Safety Enhancement Technology Development with Collaborative International Activity

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Safety Enhancement Technology Developments for Post-Fukushima NPPs

- Efficiency
- Prioritization
- Expediting

Critical Factors:

Fukushima Lessons & Learned

International Collaborations
Outline

Overview of R&Ds for Safety Enhancements

Relevance with Fukushima L&Ls

Technical Achievements

Focus: Collaborative International Activity

Role and Scheme of Collaboration

How it works

*R&Ds: Research and Developments
# R&D Activity for Safety Enhancement

<table>
<thead>
<tr>
<th>R&amp;D Area</th>
<th>Pre-Core Damage</th>
<th>Post-Core Damage (In-Vessel)</th>
<th>Post-Core Damage (Ex-Vessel)</th>
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<tbody>
<tr>
<td>Core / Debris Cooling</td>
<td>ATF (SiC: Enhanced Tolerance to Loss of Core Cooling)</td>
<td>In-Vessel Retention</td>
<td>Passive Debris Cooling / MCCI Prevention</td>
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<td>Containment Integrity</td>
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<td>Passive Decay Heat Removal</td>
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<td>Scrubbing/ Filter Venting</td>
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<td>Hydrogen Management</td>
<td>ATF (SiC: Less-H₂ Production)</td>
<td>Passive H₂ Removal with Metal Oxides</td>
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<tr>
<td>SA Simulator</td>
<td></td>
<td>MAAP Model Development/ Improvement</td>
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<tr>
<td>Instrumentation</td>
<td></td>
<td>SA-Phenomena related Parameter Measurement Technology</td>
<td></td>
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<tr>
<td>Battery</td>
<td></td>
<td>Large Capacity Li-ion Battery (SCiB™)</td>
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<tr>
<td>Seismic Protection</td>
<td></td>
<td>Oscillation Damping/ Isolation</td>
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</table>
Debris Cooling: In-Vessel Retention (IVR)

TH Test for CHF Investigation on Heated Surface Orientation

IVR Failure Probability Estimation for 4500 MWt Class PWR

ROAAM: Risk-Oriented Accident Analysis Methodology

Failure Probability: 1.0E-03 ~ 1.1E-02

H$_2$ Management: H$_2$ Removal with Metal Oxide

Concept for Massive H$_2$ Removal in Inerted Containment

H$_2$ Removal Rate Measurements with CuO

Reference: ICONE24-60917 (2016)
This activity is funded by METI (Ministry of Economy, Trade and Industry)
Instrumentation: Severe Accident Monitoring

The Performance of the Monitoring System has been Confirmed under the simulated SA Press./ Temp. Conditions.

R&D Activity with International Collaboration

1. Passive Debris Cooling:
   MCCCI Prevention Technology

2. Accident Tolerant Fuel (ATF):
   SiC Application

3. SA Simulation Technology:
   MAAP Model Enhancement
MCCI Prevention Technology

Refractory Layer for BWR Containment

Selection of Refractory Material
Establishment of the Design Method

Series of Experiments Performed:
Thermal Property Data under Severe Accident Temp. Condition
Erosion Behavior (Thermal and Chemical Interaction)
Eutectic Test Results (Example)

Debris-Refractory Material Composite: \((\text{UO}_2)-\text{(ZrO}_2)-\text{Al}_2\text{O}_3\)

Liquidus/ Solidus Temperature Data
Phase Diagram Analysis by using FactSage

Data Obtained at Several Apparatus in Japan and Kazakhstan
Different Scale Tests validated Phase Diagram Analysis.

