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Integrated Engineering, Construction, and Management Solutions

Modeling Ventilation System Response to Fire

Energy Facility Contractors Group (EFCOG), Safety Analysis Working Group (SAWG) 2007 Annual Workshop, May 19 – 24, 2007

Shilo Inn Suites Hotel, Idaho Falls, ID

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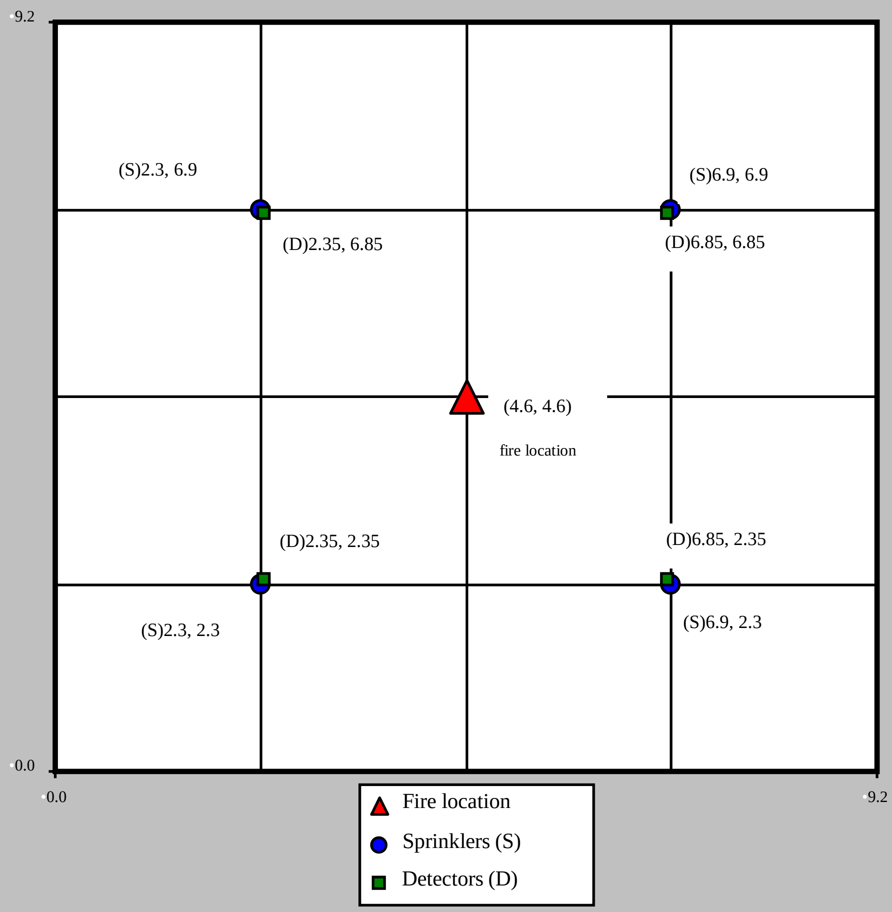
Overview of Presentation

- Problem Description
- HEPA Filter Temperature Failure Criteria
- Temperature Predictions
- HEPA Filter Soot Pluggage Criteria
- Soot Demand Predictions
- Conclusions

Problem Description

- Single room
  - Width 9.2 m (30 ft)
  - Depth 9.2 m (30 ft)
  - Height 4.75 m (16.6 ft)
- Single open door
  - Width 2.44 m (8 ft)
  - Height 2.13 m (7 ft)
- Unmitigated Dose Estimate
  - Worker High
  - Off site 5 to 20 rem



