RISK-BASED
SPACECRAFT FIRE SAFETY EXPERIMENTS

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

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

- \( T_G \) 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

Target Identification
- Crew
- Station System

Modes Identification
- Heat
- Smoke
- Toxins

Event Description
- Source
- Transport
- Deposition

Damage Time

Detection & Suppression Time
Wire Overload Phenomena

- Insulation
- Conductor
- Combustion Products
- Product Flow
**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
### NASA Lewis 2.2 sec Drop Tower

**Sample Materials**

<table>
<thead>
<tr>
<th>Material</th>
<th>Interior wiring</th>
<th>Smoke Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTFE - Teflon</td>
<td>Interior/Exterior</td>
<td>Acidic Production</td>
</tr>
<tr>
<td>[-CF&lt;sub&gt;2&lt;/sub&gt;-CF&lt;sub&gt;2&lt;/sub&gt; - ]</td>
<td>Exterior/Exterior</td>
<td>Combustible Production</td>
</tr>
<tr>
<td>ETFE - Tefzel</td>
<td></td>
<td>+ Adjacent Wire Damage</td>
</tr>
<tr>
<td>[-CF&lt;sub&gt;2&lt;/sub&gt;-CH&lt;sub&gt;2&lt;/sub&gt;]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bundles</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Twisted Pairs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PTFE
Polytetrafluorethylene
Thermal Degradation Products

\[
\begin{array}{c}
\text{TFE Monomer} \\
\text{CF}_2=\text{CF}_2 \\
\text{Perfluoroisobutylene} \\
(\text{CF}_3)_2\text{C}=\text{CF}_2 \\
\text{Hexafluoropropylene} \\
\text{CF}_3\text{CF}=\text{CF}_2 \\
\text{Carbonyl Fluoride} \\
\text{CF}_2\text{O} \\
\text{Hydrofluoric Acid} \\
\text{HF} \\
\text{Carbon Dioxide} \\
\text{CO}_2 \\
\text{Carbon Dioxide} \\
\text{CO}_2 \\
\text{Carbon Tetrafluoride} \\
\text{CF}_4 \\
\end{array}
\]

Approximate Melting Temperature

\[300^\circ\text{C}\]

\[350\]

\[400\]

\[450\]

\[500\]

\[550\]

\[600\]

\[650\]

\[700\]