RISK-BASED
SPACECRAFT FIRE SAFETY EXPERIMENTS

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PROBABILISTIC RISK ASSESSMENT
APPLIED TO FIRE SAFETY

Spacecraft fire risk can never be reduced to a zero probability.

Probabilistic risk assessment is a tool to reduce risk to an acceptable level.

MAJOR STEPS:

1. Identification of "critical" locations and the assessment of the frequency of fires: overheating, spills, smoldering, ignition, etc.

2. Estimation of the fraction of fires that can lead to damage of specified components: fire growth time and the competing detection and suppression times

3. Estimation of the fraction of fires that can lead to mission damage
Page 1: Event Tree for Closed Space Fire

Diagram:
- Fire/Smoldering Incident
  - Closed Space
    - Local System Undamaged
      - Ventilation Thru Racks
        - Rack to Rack Propagation
          - Leak to Open Space
            - Detection
              - Suppression

Page 2
Page 2: Event Tree for Open Space Fire
\[ \lambda_{\text{loss}} = \sum \lambda_j Q_{d/j,k} Q_{\text{loss } d/j,k} \]

- \( \lambda_{\text{loss}} \): frequency lost
- \( \lambda_j \): frequency of class j fires
- \( Q_{d/j,k} \): fraction of class j fires that lead to damage of the \( k^{th} \) critical system
- \( Q_{\text{loss } d/j,k} \): fraction of class j fires leading to damage of the \( k^{th} \) system that cause the loss of the spacecraft

\[ Q_{d/j} = Fr \left[ T_G < T_H / \text{fire} \right] \]

- \( T_G \): growth time
- \( T_H \): hazard time

\[ T_H = T_f + T_d + T_s \]

- \( T_f \): time to detection
- \( T_d \): detector response time
- \( T_s \): suppression time
Source - Transport - Deposition

Terrestrial

Microgravity
Fire Safety Assessment

- Damage Time
- Detection & Suppression Time

Target Identification
- Crew
- Station System

Modes Identification
- Heat
- Smoke
- Toxins

Event Description
- Source
- Transport
- Deposition
Wire Overload Phenomena

- Insulation
- Conductor
- Combustion Products
- Product Flow

Product Flow
## Damage Modes Tests Models

<table>
<thead>
<tr>
<th>Source</th>
<th>Tests</th>
<th>Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Release</td>
<td>temperature measurements</td>
<td>f(T)</td>
</tr>
<tr>
<td>Smoke Release</td>
<td>obscuration, TEM grids</td>
<td>f(T)</td>
</tr>
<tr>
<td>Toxin Release</td>
<td>IR/Mass spec. (White Sands), sampling</td>
<td>f(T)</td>
</tr>
<tr>
<td>Heat Transport</td>
<td>temperature measurements</td>
<td>fluid flow, temp., etc</td>
</tr>
<tr>
<td>Smoke Transport</td>
<td>TEM grids/visualization</td>
<td>fluid flow, temp., etc</td>
</tr>
<tr>
<td>Toxin Transport</td>
<td></td>
<td>fluid flow, temp., etc</td>
</tr>
<tr>
<td>Adjacent Wire Damage</td>
<td>pairs, bundles</td>
<td>heat release, qualitative</td>
</tr>
<tr>
<td>Particulate Deposition</td>
<td>TEM grids</td>
<td>TBD</td>
</tr>
<tr>
<td><em>Corrosivity</em></td>
<td><em>thin copper target plate</em></td>
<td>qualitative</td>
</tr>
</tbody>
</table>
# NASA Lewis 2.2 sec Drop Tower

## Sample Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
<th>Properties</th>
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</thead>
<tbody>
<tr>
<td>PTFE - Teflon</td>
<td>[-CF₂-CF₂-]</td>
<td>Interior wiring, Smoke Production, Toxic Production, Acidic Production, Combustible Production</td>
</tr>
<tr>
<td>ETFE - Tefzel</td>
<td>[-CF₂-CH₂-]</td>
<td>Exterior wiring, Acidic Production, Combustible Production</td>
</tr>
<tr>
<td>Bundles</td>
<td></td>
<td>Interior/Exterior</td>
</tr>
<tr>
<td>Twisted Pairs</td>
<td></td>
<td>Interior/Exterior</td>
</tr>
</tbody>
</table>

+ Adjacent Wire Damage
PTFE
Polytetrafluoroethylene
Thermal Degradation Products

\[
\begin{array}{ccc}
  & F & F \\
 _{-C-C-} & \text{FF} \\
 F & F \\
\end{array}
\]

Approximate Melting Temperature

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>TFE Monomer</th>
<th>Perfluorocyclobutane</th>
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</thead>
<tbody>
<tr>
<td>300</td>
<td>CF₂=CF₂</td>
<td></td>
</tr>
<tr>
<td>350</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>Hexafluoropropylene</td>
<td>CF₂=CF₂</td>
</tr>
<tr>
<td></td>
<td>CF₃CF=CF₂</td>
<td>CF₂-CF₂</td>
</tr>
<tr>
<td>450</td>
<td></td>
<td></td>
</tr>
<tr>
<td>500</td>
<td>Carbonyl Fluoride</td>
<td>Hydrofluoric Acid</td>
</tr>
<tr>
<td></td>
<td>CF₂O</td>
<td>HF</td>
</tr>
<tr>
<td>550</td>
<td></td>
<td></td>
</tr>
<tr>
<td>600</td>
<td>Carbon Dioxide</td>
<td>CO₂</td>
</tr>
<tr>
<td>650</td>
<td></td>
<td></td>
</tr>
<tr>
<td>700</td>
<td>Carbon Dioxide</td>
<td>CO₂</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Carbon Tetrafluoride</td>
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</tbody>
</table>