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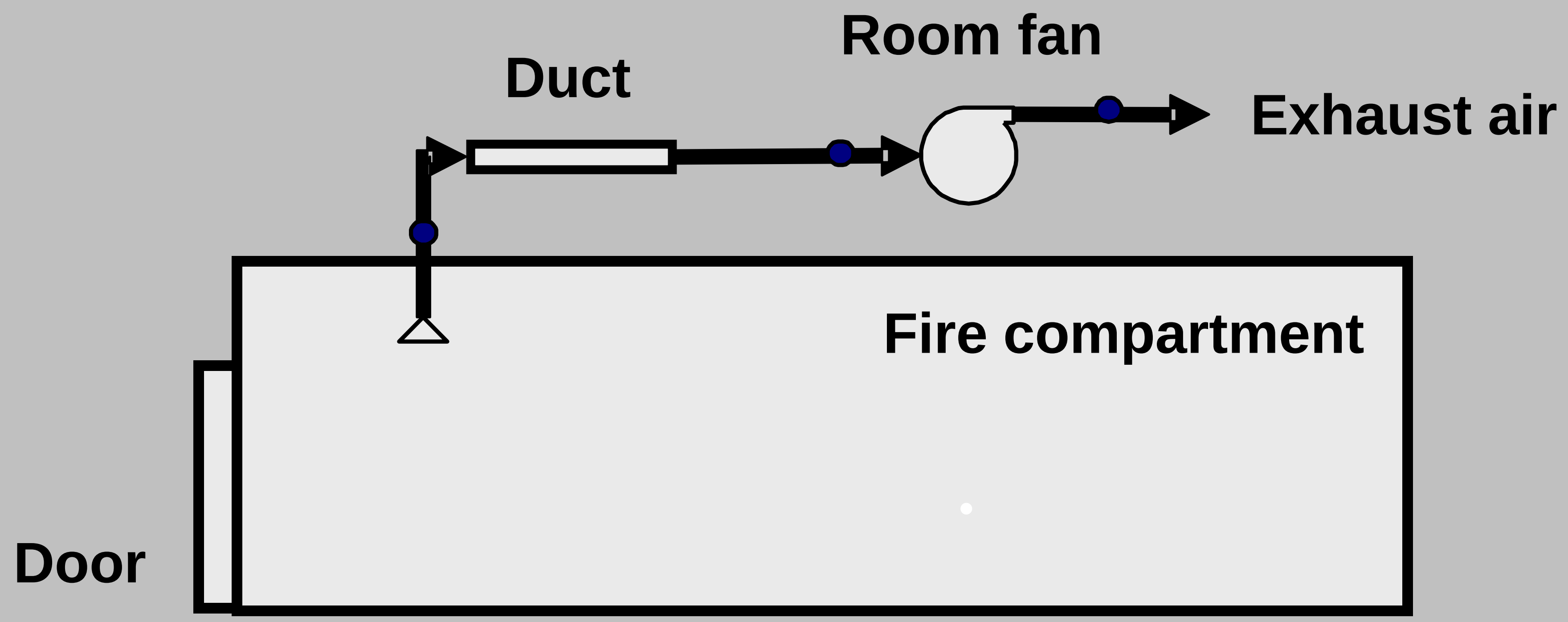
Ventilation Schematic

