SDP - HARRIS FIRE ZONE 1-A-4-CHLR
(AKA SAFE SHUTDOWN ANALYSIS AREAS 1-A-BAL-B-B2 AND 1-A-BAL-B-B1)

- Ignition sources:
  Two chiller compressors, each with 12 gal. of lube oil (per licensee engineers)
  Two chilled water pumps, each with 1 gal. of lube oil
  Two 480V motor control centers
  5 ventilation system fans
  Electrical junction boxes
  Miscellaneous hydrogen fires
  Transients
  Welding/Ordinary Combustibles
  Welding/Cables

- Combustibles:
  55 gal. drum of oil (staging area location: 1-A-4-CHLR zone, chiller room, 261' RAB - per FPP-004, Transient Combustible Control)
  55 gal. drum of oil (staging area location: 1-A-4-COM-B, 261' RAB, Boric Acid Tank area, at the edge of SSA area 1-A-BAL-B-B2 - per FPP-004)
  HP cart w/ standard contents (permanent storage location: 1-A-4-CHLR zone, RAB 261' East hallway, across from VCT - per FPP-004)
  2 gal. transient flammable liquids, with no transient combustible permit required (per FPP-004)
  5 gal. transient combustible liquids, with no transient combustible permit required (per FPP-004)
  Combustible thermal insulation on chiller piping (Assume Rubatex foam pipe insulation, HRR 47 Kw/sq. meter, 10.6 sq. meters, burning with 500 Kw HRR) - per inspector observation
  7,968 lbs. of cable insulation, per UFSAR (IEEE-383)
  Transient combustibles up to one million Btu above the analyzed combustible loading for a given fire zone are considered a low fire load and no fire watch or other compensatory action is required - per FPP-004.

Dimensions: Since the 1-A-4-CHLR zone (13,860 sq. ft.) is not separated from 1-A-4-COMB (4,187 sq. ft.) or 1-A-4-COR (1,944 sq. ft.), a total area of 19,991 sq. ft. was assumed. Then, to account for isolated rooms included in these areas (e.g., the BAT room and the VCT room), 1500 sq. ft. was deducted. The net area assumed was 18,500 sq. ft. Equivalent room dimensions of 80 ft. wide by 231 ft. long by 23 ft. high were used to input the Fire Dynamics Worksheets. Also, a vent opening (walkway to fire zone 1-A-COM-E) of 12 feet high and 10 feet wide and natural ventilation were assumed. Stacks of cable trays were estimated to be about 15 ft. above floor level and higher over the 'B' chiller in SSA area 1-A-BAL-B-B2 and about 12 ft. above floor level and higher over the RAB 261' hallway in SSA area 1-A-BAL-B1.

NN/65

Analysis: 12 gallons of oil spill from the 'B' chiller and burn, plus 500 Kw HRR from insulation on the chiller piping

Pool Fire Area (sq. ft.)	Pool Fire Heat Release Rate (kW)	Pool Fire Flame Height (ft.)	Flame Impingement to Cable Tray	Pool Fire Burning Duration (min.)	Hot Gas Layer Temp. After 1 Minute (deg. F)	Hot Gas Layer Temp. After 2 Minutes (deg. F)	Hot Gas Layer Temp. After 3 Minutes (deg. F)	Hot Gas Layer Temp. After 4 Minutes (deg. F)	Plume C/L Temp (deg. F)
20	3333	14.6	yes*	8	184	197	206	212	495
40	6667	18.8	yes	4	240	260	273	282	710
60	10000	21.8	yes	2.65	287	313	329	NA	889

*NOTE: Burning of the thermal insulation on the chiller piping would increase this flame height so that it would reach the cable trays.

Conclusion: A credible fire from the 12 gal. of oil in the 'B' chiller and the insulation on the chiller piping could have flames impinging the cable trays above the 'B' chiller. The hot gas layer remains well below the 700 degrees F needed to ignite all of the IEEE-383 cables in the room. If the oil spread over about 40 to 60 sq. ft. (approx. 7.1 to 8.7 ft. diameter) and the thermal insulation of the chiller piping burned, then a the plume centerline temperature could exceed the 700 degrees needed to ignite the IEEE-383 cables in the cable trays above the 'B' chiller. A credible fire involving a spill of one of the allowed 55 gal drums of oil could produce a higher heat release rate, flame height, and hot gas layer.

1-A-4-CHLR
LUBE OIL FIRE, 60 FT²
+ 500 KW FROM CHILLER INSULATION

METHOD OF PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN ROOM FIRE WITH NATURAL VENTILATION COMPARTMENT WITH THERMALLY THICK BOUNDARIES $\delta > 1$ inch

VERSION 1.03

The following calculations estimate the hot gas layer temperature and smoke layer height in enclosure fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent values are calculated by the spreadsheet and based on values specified in the input parameters.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	80.00	ft	24.384	m
Compartment Length (l_c)	231.00	ft	70.4088	m
Compartment Height (h_c)	23.00	ft	7.0104	m
Vent Width (w_v)	10.00	ft	3.048	m
Vent Height (h_v)	12.00	ft	3.658	m
Top of Vent from Floor (V_T)	12.00	ft	3.658	m
Interior Lining Thickness (δ)	12.00	in	0.3048	m

For thermally thick case the interior lining thickness should be greated then 1 inch.

