Overview of Accident Management and PSA Interface

Man KIM
NSNI/SAS
OVERVIEW

BACKGROUND

PART I: Defence in Depth (DiD) and Accident Management (AM)

PART II: Accident Management and PSA Interface

PART III: Accident Management Related IAEA Activities
BACKGROUND (1)

Example: Lessons Learnt from the Accident at TMI-2

- The sequence of major events [hr:min]:
  - [0:00]  Feedwater pumps and turbine trip
  - [0:00+] PORV opens at 15.55 MPa followed by reactor trip
  - [0.00++] PORV fails to reclose at 15.20 MPa (start of LOCA)
    Auxiliary feedwater flow blocked (valve left closed)
  - [0.01-] Operators manually start one makeup pump
  - [0:01]  Pressurizer water level reaches lowest level then rises
  - [0:02]  High-pressure injection (HPI) initiated and then RV pressure decreased below 11 MPa
  - [0:03]  **Pressurizer high-level alarm**
  - [0:04]  **Operator throttled HPI isolation valves and stopped one makeup pump**
  - [0:08]  Aux. Feedwater block valve opened (steam generators fill)
  - [0:12]  Pressurizer level comes back on-scale and drops rapidly.
  - [0:15]  Reactor coolant drain tank rupture disk blows
  - [1:51]  Loop A & B hot leg temperatures increase (offsacle)
  - [2:19]  **PORV block valve closed (loss of coolant halted)**
Effects of Increasing Temperature on Core Materials

- Core ‘melting’ and relocation affected by eutectic interactions among various core materials

- 3000: Melting of UO₂
- 2850: Melting of ZrO₂
- ~2600: Formation of a ceramic U-Zr-O melt
- ~2400: Formation of a ceramic α-Zr(O)-UO₂ monotectics
- 2050: Melting of Al₂O₃ burnable poison
- ~1900: Al₂O₃ – UO₂ eutectic
- 1760: Melting of fresh Zircaloy-4
- ~1450: Melting of stainless steel and Inconel
- ~1300: Fe-Zr – Al(Al₂O₃)-Zr eutectics
- 1200: Start of rapid Zr oxidation (run-away temperature escalation)
- ~940: Formation of first Fe-Zr and Ni-Zr eutectics
- ~800: Melting of Ag-In-Cd control rod alloy

[2:19]
Subsequent (unobserved) events:
- [2:20] Water level dropped to approx. mid-core
- [2:30] Start of melting, downward movement of molten cladding
- [2:54] Reactor coolant pump started and run for 17 min
- Accident Termination [4:22] after start makeup water pump

Extensive fuel damage
At least 45% of the core (62 tn) melted;
~20 tn of core debris relocated in lower plenum
Water in lower head prevented vessel failure.

Core Condition – approx. [3:00]
Zirconium

\[ \text{Zr} + 2\text{H}_2\text{O} \rightarrow \text{ZrO}_2 + 2\text{H}_2 + \text{energy} \]

Stainless Steel

\[ 2\text{Cr} + \text{Fe} + 4\text{H}_2\text{O} \rightarrow \text{FeO} \cdot \text{Cr}_2\text{O}_3 + 4\text{H}_2 + \text{energy} \]

for a typical 1000 MWe LWR the mass of zirconium in the core is about 88,000 lbm (40,000 kg)
For BWRs and 44,000 lbm (20,000 kg) for PWRs.
TMI-2: Lessons Learnt

- Accident at TMI-2 was essentially a small LOCA with ‘failure’ of coolant injection systems
  - Coolant injection systems available but isolated by operators
    - Event did not fit into framework of EOPs at the time
    - Evidence of coolant loss through open relief valve misinterpreted.
Example: Lesson Learnt from Fukushima accident

Comprehensive BDB event response guidance was not developed in advance, equipment was not pre-staged and readiness maintained, and personnel were not sufficiently trained to deal with Beyond Design Events – this significantly impacted event response.
PART I: Defence in Depth (DiD) and Accident Management (AM)
Objective of DID (INSAG-10)

- To maintain the effectiveness of the barriers by preventing damage to the plant and to the barriers themselves so as to protect people, including workers, and the environment from harm in the event that these barriers are not fully effective

