Application of Safety Analysis for Verification and Validation of SAMG

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Atomic Energy Regulatory Board, India
Outline

- Accident Management Programme
  - Approach
  - Key elements
  - Safety analysis in the development phase
- Verification and Validation of SAMG
- Safety Analysis as part Independent Verification of SAMG actions
- Regulatory Position on SAMG
- Answers to Questionnaire
- Points to Ponder
Goals of Accident Management Programme

- Preventing or delaying the occurrence of severe fuel damage
- Terminating the progress of fuel damage once it has started
- Maintaining the integrity of reactor vessel/calandria to prevent melt through
- Maintaining the integrity of the containment and preventing containment by-pass
- Minimizing releases of radioactive material from the core or at other locations of fuel
- Achieving a long term safe stable state of the reactor core and spent fuel storage

DBAs and DEC-A (without core damage)

SA/DEC (with significant core damage)
### Approach to Accident Management Programme

<table>
<thead>
<tr>
<th>Safety objective</th>
<th>Accident Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design basis accidents (DBA)</td>
<td>Design extension conditions (DEC)</td>
</tr>
<tr>
<td>Level-3 DID</td>
<td>Level-4 DID</td>
</tr>
<tr>
<td>Prevent significant fuel degradation and keep releases within acceptable limits</td>
<td>Terminate fuel damage, maintain the integrity of the containment for as long as possible. Minimize on-site and off-site releases and their adverse effects</td>
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<table>
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<tr>
<th>Accident management strategy</th>
<th>Preventive</th>
<th>Mitigative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measures</td>
<td>Credited plant equipment</td>
<td>Safety systems</td>
</tr>
<tr>
<td></td>
<td>means</td>
<td>operator actions, plant modifications, additional provisions, recovery of failed equipment, use of non-permanent systems etc.</td>
</tr>
<tr>
<td>Procedures</td>
<td>Emergency Operating Procedures</td>
<td>Severe Accident Management Guidelines</td>
</tr>
<tr>
<td></td>
<td>Preventive Guidelines</td>
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<table>
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<tr>
<th>Analysis</th>
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<tbody>
<tr>
<td>Deterministic safety</td>
<td>Equipment qualification</td>
</tr>
<tr>
<td>Plant specific analysis for DBA and DEC-A</td>
<td>Equipment survivability assessment</td>
</tr>
<tr>
<td>Probabilistic safety</td>
<td></td>
</tr>
<tr>
<td>Level-1 PSA</td>
<td></td>
</tr>
<tr>
<td>Plant specific analysis for DEC-B</td>
<td></td>
</tr>
</tbody>
</table>
Key Elements in Setting-up of an AMP

- Identification of Plant Vulnerabilities
- Identification of Plant Capabilities
- Development of Accident Management strategies and measure
- Development of Procedures and Guidelines
- Hardware Provisions for Accident Management
- Instrumentation and Control
- Equipment Requirements and Survivability (IAEA-TM-52058, 12-15 April, 2016)
- Verification and Validation
- Personnel Staffing and Needs
- Interfaces with Emergency Preparedness and Response
- Responsibilities and Lines of Authorization
- Accident management training, exercises and drills
- Updating accident management programme
Development and implementation of the accident management programme should be supported by appropriate computational analysis showing progression of representative accident scenarios for formulation of the technical basis for developed strategies, procedures and guidelines.

Suitable analysis methods with appropriate risk metrics should be used to aid in decision making regarding plant upgrades.

Analysis in the field of severe accident management is usually not conservative but of best estimate analysis, and does not in itself create margins.

Address all phenomena (thermal-hydraulic, structural) important for assessment of challenges to integrity of barriers against releases of radioactive materials as well as for source term assessment.

Address a sufficiently broad set of accident scenarios adequately covering potential evolutions of IEs into DEC.

