Aspects Related to Fire Dynamics in Space Systems

David Hirsch
Harold Beeson
NASA JSC White Sands Test Facility
Sandra Olson
NASA Glenn Research Center
Theresa Castillo
NASA Johnson Space Center

ISO Space Systems and Operations
Working Group on Spacecraft Materials and Processes and Human Space Flight
Las Cruces, New Mexico, USA
October 23-25, 2012

Agenda

- Spacecraft environments
- Incipient fire growth
- Developing fires; experimental data on HRR vs time in 1-g
- Responsiveness of fire detectors
- Discussion and potential payback for better understanding spacecraft fire dynamics

Common Spacecraft Environments

- Enclosed environment
- Oxygen concentration and total pressure
- Ventilation
- Gravity level

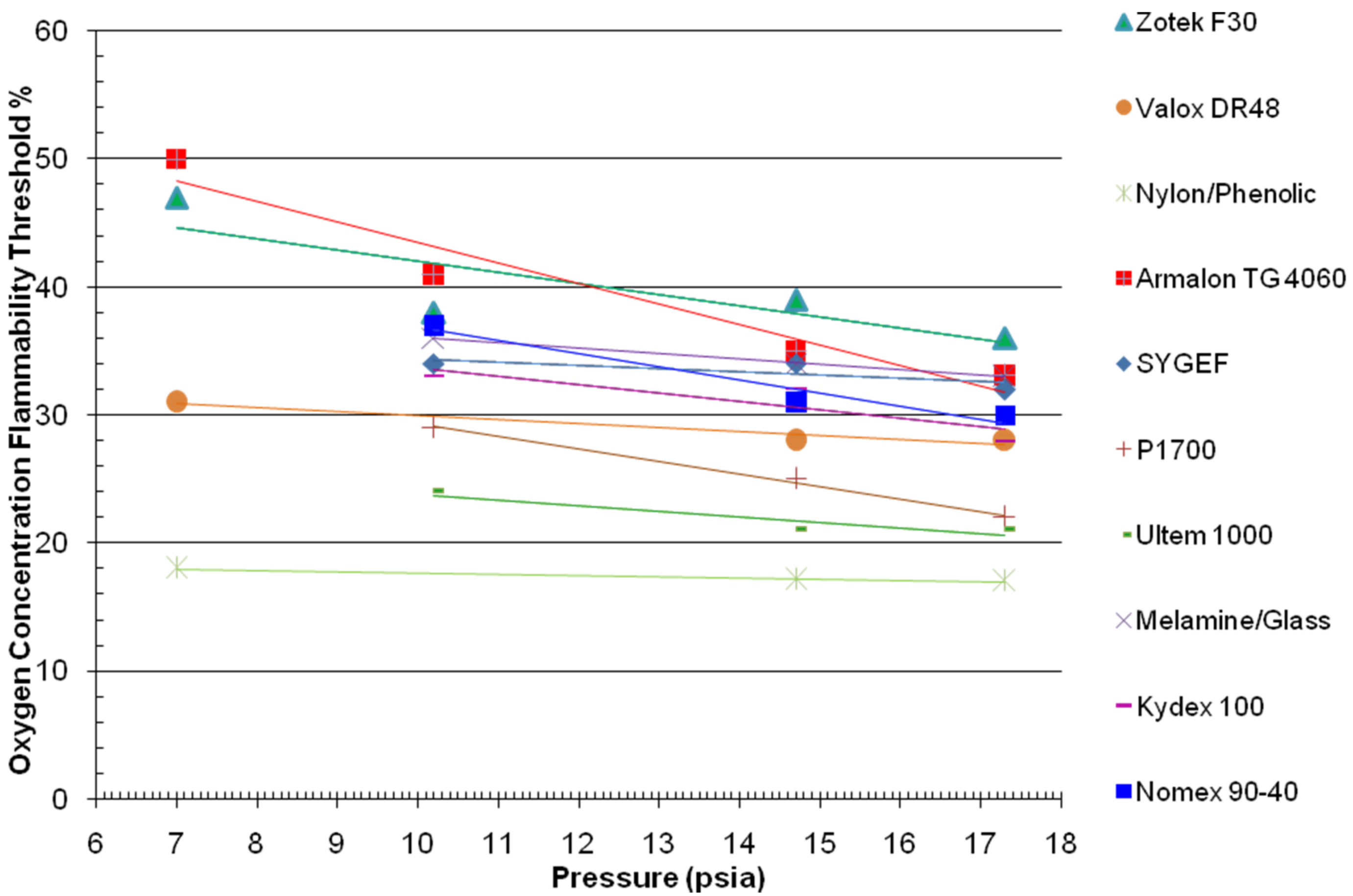
Fires In Enclosures: Estimated Amounts of Material Consumed During Combustion in a 15 cu m Module before the O_2 Concentration Falls Below Values Noted in Column 1