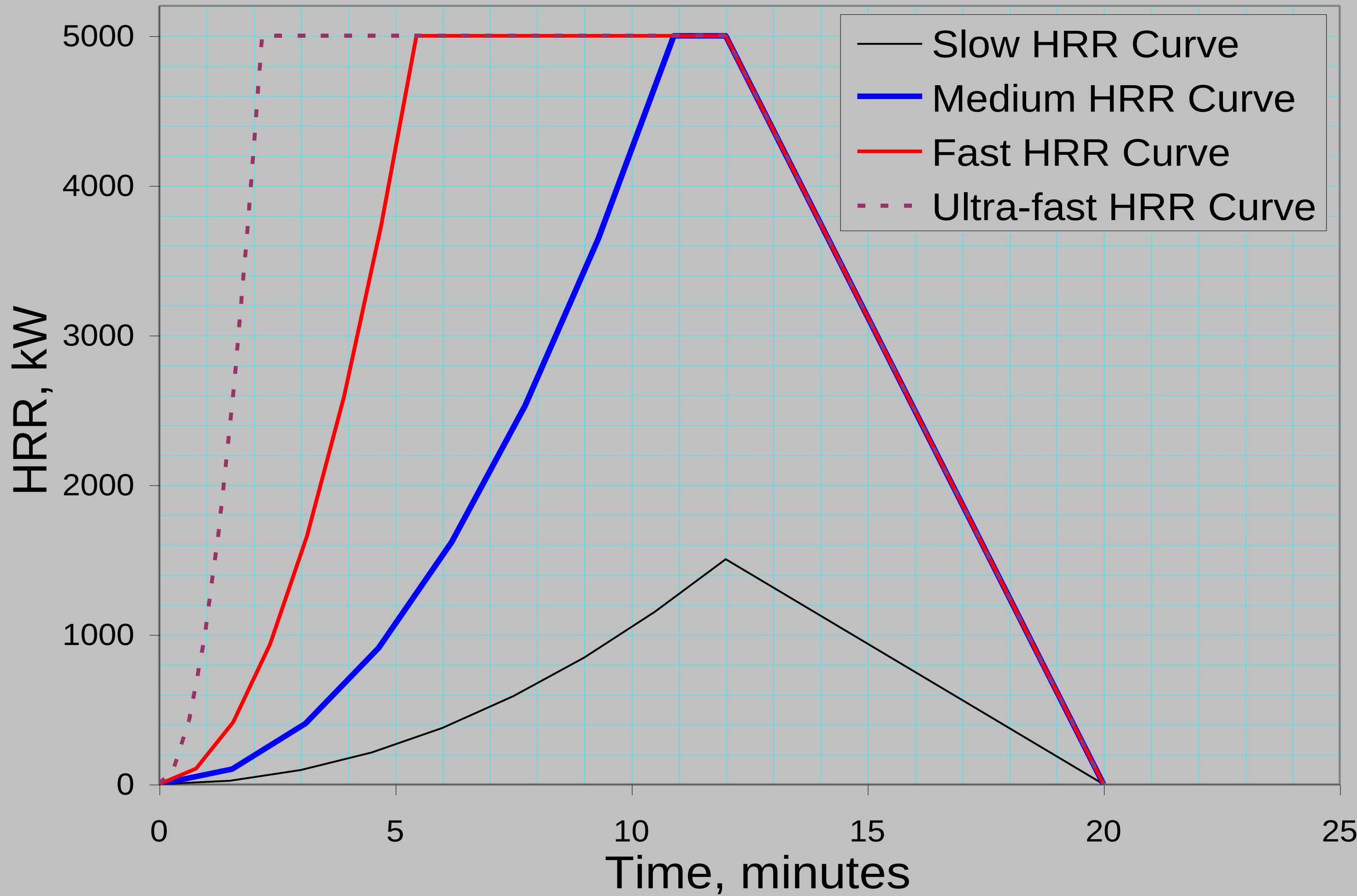


Fixed flow: 1.12 m3/s (2,400 cfm)

HRR Curve & Fire Protection Assumptions

- **HRR Curve**
  - Model four t^2 growth rates (Slow, medium, fast & ultrafast)
  - Fire starts in center of room
  - Combustible material: Polyethylene
  - Heat of combustion: 43 MJ/kg
  - Combustion efficiency: 0.65
- **Fire protection**
  - Sprinklers: 77C (170F)
  - Smoke detectors

