Development of the Methodologies for Evaluating Severe Accident Management

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December 13, 2016
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- Theoretical Background
- Methodology
- Preliminary Results
- Concluding Remarks & Future Work
Introduction
Nuclear Power Generation in Korea

- **25 Power Reactors Operation**
  - 21 PWRs and 4 PHWRs
  - Installed capacity of 23.1 GWe
  - 30 ~ 35% share of electricity supply

- **3 PWRs (APR1400) under Construction**

- **4 PWRs (APR1400) under Planning**

- **The Most Economical, Reliable & Semi-domestic Electricity Source in Korea**
Domestic severe accident legislation

- **Amendment of Nuclear safety act**
  - **Purpose**
    - Severe accident management performed by administrative order with weak legal basis
    - Clarification of responsibility for accident management and regulatory requirements in Nuclear Safety Act
    - Even in case of a severe accident, to minimize the release of radioactive materials and to restore the NPP to a safe condition through accident management program
    - To introduce accident management program as a licensing document
  - **Application**
    - New NPP: AMP is required to obtain operating license
    - NPP in operation: AMP is required to submit within 3 years (June 23, 2019)
The new nuclear safety act

Purpose

- Evaluate the effectiveness of the severe accident management strategies using probabilistic manner
- Combine PSA, AMP, and severe accident research
Theoretical Background
# Background

- **Integrated ROAAM**
  - ROAAM + level 2 PSA
  - PSA is a tool for determining relevant sequences that must be mitigated in the SAM approach
  - ROAAM increases the credibility and transparency of the level 2 PSA study providing a framework for modeling and quantifying complex physical phenomena.
  - Application
    - Westinghouse AP600 : passive LWR design

- **SAMEM**
  - Performed the development and demonstration of integrated models for the evaluation of severe accident management strategies using PSA and ROAAM

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- The development and demonstration of integrated models for the evaluation of severe accident management strategies-SAMEM : M.L. Ang(2001)
Methodology
Korean Level 2 PSA Process

**Level 1 PSA**

<table>
<thead>
<tr>
<th>Initiating Event</th>
<th>Core Damage Prevention</th>
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<td>Large LOCA</td>
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<td>SGTR</td>
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<td>ISLOCA</td>
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<tr>
<td>RVR</td>
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**Level 2 PSA**

<table>
<thead>
<tr>
<th>Containment Failure Mitigation</th>
<th>Severe Accident Phenomena</th>
<th>Containment Failure Mode</th>
<th>Source Term Category</th>
<th>Fission Product</th>
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</thead>
<tbody>
<tr>
<td>CIS Containment Isolation before Core Damage</td>
<td>Molten Core-Concrete Interaction</td>
<td>BYPASS</td>
<td>STC1 (SGTR)</td>
<td>Noble Gas</td>
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<td>SDR Sudden Depressurization for mitigation</td>
<td>In-Vessel Steam Explosion</td>
<td>NOTISO</td>
<td>STC2 (ISLOCA)</td>
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<td>RACV Power Recovery before Reactor Vessel Failure</td>
<td>Ex-Vessel Steam Explosion</td>
<td>NOCF</td>
<td>STC3 (NOTISOCS)</td>
<td>Cs</td>
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<td>RACC Power Recovery before Containment Failure</td>
<td>Hydrogen Generation &amp; Reaction</td>
<td>BMT</td>
<td>STC4 (NOTISONOCS)</td>
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<td>INJ Coolant Injection to Reactor Vessel</td>
<td>High Pressure Melt Ejection</td>
<td>ECF</td>
<td>STC5 (CFBRB)</td>
<td>Sb</td>
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<td>CFS Reactor Cavity Flooding</td>
<td>Direct Containment Heating</td>
<td>LCF</td>
<td>STC6 (MELTSTOP)</td>
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<td>HMSI Hydrogen Control System Operation</td>
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<td>STC7 (NOCF)</td>
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<td>CHR Containment Heat Removal</td>
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**Fission Product Release Frequency**

**Core Damage Frequency**

**Plant Damage State Frequency**

**Containment Failure Probability**
Database the level 2 PSA information

- **Transfer to database**
  - Accident progress
    - Core Damage Prevention function
    - Severe accident mitigation function
  - PDS group of Accident Sequences
  - Screening PDS ET
    - Containment failure sequence
    - Frequency: Below $10^{-14}$ /RY
  - Success/failure of the functions
    - Success: (AAC)
    - Failure: **AAC**

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Plant Damage State Event Tree
Database the level 2 PSA information

Source term release fraction

• The mass of the initial fission product in a reactor core and the mass fraction of the fission product released into the environment

• Each PDS has its own 17 STC quantification values and the probabilities by containment failure modes

• 10 fission products
  – Noble gas, I, Cs, Te, Sb, Sr, Ru, Ba, La, Ce

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Database the level 2 PSA information

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<th>Initiating Event</th>
<th>Core Damage Prevention Functions</th>
<th>Severe Accident Mitigation Function</th>
<th>Source Term</th>
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### Initiating Event

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<th>Description</th>
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### Core Damage Prevention Functions

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### Severe Accident Mitigation Function

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### Source Term

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Preliminary application

• **APR1400**
  - Thermal power: 4,000 MWth
  - Hot-leg temperature: 615 °F (323.9 °C)
  - Severe accident respond facilities
    - Cavity flooding system
    - Passive auto-catalytic recombiner
    - ECSBS

