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
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

Source
- Heat
- Smoke
- Toxins

Target Identification
- Crew
- Station System

Event Description
- Source
- Transport
- Deposition
### Damage Modes Tests Models

**Source**
- Heat Release: temperature measurements, \( f(T) \)
- Smoke Release: obscuration, TEM grids, \( f(T) \)
- Toxin Release: IR/Mass spec. (White Sands), sampling, \( f(T) \)

**Transport**
- Heat Transport: temperature measurements, fluid flow, temp., etc
- Smoke Transport: TEM grids/visualization, fluid flow, temp., etc
- Toxin Transport: fluid flow, temp., etc

**Deposition**
- Adjacent Wire Damage: pairs, bundles, heat release, qualitative
- Particulate Deposition: TEM grids, TBD
- Corrosivity: thin copper target plate, qualitative
### Sample Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Interior wiring</th>
<th>Exterior wiring</th>
<th>Smoke Production</th>
<th>Toxic Production</th>
<th>Acidic Production</th>
<th>Combustible Production</th>
<th>Adjacent Wire Damage</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE - Teflon</td>
<td>Interior wiring</td>
<td>Exterior wiring</td>
<td>Smoke Production</td>
<td>Toxic Production</td>
<td>Acidic Production</td>
<td>Combustible Production</td>
<td>Adjacent Wire Damage</td>
</tr>
<tr>
<td>[-CF₂-CF₂-]</td>
<td></td>
<td></td>
<td>Smoke Production</td>
<td>Toxic Production</td>
<td>Acidic Production</td>
<td>Combustible Production</td>
<td>Adjacent Wire Damage</td>
</tr>
<tr>
<td>ETFE - Tefzel</td>
<td></td>
<td></td>
<td>Acidic Production</td>
<td>Combustible Production</td>
<td>Adjacent Wire Damage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[-CF₂-CH₂-]</td>
<td></td>
<td></td>
<td>Acidic Production</td>
<td>Combustible Production</td>
<td>Adjacent Wire Damage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bundles</td>
<td>Interior/Exterior</td>
<td>Interior/Exterior</td>
<td>Adjacent Wire Damage</td>
<td>Adjacent Wire Damage</td>
<td>Adjacent Wire Damage</td>
<td>Adjacent Wire Damage</td>
<td>Adjacent Wire Damage</td>
</tr>
<tr>
<td>Twisted Pairs</td>
<td>Interior/Exterior</td>
<td>Interior/Exterior</td>
<td>Adjacent Wire Damage</td>
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</tr>
</tbody>
</table>
PTFE
Polytetrafluorethylene
Thermal Degradation Products

\[
\begin{array}{c}
\text{TFE Monomer} \\
\text{Perfluorobutylene} \\
\text{Perfluorocyclobutane} \\
\text{Carbonyl Fluoride} \\
\text{Hydrofluoric Acid} \\
\text{Carbon Dioxide} \\
\text{Carbon Tetrafluoride}
\end{array}
\]

Approximate Melting Temperature

- 300°C
- 350°C
- 400°C
- 450°C
- 500°C
- 550°C
- 600°C
- 650°C
- 700°C