Strategy of DID

- To prevent accidents and,
- If prevention fails, to limit their potential consequences and prevent any evolution to more serious conditions
Defence in Depth (DiD) and AM (2)

<table>
<thead>
<tr>
<th>Levels of Defence</th>
<th>Objective</th>
<th>Essential Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 1</td>
<td>Prevention of abnormal operation and failures</td>
<td>Conservative design and high qualify in construction and operation</td>
</tr>
<tr>
<td>Level 2</td>
<td>Control of abnormal operation and detection of failures</td>
<td>Control, limiting and protection systems and other surveillance features</td>
</tr>
<tr>
<td>Level 3</td>
<td>Control of accidents within the design basis (DBA)</td>
<td>Engineered safety features and accident procedures</td>
</tr>
<tr>
<td>Level 4 (after TMI)</td>
<td>Control of plant conditions (BDBA + Severe Accidents) including: - prevention of accident progression - mitigation of the consequences</td>
<td>Complementary measures, back fitting measures, accident management (AM) procedures (EOP) and guidelines (SAMG)</td>
</tr>
<tr>
<td>Level 5</td>
<td>Mitigation of radiological consequences of significant releases of radioactive materials</td>
<td>Off-site emergency response</td>
</tr>
</tbody>
</table>

**Accident Severity**
- Normal Operation
- Transient
- Reactor Trip
- Safety Injection
- Core Uncovery
- Core Damage
- Vessel Failure
- Containment Failure/Vent

**Levels**
- Level 1 - 2
- Level 3: BDBA
- Level 4
- Level 5

**Containment**

**Env.**
Goals of Accident Management

• Delay or prevent damage to core (preventive)

• Terminate fission product releases from the plant (mitigative)

• Maintain or return the containment to a controlled, stable state (mitigative)

• Return the core to a controlled, stable state (mitigative)
Development of an Approach
## Development of an Approach

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Emergency Operating Procedure</th>
<th>Severe Accident Management Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Priority to protection of:</td>
<td>Core</td>
<td>Containment</td>
</tr>
<tr>
<td>Preventive / mitigative?</td>
<td>Preventive</td>
<td>Mitigative</td>
</tr>
<tr>
<td>Procedure or guideline?</td>
<td>Procedure</td>
<td>Guideline</td>
</tr>
<tr>
<td>Symptom based?</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Event specific or independent?</td>
<td>Both</td>
<td>Event-independent</td>
</tr>
<tr>
<td>Entry basis</td>
<td>Reactor trip /</td>
<td>Symptom indicating core damage</td>
</tr>
<tr>
<td></td>
<td>Safeguards actuation</td>
<td></td>
</tr>
<tr>
<td>Exit basis</td>
<td>Stable shutdown</td>
<td>Controlled stable state</td>
</tr>
</tbody>
</table>
Example ‘Preventive’ Strategies for PWRs (John)

- Maintain Coolant Inventory:
  - refill RWST with borated water or CST with condensate
  - reduce containment flow rate to conserve water for core injection
  - use charging pumps for core injection
  - use alternate injection for RCP seal cooling
  - fast secondary side cool-down to utilise water sources for low pressure systems

- Maintain Decay Heat Removal:
  - use condenser or start-up pumps for feedwater injection
  - enable emergency connection of feedwater to rivers, reservoirs or municipal water systems
  - enable emergency cross-tie of service water and CCW to feedwater
  - use diesel driven pumps for injection to containment spray or steam generators
  - initiation of RHR system outside normal ranges

- Reactivity Control:
  - ensure an abundant supply of borated water

- Maintain Support Systems:
  - conserve battery capacity by shedding non-essential loads
  - use portable battery charger to recharge batteries
  - enable emergency cross-tie of AC power between two units or to onsite gas turbine
PREVENTIVE Accident Management

- **Preventive Actions:** delay or prevent core damage
  - Preventive actions are usually *procedurized* and instructions are given in the *Emergency Operating Procedures (EOPs)*

