Fire PRA Insights from a Review of NPP Fire Events

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This presentation is based on:
Fire Risk Methods Program Task 5: NPP Fire Events Review

• Sponsored by USNRC/RES/PRAB

• One of several technical tasks designed to improve fire PRA methods in key need areas

• Task Objectives:
  – Identify fire risk/PRA insights from NPP fire events
  – Identify areas for improvement in fire PRA methods
Approach

• Event Selection Criteria:
  – “Severe” Fires - classical fire protection perspective
  – “Challenging” Fires - nuclear safety perspective
  – “Interesting” Fires - illustrates unique behavior

• Analyzed each event from two angles
  – Reviewed the chronology of each event to verify how fire PRA would address the elemental occurrences
  – Matched the elemental occurrences of an event against elements of a fire PRA
25 Nuclear Industry Fire Events Reviewed

- San Onofre, Mar. 12, 1968
- Mühleberg, July 21, 1971
- Browns Ferry, Mar. 22, 1975
- Greifswald, Dec. 7, 1975
- Beloyarsk, Dec. 31, 1978
- Fort St. Vrain, Oct. 3, 1987
- North Anna, July 3, 1981
- Armenia NPP, Oct. 15, 1982
- Rancho Seco, Mar. 19, 1984
- South Ukraine, Dec. 15, 1984
- Zaporozhye, Jan. 27, 1984
- Kalinin, Dec. 18, 1984
- Maanshan, July 1, 1985
- Waterford, July 14, 1985
- Ignalina, Sep. 5, 1988
- Oconee Jan. 3, 1989
- Calvert Cliffs, Mar. 1, 1989
- Shearon Harris, Oct. 9, 1989
- Vandellos, Oct. 19, 1989
- Chernobyl 2, Oct. 11, 1991
- Salem, Nov. 9, 1991
- Narora, Mar. 31, 1993
- Waterford, Mar. 31, 1993
- Waterford, June 10, 1995
- Palo Verde, Apr. 4, 1996

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Key Observations

• Fire can pose a serious threat to nuclear safety
• Operator actions are influenced by and do influence the chain of events in a fire incident.
• Multiple fires are a possibility
• Fire in non-safety areas may be important
Key Observations (cont.)

• Materials of construction and plant layout can have a strong influence on the outcome of a fire
• Smoke propagation can be an important element of a fire scenario
• A fire involving cables may cause unexpected circuit faulting effects
• Long duration fires may not be so rare
Fire Posing a Serious Threat to Nuclear Safety

- Browns Ferry, 1975 – Loss of normal cooling
- Greifswald, 1975 – Station blackout, PORV fail open (independent event)
- Beloyarsk, 1978 – Significant loss of core cooling functions
- Armenia, 1982 – Station blackout
- Narora, 1993 – Station blackout
Operator Actions and Fire

• Actions under adverse conditions:
  – Browns Ferry, 1975 – Used an unconventional core cooling method
  – Greifswald, 1975 – Laid down cables to restore power
  – Armenia, 1982 – Laid down cables to restore power; worked in smoke filled control room
  – Narora, 1993 – Connected a diesel driven fire pump to recharge a steam generator

• Actions that aggravated the chain of events:
  – Waterford, 1985 – Called for the wrong pump to be shutdown
  – Waterford, 1995 – Delayed fire brigade activation
  – Oconee, 1989 – Operator error led to overcooling
Operator Actions and Fire (continued)

• Actions prior to fire occurrence:
  – Browns Ferry, 1975 – Similar ignitions were experienced a few days before the March 22 fire
  – Armenia, 1982 and South Ukraine, 1984 – Fire suppression system was switched to manual mode
  – H.B. Robinson, 1989 – Maintenance crew error led to multiple fires
Possibility of Multiple Fires

- An initiating event may lead to multiple fires
  - Armenia, 1982 – Multiple fires due to the same cause
  - Kalinin, 1984 – Pump motor failure led to other electrical fires
  - H.B. Robinson, 1989 – Maintenance crew error led to hydrogen release at multiple points
Possibility of Multiple Fires (continued)