Heat Release Rate Curves



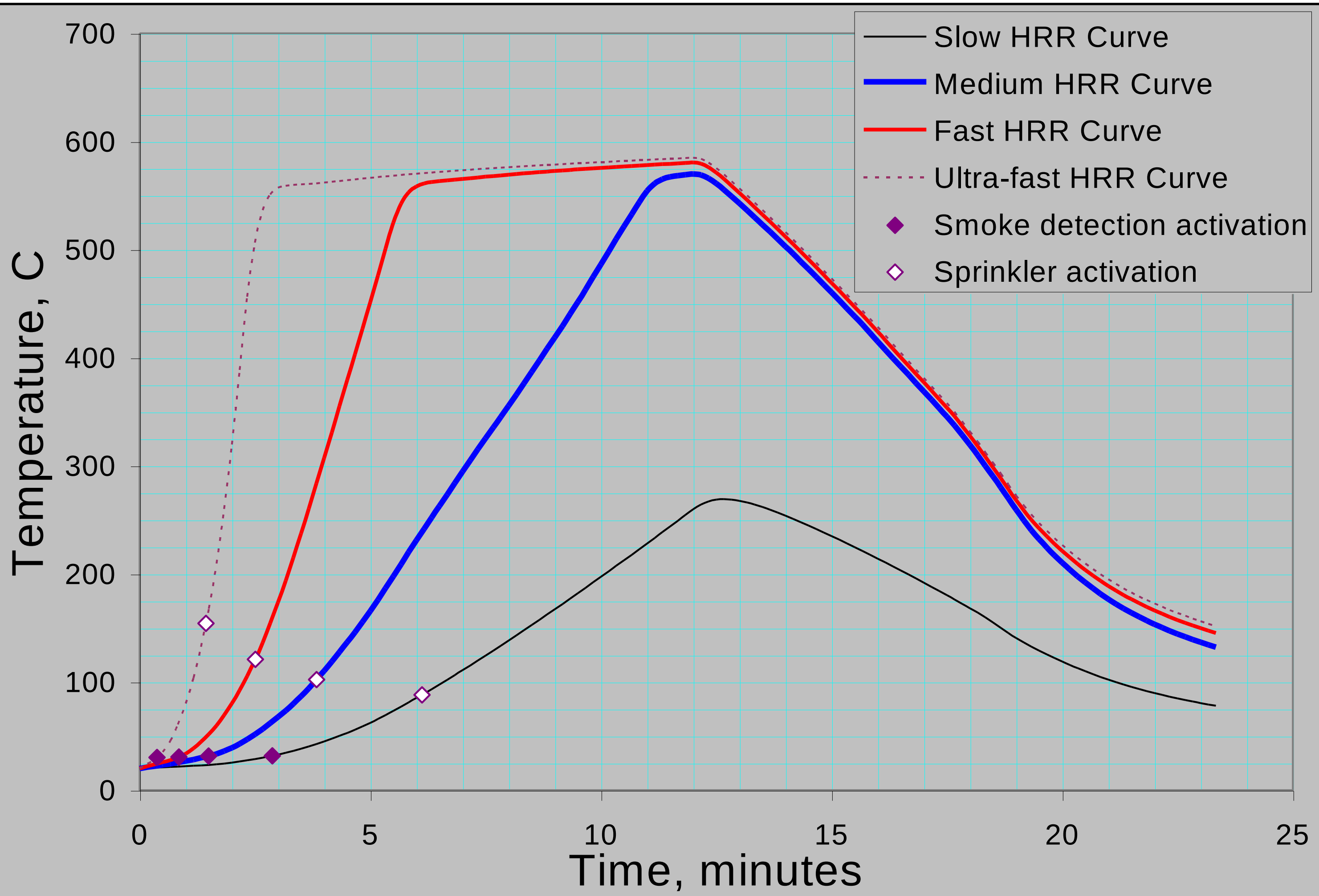
Possible Fire Scenarios

- Process Cabinet Fire
  - Involves contents of hood or glove box
  - Fires stays in cabinet but spreads contamination to the process room
- Process Room Fire
  - Involves contents of room containing significant quantity of radioactive material
  - Fire stays in room but spreads contamination to corridor
- Multi-room Fire that Starts in Process Room
  - Involves contents of room
  - Fire spreads to corridor but contamination spreads prior to filter pluggage
  - Widespread contamination migration
- Multi-room Fire that Starts in Non-process Room
  - Involves contents of non-process room
  - Fire spreads to process, filter pluggage before contamination spread
  - Widespread contamination migration

Filter Failure Criteria

- High approach temperature at filters
  - < 150˚C – no effect
  - < 399˚C & < 121˚C for more than 5 minutes – limited release
  - > 399˚C or > 121˚C for more than 5 minutes - fails
- Soot pluggage
  - Establish soot loading to produce filter pressure drop > 10”H_2O
  - Soot demand > soot capacity

