particulate Yield (y_p)

Polyvinylchloride (PVC)

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m m_p$$

Where,
S = visibility through smoke (m)
K = proportionality constant
α_m = specific extinction coefficient (m^2/kg)
m_p = mass concentration of particulate (kg/m^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

Where,
V = volume of the compartment (m^3)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

V = 99.90 m^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p M_f$$

Where,
M_p = mass of particulates produced (kg)
y_p = particulates yield
M_f = mass of fuel consumed (kg)

M_p = 0.51600 kg

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
m_p = mass concentration of the particulates (kg/m^3)
M_p = mass of particulates produced (kg)
V = volume of the compartment (m^3)

m_p = 5.16517E-03 kg/m^3

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

Results Summary

Visibility Through Smoke Calculation

$$S = K / \alpha_m m_p$$

Answer	S =	0.08 m	0.25 ft

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: Date: Organization:

Checked by: Date: Organization:

Additional Information:

CHAPTER 18

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

The following calculations estimate the smoke obscuration during a fire.

Parameters in YELLOW CELLS are Entered by the User.

Parameters in GREEN CELLS are Automatically Selected from each DROP DOWN MENU for the Situation, Mode of Combustion and 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.

Project / Inspection Title: **Example 18.11-3b**

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	3.00	m
Compartment Length (l_c)	9.00	m
Compartment Height (h_c)	3.70	m
Mass of Fuel Burn (M_f)	3.00	kg
Situation / Proportionality Constant for Visibility (K)	3	
Mode of Combustion / Specific Extinction Coefficient (α_m)	4301.1	m^2/kg
Material / Particulate Yield (y_p)	0.172	

Calculate

RECOMMENDED SITUATION / PROPORTIONALITY CONSTANTS FOR VISIBILITY

Situation	Proportionality Constant K
Building Components in Reflected Light	3
Illuminated Signs	8
Reflecting Signs	3
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 31.

Select Situation / Proportionality Constant for Visibility (K)

Reflecting Signs

Scroll to desired Situation **then**
Click on selection

MODE OF COMBUSTION / SPECIFIC EXTINCTION COEFFICIENT

Mode of Combustion	Specific Extinction Coefficient α_m (m^2/kg)
Flaming Combustion	7578.2
Smoldering Combustion	4301.1
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

Select Mode of Combustion / Specific Extinction Coefficient (α_m)

Smoldering Combustion

Scroll to desired Mode of Combustion **then**
Click on selection

MATERIAL / PARTICULATE YIELD OF SOLID FUELS (WELL-VENTILATED FIRES)

Material	Particulate Yield (y_p)
Acrylonitrile-Butadiene-Styrene (ABS)	0.105
Ethylenetetrafluoroethylene (ETFE; Tefzel™)	0.042
Fiberboard	0.008
Fluorinated Polyethylene-Polypropylene (FEP; Teflon™)	0.003
Nylon	0.075
Perfluoroalkoxy (PFA; Teflon™)	0.002
Phenolic Foam	0.002
Polyester	0.09
Polyethylene (PE)	0.06
Polyethylene Foam	0.076
Polymethylemethacrylate (PMMA; Plexiglas™)	0.022
Polypropylene	0.059
Polystyrene	0.164
Polystyrene Foam	0.194
Polyurethane Foam (Flexible)	0.188
Polyurethane Foam (Rigid)	0.118
Polyvinylchloride (PVC)	0.172
Silicone	0.065
Silicone Rubber	0.078
Tetrafluoroethylene (TFE; TeflonTM)	0.003
Wood (Douglas Fir)	0.018
Wood (Hemlock)	0.015
Wood (Red Oak)	0.015
Wool 100%	0.008
User Specified Value	Enter Value

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 35.

Select Material / Particulate Yield (y_p)

Polyvinylchloride (PVC)

Scroll to desired Material **then**
Click on selection

ESTIMATING VISIBILITY THROUGH SMOKE
METHOD OF JIN

Reference: John H. Klote & James A. Milke, Principles of Smoke Management, 2002, Page 32.

$$S = K / \alpha_m m_p$$

Where,
S = visibility through smoke (m)
K = proportionality constant
α_m = specific extinction coefficient (m^2/kg)
m_p = mass concentration of particulate (kg/m^3)

Compartment Volume Calculation

$$V = w_c \times l_c \times h_c$$

Where,
V = volume of the compartment (m^3)
w_c = compartment width (m)
l_c = compartment length (m)
h_c = compartment height (m)

V = 99.90 m^3

Mass of Particulates Produced (airborne particulate)

$$M_p = y_p M_f$$

Where,
M_p = mass of particulates produced (kg)
y_p = particulates yield
M_f = mass of fuel consumed (kg)

M_p = 0.51600 kg

Mass Concentration of the Particulates Calculation

$$m_p = M_p / V$$

Where,
m_p = mass concentration of the particulates (kg/m^3)
M_p = mass of particulates produced (kg)
V = volume of the compartment (m^3)

m_p = 5.16517E-03 kg/m^3

ESTIMATING VISIBILITY THROUGH SMOKE

Version 1805.1
(English Units)

Results Summary

Visibility Through Smoke Calculation

$$S = K / \alpha_m m_p$$

Answer	S =	0.14 m	0.44 ft

Visibility in smoke is defined in terms of the furthest distance at which an object can be perceived.

NOTE:

The above calculations are based on principles developed in the Principles of Smoke Management by Klote and Milke 2002. Calculations are based on certain assumptions and have inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation and should only be interpreted by an informed user. Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations. Any questions, comments, concerns and suggestions or to report an error(s) in the spreadsheets, please send an email to David.Stroup@nrc.gov or Naeem.Iqbal@nrc.gov.

Prepared by: ______ Date: ______ Organization: ______

Checked by: ______ Date: ______ Organization: ______

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NRC FORM 335 (12-2010) NRCMD 3.7

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10. SUPPLEMENTARY NOTES

M.H. Salley, NRC Project Manager

11. ABSTRACT (200 words or less)

The U.S. Nuclear Regulatory Commission (NRC) has developed quantitative methods, known as “Fire Dynamics Tools” (FDTs), for analyzing the impact of fire and fire protection systems in nuclear power plants (NPPs). These methods have been implemented in spreadsheets and taught at the NRC’s quarterly regional inspector workshops. The FDTs were developed using state-of-the-art fire dynamics equations and correlations that were preprogrammed and locked into Microsoft Excel® spreadsheets. These FDTs enable inspectors to perform quick, easy, first-order calculations for 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 NPPs. This NUREG-series report documents a new spreadsheet that has been added to the FDTs suite and describes updates, corrections, and improvements to the existing spreadsheets. The majority of the original FDTs were developed using principles and information from the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, the National Fire Protection Association (NFPA) Fire Protection Handbook, and other fire science literature. The new spreadsheet predicts the behavior of power cables, instrument cables, and control cables during a fire. The thermally-induced electrical failure (THIEF) model was developed by the National Institute of Standards and Technology (NIST) as part of the Cable Response to Live Fire (CAROLFIRE) program sponsored by the NRC. The experiments for CAROLFIRE were conducted at Sandia National Laboratories, Albuquerque, New Mexico. THIEF model predictions have been compared to experimental measurements of instrumented cables in a variety of configurations, and the results indicate that the model is an appropriate analysis tool for NPP applications. The accuracy and simplicity of the THIEF model have been shown to be comparable to that of the activation algorithms for various fire protection devices (e.g., sprinklers, heat and smoke detectors).

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

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