PSA Level 1 and 2 in combination with engineering judgment should be used for selection of the scenarios.
Safety Analysis in the Developmental Phase of Accident Management Programme (2/3)

- Provide sufficient input for development of procedures and guidelines
  - identification of the key challenges and vulnerable plant systems and barriers
  - evaluate the timing of such challenges, in order to improve the potential for successful human intervention
  - specification of set-points to initiate and to exit individual strategies
  - positive and negative impacts of accident management actions
  - time windows available for performing the actions
  - prioritisation and optimisation of strategies
  - evaluation of capability of systems to perform intended functions
  - expected trends in the accident progression
  - conditions for leaving SAM domain
  - Development and validate computational aids
  - Information regarding environmental conditions for assessment of the survivability of the equipment and working conditions

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Safety Analysis in the Developmental Phase of Accident Management Programme (3/3)

- The accident analysis should take into account of various scenarios that would lead to core damage and subsequent potential challenge to fission products barriers:
  - Sequences with no operator action or inappropriate operator actions (errors of omission or errors of commission) leading to core damage;
  - Availability and functionality of equipment, including instrumentation, and the habitability of working places under anticipated environmental conditions; and
  - Potential cliff-edge effects

- Use of computer codes that have the capability of modelling severe accident phenomena with reasonable accuracy in prediction of key physical phenomena, timing of failure of barriers with validation to the extent as far as reasonably practicable
Verification and Validation of SAMG
### Accident Management Programme

#### Accident Management

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<td>Safety systems</td>
</tr>
<tr>
<td></td>
<td>Safety systems</td>
<td>Additional safety systems, complementary safety features</td>
</tr>
<tr>
<td>Procedures</td>
<td>Emergency Operating Procedures</td>
<td>Preventive Guidelines</td>
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The table above outlines the key aspects of the Accident Management Programme, focusing on the different accident scenarios (Design basis accidents (DBA) and Design extension conditions (DEC)) and their corresponding safety objectives, management strategies, measures, and procedures. The analysis and equipment and instrumentation are also detailed, highlighting the specific activities and guidelines associated with each level of severity.
Verification and Validation of SAMG (1/3)

- The effectiveness of an accident management programme strongly relies on the verification and validation of the measure/action, procedures and guidelines.
- Verification and validation processes should assess the technical accuracy and adequacy of the instructions, and the ability of personnel to follow and implement them. [IAEA DS-483]
- The verification process should confirm the compatibility of document instructions with referenced equipment, user-aids and supplies (e.g., non-permanent equipment, posted job aids, strategy evaluation materials, etc.).
- The validation process should demonstrate that the document provides the instructions necessary to implement the guidance.

Points to ponder: Rework/reframe the definitions of V & V based on the discussion during the TM

: What is the scope of verification and validation? Should this include the methods used for verification of AMG actions in the developmental phase
Verification and Validation of SAMG (2/3)

- **Possible methods** for validation of the procedures and guidelines
  - use of deterministic and probabilistic safety analysis in the development phase
  - full scope simulator
  - an engineering simulator
  - plant analyser tool, or a table top method.

- Validation **should encompass the uncertainties** in the magnitude and timing of phenomena (both phenomena that result from the accident progression and phenomena that result from recovery actions).
  - A degraded or unavailable instrumentation response, or a delay in obtaining the information should be simulated.

- **Should include conditions that realistically simulate** the conditions present during an emergency
  - response actions, hazardous work conditions, time constraints, practicality, etc.

- **Necessary Cross-functional safety review** of the plant for the full understanding of the implications of all accident management actions.
Verification and Validation of SAMG (3/3)

- V&V of issues related to reliance on human performance, interfaces between onsite accident management and off-site emergency preparedness activities, implementation of training program framework.

- Staff involved in the validation of the procedures and guidelines should be different from those who developed the procedures and guidelines.
SAMG Independent Verification Analysis in AERB
SAMG Verification Analysis in AERB

Some Recent Studies:
- SAMG Independent Verification Studies for PHWRs
  - LOCA+LECCS+LMODC – with credit of hook-up to Calandria
  - SBO+FW system failure to SG – with credit of hook-up to Calandria
  - No injection is considered for the SGs & PHT
- In-vessel Retention Analysis
- Containment Hydrogen Distribution and Management Studies
SAMG Verification Analysis in AERB (Cont.)

**LOCA+LECCS+LMODC with Calandria Hook-up (1/4)**

- Case 1: PT-CT contact is assumed when the temperature at least in one location of any PT reaching to a specified value.
- Case 2: PT-CT contact is assumed when the temperature of all PTs in all locations reaching to a specified value.