AMBIENT CONDITIONS

Ambient Air Temperature (T_0)	77.00	°F	25.00	C
			298.00	K
Specific Heat of Air (c_p)	1.00	kJ/kg-K		
Ambient air Density (ρ_0)	1.20	kg/m³		

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Interior Lining Thermal Inertia ($k\rho c$)	2.9	(kW/m²-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/m³

INTERIOR LINING EXPERIMENTAL THERMAL PROPERTIES FOR COMMON MATERIALS

Material	kρc (kW/m²-K)²-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m³)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	3.7E-05	0.8	60
Expanded Polystyrene	0.001	3.4E-05	1.5	20

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

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 10500.00 kW

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-139)

$\Delta T_g = 6.85[Q^2/(A_0(h_v)^{1/2})(A_T h_k)]^{1/3}$

Where $\Delta T_g = T_g - T_0$, upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_0 = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat trensfer 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

$A_0 = (w_v)(h_v)$

$A_0 =$ **11.15** m^2

Thermal Penetration Time Calculation Thermally Thick Material

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

Where ρ = interior construction density (kg/m^3)
c_p = interior construction heat capacity (kJ/Kg-K)
k = interior construction thermal conductivity (kW/m-K)
δ = interior construction thickness (m)

$t_p =$ **26128.98** sec

Heat Transfer Coefficient Calculation

$h_k = (k\rho c/t)^{1/2}$ for $t < t_p$

Where $k\rho c$ = 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)

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c x l_c) + 2(h_c x w_c) + 2(h_c x l_c)] - A_0$

$A_T =$ **4751.62** m^2

Compartment Hot Gas Layer Temperature With Natural Ventilation

$\Delta T_g = 6.85[Q^2/(A_0(h_v)^{1/2})(A_T h_k)]^{1/3}$

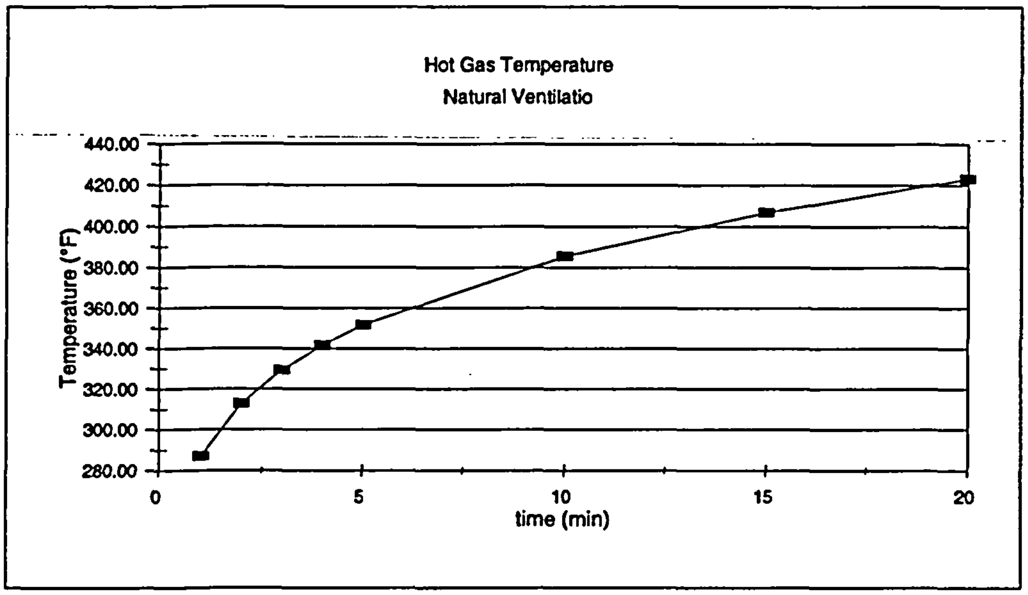
$\Delta T_g = T_g - T_0$

$T_g = \Delta T_g + T_0$

RESULTS:

Time After		h_k	ΔT_g	T_g	T_g	T_g
(min)	(s)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
1	60	0.22	116.74	414.74	141.74	287.13
2	120	0.16	131.04	429.04	156.04	312.87
3	180	0.13	140.20	438.20	165.20	329.36
4	240	0.11	147.09	445.09	172.09	341.75
5	300	0.10	152.66	450.66	177.66	351.78

10	600	0.07	171.35	469.35	196.35	385.44
15	900	0.06	183.33	481.33	208.33	407.00
20	1200	0.05	192.34	490.34	217.34	423.21