- **Examples** of preventive actions:
  - Primary system feed and bleed cooling (restore core cooling) (FR-H.1)
  - Establish feed to steam generators (restore heat sink) (FR-H.1)
  - Depressurize reactor system to inject low pressure water sources (restore core cooling) (FR-C.1)
  - The effectiveness of preventive measures can be quantified using Level 1 PSA (quantification of core damage frequency)
Example ‘Mitigative’ Strategies for PWRs (John)

- Prevent Vessel Failure:
  - use RCP pumps to force flow through the core
  - depressurise and inject coolant into the RCS
  - remove RCS heat using steam generators (secondary feed and bleed)
  - remove RCS heat using PORV (primary feed and bleed)
  - flood cavity to cool vessel

- Prevent Containment Failure by Slow Over-pressurisation:
  - use containment sprays to remove containment heat
  - use fan coolers to remove containment heat
  - flood cavity before or after vessel failure to delay or prevent core/concrete interaction
  - use recombiners or ignitors to control combustible gases
  - vent containment to relieve pressure

- Prevent Containment Failure by Rapid Over-pressurisation:
  - depressurise RCS to prevent direct containment heating
  - flood cavity before or after vessel failure to break up and cool core debris
  - vent containment to control combustible gases (pre-vessel failure and/or post-vessel failure)
Example ‘Mitigative’ Strategies for PWRs

• Prevent Basement Melt-Trough:
  - flood cavity to cool core debris before vessel failure and/or after vessel failure

• Mitigate Fission Product Release:

• Control Transport Out of RCS
  - use auxiliary pressurised spray to scrub fission product before they are released through the PORV
  - flood cavity before and/or after vessel failure

• Control Transport Outside Containment:
  - flood leak location
  - re-establish containment isolation
  - depressurise containment to reduce driving forces across leak
  - depressurise RCS (steam generator tube rupture)
  - flood steam generator secondary (SGTR)
  - flood break location/interfacing system (LOCA)
Mitigative Accident Management
= Severe Accident Management

- Mitigative Actions: **mitigate core damage and protect fission product boundaries**
  - Guidance is provided in the *Severe Accident Management Guidelines (SAMG)*
  - Normally, SAMG are structured, but not rigid procedures

- **Examples of Mitigative Actions:**
  - Vent containment (protect containment boundary integrity) (SCG-2)
  - Establish feed to steam generators (protect SG tube integrity, scrub releases) (SAG-1)
  - Depressurize reactor system (prevent high pressure vessel failure) (SAG-2)

- The effectiveness of mitigative measures can be quantified using Level 2 PSA (quantification of fission product release frequency and magnitude)
MITIGATIVE Accident Management  
= Severe Accident Management

<table>
<thead>
<tr>
<th>SACRGs</th>
<th>Severe Accident Control Room Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>SACRG-1</td>
<td>Severe Accident Control Room Guideline Initial Response</td>
</tr>
<tr>
<td>SACRG-2</td>
<td>Severe Accident Control Room Guideline for Transients After the TSCis Functional</td>
</tr>
</tbody>
</table>

**DFC TSC Diagnostic Flow Chart**

<table>
<thead>
<tr>
<th>SAMGs</th>
<th>Severe Accident Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAG-1</td>
<td>Inject into the Steam Generators</td>
</tr>
<tr>
<td>SAG-2</td>
<td>Depressurize the RCS</td>
</tr>
<tr>
<td>SAG-3</td>
<td>Inject into the RCS</td>
</tr>
<tr>
<td>SAG-4</td>
<td>Inject into Containment</td>
</tr>
<tr>
<td>SAG-5</td>
<td>Reduce Fission Product Releases</td>
</tr>
<tr>
<td>SAG-6</td>
<td>Control Containment Conditions</td>
</tr>
<tr>
<td>SAG-7</td>
<td>Reduce Containment Hydrogen</td>
</tr>
<tr>
<td>SAG-8</td>
<td>Flood Containment</td>
</tr>
<tr>
<td>SCST</td>
<td>TSC Severe Challenge Status Tree</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCGs</th>
<th>Severe Challenge Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCG-1</td>
<td>Mitigate Fission Product Releases</td>
</tr>
<tr>
<td>SCG-2</td>
<td>Depressurize Containment</td>
</tr>
<tr>
<td>SCG-3</td>
<td>Control Hydrogen Flammability</td>
</tr>
<tr>
<td>SCG-4</td>
<td>Control Containment Vacuum</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCG</th>
<th>Severe Challenge Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAEGs</td>
<td>Severe Accident Exit Guidelines</td>
</tr>
<tr>
<td>SAEG-1</td>
<td>TSC Long Term Monitoring Activities</td>
</tr>
<tr>
<td>SAEG-2</td>
<td>SAMG Termination</td>
</tr>
</tbody>
</table>