Upper Layer Temperatures



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Approach Temperature Evaluation

$$T_{filter} = \frac{T_{fire}\,Q_{fire} + T_2\,Q_2 + T_3\,Q_3}{3Q} \approx \frac{T_{fire} + T_2 + T_3}{3}$$

Neglecting sprinkler system:

$$T_{filter} = \frac{598C + 20C + 20C}{3} = 213C$$

Temperature exceeds 150C, so must limit maximum temperature to 399C, & the time above 121C to less than 5 minutes

Soot Analysis Methodology

- **Predict the Soot Demand**
  - Establish the soot yield fraction for the material present (kg-soot per kg-fuel pyrolized)
  - Calculate the soot demand (product of soot fraction & combustible loading)
- **Predict the System Capacity**
  - Establish a specific HEPA filter soot capacity (kg-soot/filter)
  - Estimate the HEPA filter capacity for number of filters present (kg-soot)
- **Is demand < capacity?**
- **Try and keep it simple**

Smoke Yields for Flaming Combustion in Air

	Butler & Mulholland Table 1	Butler & Mulholland Table 2	Minimum	Maximum
Asphalt	···	0.14	0.14	0.14
Flexible polyurethane (PU) foam	0.131–0.227	0.034	0.034	0.227
Nylon	0.075	···	0.075	0.075
Polycarbonate (PC)	0.112	···	0.112	0.112
Polyester (PET)	0.089–0.091	···	0.089	0.091
Polyethylene (PE)	0.06	0.015–0.018	0.06	0.06
Polymethylmethacrylate (PMMA)	0.022	0.042	0.022	0.022
Polypropylene (PP)	0.059	0.041	0.059	0.059
Polystyrene (PS)	0.164	0.105–0.185	0.164	0.164
Polyvinylchloride (PVC)	0.172	···	0.172	0.172
Rigid polyurethane (PU) foam	0.104–0.130	0.012	0.012	0.13
Teflon (PTFE)	0.003	···	0.003	0.003
Wood (birch)	···	0.0035-0.053	0.0035	0.053
Wood (douglas fir)	···	0.0009-0.035	0.0009	0.035
Wood (red oak)	0.015	···	0.015	0.015
			0.0009	0.227

