Utilizing Plume Rise for Fire Scenarios

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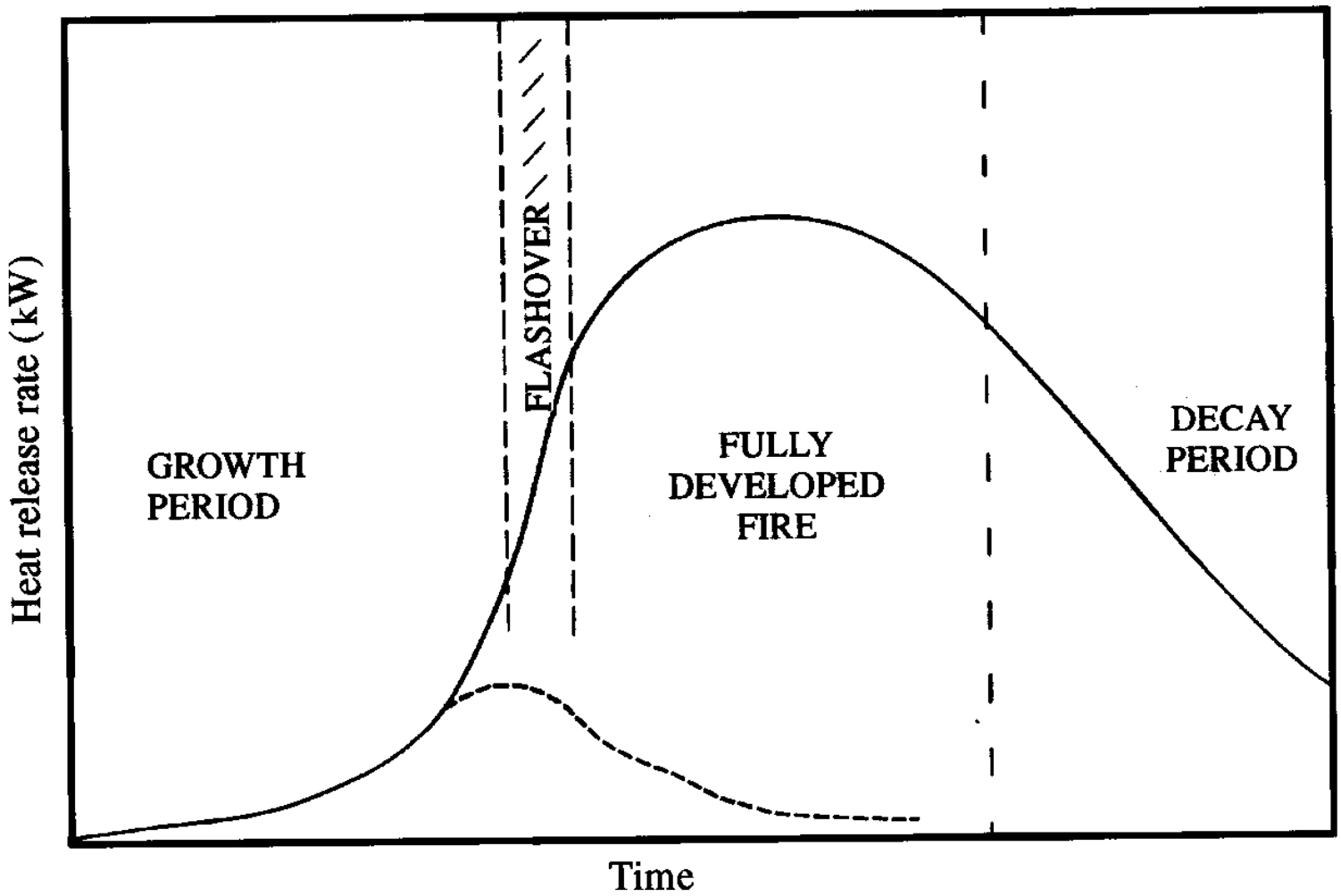
Generic Compartment Fire



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Process or Small Fires

- Small fire is defined as a fire with the heat release rate (HRR) of 0-1 MW or a fire in the early growth stage.
  - This is generally self controlling (a lack of combustible loading) or operator controlled prohibiting the fire to progress to a larger fire.
  - It will generally burn out or extinguished within 10 minutes
  - Plume is non-lofting as the building is not breached and the plume would have cooled before reaching the outside
  - Outdoor fire still should be considered non-lofted, ground-level release as the energy release is considered small
  - A smoldering outdoor fire should be modeled as a non-lofted, ground-level release
  - Smoke loading may cause plugging of HEPA but this is not expected

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Single Room or Medium Fire

- Medium fire is defined as a fire with the heat release rate (HRR) of 1-5 MW or a fire in the middle to later growth stages.
  - This is generally hot enough to activate the sprinkler and require a fire department response.
  - Sprinklers and the fire department will generally extinguish the fire within 20 minutes
  - Plume should be considered non-lofted because it is not intense enough to break through roof and would cool before reaching outside
  - Smoke loading may cause plugging of HEPAs providing an unfiltered pathway to the outside, but again this is not expected
  - An outdoor fire should be considered lofted