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<tr>
<th>SCST</th>
<th>TSC Severe Challenge Status Tree</th>
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<td>SCST</td>
<td>TSC Severe Challenge Status Tree</td>
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</tbody>
</table>
Approaches to EOP-SAMG Transition: WOG
PART II: Accident Management (AM) and PSA Interface
SAMG Development Process

1. Goals
   - Principles

2. Develop approach
   - SAMG structure and philosophy
   - PSA Level 1 & 2
   - Plant specific analysis

3. Adapt approach to plant design
   - Plant design information
   - Plant specific analysis

4. Implement on-site
   - Plant organisation
   - Emergency plan
   - V & V
   - Analysis

EPRI Severe Accident Management Guidance Technical Basis Reports (TBR)
SAMG Development Process

AMP Developer

1. Define approach
2. Identify Challenges and vulnerabilities
3. High level strategies
4. Guidelines / detailed strategies
5. Implementation / validation

Analyst

1. Preliminary phase analysis without operator actions
2. Development phase analysis for strategies and guidelines
3. Implementation phase analysis

Relation between AMP Developers and Supporting Analysts
SAMG Development Process

- **Preliminary Phase Analysis** supports the development of technical bases
- **Development Phase Analysis** supports the SAMG development
- **Implementation Phase Analysis** supports the implementation phase
Preliminary Phase Analysis: 
Basis for Selection of Scenarios for Preliminary Analysis

Step 1:

- Define spectrum of severe accident sequences (use of level 1 PSA)
- Develop a suitable categorisation approach, and a set of damage states. One method of achieving this is summarized in the following slide.
- Screen the full list of damage states to identify a limited set, considering contribution to core damage frequency and ensuring that all initiators are represented.
- Choose one or more accident sequences considering total contribution to core damage frequency to accident management measures.
### Example:

<table>
<thead>
<tr>
<th>Initiating event</th>
<th>Decision point 1</th>
<th>Decision point 2</th>
<th>Decision point 3</th>
<th>Decision point 4</th>
</tr>
</thead>
</table>

![Decision tree diagram](image)

- Sequence 1 (expected outcome)
  - Sequence 2
  - Sequence 3
  - Sequence 4
  - Sequence 5
  - Sequence 6
  - Sequence 7
  - Sequence 8
  - Sequence 9
  - Sequence 10
### Example: Scheme for Categorising Accident Sequences

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Possible Values</th>
<th>Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiating event</td>
<td>Small LOCA&lt;br&gt;Medium LOCA&lt;br&gt;Large LOCA&lt;br&gt;Steam generator tube rupture&lt;br&gt;Secondary break&lt;br&gt;Complete loss of a.c.&lt;br&gt;ATWS&lt;br&gt;Transient</td>
<td>S&lt;br&gt;M&lt;br&gt;A&lt;br&gt;W&lt;br&gt;TS&lt;br&gt;T_B&lt;br&gt;T_A&lt;br&gt;T</td>
</tr>
<tr>
<td>Emergency core cooling system status</td>
<td>All failed&lt;br&gt;HPI success HPR fail&lt;br&gt;HPI success HPR success&lt;br&gt;LPI success LPR fail&lt;br&gt;LPI success LPR success</td>
<td>1&lt;br&gt;2&lt;br&gt;3&lt;br&gt;4&lt;br&gt;5</td>
</tr>
<tr>
<td>Secondary heat sink</td>
<td>Fail&lt;br&gt;Success</td>
<td>F&lt;br&gt;S</td>
</tr>
<tr>
<td>Containment heat removal (CHR)</td>
<td>Fail&lt;br&gt;Success (either spray, HPI or LPI systems operating in recirculation, with heat exchanger. If ECCS status 3 or 5, CHR status is S)</td>
<td>F&lt;br&gt;S</td>
</tr>
<tr>
<td>Containment boundary status</td>
<td>Isolation success, normal leakage&lt;br&gt;Isolation failed&lt;br&gt;Bypassed&lt;br&gt; (fully dependent on initiator)</td>
<td>S&lt;br&gt;I&lt;br&gt;B</td>
</tr>
</tbody>
</table>