ESTIMATING SMOKE LAYER HEIGHT METHOD OF YAMANA AND TANAKA

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

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

Compartment Area Calculation

$A_c =$ $(w_c)(l_c)$

$A_c =$ **1716.85** m^2

Hot Gas Layer Density Calculation

$\rho_g =$ $353/T_g$

Calculation for Constant K

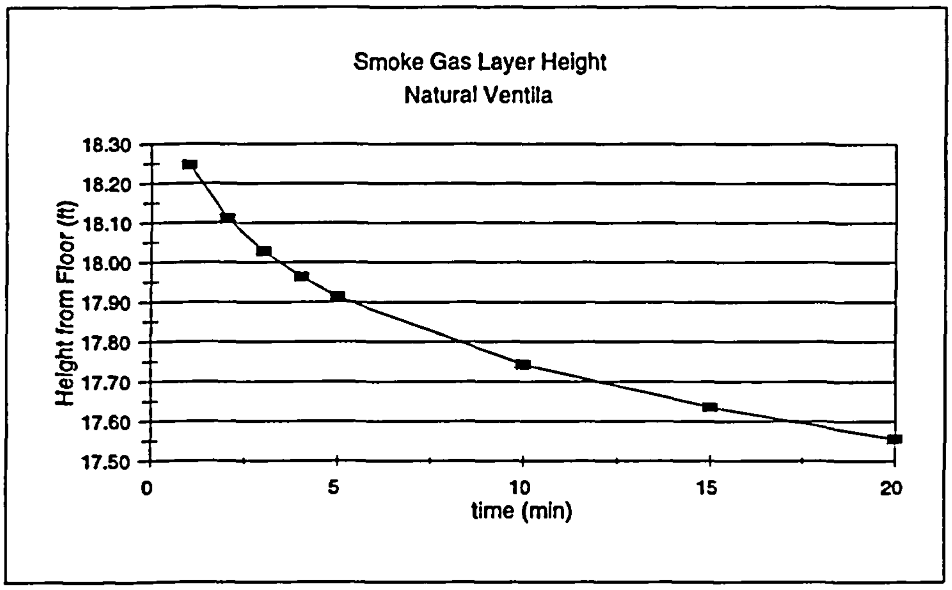
$k =$ $0.076/\rho_g$

Smoke Gas Layer Height With Natural Ventilation

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

RESULTS:

t	ρ_g	k	z	z
(min)	kg/m^3		(m)	(ft)
1	0.85	0.089	5.56	18.25
2	0.82	0.092	5.52	18.11
3	0.81	0.094	5.49	18.03
4	0.79	0.096	5.48	17.96
5	0.78	0.097	5.46	17.91
10	0.75	0.101	5.41	17.74
15	0.73	0.104	5.38	17.64
20	0.72	0.106	5.35	17.56



NOTE

The above calculations are based on principles developed in the Society of Fire Protection Engineers (SFPE) Handbook of Fire Protection Engineering, 2nd Edition 1995.
Calculations are based on certain assumptions and has inherent limitations. The results of such calculations may or may not have reasonable predictive capabilities for a given situation, and should only be interpreted by an informed user.
Although each calculation in the spreadsheet has been verified with the results of hand calculation, there is no absolute guarantee of the accuracy of these calculations.
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1 - A - 4 - CHLR
LUBE OIL FIRE, 60 FT², 12 GAL
+ 500 KW FROM THERMAL INSULATION

METHOD OF ESTIMATING TEMPERATURE OF A BUOYANT FIRE PLUME VERSION 1.0

The following calculations estimate the centerline plume temperature in a compartment fire
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent values are calculated by the spreadsheet, and based on values specified in the input parameters.

INPUT PARAMETERS

Heat Rlease Rate of the Fire (Q)	10500.00	kW	
Distance from the Top of the Fuel to the Ceiling (z)	20.00	ft	6.10
Area of Combustible Fuel (A_c)	60.00	ft²	5.57

AMBIENT CONDITIONS

Ambient Air Temperature (T_0)	77.00	°F	25.00 / 298.00
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_0)	1.20	kg/m³	
Acceleration of Gravity (g)	9.81	m/sec²	
Convective Heat Release Fraction (χ_c)	0.50		

ESTIMATING PLUME CENTERLINE TEMPERATURE

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 2-9)

$$T_{p(centerline)} - T_0 = 9.1\,(T_0/g\,c_p^2\,\rho_0^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$$

Where
Q_c = Convective portion of the heat release rate (kW)
T_0 = ambient air temperature (K)
g = acceleration of gravity (m/sec²)
c_p = specific heat of air (kJ/kg-K)
ρ_0 = ambient air density (kg/m³)
z = distance from the top of the fuel package to the ceiling (m)
z_0 = hypothetical virtual origin of the fire (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c\,Q$

Where
Q = heat release rate of the fire (kW)
χ_c = convective heat release fraction
Q_c = **5250 kW**

Pool Fire Diameter Calculation

$A_{dike} = \pi D^2/4$
$D = (4\,A_{dike}/\pi)^{1/2}$
D = **2.66** 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 = diameter of pool fire (m)

z_0/D = 0.24
z_0 = **0.65** m

Centerline Plume Temperature Calculation

$$T_{p(centerline)} - T_0 = 9.1\,(T_0/g\,c_p^2\,\rho_0^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$$

$T_{p(centerline)} - T_0 =$ 450.84

$T_{p(centerline)} =$ 748.84 K

$T_{p(centerline)} =$ 475.84 °C 888.51 °F ANSWER

NOTE

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1-A-4- CHLR

LUBE OIL FIRE, 40 FT², x2 GAL + 500 KW FROM CHILLER INSULATION

METHOD OF PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN ROOM FIRE WITH NATURAL VENTILATION COMPARTMENT WITH THERMALLY THICK BOUNDARIES δ > 1 inch

VERSION 1.03

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

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

All subsequent values are calculated by the spreadsheet and based on values specified in the input parameters.

INPUT PARAMETERS

COMPARTMENT INFORMATION

Compartment Width (w_c)	80.00	ft	24.384 m
Compartment Length (l_c)	231.00	ft	70.4088 m
Compartment Height (h_c)	23.00	ft	7.0104 m
Vent Width (w_v)	10.00	ft	3.048 m
Vent Height (h_v)	12.00	ft	3.658 m
Top of Vent from Floor (V_T)	12.00	ft	3.658 m
Interior Lining Thickness (δ)	12.00	in	0.3048 m

For thermally thick case the interior lining thickness should be greated then 1 inch.