Post-combustion O_2, vol% (starting: 20.9% O_2, 14.7 psia)	**Estimated amount of material consumed (g)**					
	For most common materials (HoC approx 6 kcal/g)		For materials with HoC at the high end (i.e. PE, 11 kcal/g)		For materials with HoC at the low end (approx 3 kcal/g)	
	Likely	Conservatively estimated	Likely	Conservatively estimated	Likely	Conservatively estimated
19	198	291	108	159	396	582
18	302	444	165	243	605	889
17 (most materials extinguish in ground lab tests)	407	599	222	326	813	1195
16	511	752	279	410	1022	1502
15	615	905	336	494	1230	1808

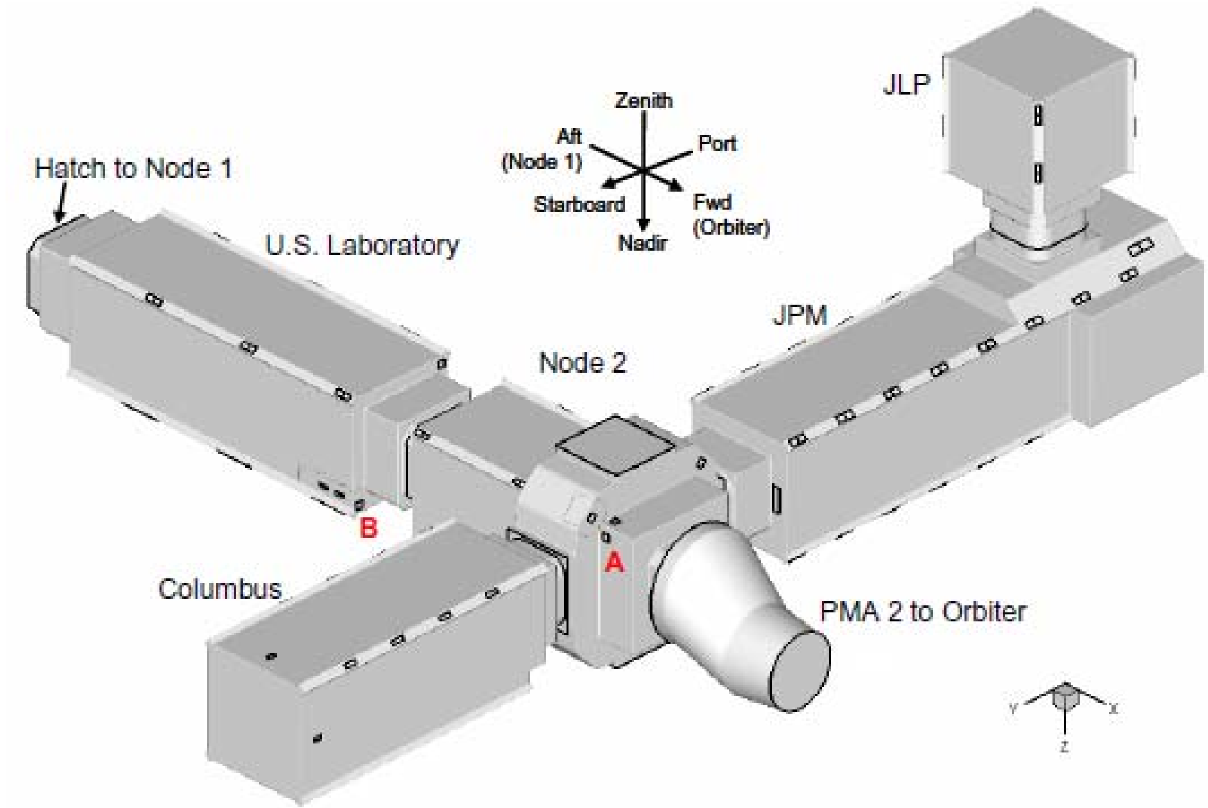
Fires In Enclosures: Estimated Amounts of Material Consumed During Combustion in a 300 cu ft ISS Module before the O_2 Partial Pressure Falls Below Values Noted In Column 1

