Module 1

Electrical Cable Aging: What are the Technical Issues?

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Objective: To Understand...

- Nuclear Safety and Risk Implications of Aging
  - Management of Electrical Cable Aging
    - Quality Assurance
    - Environmental Qualification
  - Maintenance
    - Chemical, Physics, Materials Issues
Nuclear Safety and Risk Implications of Electrical Cable Aging

- Risk assessments performed for many different NPP designs
- All show sensitivity to assumptions of electrical system failure probabilities and aging
- Results from Barselina PSA indicates essentially same risk sensitivity.
Table 9. Sensitivity and importance calculations for basic event groups.

<table>
<thead>
<tr>
<th>System/function</th>
<th>Fractional contribution</th>
<th>Risk decrease factor (RDF)</th>
<th>Risk increase factor (RIF)</th>
<th>Sensitivity</th>
<th>Sens high</th>
<th>Sens low</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 MFWS</td>
<td>1.8E-05</td>
<td>1.0E+00</td>
<td>1.2E+00</td>
<td>1.0E+00</td>
<td>5.9E-06</td>
<td>5.9E-06</td>
</tr>
<tr>
<td>2 BRUD</td>
<td>3.4E-05</td>
<td>1.0E+00</td>
<td>7.2E+01</td>
<td>1.0E+00</td>
<td>5.9E-06</td>
<td>5.9E-06</td>
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<tr>
<td>3 CONDENSATE</td>
<td>2.6E-03</td>
<td>1.0E+00</td>
<td>1.3E+00</td>
<td>1.0E+00</td>
<td>6.0E-06</td>
<td>5.9E-06</td>
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<tr>
<td>4 ALS</td>
<td>1.0E-02</td>
<td>1.0E+00</td>
<td>9.6E+00</td>
<td>1.6E+00</td>
<td>9.3E-06</td>
<td>5.8E-06</td>
</tr>
<tr>
<td>5 MSRV</td>
<td>1.4E-02</td>
<td>1.0E+00</td>
<td>6.8E+03</td>
<td>1.8E+00</td>
<td>1.0E-05</td>
<td>5.8E-06</td>
</tr>
<tr>
<td>6 BRUB</td>
<td>2.6E-02</td>
<td>1.0E+00</td>
<td>2.2E+02</td>
<td>1.3E+00</td>
<td>7.6E-06</td>
<td>5.7E-06</td>
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<tr>
<td>7 EDAF</td>
<td>3.0E-02</td>
<td>1.0E+00</td>
<td>5.0E+02</td>
<td>2.8E+00</td>
<td>1.6E-05</td>
<td>5.7E-06</td>
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<tr>
<td>8 ECCS</td>
<td>4.0E-02</td>
<td>1.0E+00</td>
<td>8.3E+04</td>
<td>2.5E+00</td>
<td>1.4E-05</td>
<td>5.7E-06</td>
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<tr>
<td>9 AFWS</td>
<td>5.5E-02</td>
<td>1.1E+00</td>
<td>9.3E+02</td>
<td>2.5E+00</td>
<td>1.4E-05</td>
<td>5.6E-06</td>
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<tr>
<td>10 CGF events</td>
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<td>1.1E+00</td>
<td>1.8E+06</td>
<td>1.6E+00</td>
<td>9.0E-06</td>
<td>5.6E-06</td>
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<tr>
<td>11 SWS</td>
<td>9.5E-02</td>
<td>1.1E+00</td>
<td>1.7E+06</td>
<td>3.2E+01</td>
<td>1.7E-04</td>
<td>5.3E-06</td>
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<tr>
<td>12 Diesel gen</td>
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<td>2.2E+01</td>
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<td>5.2E-06</td>
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<tr>
<td>13 ICC</td>
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<td>9.7E+03</td>
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<td>1.1E-03</td>
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<td>15 Human errors</td>
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<td>2.0E+00</td>
<td>2.8E+05</td>
<td>5.0E+01</td>
<td>1.6E-04</td>
<td>3.1E-06</td>
</tr>
</tbody>
</table>

Table 9 uses the following notations:

*Sens high*: calculation of core damage when all the group components reliability values (unavailability, frequency) are set to nominal multiplied by 10.