AMBIENT CONDITIONS

Ambient Air Temperature (T_0)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient air Density (ρ_0)	1.20	kg/m³	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Interior Lining Thermal Inertia ($k\rho c$)	2.9	(kW/m²-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/m³

INTERIOR LINING EXPERIMENTAL THERMAL PROPERTIES FOR COMMON MATERIALS

Material	kρc (kW/m²-K)²-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m³)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	3.7E-05	0.8	60
Expanded Polystyrene	0.001	3.4E-05	1.5	20

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

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) 7167.00 kW

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-139)

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

Where $\Delta T_g = T_g - T_O$, upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_O = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat trensfer 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

$A_O = (w_v)(h_v)$
$A_O =$ **11.15** m^2

Thermal Penetration Time Calculation Thermally Thick Material

$t_p = (\rho c_p/k)(\delta/2)^2$
Where ρ = interior construction density (kg/m^3)
c_p = interior construction heat capacity (kJ/Kg-K)
k = interior construction thermal conductivity (kW/m-K)
δ = interior construction thickness (m)
$t_p =$ **26128.98** sec

Heat Transfer Coefficient Calculation

$h_k = (k\rho c/t)^{1/2}$ for $t < t_p$
Where $k\rho c$ = 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)

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)] - A_O$
$A_T =$ **4751.62** m^2

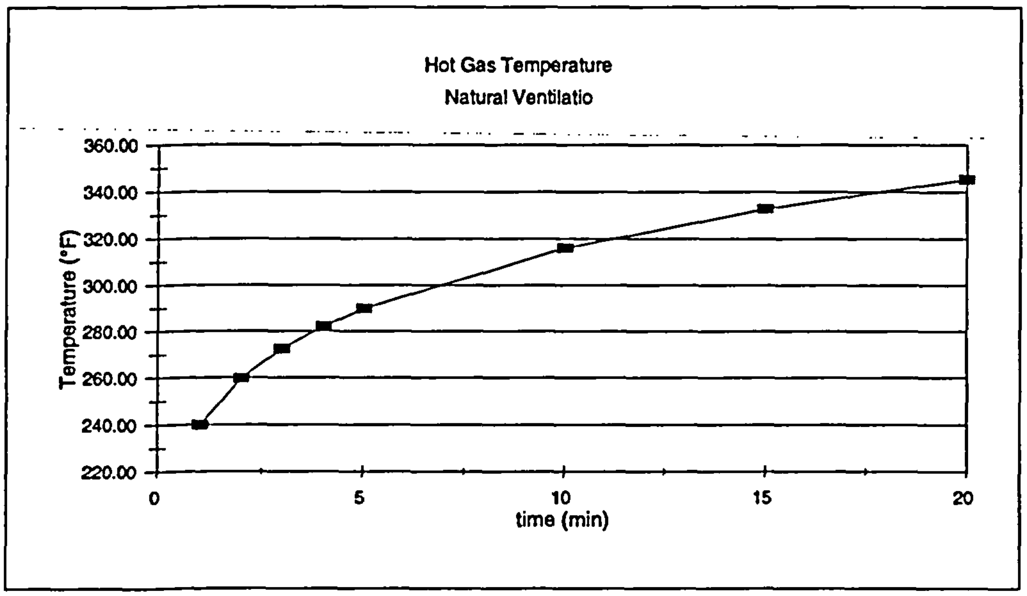
Compartment Hot Gas Layer Temperature With Natural Ventilation

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

RESULTS:

Time After		h_k	ΔT_g	T_g	T_g	T_g
(min)	(s)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
1	60	0.22	90.50	388.50	115.50	239.90
2	120	0.16	101.58	399.58	126.58	259.85
3	180	0.13	108.69	406.69	133.69	272.64
4	240	0.11	114.03	412.03	139.03	282.25
5	300	0.10	118.35	416.35	143.35	290.02

10	600	0.07	132.84	430.84	157.84	316.11
15	900	0.06	142.13	440.13	167.13	332.83
20	1200	0.05	149.11	447.11	174.11	345.39



ESTIMATING SMOKE LAYER HEIGHT METHOD OF YAMANA AND TANAKA

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

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

Compartment Area Calculation

$A_c =$ $(w_c)(l_c)$
$A_c =$ **1716.85** m^2

Hot Gas Layer Density Calculation

$\rho_g =$ $353/T_g$

Calculation for Constant K

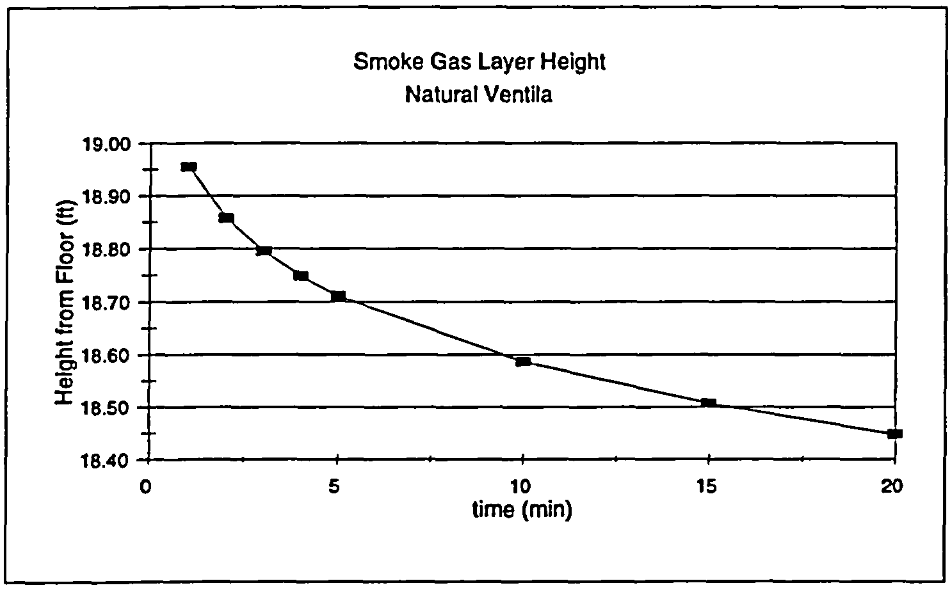
$k =$ $0.076/\rho_g$

Smoke Gas Layer Height With Natural Ventilation

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

RESULTS:

t	ρ_g	k	z	z
(min)	kg/m³		(m)	(ft)
1	0.91	0.084	5.78	18.96
2	0.88	0.086	5.75	18.86
3	0.87	0.088	5.73	18.80
4	0.86	0.089	5.71	18.75
5	0.85	0.090	5.70	18.71
10	0.82	0.093	5.67	18.59
15	0.80	0.095	5.64	18.51
20	0.79	0.096	5.62	18.45