Post-combustion O_2 partial pressure, torr (starting: 159 torr for 20.9% O_2, @ 14.7 psia)	Estimated amount of material consumed (g)					
	For most common materials (HoC approx 6 kcal/g)		For materials with HoC at the high end (i.e. PE, 11 kcal/g)		For materials with HoC at the low end (approx 3 kcal/g)	
	Likely	Conserv-atively estimated	Likely	Conserv-atively estimated	Likely	Conserv-atively estimated
148	82.6	56.2	45.1	30.7	165.2	112.4
135	182.9	124.4	99.8	67.9	365.8	248.8
IDLH, 100	454.4	309.1	247.9	168.6	908.8	618.2

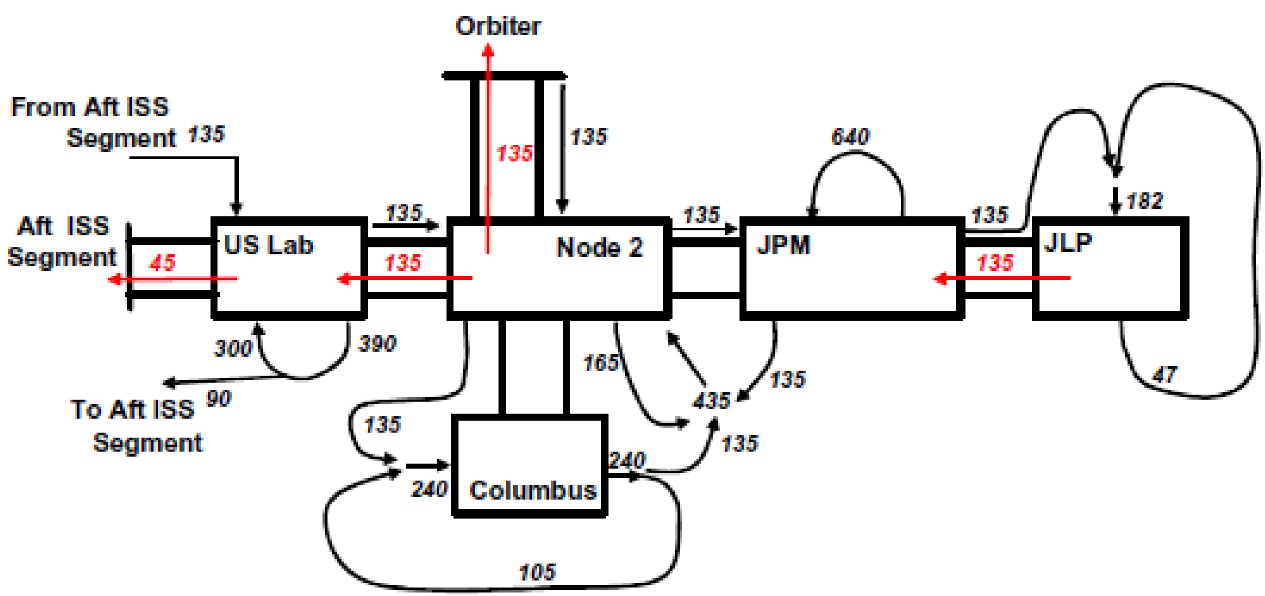
Oxygen Concentration and Pressure Effects. Pressure Effects on Oxygen Concentration Flammability Thresholds