### Chronological Sequence of Events

<table>
<thead>
<tr>
<th>Time (s)</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Case 1</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Case 2</strong></td>
</tr>
<tr>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>LB LOCA</td>
</tr>
<tr>
<td></td>
<td>Loss of ECCS</td>
</tr>
<tr>
<td></td>
<td>Loss of moderator cooling</td>
</tr>
<tr>
<td>400.0</td>
<td>715.0</td>
</tr>
<tr>
<td></td>
<td>PT-CT contact</td>
</tr>
<tr>
<td>820</td>
<td>960.2</td>
</tr>
<tr>
<td></td>
<td>OPRD rupture on moderator pressure &gt; 2.4325 bar</td>
</tr>
<tr>
<td>825.5</td>
<td>973.0</td>
</tr>
<tr>
<td></td>
<td>Injection begins on Calandria Level &lt; 5.55 m (92.5% FT)</td>
</tr>
</tbody>
</table>

### Hook-up injection

<table>
<thead>
<tr>
<th>Time (hrs)</th>
<th>Flow rate (kg/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beginning of the injection - 4.0</td>
<td>11.11</td>
</tr>
<tr>
<td>4.0 - 24.0</td>
<td>4.17</td>
</tr>
<tr>
<td>24.0 Onwards</td>
<td>1.94</td>
</tr>
</tbody>
</table>
SAMG Verification Analysis in AERB (Cont.)

LOCA+LECCS+LMODC with Calandria Hook-up (2/4)
SAMG Verification Analysis in AERB (Cont.)

LOCA+LECCS+LMODC with Calandria Hook-up (3/4)

Maximum Clad Surface Temperature

CT Temperature

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- Inventory decreases due to OPRD rupture and heat addition to the moderator.
- Increases due to water addition through hook-up
- Injection flow rate decided by the utility is sufficient to remove the heat produced during the accident scenario.
- Hydrogen generation significantly reduced due to calandria injection and is on lower side compared to the utility predictions.
Case 1: PT-CT contact is assumed when the temperature at least in one location of any PT reaching to a specified value.

Case 2: PT-CT contact is assumed when the temperature of all PTs in all locations reaching to a specified value.

**Chronological Sequence of Events**

<table>
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<th>Time (s)</th>
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</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>SBO, PCPs trip, Reactor trip</td>
</tr>
<tr>
<td></td>
<td>Turbine stop valve closes</td>
</tr>
<tr>
<td></td>
<td>Feed water supply to SGs stops</td>
</tr>
<tr>
<td>11657.0 s</td>
<td>PT-CT contact</td>
</tr>
<tr>
<td>12585.0 s</td>
<td>OPRD rupture on moderator pressure &gt; 2.4325 bar (abs)</td>
</tr>
<tr>
<td>12592.0 s</td>
<td>Injection begins on Calandria Level &lt; 5.55 m (92.5% FT)</td>
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**Hook-up injection rate**

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<tr>
<td>Beginning of the</td>
<td>11.11</td>
</tr>
<tr>
<td>injection* to 4.0</td>
<td></td>
</tr>
<tr>
<td>4.0 to 24.0</td>
<td>4.17</td>
</tr>
<tr>
<td>24.0 Onwards</td>
<td>1.94</td>
</tr>
</tbody>
</table>
SAMG Verification Analysis in AERB (Cont.)

SBO+Loss of FW to SGs - with Calandria hook-up (2/4)

- Crash cooldown at 6 mins
- IRV opening at 30 mins
SAMG Verification Analysis in AERB (Cont.)

SBO+Loss of FW to SGs - with Calandria hook-up (3/4)

[Diagram showing Maximum Clad Surface Temperature and CT Temperature over time for Case-1 and Case-2.]
Secondary inventory decreases due to crash cooldown. Primary inventory decreases due to loss through relief.

- Moderator inventory replenishes through hook-up injection.
- Injection flow rate decided by the utility has been found to be sufficient to remove the heat produced during the accident scenario.
- Calandria did not fill completely with the specified flow rate in the present analysis.
- Insignificant hydrogen generation.
- Large time is available for the calandria hook-up injection from the beginning of accident scenario to moderator low level.
Code Adaption/Development at AERB for SAMG

- ASTEC
- CFD
- ABAQUS
- SCDAP/RELAP5

- ANSYS
- ABAQUS
- COMSOL

Reactors Thermal Hydraulics, core heat-up etc.