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1-A-4-CHK

LUBE OIL FIRE, 20 FT², 12 GAL + 500 KW FROM CHILLER INSULATION

METHOD OF PREDICTING HOT GAS LAYER TEMPERATURE AND SMOKE LAYER HEIGHT IN ROOM FIRE WITH NATURAL VENTILATION COMPARTMENT WITH THERMALLY THICK BOUNDARIES $\delta > 1$ inch
VERSION 1.03

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Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
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Compartment Width (w_c)	80.00	ft	24.384 m
Compartment Length (l_c)	231.00	ft	70.4088 m
Compartment Height (h_c)	23.00	ft	7.0104 m
Vent Width (w_v)	10.00	ft	3.048 m
Vent Height (h_v)	12.00	ft	3.658 m
Top of Vent from Floor (V_T)	12.00	ft	3.658 m
Interior Lining Thickness (δ)	12.00	in	0.3048 m

For thermally thick case the interior lining thickness should be greated then 1 inch.

AMBIENT CONDITIONS

Ambient Air Temperature (T_0)	77.00	°F	25.00 °C 298.00 K
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient air Density (ρ_0)	1.20	kg/m³	

THERMAL PROPERTIES OF COMPARTMENT ENCLOSING SURFACES FOR

Interior Lining Thermal Inertia ($k\rho c$)	2.9	(kW/m²-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/m³

INTERIOR LINING EXPERIMENTAL THERMAL PROPERTIES FOR COMMON MATERIALS

Material	kρc (kW/m²-K)²-sec	k (kW/m-K)	c (kJ/kg-K)	ρ (kg/m³)
Aluminum (pure)	500	0.206	0.895	2710
Steel (0.5% Carbon)	197	0.054	0.465	7850
Concrete	2.9	0.0016	0.75	2400
Brick	1.7	0.0008	0.8	2600
Glass, Plate	1.6	0.00076	0.8	2710
Brick/Concrete Block	1.2	0.00073	0.84	1900
Gypsum Board	0.18	0.00017	1.1	960
Plywood	0.16	0.00012	2.5	540
Fiber Insulation Board	0.16	0.00053	1.25	240
Chipboard	0.15	0.00015	1.25	800
Aerated Concrete	0.12	0.00026	0.96	500
Plasterboard	0.12	0.00016	0.84	950
Calcium Silicate Board	0.098	0.00013	1.12	700
Alumina Silicate Block	0.036	0.00014	1	260
Glass Fiber Insulation	0.0018	3.7E-05	0.8	60
Expanded Polystyrene	0.001	3.4E-05	1.5	20

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

FIRE SPECIFICATIONS

Fire Heat Release Rate (Q) | 3833.00 | kW

METHOD OF McCAFFREY, QUINTIERE, AND HARKLEROAD (MQH)

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-139)

$\Delta T_g = 6.85[Q^2/(A_0(h_v)^{1/2})\ (A_T h_k)]^{1/3}$

Where $\Delta T_g = T_g - T_0$, upper layer gas temperature rise above ambient (K)
Q = heat release rate of the fire (kW)
A_0 = area of ventilation opening (m^2)
h_v = height of ventilation opening (m)
h_k = convective heat trensfer 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

$A_0 = (w_v)(h_v)$
$A_0 =$ **11.15** m^2

Thermal Penetration Time Calculation Thermally Thick Material

$t_p = (\rho c_p/k)(\delta/2)^2$
Where ρ = interior construction density (kg/m^3)
c_p = interior construction heat capacity (kJ/Kg-K)
k = interior construction thermal conductivity (kW/m-K)
δ = interior construction thickness (m)
$t_p =$ **26128.98** sec

Heat Transfer Coefficient Calculation

$h_k = (k\rho c/t)^{1/2}$ for $t < t_p$
Where $k\rho c$ = 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)

Area of Compartment Enclosing Surface Boundaries

$A_T = [2(w_c \times l_c) + 2(h_c \times w_c) + 2(h_c \times l_c)] - A_0$
$A_T =$ **4751.62** m^2