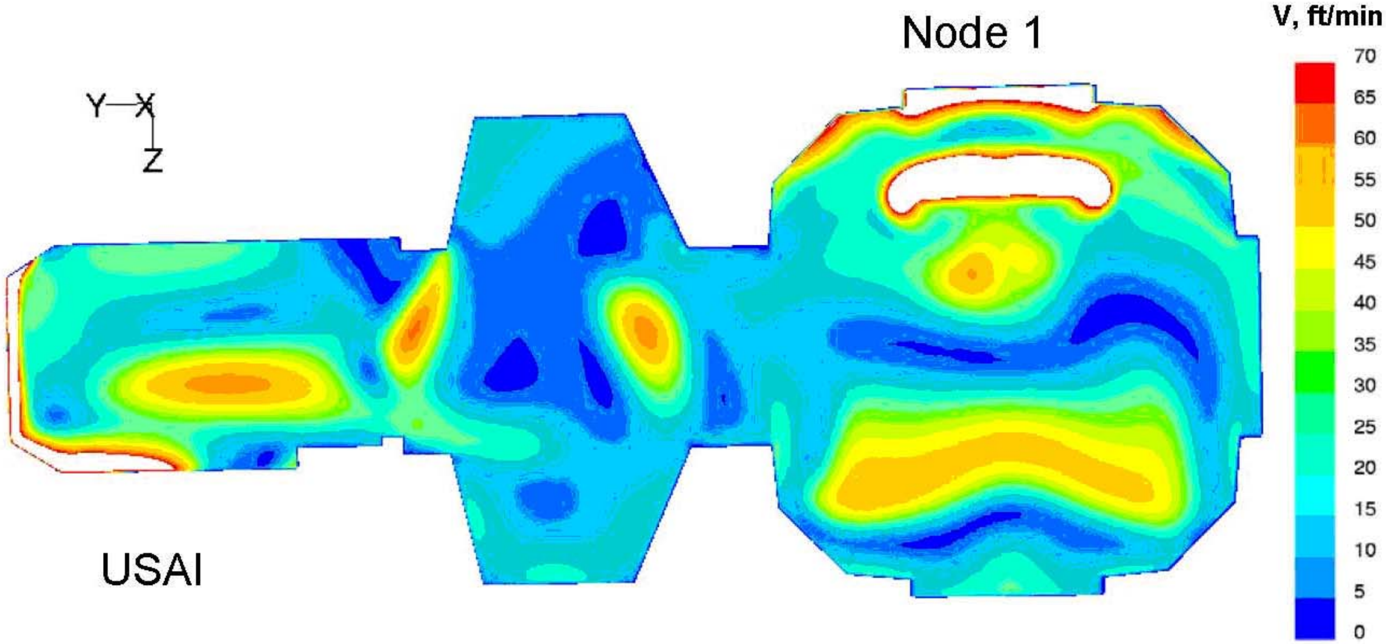
Spacecraft Ventilation: Placement of Diffusers and Return Grills on Selected ISS Segments



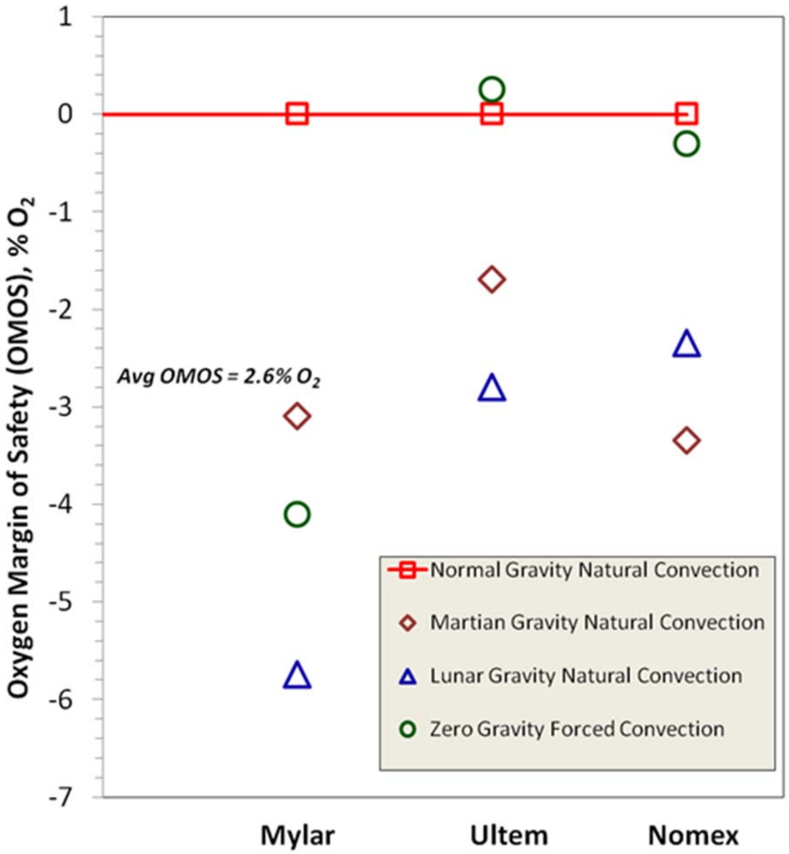
ISS Basic Ventilation Configuration; Flow Rates in cfm