**IAEA**

Atoms for Peace: The First Half Century

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Phase Analysis Example: 
Scheme for Categorising Accident Sequences

Analysis

• Step 2: Update Scenario List to Cover Required BDBA Aspects (if applicable)

• Step 3: Update Scenario List to Cover Severe Accident Vulnerability and Challenge Mechanisms,
  • e.g.: hydrogen behaviour-high pressure melt ejection-molten core debris dispersal-molten core concrete attack-containment overpressurisation-containment bypass
### Analysis Examples of Scenarios for Preliminary Analysis

<table>
<thead>
<tr>
<th>Plant Damage State</th>
<th>Representative Sequence(s)</th>
<th>Reason (see notes)</th>
<th>Potential Sensitivity Studies or Future AM Analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1S</td>
<td>1. Unisolated small or very small LOCA with failure of safety injection</td>
<td>1, 3, 4</td>
<td>Depressurisation of RCS (LPI unavailable)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Secondary depressurisation after degraded core cooling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basis for 650C entry to FR-C.1</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Primary depressurisation after inadequate core cooling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Severe accident phenomena: HPME, and possibly induced bypass</td>
</tr>
<tr>
<td>S2SSS</td>
<td>1. Unisolated very small LOCA, LP tank overflow and associated loss of HP recirculation</td>
<td>1, 3, 4</td>
<td>Sensitivity to break size (small and very small)</td>
</tr>
<tr>
<td></td>
<td>Containment isolation and heat removal success</td>
<td></td>
<td>Break size for small/medium boundary.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Symptoms for R.C.P., trip after SLOCA</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Severe accident phenomena: Hydrogen deflagration, DDT, HPME and possibly induced bypass</td>
</tr>
<tr>
<td>M1SFI</td>
<td>1. Stuck open pressurizer safety valve with failure of safety injection</td>
<td>1, 3, 4</td>
<td>Depressurisation of RCS (LPI unavailable)</td>
</tr>
<tr>
<td></td>
<td>2. Medium LOCA with failure of safety injection, failed containment heat removal and failed containment isolation</td>
<td></td>
<td>Secondary depressurisation after degraded core cooling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Basis for 650C entry to FR-C.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Primary depressurisation after inadequate core cooling</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Severe accident phenomena: Impaired containment isolation</td>
</tr>
<tr>
<td>M2S</td>
<td>1. Medium LOCA with HP injection, LP tank overflow and associated loss of HP recirculation</td>
<td>1, 3</td>
<td>Break size for small/medium boundary.</td>
</tr>
<tr>
<td>A1xFS</td>
<td>1. Double ended hot leg break with failure of safety injection, no containment heat removal</td>
<td>2, 4</td>
<td>Severe accident phenomena: hydrogen deflagration, DDT and CCI</td>
</tr>
<tr>
<td>Scenario code</td>
<td>Scenario description</td>
<td>ECCS</td>
<td>FW</td>
</tr>
<tr>
<td>---------------</td>
<td>----------------------------------------------------------</td>
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<td>-----</td>
</tr>
<tr>
<td>Lmin-1SSS</td>
<td>LOCA with minimum or small diameter, variation on hot and cold leg</td>
<td>HPI: No, LPI: No, HA: Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lmin-2SSS</td>
<td>LOCA with minimum or small diameter, variation on hot and cold leg</td>
<td>HPI: Yes, HPI-R: No, LPI: No, HA: Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lmedium-2SSS</td>
<td>Selected LOCA with medium diameter, variation on hot and cold leg</td>
<td>HPI: Yes, HPI-R: No, LPI: No, HA: Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Llarge-1xFS</td>
<td>LOCA with large diameter (maximum design), variation on hot and cold leg</td>
<td>HPI: No, LPI: No, HA: Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Llarge-1xSS</td>
<td>LOCA with large diameter (maximum design), variation on hot and cold leg</td>
<td>HPI: No, LPI: No, HA: Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>IFLxxx-2SSS</td>
<td>SGTR, one and several tubes</td>
<td>HPI: Yes, HPI-R: No, LPI: No, HA: Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
### Potential Challenges to Fission Product Boundaries