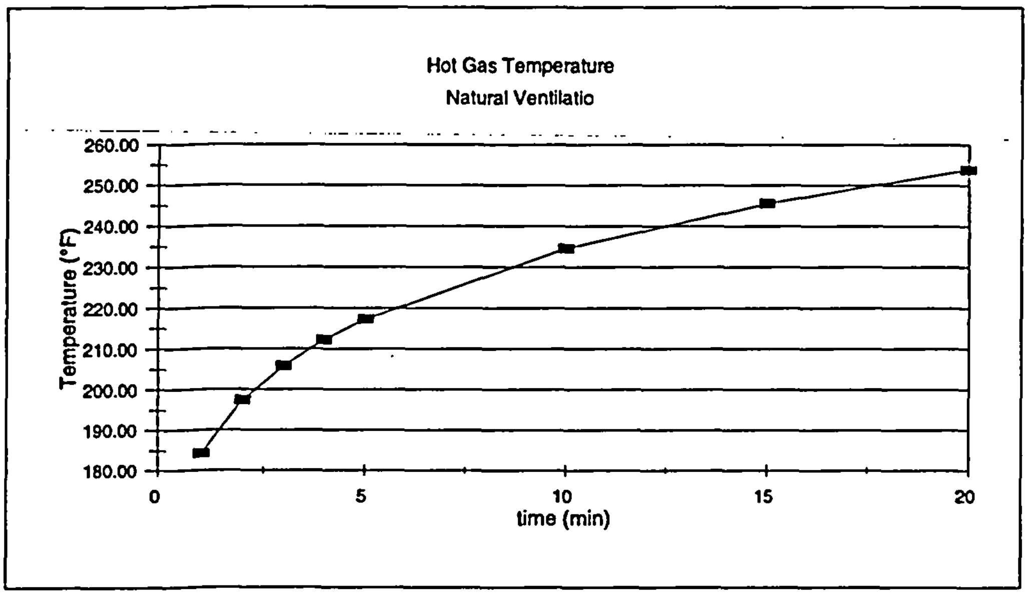
Compartment Hot Gas Layer Temperature With Natural Ventilation

$\Delta T_g = 6.85[Q^2/(A_0(h_v)^{1/2})\ (A_T h_k)]^{1/3}$
$\Delta T_g = T_g - T_0$
$T_g = \Delta T_g + T_0$

RESULTS:

Time After		h_k	ΔT_g	T_g	T_g	T_g
(min)	(s)	(kW/m^2-K)	(K)	(K)	(°C)	(°F)
1	60	0.22	59.63	357.63	84.63	184.33
2	120	0.16	66.93	364.93	91.93	197.48
3	180	0.13	71.61	369.61	96.61	205.90
4	240	0.11	75.13	373.13	100.13	212.23
5	300	0.10	77.97	375.97	102.97	217.35

10	600	0.07	87.52	385.52	112.52	234.54
15	900	0.06	93.64	391.64	118.64	245.56
20	1200	0.05	98.24	396.24	123.24	253.84



ESTIMATING SMOKE LAYER HEIGHT METHOD OF YAMANA AND TANAKA

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

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

Compartment Area Calculation

$A_c =$ $(w_c)(l_c)$
$A_c =$ **1716.85** m^2

Hot Gas Layer Density Calculation

$\rho_g =$ $353/T_g$

Calculation for Constant K

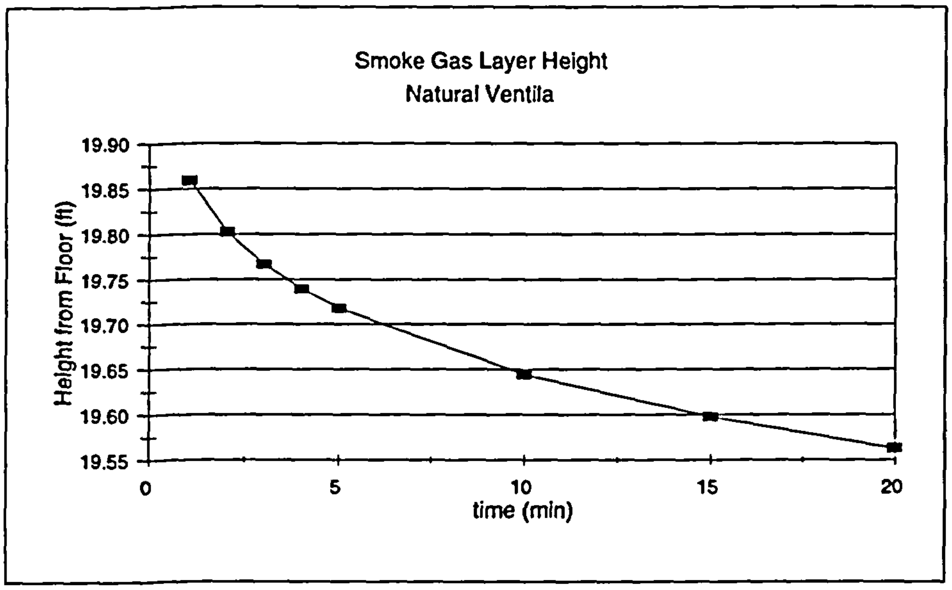
$k =$ $0.076/\rho_g$

Smoke Gas Layer Height With Natural Ventilation

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

RESULTS:

t	ρ_g	k	z	z
(min)	kg/m^3		(m)	(ft)
1	0.99	0.077	6.05	19.86
2	0.97	0.079	6.04	19.80
3	0.96	0.080	6.02	19.77
4	0.95	0.080	6.02	19.74
5	0.94	0.081	6.01	19.72
10	0.92	0.083	5.99	19.64
15	0.90	0.084	5.97	19.60
20	0.89	0.085	5.96	19.56



NOTE

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1-A-4 - CHLR
Lube Oil Tank, 60 ft²

METHOD OF ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE, HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT

VERSION 1.03

The following calculations estimate the heat release rate, burning duration, and flame height for liquid pool fire.

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

All subsequent values are calculated by the spreadsheet, and based on values specified in the input parameters.