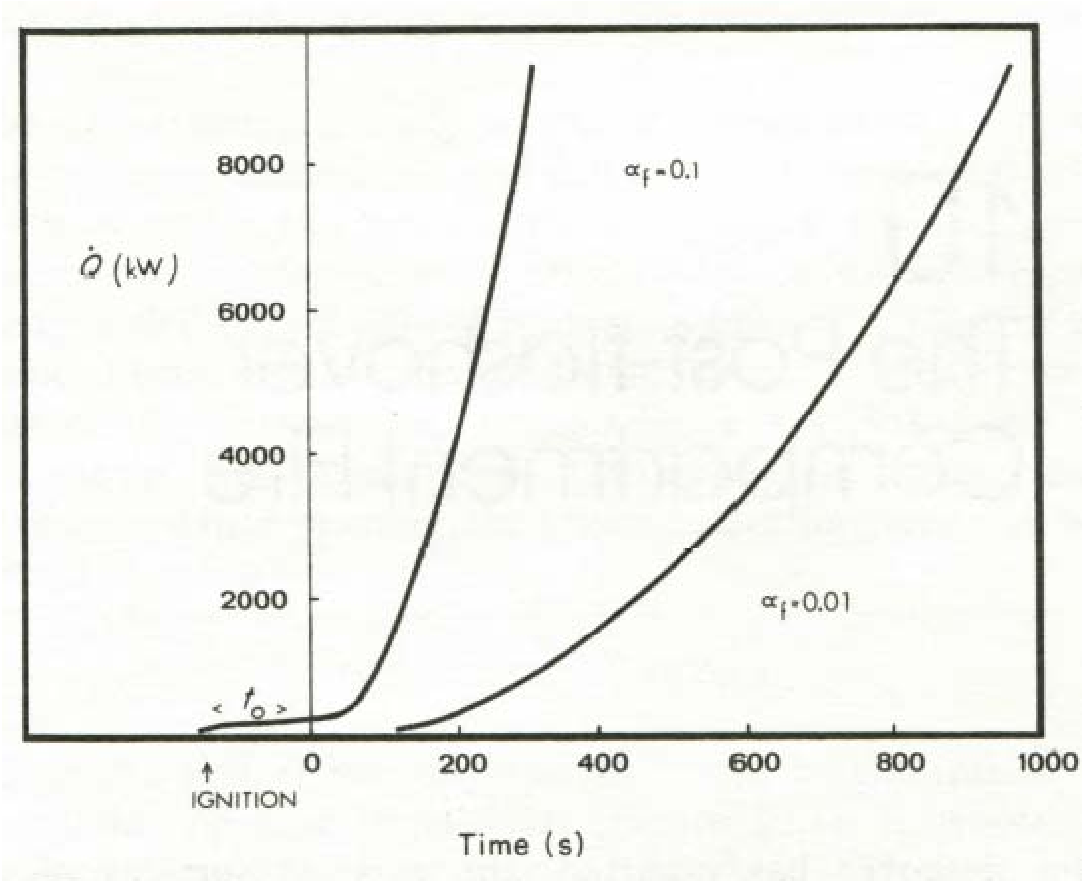
Spacecraft Ventilation: Air Velocity Magnitude Contours at Aft-Forward Mid-Section of the U.S. Airlock Module