<table>
<thead>
<tr>
<th>Containment Failure Mode</th>
<th>Associated Phenomena</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early failure - hydrogen combustion</td>
<td>Deflagration</td>
</tr>
<tr>
<td></td>
<td>Accelerated flames</td>
</tr>
<tr>
<td></td>
<td>DDT</td>
</tr>
<tr>
<td></td>
<td>Direct detonation</td>
</tr>
<tr>
<td>Early failure - HPME</td>
<td>Overpressurisation of reactor shaft or cavity access doors</td>
</tr>
<tr>
<td></td>
<td>Vessel rocketing</td>
</tr>
<tr>
<td></td>
<td>DCH/debris dispersal</td>
</tr>
<tr>
<td>Early failure - penetration failure</td>
<td>Debris attack to cavity access doors</td>
</tr>
<tr>
<td></td>
<td>Penetration overtemperature failure</td>
</tr>
<tr>
<td>Late failure - overpressurisation</td>
<td>Steam generation from ex-vessel debris</td>
</tr>
<tr>
<td></td>
<td>Non-condensable gas and steam generation from concrete attack (MCCI)</td>
</tr>
<tr>
<td>Late failure - basemat penetration</td>
<td>Long term MCCI</td>
</tr>
<tr>
<td>Containment bypass</td>
<td>Unisolable SGTR or ISLOCA</td>
</tr>
<tr>
<td>Containment bypass (induced)</td>
<td>Induced tube failure by heatup of tubes due to RCS natural recirculation</td>
</tr>
<tr>
<td>Containment isolation failure</td>
<td>System malfunction</td>
</tr>
</tbody>
</table>
(2) AMP Development Phase

Development Phase Analysis
(1)
Perform development phase analysis
Interpretation / Presentation
Sensitivity studies

Development Phase Analysis
(2)
Select validation scenarios
Analyse validation scenarios and variants

Verification and optimization requirements for strategies
Calculation requirements for setpoints
Calculation requirements for computational aids
Calculation requirements for validation

Development phase
(2) **AMP Development Phase**

- Evaluate systems capabilities
- Confirm choice of symptoms and strategies
- Support set-point calculations
- Investigate potential plant modification
(2) AMP Development Phase

Identification of Possible Event Paths for a Validation

<table>
<thead>
<tr>
<th>Initiating event</th>
<th>Decision point 1</th>
<th>Decision point 2</th>
<th>Decision point 3</th>
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</table>

Sequence 1 (expected outcome)
- Sequence 2
- Sequence 3
- Sequence 4
- Sequence 5
- Sequence 6
- Sequence 7
- Sequence 8
- Sequence 9
- Sequence 10
### (2) AMP Development Phase

**PRELIMINARY Supporting Analysis for the Entry Condition**

<table>
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<tr>
<th>Case</th>
<th>Peak $T_{\text{clad}}$ (°C)</th>
<th>Peak $T_{\text{cet}}$ (°C)</th>
<th>Reactor system pressure (bar abs)</th>
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<table>
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<tr>
<th>Case</th>
<th>Peak $T_{\text{clad}}$ (°C)</th>
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</table>
Example of SAM Measure: Passive Autocatalytic Recombiners

- Passive Autocatalytic Recombiner (PAR) system in large dry containments.
  - The following specific topics have been investigated:
    - positioning of catalytic recombiners in a multi-compartment containment configuration (development of generic criteria)
    - determination of the local and overall capacity of a recombiner system, needed to prevent high hydrogen accumulation and global combustion
    - influence of the recombiner system on the gas distribution in the containment under accidental conditions (extent of gas mixing)
    - consequences of a failure of local catalytic devices due to blow-down forces or catalytic poisons
(2) **AMP Development Phase**