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Multiple Room or Large/Major Fire

- Large or Major fire is defined as a fire with the heat release rate (HRR) of >5 MW or a fire that is fully developed and cannot be easily suppressed
  - This is generally hot enough burn through the roof of a building creating a direct pathway outside
  - This may burn from 40 minutes to over 2 hr until suppressed.
  - Plume should be considered lofted because it is intense enough to break through roof and/or cause significant damage to ventilation systems – Plugging of HEPA providing an unfiltered pathway to outside
  - An outdoor fire should be considered a lofted release
  - Initial plume is caught in the building wake making the maximum concentration close to the building but as buoyancy of the plume increases, the maximum near-ground concentration is pushed further downwind

Critical Factor: Release Radius

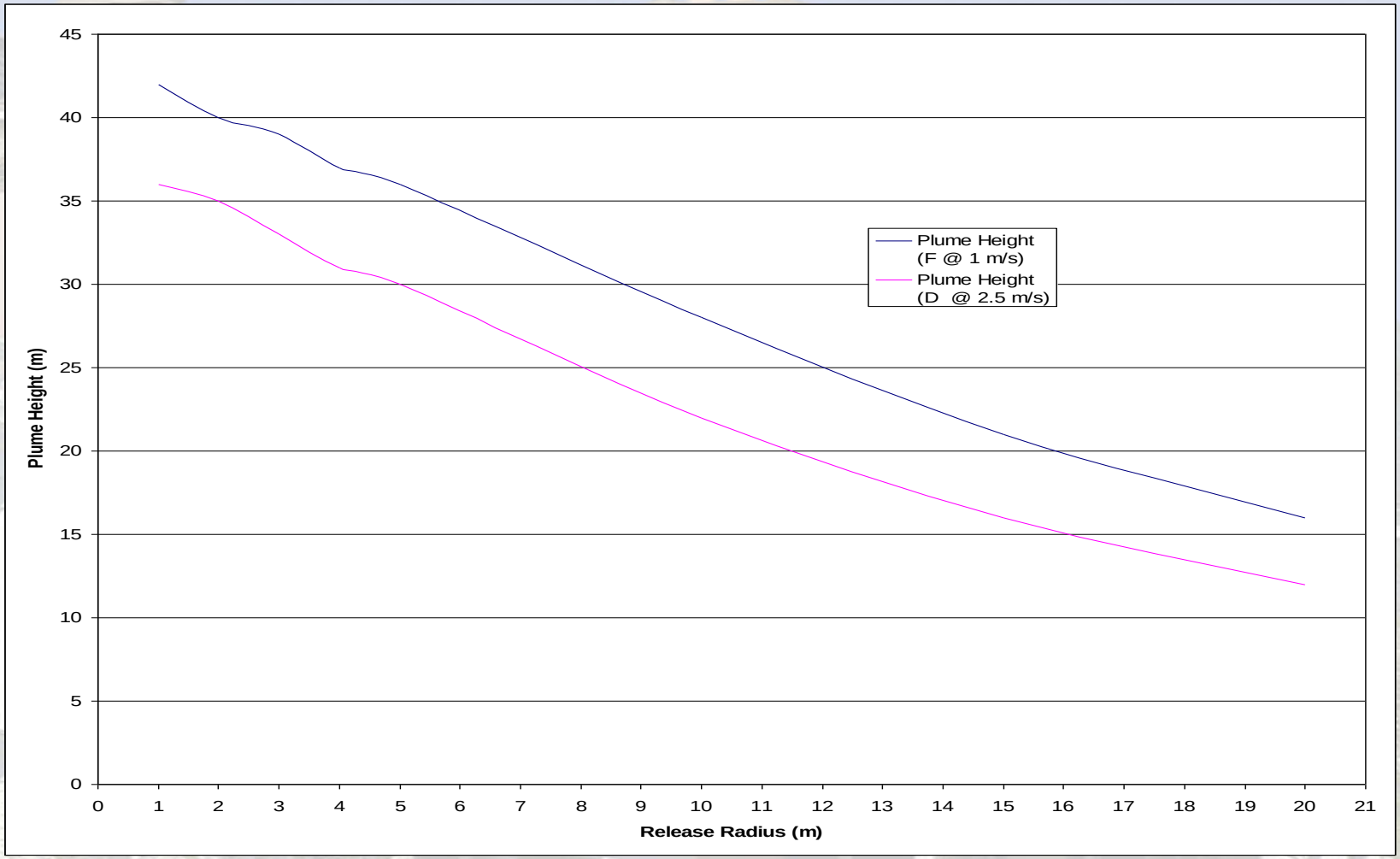
- This generally equates to the amount of energy that is released from a circular area
- Most buildings are not circular, therefore, an approximation can be estimated by:

$$R = D/2 = (4\ A_f / \pi)^{0.5} \qquad \text{(Eq. 2)}$$

where A_f is the surface area of the fire

- With the heat release rate being held constant
  - the smaller the release radius means the more energy is concentrated into a smaller area resulting in a higher the effective plume height. The higher the effective plume height is the lower the consequences at ground level in the near field.
  - A larger release radius will disperse the energy over a larger area resulting a lower effective release height and thus higher consequences in the near field.