Gravity Effects on Oxygen Concentration Flammability Thresholds



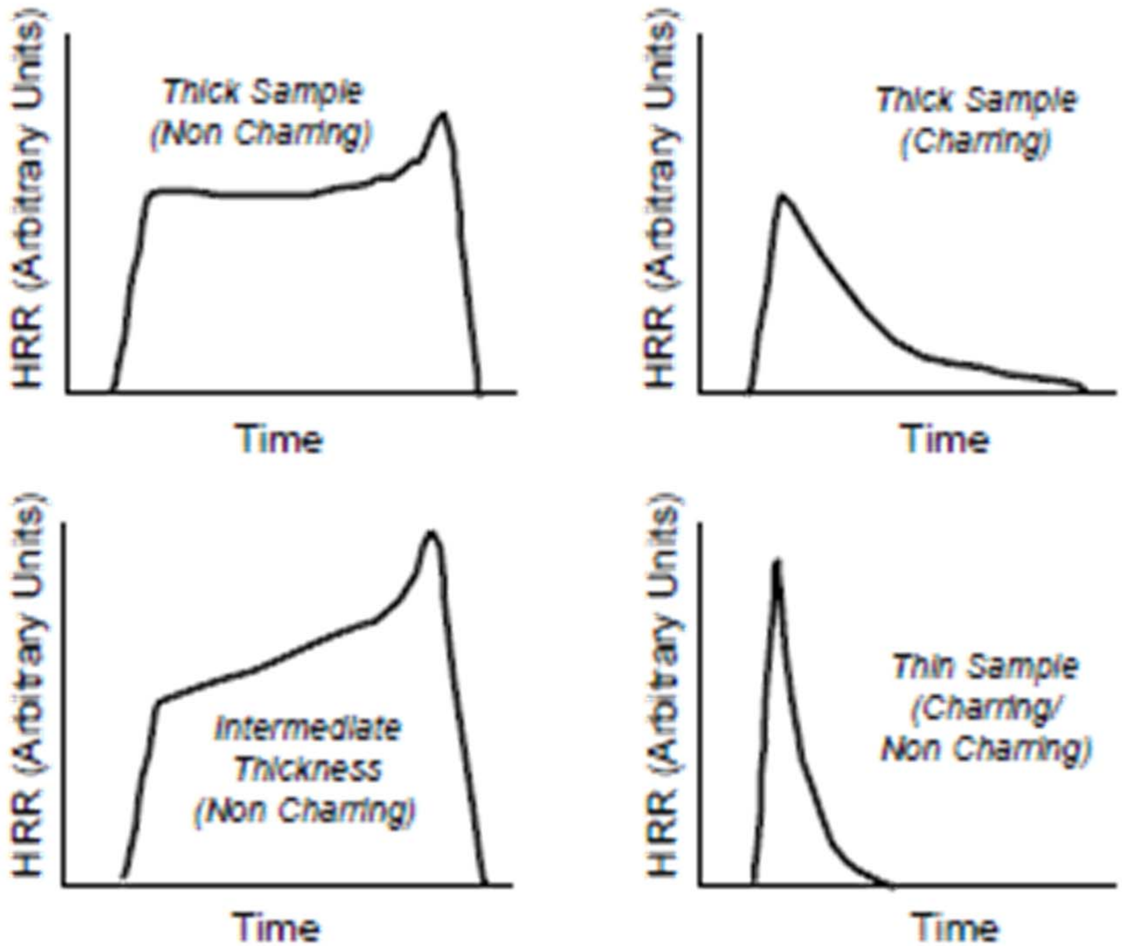
Incubation (t_0) and Fire Growth (Commonly Assumed Parabolic) (Representative, Units Aribtrary)