*Sens low*: calculation of core damage when all the group components reliability values (unavailability, frequency) are set to nominal divided by 10.

*Sensitivity*: calculated as *Sens high* divided by *Sens low*.

*Fractional contribution, RIF, RDF*: these sensitivity measures are common and well described in the PSA references.

Sensitivity calculations indicate that the model is the most sensitive to EPSS system (factor 220), human errors (factor 50), SWS system (factor 32) and diesel generators.
Typical Electrical Power Cable

- **Jacket**
- **Filler**
- **Tape**
- **Uncoated Copper Conductors**
- **Copper Grounding Conductor**
Typical Instrumentation Cable

- Aluminum/Polyester Foil Tape
- Tinned Copper Wire
- Copper Conductor
- PVC Jacket
- Polyester Binder Tape
- PVC Insulation
# Aging Issues:

<table>
<thead>
<tr>
<th>Power Cables:</th>
<th>Instrumentation Cables:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degraded signal transfer characteristics (degraded functioning)</td>
<td>Degraded signal transfer characteristics (degraded functioning)</td>
</tr>
<tr>
<td>Integrity of electrical connections (loss of function)</td>
<td>Integrity of electrical connections (loss of function)</td>
</tr>
<tr>
<td>Degraded insulation characteristics (short to ground, short to power)</td>
<td>Degraded insulation characteristics (short to ground, short to power)</td>
</tr>
<tr>
<td>Electrical faults leading to cable fire</td>
<td></td>
</tr>
</tbody>
</table>
Aging is Primarily Related to Materials Issues:

- Chemical decomposition and build-up of gas voids in insulating materials
- Loss of ductility
- Embrittlement of insulator materials and cracking
- Moisture buildup within cable bundle
- Corrosion build-up on electrical connectors
Chemical Decomposition Reactions

- Insulation materials can be subject to long term self-decomposition chemical reactions
- Self-decomposition: $X \rightarrow A + B$
- Physical properties change proportional to buildup of new species.
- Reaction rate is given by simple law:

$$\frac{d[X]}{dt} = -k(T) \cdot X \cdot [X]$$
Decomposition rate constant: $k(T)$ can be experimentally determined and depends on temperature.

- **Arrhenius law:** $k(T) = A \exp\left(-\Phi / kT\right)$
- $\Phi$ is the activation energy in eV
- $k = 0.8617 \times 10^{-4}$ eV / °K (Boltzmann’s constant)
- $T$ is absolute temperature in °K
Chemical Oxidation Reactions

- Insulation materials can be subject to long term oxidation reactions
- Oxidation Reactions: $X + O_2 \rightarrow YO_n + Z$
- Physical properties change proportional to buildup of new species.
- Initial reaction rate is given by simple law:

$$\frac{d[X]}{dt} = -k(T)O_2 - X[X][O_2]$$
Chemical Oxidation Reactions

- Oxidation reaction rate over longer term becomes more complex.
- As outer surface layer becomes fully oxidized, incoming $O_2$ must diffuse through outer layers of reacted material to reach fresh “X”.
- “Diffusion-limiting” tends to reduce rate of oxidation over the longer term, unless material cracking opens up new surface area and fresh source of “X” to react.
- Strong need to understand relationships between: oxidation – embrittlement – long term reaction rates.
For purposes of aging assessment, in most cases assumption of simple binary reaction: \( X + O_2 \rightarrow YO_n + Z \) without diffusion limiting is conservative.
Many NPP components can be removed for maintenance or repair.

Many NPP components are replaced.

Cabling is typically not designed for ease of inspection or for performing maintenance / replacement.
Cabling Is Not Always Accessible for Inspection of Aging Related Degradation

- Cable tray geometry is complicated!
- Fire protective coatings often obscure cable, connectors
- Fire seals in walls totally obscure cables
- Lifting and moving aged brittle cables to inspect them may cause more damage!
Aging ↔ Environmental Qualification

- Electrical equipment must be capable of functioning in last intended year of operation.
- Functioning includes: proper performance in both normal and accident environments.
- Aging can degrade materials ability to perform under accident environments.
Aging ↔ Quality Assurance

- Pre-installation storage of electrical cables
- Moisture ingress
- Installation procedures used in “pulling cables” can tear or pre-weaken cable insulation making it more susceptible to aging related failure.