Fire Chemistry – Establish the Soot Demand

- **Complete combustion - theory**

$$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O$$

- **Flaming combustion – empirically observed**

Soot

$$C_2H_4 + 2.848O_2 = 1.836CO_2 + 2H_2O + 0.024CO + 0.06C$$

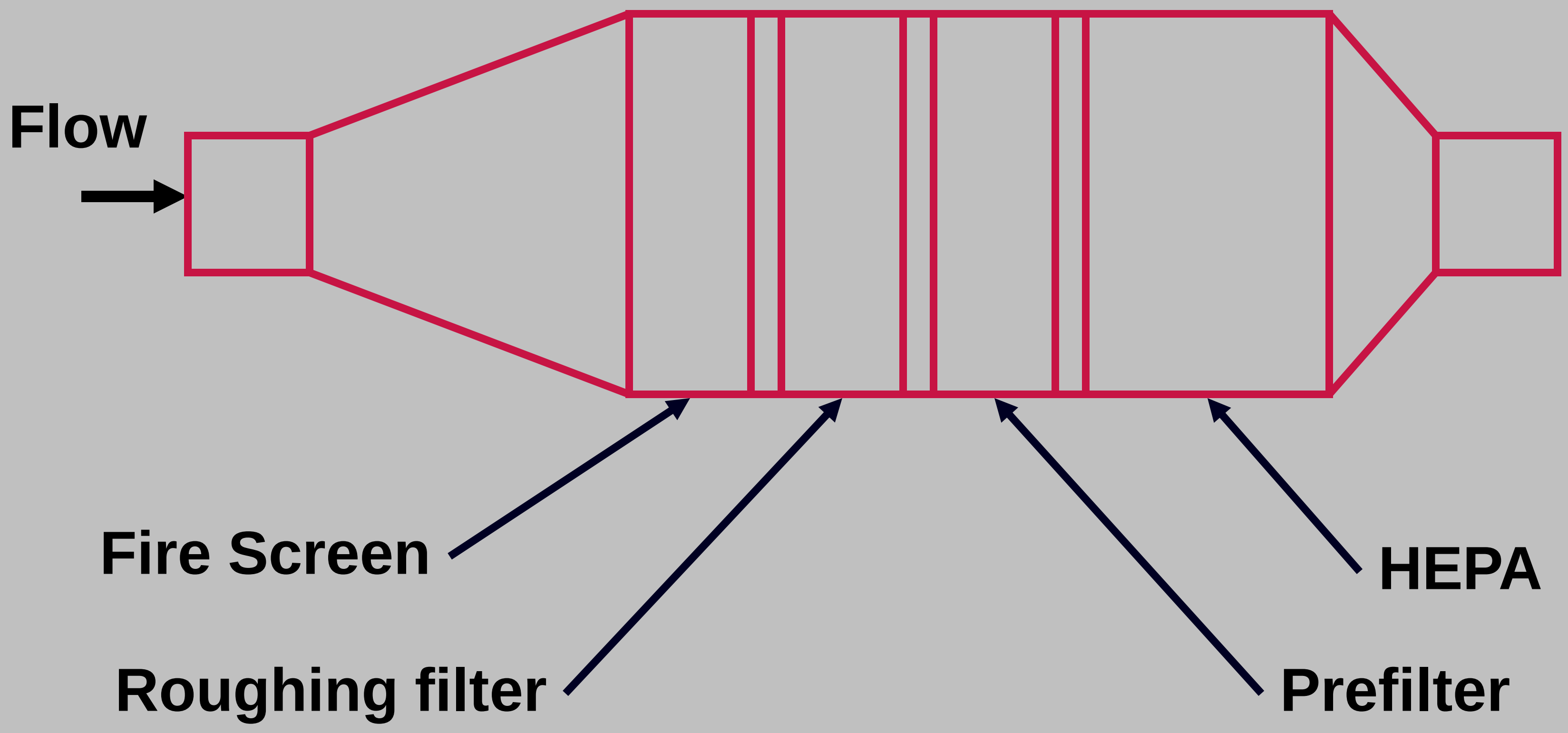
- **Ventilation-limited combustion**

$$C_2H_4 + aO_2 = bCO_2 + cH_2O + dCO + eC + \text{other stuff}$$

Soot & tars

Soot fraction design value range 0.1 to 0.3

Clemson Filter Pluggage Testing – Capacity



Filter Pluggage Data (Clemson Tests)

	Test Run 1		Test Run 2		Test Run 3	
Filter	Soot, grams	Percent	Soot, grams	Percent	Soot, grams	Percent
HEPA	200	35.1	240	36.4	270	36.5
Prefilter	308	54.1	350	53.0	310	41.9
Roughing	62	10.9	70	10.6	160	21.6
Total	570	100	660	100	740	100

$$M_{90\%}=[(657\text{ g}) - (1.89)(85\text{ g}) = 500\text{ g} = 0.5\text{ kg/filter}$$

$$M_{6\text{ filters}} = (0.5\text{ kg/filter})(6\text{ filters}) = 3.0\text{ kg}$$