INPUT PARAMETERS

Fuel Spill Volume (V)	12.00	gallons	0.0454 m^3
Fuel Spill Area or Dike Area (A_{dike})	60.00	ft^2	5.574 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	

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)
Methanol	0.017	20,000	796
Ethanol	0.015	26,800	794
Butane	0.078	45,700	573
Benzene	0.085	40,100	874
Hexane	0.074	44,700	650
Heptane	0.101	44,600	675
Xylene	0.09	40,800	870
Acetone	0.041	25,800	791
Dioxane	0.018	26,200	1035
Diethy Ether	0.085	34,200	714
Benzine	0.048	44,700	740
Gasoline	0.055	43,700	740
Kerosine	0.039	43,200	820
Diesel	0.045	44,400	918
JP-4	0.051	43,500	760
JP-5	0.054	43,000	810
Transformer Oil, Hydrocarbon	0.039	46,000	760
Fuel Oil, Heavy	0.035	39,700	970
Crude Oil	0.0335	42,600	855
Lube Oil	0.039	46,000	760

Referenc: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-2)

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-4)

$$Q = m'' \Delta H_{c,eff} A_f$$

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

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

$Q = m''\Delta H_c A_f$

Q = 10000.08 kW 9478.28 BTU/sec **ANSWER**

ESTIMATING POOL FIRE BURNING DURATION

Reference: SFPE Handbook of Fire Protection Engineering 2^{nd} Edition (Page 3-197)

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

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

Pool Fire Diameter Calculation

$A_f = \pi D^2/4$
$D = (4A_f/\pi)^{1/2}$
D = **2.664** m

Calculation for Regression Rate

$v = m''/\rho$
Where m'' = mass burning rate of fuel (kg/m^2-sec)
ρ = liquid fuel density (kg/m^3)
v = **0.000051** m/sec

Burning Duration Calculation

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

t_b = 158.80 sec 2.65 minutes **ANSWER**

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

ESTIMATING POOL FIRE FLAME HEIGHT

Reference: SFPE Handbook of Fire Protection Engineering 2^{nd} Edition (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 = 6.64 m 21.78 ft **ANSWER**

NOTE

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LUBE OIL FIRE

METHOD OF ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE, HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT

VERSION 1.03

The following calculations estimate the heat release rate, burning duration, and flame height for liquid pool fire.

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

All subsequent values are calculated by the spreadsheet, and based on values specified in the input parameters.

INPUT PARAMETERS

Fuel Spill Volume (V)	12.00	gallons	0.0454 m^3
Fuel Spill Area or Dike Area (A_{dike})	40.00	ft^2	3.716 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	

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)
Methanol	0.017	20,000	796
Ethanol	0.015	26,800	794
Butane	0.078	45,700	573
Benzene	0.085	40,100	874
Hexane	0.074	44,700	650
Heptane	0.101	44,600	675
Xylene	0.09	40,800	870
Acetone	0.041	25,800	791
Dioxane	0.018	26,200	1035
Diethy Ether	0.085	34,200	714
Benzine	0.048	44,700	740
Gasoline	0.055	43,700	740
Kerosine	0.039	43,200	820
Diesel	0.045	44,400	918
JP-4	0.051	43,500	760
JP-5	0.054	43,000	810
Transformer Oil, Hydrocarbon	0.039	46,000	760
Fuel Oil, Heavy	0.035	39,700	970
Crude Oil	0.0335	42,600	855
Lube Oil	0.039	46,000	760

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-2)

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-4)

$$Q = m''\Delta H_{c,eff} A_f$$

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

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

$Q = m''\Delta H_c A_f$

Q = 6666.72 kW 6318.85 BTU/sec ANSWER

ESTIMATING POOL FIRE BURNING DURATION

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-197)

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

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

Pool Fire Diameter Calculation

$A_f = \pi D^2/4$

$D = (4A_f/\pi)^{1/2}$

D = **2.175** m

Calculation for Regression Rate

$v = m''/\rho$

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

v = **0.000051** m/sec

Burning Duration Calculation

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

t_b = 238.21 sec 3.97 minutes ANSWER

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

ESTIMATING POOL FIRE FLAME HEIGHT

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (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 = 5.74 m 18.82 ft ANSWER

NOTE

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1-A-4-CHLR

LUBE OIL FIRE, 20 FT²

METHOD OF ESTIMATING BURNING CHARACTERISTICS OF LIQUID POOL FIRE, HEAT RELEASE RATE, BURNING DURATION, AND FLAME HEIGHT

VERSION 1.03

The following calculations estimate the heat release rate, burning duration, and flame height for liquid pool fire.

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

All subsequent values are calculated by the spreadsheet, and based on values specified in the input parameters.

INPUT PARAMETERS

Fuel Spill Volume (V)	12.00	gallons	0.0454 m^3
Fuel Spill Area or Dike Area (A_{dike})	20.00	ft^2	1.858 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	

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)
Methanol	0.017	20,000	796
Ethanol	0.015	26,800	794
Butane	0.078	45,700	573
Benzene	0.085	40,100	874
Hexane	0.074	44,700	650
Heptane	0.101	44,600	675
Xylene	0.09	40,800	870
Acetone	0.041	25,800	791
Dioxane	0.018	26,200	1035
Diethy Ether	0.085	34,200	714
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Gasoline	0.055	43,700	740
Kerosine	0.039	43,200	820
Diesel	0.045	44,400	918
JP-4	0.051	43,500	760
JP-5	0.054	43,000	810
Transformer Oil, Hydrocarbon	0.039	46,000	760
Fuel Oil, Heavy	0.035	39,700	970
Crude Oil	0.0335	42,600	855
Lube Oil	0.039	46,000	760

Referenc: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-2)

ESTIMATING POOL FIRE HEAT RELEASE RATE

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 3-4)

$$Q = m"\Delta H_{c,eff} A_f$$

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

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

$Q = m''\Delta H_c A_f$

Q = 3333.36 kW 3159.43 BTU/sec ANSWER

ESTIMATING POOL FIRE BURNING DURATION

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (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)