Core Disassembly

Containment Phenomena

IVR

In house CFD models

- Wall condensation
- Bulk condensation
- Deflagration and detonation
- Sump model

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## Regulatory Position on SAMG

<table>
<thead>
<tr>
<th>Document Reference</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>AERB/NPP/SC/O (Rev. 1) (2008)</td>
<td>Emergency operating procedures or guidance shall be developed for managing severe accidents.</td>
</tr>
<tr>
<td>AERB/NPP-PHWR/SC/D (Rev.1) (2009)</td>
<td>Accident management procedures shall be established, taking into account representative and dominant severe accident scenarios.</td>
</tr>
<tr>
<td>AERB/NPP-LWR/SC/D (Jan 2015)</td>
<td>SAMG shall be prepared, taking into account the plant design features and the understanding of accident progression and associated phenomena.</td>
</tr>
<tr>
<td>NPCIL/AERB</td>
<td>Severe accident management guidelines are being developed by utility and are reviewed by AERB including independent verification analysis.</td>
</tr>
<tr>
<td>Fukushima</td>
<td>Several hook – up arrangements are incorporated in various Indian NPPs post-Fukushima for severe accident management.</td>
</tr>
<tr>
<td>International guidance</td>
<td>e.g., IAEA NSG 2.15 (2009), CNSC REGDOC 2.3.2 (September 2013), DS483.</td>
</tr>
</tbody>
</table>
Answers to questionnaire

1. What kinds of SAMGs are, or will be, used in your country?

- **Generic SAMGs (WOG, BOG, COG) are not adopted.**

- **Generic Technical basis document for SAMG (separate for PHWRs, PWRs and BWRs) was prepared by the Utility (NPCIL) and are being review by the regulator (AERB). Based on this, plant specific SAMGs are prepared (PHWR)/being prepared (BWR) and implemented.**

- **With respect to verification of SAMG in the development phase, deterministic safety analysis and experimental studies are being used for verification with respect to assessment of phenomena, efficacy of the action and time of action.**
2. Are there any regulatory and industry requirements and guidance specifically for V&V of SAMGs in your country?

- A Safety guide (draft stage) is being prepared based on international guidelines (IAEA NSG 2.15, IAEA DS-483, IAEA SRS-32, CNSC REGDOC 2.3.2, etc.) in addition to requirements based on experience and practice in India.

3. Provide a summary of the current status or plans to re-evaluate V&V of SAMGs in the light of the Fukushima Daiichi accident.

- The AMGs that are being put in place were evaluated considering scenario that include Fukushima conditions. Severe accident management actions are verified against parameters that include flooding, earthquake effects, hydrogen combustion, accessibility, etc.
4. What kind of approaches (a method or combination of methods, tools, data and computational aids, etc.) are, or will be, used in your country or organization for the V&V of SAMGs in general?

- Deterministic safety analysis is generally used for assessing the effectiveness of the SAMG. In addition, experimental programs are also conducted to study the effectiveness of SAMG actions.

- Some of the tools that are used include RELAP/SCDAP, ASTEC, and other in-house developed codes.

- India also participates in international programs that are aimed at validation of codes and tool that will be used for V & V of SAMG.
Answers to questionnaire

5. Are there any commendable practices regarding exercises, drills and plant walk-downs as a means of V&V of SAMGs?

- Calibration of SAMG actions are carried out through desktop models, conducting exercises, plant walk-downs and drills.
- A surveillance programme is also put in place for the identified SAM measures.
- Training and qualification in severe accident management is also a part of operator licensing programme.
Points to Ponder

- Rework/reframe the definitions of V & V based on the discussion during the TM scope of verification and validation? Should this include the methods used for verification of AMG actions in the developmental phase
- Identification of appropriate V&V methods and tools for different aspects/sections of AMP
- clarity with respect to the application of safety analysis as part of justification and development of SAM measure, and their use and qualification for verification and validation purpose.
- Validation of extended used of existing systems and components as part of SAMG measure.
Thank you