Effects of Release Radius on Plume Height for a 1 MW Fire



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Critical Factor: Heat Release Rate

- Fire development is generally characterized in terms of heat emission rate vs. time
- Estimates of fire source intensities (heat emission rate or heat release rate (HRR)) can be based on fire measurements of the burning rate, similar large fuel configurations, and the extrapolation of small-scale test data obtained under simulated conditions
- A common method of assessing the HRR is to measure the burn rate or mass loss rate of the substance being evaluated then calculate the HRR. This requires knowledge of the types of materials present and their surface areas for a realistic evaluation

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Heat Release Rate

The HRR is calculated by:

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

where

Q' = heat emission rate (kW)

m' = burning or mass loss rate per unit area (kg/m^2-sec)

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

A_f = the horizontal burning area of the fuel (m^2)

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

D = diameter of burning area (m)

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Thermal Properties of Common Solid Combustible Materials (NUREG-1805)

Materials	Heat Emission Rate per Unit Floor Area (kW/m^2)	Heat of Combustion $\Delta H_{c,eff}$ (kj/kg)	Mass Burn Rate m' (kg/m^2-sec)
PE/PVC	589	24000	0.0044
XPE/FRXPE	475	28300	0.0037
XPE/Neoprene	354	10300	0.0043
PE, Nylon/PVC, Nylon	231	9200	0.0034
Teflon	98	3200	0.007
Douglas Fir Plywood	221	17600	0.055
Fire-retardant treated plywood	81	13500	--
Particle board, 19 mm thick	1900	17500	0.0091
Nylon 6/6	1313	32000	0.0034
Polymethlmethacrylate (PMMA)	665	26000	0.016
Polypropylene (PP)	1509	43200	0.0026
Polystyrene (PS)	1101	42000	--
Polyethylene (PE)	1408	46500	0.0026
Polycarbonate	420	24400	--
Polyurethene	710	45000	--
PVC flexible	237	15700	--
Strene-butadiene Copolymers (SBR)	163	44000	--
Ethylene Propylene Dien rubber	956	28800	--
Empty cartons 15 ft high	1700	12700	--
Wood Pallets, stacked 1.5 ft high	1420	14000	0.055
Wood Pallets, stacked 5 ft high	3970	14000	0.055
Wood Pallets, stacked 10 ft high	6,800	14000	0.055
Generic Workstation Cubicle [1]	1,200	16,900	0.043 – 0.069

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Burning Rate Data for Liquid Hydrocarbon Fuels

Fuel	Mass Burning Rate m" (kg/m2-sec)	Heat of Combustion ΔHc,eff (kJ/kg)	Density r (kg/m3)	Empirical Constant kb (m-1)
Methanol	0.017	20000	796	100
Ethanol	0.015	26800	794	100
Butane	0.078	45700	573	2.7
Benzene	0.085	40100	874	2.7
Hexane	0.074	44700	650	1.9
Heptane	0.101	44600	675	1.1
Xylene	0.09	40800	870	1.4
Acetone	0.041	25800	791	1.9
Dioxane	0.018	26200	1035	5.4
Diethy Ether	0.085	34200	714	0.7
Benzine	0.048	44700	740	3.6
Gasoline	0.055	43700	740	2.1
Kerosine	0.039	43200	820	3.5
Diesel	0.045	44400	918	2.1
JP-4	0.051	43500	760	3.6
JP-5	0.054	43000	810	1.6
Transformer Oil, Hydrocarbon	0.039	46000	760	0.7
561 Silicon Transformer Fluid	0.005	28100	960	100
Fuel Oil, Heavy	0.035	39700	970	1.7
Crude Oil	0.0335	42600	855	2.8
Lube Oil	0.039	46000	760	0.7

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

Hotspot and EPIcode Modeling

- Three different ways to calculate plume rise
  - Cloud top and Release Radius
    - One inputs the observed cloud top (real time observation) or uses an assumed fixed release height
  - Heat Emission Rate and Release Radius
    - One inputs the calculated HRR or approximate a HRR that is realistic but conservative
  - Fuel, Burn Duration, and Release Radius
    - One inputs the volume (gallons) of the fuel, the heat of combustion, and the burn duration for the fuel
    - Generally used for pool fires

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Recommendations for Modeling Building Fires

- Small fires or room fires that do not break through the roof or provide a direct pathway to the outside:
  - No Plume Rise (Most conservative for all fires)
- To credit plume rise due to a heated buoyant plume:
  - Calculate the fire radius using Equation 2
  - Room fire that breaks through roof or provides a direct pathway to outside: Use 1 MW HRR
  - Multiple room fire that breaks through roof or provides a direct pathway to outside: Determine the total composite area and determine the HRR using the NFPA 25 kW/m^2 value.*
  - Building Fire. Determine the area of the facility and and determine the HRR using the NFPA 25 kW/m^2 value*

* If the calculated HRR is less than the HRR for a room fire (e.g., the building area is less than 40 m^2) use the 1 MW as the HRR.