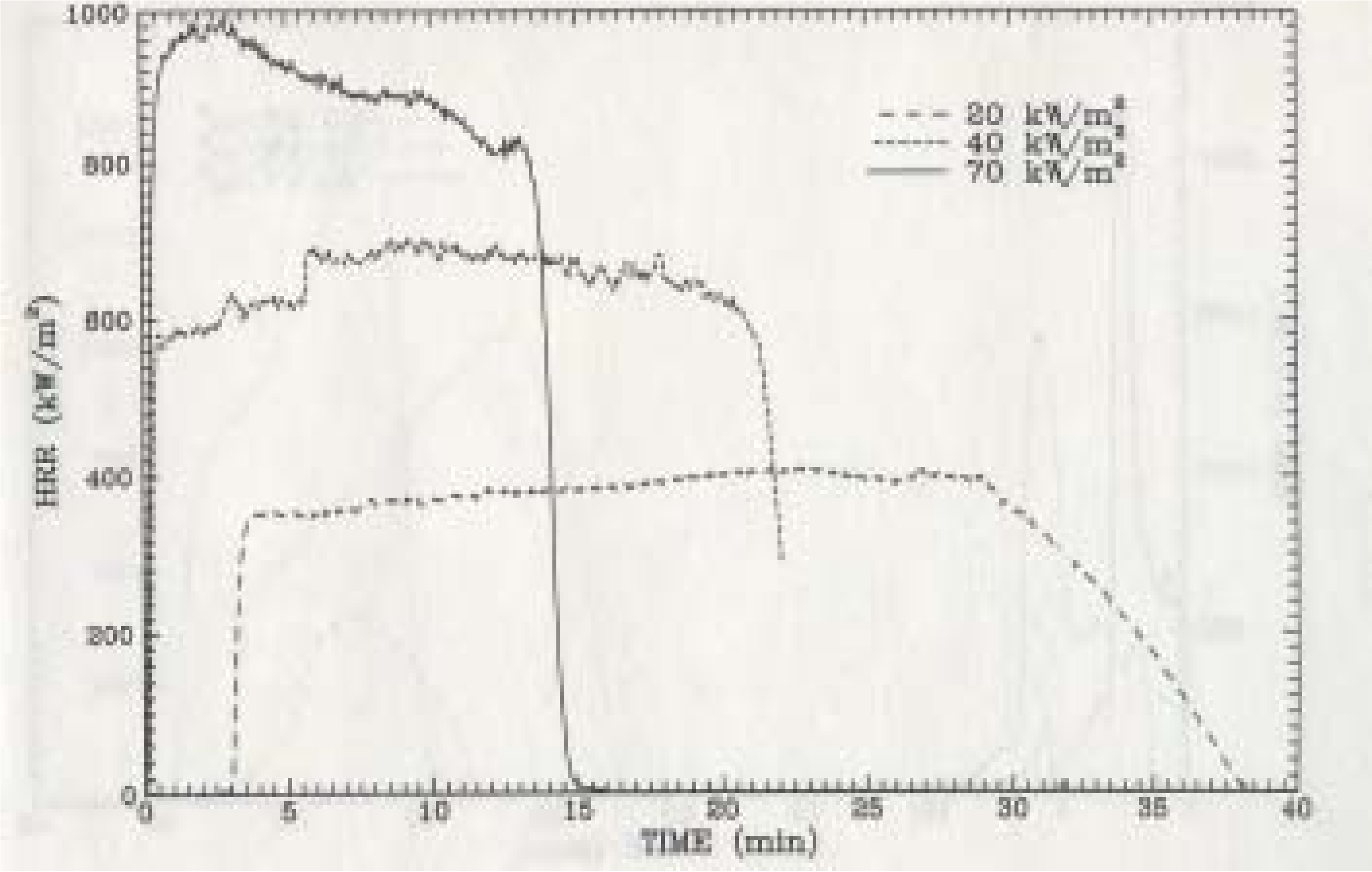
Mass Loss Rate and HRR at Ignition and Incipient Burning

Polymer	HOC (kJ/g)	MLR (g/ft^{2}s)	HRR (kW/ft^2)	HRR (kW/m^2)
PA6	29.8	0.28	8.3	89
PE	40.3	0.12 – 0.23	6.8	73
PP	41.9	0.10 – 0.25	6.7	72
PC	21.2	0.32	6.7	72
PEEK	21.3	0.31	6.5	70
PMMA	24.8	0.18 – 0.30	5.7	61
PU	23.7	0.19	4.4	47
POM	14.4	0.16 – 0.42	3.7	40