• **Selection of initiating event**
  - Based on CDF contribution
Risk information to display

- **Severe Accident Prevention / Mitigation**
  - Core Damage Frequency
  - Conditional Containment Failure Probability

\[
CFF = \text{FREQ} \times CFP
\]

\[
CCFP = \frac{CFF}{CDF} = \frac{\text{FREQ}}{CDF} \times CFP
\]

- **Containment failure / Source term release**
  - Containment Failure Frequency
  - Source Term Release Fraction
Preliminary Results
Database of the risk information

| No. | STATION BLACKOUT | AAC | DELIVER AUX. FEEDWATER (TD PUMPS) | RCP SEAL FAILURE | RECOVER AC POWER (EN HRS) | DEL. AAPW AND REM. STEAM (MESSI) | DEL. ATFW AND REM. STEAM (ADV) | RECOVER AC POWER LATE | REFUEL AAC STORAGE TANK | SHUT DOWN COOLING | MAINTAIN SECONDARY HEAT REMOVAL | RECOVER AC POWER AND REFUELING AAC | SAFETY DEPRESSURIZATION | SAFETY INJECTION FOR FEED (2/4) | CONTAINMENT HEAT REMOVAL (COOL ENGINE) | CONTAINMENT HEAT REMOVAL (CS SPRAY) | CDF (Level 3 Accident Sequence CDF) | CONTAINMENT ISOLATION SYSTEM | CONTAINMENT FAILURE MITIGATION | RECOVER AC POWER PRIOR TO CONTAINMENT | RECOVER AC POWER PRIOR TO VESSEL | IN-VESSEL INJECTION | CAUSTIC FLOODING SYSTEM | HYDROGEN CONTROL SYSTEM | CONTAINMENT HEAT REMOVAL | FREQU (Accident Sequence Frequency) | CLP (PDS No.) | CCF (CFR/CFF) | CFF (Freq CFP) | Cs |
|-----|------------------|-----|----------------------------------|------------------|--------------------------|-------------------------------|-------------------------------|-----------------------------|--------------------------|-------------------------|--------------------------------|-------------------------------|-----------------------------|---------------------------|-------------------------------|-------------------------------|------------------|--------------------------|-------------------------------|-----------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| 83  | SBO (AAC)        | -   | -                                | -                | -                        | -                             | -                             | -                           | -                        | -                       | -                              | -                             | -                           | -                         | -                             | -                             | 1.98E-10 | (AAC)                    | -                             | -                           | -                        | -                       | -                        | -                       | -                        | -                       | -                        |
| 85  | SBO (AAC)        | -   | -                                | -                | -                        | -                             | -                             | -                           | -                        | -                       | -                              | -                             | -                           | -                         | -                             | -                             | 1.98E-10 | (AAC)                    | -                             | -                           | -                        | -                       | -                        | -                       | -                        | -                       | -                        |
| 124 | SBO (AAC)        | -   | -                                | -                | -                        | -                             | -                             | -                           | -                        | -                       | -                              | -                             | -                           | -                         | -                             | -                             | 1.98E-10 | (AAC)                    | -                             | -                           | -                        | -                       | -                        | -                       | -                        | -                       | -                        |
| 208 | SBO (AAC)        | -   | -                                | -                | -                        | -                             | -                             | -                           | -                        | -                       | -                              | -                             | -                           | -                         | -                             | -                             | 1.98E-10 | (AAC)                    | -                             | -                           | -                        | -                       | -                        | -                       | -                        | -                       | -                        |
| 418 | SBO (AAC)        | -   | -                                | -                | -                        | -                             | -                             | -                           | -                        | -                       | -                              | -                             | -                           | -                         | -                             | -                             | 1.98E-10 | (AAC)                    | -                             | -                           | -                        | -                       | -                        | -                       | -                        | -                       | -                        |
| 440 | SBO (AAC)        | -   | -                                | -                | -                        | -                             | -                             | -                           | -                        | -                       | -                              | -                             | -                           | -                         | -                             | -                             | 1.98E-10 | (AAC)                    | -                             | -                           | -                        | -                       | -                        | -                       | -                        | -                       | -                        |
| 473 | SBO (AAC)        | -   | -                                | -                | -                        | -                             | -                             | -                           | -                        | -                       | -                              | -                             | -                           | -                         | -                             | -                             | 1.98E-10 | (AAC)                    | -                             | -                           | -                        | -                       | -                        | -                       | -                        | -                       | -                        |
Distribution chart

- **CDF Vs CCFP**
  - Core Damage Frequency
  - Conditional Containment Failure Probability
Distribution chart

- **Source term release fraction**
  - CFF Vs RF (2D)
  - CCFP Vs CDF Vs RF (3D)
Concluding Remarks & Future Work
Insight from this works

- **Effective evaluation for SAMP**
  - Legislation
  - Verify the impact of mitigation success and failure

- **Prioritization of severe accident management strategies**
  - Selection of the most important mitigation functions
  - Application
    - Improvement of the equipment
    - Modification of Technical specification
    - Personnel training
Further Work

- Concept for evaluating severe accident
- Methodology for DET/CET branch probability calculation
- Uncertainty analysis of CET using computational code
- Level 2 PSA re-quantification
  - The new index for measuring the effectiveness of AMP
Thank you!!