<table>
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<tr>
<th>Time</th>
<th>Event Description</th>
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<tr>
<td>Fast</td>
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<tr>
<td>(0.5 - 1.5 h)</td>
<td>- rupture of the surge line</td>
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<tr>
<td>Intermediate (1 - 3 h)</td>
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<tr>
<td></td>
<td>(primary depressurization not required)</td>
</tr>
<tr>
<td></td>
<td>- Leak of 50 cm², hot leg, without secondary side depressurization</td>
</tr>
<tr>
<td>Partial core damage</td>
<td>Total loss of power (station blackout)</td>
</tr>
<tr>
<td></td>
<td>- with primary depressurization and flooding of a partially damaged core</td>
</tr>
<tr>
<td></td>
<td>after restoration of the power supply (only in-vessel)</td>
</tr>
<tr>
<td>Slow</td>
<td>Loss of secondary feedwater supply with primary depressurization</td>
</tr>
<tr>
<td>(&gt; 3 h)</td>
<td>SBLOCA:</td>
</tr>
<tr>
<td></td>
<td>(primary depressurization not required)</td>
</tr>
<tr>
<td></td>
<td>- Leak of 50 cm², hot leg, with secondary side depressurization</td>
</tr>
</tbody>
</table>
(2) AMP Development Phase

Approach used to Analyse the representative Cases

- MELCOR integral analyses to get “source data” from RCS / cavity into containment
- RALOC / COCOSYS detailed containment analysis for set-up of PAR concept - each room in containment modelled separately: ~130 volumes and 460 flow paths
## (2) AMP Development Phase

Example of a SAMG Validation Exercise Cross Reference Sheet

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<th>TSC-3</th>
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</table>
PART III: Accident Management
Related IAEA Activities
IAEA Safety Standard on SA and AMP (1)

- Safety Assessment for Facilities and Activities No.GSR-4 (2009)
- Safety of NPPs: Operation No.SSR-2/2 (2011)
- Severe Accident Management Programme for NPPs NS-G-2.15 (2009)
- Severe Accident Analysis Tools SRS-56 (2008)
- Overview of Training Methodology TECDOC-1440 (2005)
- Analysis of SA in PHWR TECDOC-1594 (2008)
AMP Development (2)

1. INTRODUCTION
2. CONCEPT OF AMP
   - Requirements
   - Concept of Accident Management
   - Scope and Principles
   - Equipment Upgrades
   - Form of AMG
   - Roles and Responsibilities
3. ATTRIBUTES OF AMP
   - Identification of plant vulnerabilities
   - Identification of plant capabilities
   - Development of AM strategies
   - Development of procedures and guidelines
   - Hardware provisions for AM
   - Role of instrumentation and control
   - Responsibility, lines of authorisation
   - Verification and validation
   - Education and training
   - Processing new information
   - Supportive analysis
   - Quality assurance
Annex: Example for accident sequence categorization scheme
AMP Development (3)

CONTENTS
1. INTRODUCTION
2. BASIC FEATURES OF AMPs
3. PREPARATION OF THE ACCIDENT MANAGEMENT PROGRAMME
   3.1. Team formation
   3.2. Familiarization
   3.3. Selection and definition of an AMP
   3.4. Review of available safety analyses and specification of further information needs
   3.5. Evaluation of the plant equipment and instrumentation performance
4. DEVELOPMENT OF AN AMP
   4.1. Selection and development of severe accident management strategies
   4.2. Development of accident management procedures and guidelines
   4.3. Supporting accident analysis for development of procedures and guidelines
   4.4. Determination of the needs for plant instrumentation, equipment and material, and necessary upgrades
   4.5. Integration of procedures, guidelines and the plant’s emergency arrangements
   4.6. Verification and validation of procedures and guidelines
   4.7. Specification of training needs
   4.8. Review of the AMP
   4.9. Involvement of the regulatory body
5. IMPLEMENTATION
   5.1. Overview of the plant’s emergency organization
   5.2. Training
   5.3. Staffing and qualification
   5.4. Revisions to the AMP
APPENDIX
REFERENCES
ANNEX
Thank you for your attention
Any questions?