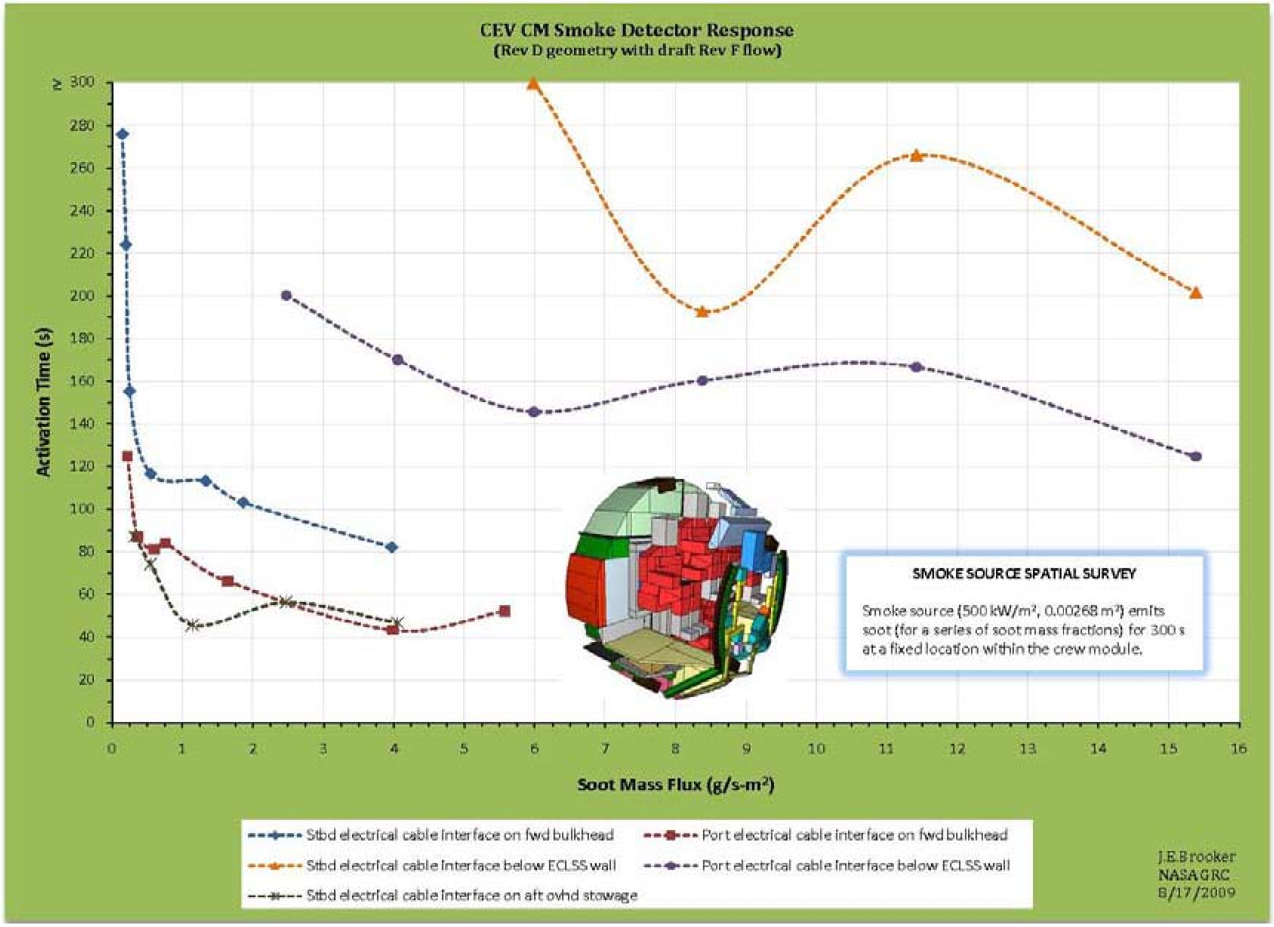
Uncontrolled Developing Fires: Representative HRR Histories in Flaming Combustion for Thick and Thin Samples Charring Polymers



Developing Fires: Heat Release Rate vs Time for PMMA



CEV CM Smoke Detector Activation Times as a Function of Soot Mass Flux



Initial Thoughts for a Discussion

- Develop a time history of fire growth
- What is the likely (and worst case) size of fire when the smoke detectors activate?
- What are optimum choices for a fire response?
- Some information needed (in addition to CFD of ventilation flows) to answer these questions
  - 1-g data on ignitibility/pyrolisis, incipient and immediately developing fires and extinguishment (heat release rate; combustion/pyrolisis products (smoke detector activators) release rate; flammability extinguishment limits)
  - Smoke detectors response time for various materials’ combustion/pyrolisis products
  - Correlation of 1-g combustion/smoke detectors data with data in spacecraft environments
  - All information churned through probabilistic analysis

Potential Payback to Better Understanding Spacecraft Fire Dynamics

- Developing representative time histories of incipient to developing fires within the context of spacecraft environments and fire detectors response time will allow realistic probabilistic fire risk assessments and selection of optimal fire response strategies.
- Knowledge of probabilistic fire risk assessment response to changes in systems and architecture will allow their improvement for increased fire safety (i.e. optimization of ventilation flows and placement of fire detection sensors, equipment and module geometry; etc.).
- Identification of the knowledge gap which could lead to improved spacecraft fire safety