Pool Fire Diameter Calculation

$A_f = \pi D^2/4$

$D = (4A_f/\pi)^{1/2}$

D = **1.538** m

Calculation for Regression Rate

$\nu = m''/\rho$

Where 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 = 476.41 sec 7.94 minutes ANSWER

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

ESTIMATING POOL FIRE FLAME HEIGHT

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (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 = 4.46 m 14.63 ft ANSWER

NOTE

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1-A-4-CHILL

LUBE OIL FIRE, 60 FT², 12 GAL
+500 KW FROM THERMO INSULATION

METHOD OF ESTIMATING TEMPERATURE OF A BUOYANT FIRE PLUME VERSION 1.0

The following calculations estimate the centerline plume temperature in a compartment fire

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

All subsequent values are calculated by the spreadsheet, and based on values specified in the input parameters.

INPUT PARAMETERS

Heat Rlease Rate of the Fire (Q)	3833.00	kW	
Distance from the Top of the Fuel to the Ceiling (z)	20.00	ft	6.10
Area of Combustible Fuel (A_c)	20.00	ft²	1.86
AMBIENT CONDITIONS			
Ambient Air Temperature (T_0)	77.00	°F	25.00
			298.00
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_0)	1.20	kg/m³	
Acceleration of Gravity (g)	9.81	m/sec²	
Convective Heat Release Fraction (χ_c)	0.50		

ESTIMATING PLUME CENTERLINE TEMPERATURE

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 2-9)

$$T_{p(centerline)} - T_0 = 9.1\,(T_0/g\,c_p^2\,\rho_0^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$$

Where
Q_c = Convective portion of the heat release rate (kW)
T_0 = ambient air temperature (K)
g = acceleration of gravity (m/sec²)
c_p = specific heat of air (kJ/kg-K)
ρ_0 = ambient air density (kg/m³)
z = distance from the top of the fuel package to the ceiling (m)
z_0 = hypothetical virtual origin of the fire (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c\,Q$

Where
Q = heat release rate of the fire (kW)
χ_c = convective heat release fraction
Q_c = **1916.5** kW

Pool Fire Diameter Calculation

A_{dike} = $\pi D^2/4$
D = $(4\,A_{dike}/\pi)^{1/2}$
D = **1.54** 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 = diameter of pool fire (m)

z_0/D = 0.44
z_0 = **0.68** m

Centerline Plume Temperature Calculation

$T_{p(centerline)} - T_0 = 9.1\ (T_0/g\ c_p^2\ \rho_0^2)^{1/3}\ Q_c^{2/3}\ (z - z_0)^{-5/3}$

$T_{p(centerline)} - T_0 =$	232.46
$T_{p(centerline)} =$	530.46 K

$T_{p(centerline)}$ = 257.46 °C 495.43 °F ANSWER

NOTE

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1-A-4-CHHR

LUBE OIL FIRE, 40 FT², 12 GAL
+ 500 KW FROM THERMAL INSULATION

METHOD OF ESTIMATING TEMPERATURE OF A BUOYANT FIRE PLUME VERSION 1.0

The following calculations estimate the centerline plume temperature in a compartment fire.
Parameters should be specified ONLY IN THE YELLOW INPUT PARAMETER BOXES.
All subsequent values are calculated by the spreadsheet, and based on values specified in the input parameters.

INPUT PARAMETERS

Heat Rlease Rate of the Fire (Q)	7167.00	kW	
Distance from the Top of the Fuel to the Ceiling (z)	20.00	ft	6.10
Area of Combustible Fuel (A_c)	40.00	ft²	3.72
AMBIENT CONDITIONS			
Ambient Air Temperature (T_0)	77.00	°F	25.00 / 298.00
Specific Heat of Air (c_p)	1.00	kJ/kg-K	
Ambient Air Density (ρ_0)	1.20	kg/m³	
Acceleration of Gravity (g)	9.81	m/sec²	
Convective Heat Release Fraction (χ_c)	0.50		

ESTIMATING PLUME CENTERLINE TEMPERATURE

Reference: SFPE Handbook of Fire Protection Engineering 2nd Edition (Page 2-9)

$T_{p(centerline)} - T_0 = 9.1\,(T_0/g\,c_p^2\,\rho_0^2)^{1/3}\,Q_c^{2/3}\,(z - z_0)^{-5/3}$

Where
Q_c = Convective portion of the heat release rate (kW)
T_0 = ambient air temperature (K)
g = acceleration of gravity (m/sec²)
c_p = specific heat of air (kJ/kg-K)
ρ_0 = ambient air density (kg/m³)
z = distance from the top of the fuel package to the ceiling (m)
z_0 = hypothetical virtual origin of the fire (m)

Convective Heat Release Rate Calculation

$Q_c = \chi_c Q$

Where
Q = heat release rate of the fire (kW)
χ_c = convective heat release fraction
Q_c = **3583.5 kW**

Pool Fire Diameter Calculation

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

$D = (4\,A_{dike}/\pi)^{1/2}$

D = **2.18** 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 = diameter of pool fire (m)

z_0/D = **0.31**

z_0 = **0.67** m

Centerline Plume Temperature Calculation

$T_{p(centerline)} - T_0 = 9.1\ (T_0/g\ c_p^2\ \rho_0^2)^{1/3}\ Q_c^{2/3}\ (z - z_0)^{-5/3}$

$T_{p(centerline)} - T_0 =$	351.80
$T_{p(centerline)} =$	649.80 K

$T_{p(centerline)} =$ 376.80 °C 710.24 °F ANSWER

NOTE

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