• A fire may lead to other (secondary) fires
  – Armenia, 1982 – Secondary fire occurred due to equipment failure
  – Kalinin, 1984 – Cable fire inside containment led to relay coil fire outside the containment
  – Browns Ferry, 1975 – Cable fire led to small fire inside a MCR control panel
  – Sharon Harris, 1989 – Hydrogen fire led to oil leak and fire.
Fire in Non-Safety Areas

• Large turbine building fires have had significant impact
  – Mühleberg, 1971 – Structural damage and potential loss of multiple trains
  – Beloyarsk, 1978 – Structural damage and propagation to control building.
  – Vandellos, 1989 – Multiple safety train failure, flooding in basement of turbine and auxiliary buildings, and structural damage.
  – Narora, 1993 – Significant cable damage and smoke propagation leading to station blackout, loss of control room habitability, and loss of power to alternate control station.

• Oconee 1989 - Overcooling incident occurred as a result of non-safety switchgear fire
Influence of Design Characteristics, Layout and Materials of Construction

• Location of cables influenced the outcome of the fire

• Self ignited cable fires were experienced (San Onofre and Soviet-designed plants)

• Rapid propagation of fire was experienced in cable shafts (Soviet-designed plants)

• Barrier failure was experienced under various conditions (Soviet-designed plants)

• Automatic fire suppression system was overwhelmed in a few cases
Importance of Smoke Propagation

- Browns Ferry, 1975 – Smoke hindered recovery actions and fire fighting
- Beloyarsk, 1978 – Smoke adversely affected control room operators
- Armenia, 1982 – Smoke hindered fire fighting and entered the control room
- Fort St. Vrain, 1987 - Smoke entered control room forcing operators to use air masks
- Vandello, 1989 – Smoke entered the control room and other parts of the plant
- Narora, 1993 – Smoke caused control room evacuation
Circuit Faulting Effects Caused by Cable Fire

- Browns Ferry, 1975 – Possible wrong indications and spurious actuations
- Armenia, 1982 – Main generator breaker closed, diesel generator disconnected, and one feedwater pump started
- Ignalina, 1988 – Breakers opened and equipment tripped inadvertently
- Chernobyl, 1991 – Damaged cable initiated the chain of events
- Waterford, 1995 – Erratic indications on the control panel
## Duration of Fire

<table>
<thead>
<tr>
<th>Duration</th>
<th># of events</th>
<th>Events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1 minute</td>
<td>3</td>
<td>Robinson, Calvert Cliffs, Palo Verde</td>
</tr>
<tr>
<td>1 to 10 minutes</td>
<td>1</td>
<td>Waterford (1985)</td>
</tr>
<tr>
<td>10 to 30 minutes</td>
<td>3</td>
<td>Fort St. Vrain, Rancho Seco, Salem</td>
</tr>
<tr>
<td>30 minutes to 1 hour</td>
<td>3</td>
<td>San Onofre, Ignalina, Oconee</td>
</tr>
<tr>
<td>1 to 2 hours</td>
<td>2</td>
<td>Greifswald, North Anna</td>
</tr>
<tr>
<td>2 to 5 hours</td>
<td>4</td>
<td>Mühleberg, Kalinin, Shearon Harris</td>
</tr>
<tr>
<td>between 5 and 10 hours</td>
<td>6</td>
<td>Browns Ferry, Armenia, South Ukraine, Vandellos, Chernobyl, Narora</td>
</tr>
<tr>
<td>greater than 10 hours</td>
<td>3</td>
<td>Beloyarsk (22 hrs.), Zaporozhye (18 hrs.), Maanshan (10 hrs)</td>
</tr>
</tbody>
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Duration of Fire (Continued)

- Long fire duration can be attributed to:
  - Severity of fire
  - Dense smoke
  - Delayed decision to activate fire brigade
  - Delayed decision to use water on an electrical fire (three cases)
Conclusion

• Key elements of fire PRAs were found to be consistent with elements of the events
• Current techniques are capable of addressing most of the issues raised in this study
• Fire can lead to nuclear safety challenges