Aspects Related to Fire Dynamics in Space Systems

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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
<table>
<thead>
<tr>
<th>Post-combustion O₂, vol% (starting: 20.9% O₂, 14.7 psia)</th>
<th>Estimated amount of material consumed (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>For most common materials (HoC approx 6 kcal/g)</td>
</tr>
<tr>
<td></td>
<td>Likely</td>
</tr>
<tr>
<td>19</td>
<td>198</td>
</tr>
<tr>
<td>18</td>
<td>302</td>
</tr>
<tr>
<td>17 (most materials extinguish in ground lab tests)</td>
<td>407</td>
</tr>
<tr>
<td>16</td>
<td>511</td>
</tr>
<tr>
<td>15</td>
<td>615</td>
</tr>
</tbody>
</table>
Fires In Enclosures: Estimated Amounts of Material Consumed During Combustion in a 300 cu ft ISS Module before the O₂ Partial Pressure Falls Below Values Noted In Column 1

<table>
<thead>
<tr>
<th>Post-combustion O₂ partial pressure, torr (starting: 159 torr for 20.9% O₂, @ 14.7 psia)</th>
<th>Estimated amount of material consumed (g)</th>
</tr>
</thead>
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<tr>
<td></td>
<td>For most common materials (HoC approx 6 kcal/g)</td>
</tr>
<tr>
<td></td>
<td>Likely</td>
</tr>
<tr>
<td>148</td>
<td>82.6</td>
</tr>
<tr>
<td>135</td>
<td>182.9</td>
</tr>
<tr>
<td>IDLH, 100</td>
<td>454.4</td>
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</tbody>
</table>
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

Avg OMOS = 2.6% O₂

- Normal Gravity Natural Convection
- Martian Gravity Natural Convection
- Lunar Gravity Natural Convection
- Zero Gravity Forced Convection

Mylar, Ultem, Nomex
Incubation ($t_0$) and Fire Growth (Commonly Assumed Parabolic)  
(Representative, Units Arbitrary)
## Mass Loss Rate and HRR at Ignition and Incipient Burning

<table>
<thead>
<tr>
<th>Polymer</th>
<th>HOC (kJ/g)</th>
<th>MLR (g/ft²s)</th>
<th>HRR (kW/ft²)</th>
<th>HRR (kW/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA6</td>
<td>29.8</td>
<td>0.28</td>
<td>8.3</td>
<td>89</td>
</tr>
<tr>
<td>PE</td>
<td>40.3</td>
<td>0.12 – 0.23</td>
<td>6.8</td>
<td>73</td>
</tr>
<tr>
<td>PP</td>
<td>41.9</td>
<td>0.10 – 0.25</td>
<td>6.7</td>
<td>72</td>
</tr>
<tr>
<td>PC</td>
<td>21.2</td>
<td>0.32</td>
<td>6.7</td>
<td>72</td>
</tr>
<tr>
<td>PEEK</td>
<td>21.3</td>
<td>0.31</td>
<td>6.5</td>
<td>70</td>
</tr>
<tr>
<td>PMMA</td>
<td>24.8</td>
<td>0.18 – 0.30</td>
<td>5.7</td>
<td>61</td>
</tr>
<tr>
<td>PU</td>
<td>23.7</td>
<td>0.19</td>
<td>4.4</td>
<td>47</td>
</tr>
<tr>
<td>POM</td>
<td>14.4</td>
<td>0.16 – 0.42</td>
<td>3.7</td>
<td>40</td>
</tr>
</tbody>
</table>
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

CEV CM Smoke Detector Response
(Rev D geometry with draft Rev F flow)

Soot Mass Flux (g/s/m²)

Activation Time (s)

SMOKE SOURCE SPATIAL SURVEY
Smoke source (300 kW/m², 0.00266 m/s) emits soot for a series of soot mass fractions for 300 s at a fixed location within the crew module.
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/pyrolysis, incipient and immediately developing fires and extinguishment (heat release rate; combustion/pyrolysis products (smoke detector activators) release rate; flammability extinguishment limits)
  - Smoke detectors response time for various materials’ combustion/pyrolysis products
  - Correlation of 1-g combustion/smoke detectors data with data in spacecraft environments
  - All information churned through probabilistic analysis
• 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