International Collaborations

Efficient Use of Expertise available Worldwide

Small-Scale Erosion & Property Tests performed in Japan
Efficient & Effective for accumulation of data for different material

National Nuclear Center (NNC), Republic of Kazakhstan
Accumulated experiences and expertise for debris experiments
Variety of test facilities dedicated for high-temp. UO2 debris test
including a Large-scale test
Effective for the validation of small-scale test results obtained in Japan

# ATF(SiC Application) Development Plan

<table>
<thead>
<tr>
<th>2012~2015</th>
<th>2016~2020</th>
<th>2021~2025</th>
<th>2026~2030</th>
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<tbody>
<tr>
<td>Phase-1 (Feasibility Study)</td>
<td><strong>Phase-2</strong></td>
<td>Phase-3</td>
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### SiC Channel box
- Development of Fabrication tech, Design tech.
- Mechanical tests
- Environmental tests
- Irradiation test in test reactor
- Full length fabrication
- Preparation of licensing for LTR
- Lead test Channel box in commercial reactor
- Commercial use

### SiC Fuel cladding
- Development of Fabrication tech, Design tech.
- Mechanical tests
- Environmental tests
- Irradiation test in test reactor
- Full length fabrication
- Preparation of licensing for LTR
- Licensing for LTR
- LTR irradiation in commercial reactor
- Licensing for LTA
- LTA irradiation in commercial reactor
- Licensing for reload batch
- Commercial use

**Phase 1:** Feasibility Study for Material Design and Fabrication  
**Phase 2:** Full Scale Fabrication and Irradiation Tests

### ATF Fabrication Technology Development

<table>
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<tr>
<th>Process</th>
<th>Advantages</th>
<th>Issues</th>
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<tbody>
<tr>
<td>Chemical Vapor Infiltration (CVI)</td>
<td>✓ Lower process temp.</td>
<td>● Porous matrix</td>
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<tr>
<td></td>
<td>✓ High purity matrix (Stoichiometric)</td>
<td>● Scalability</td>
</tr>
<tr>
<td></td>
<td>✓ Suited to thin-walled structures</td>
<td>● Fabrication cost</td>
</tr>
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</table>

Topfuel2016, ‘Progress on ATF Development of SiC for LWR,’ (2016)

CVD Coating on CVI-SiC Surface to Reduce Porosity  
(CVD: Chemical Vapor Deposition)

Part-Length Channel Box  
(W132.5mm x H1000mm)

Part-Length Cladding Tube  
(Ø10mm x H800mm)
International Collaborations

Efficient Approach for Multidisciplinary & Longterm R&Ds Needs International Expertise and Facility Use

On-Going International Collaboration

OECD/NEA Expert Group on ATF (EGATFL)

Potential Fields for Collaboration
- Irradiation Tests in Test Reactors
- Lead Test Rods/ Assemblies
- Licensing
SA Simulation Technology: MAAP Enhancement

MAAP Enhancement to Support the Decommissioning of 1F Units
- Model Enhancement: EPRI/FAI (USA)
- 1F Accident Analysis: Japanese Industry

International Research Institute for Nuclear Decommissioning (IRID)

TOSHIBA Corporation

Hitachi-GE Nuclear Energy

Electric Power Research Institute (EPRI)

Fauske & Associates, LLC (FAI)

TEPCO
MAAP Model Enhancement

Enhancements Identified from 1F Analysis including:

✓ Corium relocation path, interaction between corium and core structures
✓ Corium behavior in the lower plenum
  • unsymmetrical corium accumulation
  • partial failure of CRD tubes for improving RPV failure mode
✓ Corium spreading in the containment floor
✓ MCCI model


This activity is funded by METI (Ministry of Economy, Trade and Industry)
International Collaborations

Global Needs for SA Model Enhancements

NPP Safety Enhancements including AM
Operator Training and Education

Collaborative International Network:

Japanese National PJ supporting MAAP Enhancement
Model Enhancements: EPRI/ FAI (USA)
Evaluation in Light of 1F: Japan (incl. Toshiba, TEPCO)

OECD/NEA/BSAF
Benchmark Study of the Accident at the 1F
Identification of Further Improvements

MAAP Users Group
More than 60 Organizations from 15 Countries
Operators, Manufactures & Universities
Dissemination and Evaluation of Enhanced MAAP
Summary

A wide range of the Post-Fukushima R&D activities conducted for Safety Enhancement for NPP

R&Ds Selected in Light of Fukushima Lessons & Learned

Critical Role of Collaborative International Activities:

✓ Efficient use of the expertise, facilities and experiences available worldwide.
✓ Pursuing efficient approach for multidisciplinary and long-term research works.
✓ Dissemination of R&D achievements to the international community