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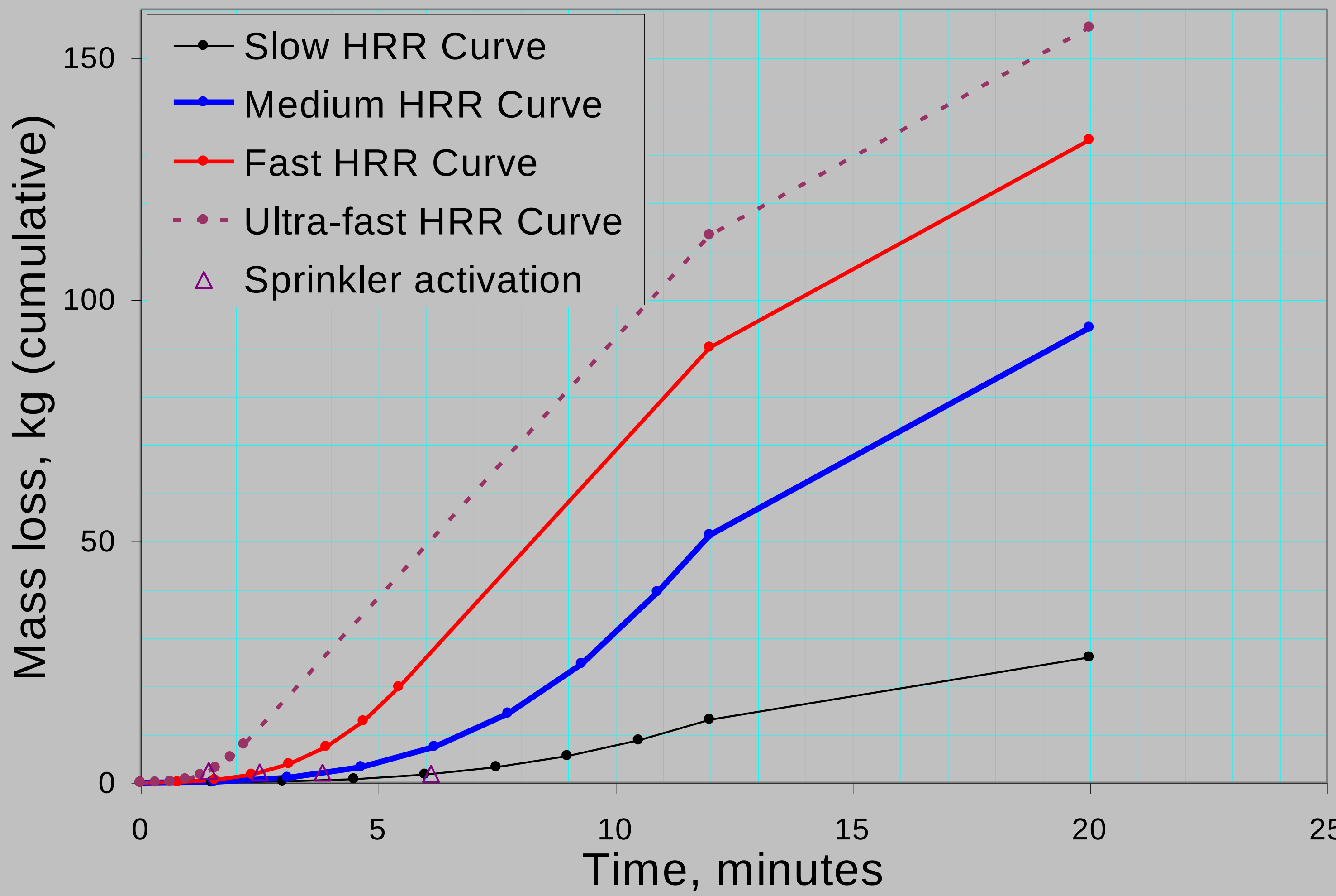
Cumulative Mass Loss - Demand



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Soot Generation - Demand

HRR Curve	Sprinkler activation time, seconds	Conditions at sprinkler activation		
		Upper layer air temperature, C	Cumulative mass loss, kg	Soot produced based on 0.2 soot fraction, kg
Slow	364	85	1.7	0.34
Medium	230	101	2.0	0.40
Fast	151	119	2.1	0.42
Ultra-fast	86	152	2.4	0.48

$$M_{6\ filters} = (0.5\ kg/filter)\ (6\ filters) = 3.0\ kg$$

Summary

- Parametric solution
  - 4 Heat release rate curves
  - Combustible: polyethylene
  - Efficiency: 0.65
- Scenario conclusions
  - Suppression activation timing - 2.5 to 6 minutes (most fires)
  - May need to limit ultra-fast type combustibles
  - Facility pluggage not expected before suppression activation
  - Once fire is controlled or extinguished driving force reduced
  - While filter pluggage can't be precluded, LPF should be low
- Potential controls
  - Suppression & active ventilation – Safety Significant
  - Passive ventilation – Safety Class