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Safety Research Activities on Severe Accident Management in S/NRA/R after Fukushima Daiichi Nuclear Power Plant Accident

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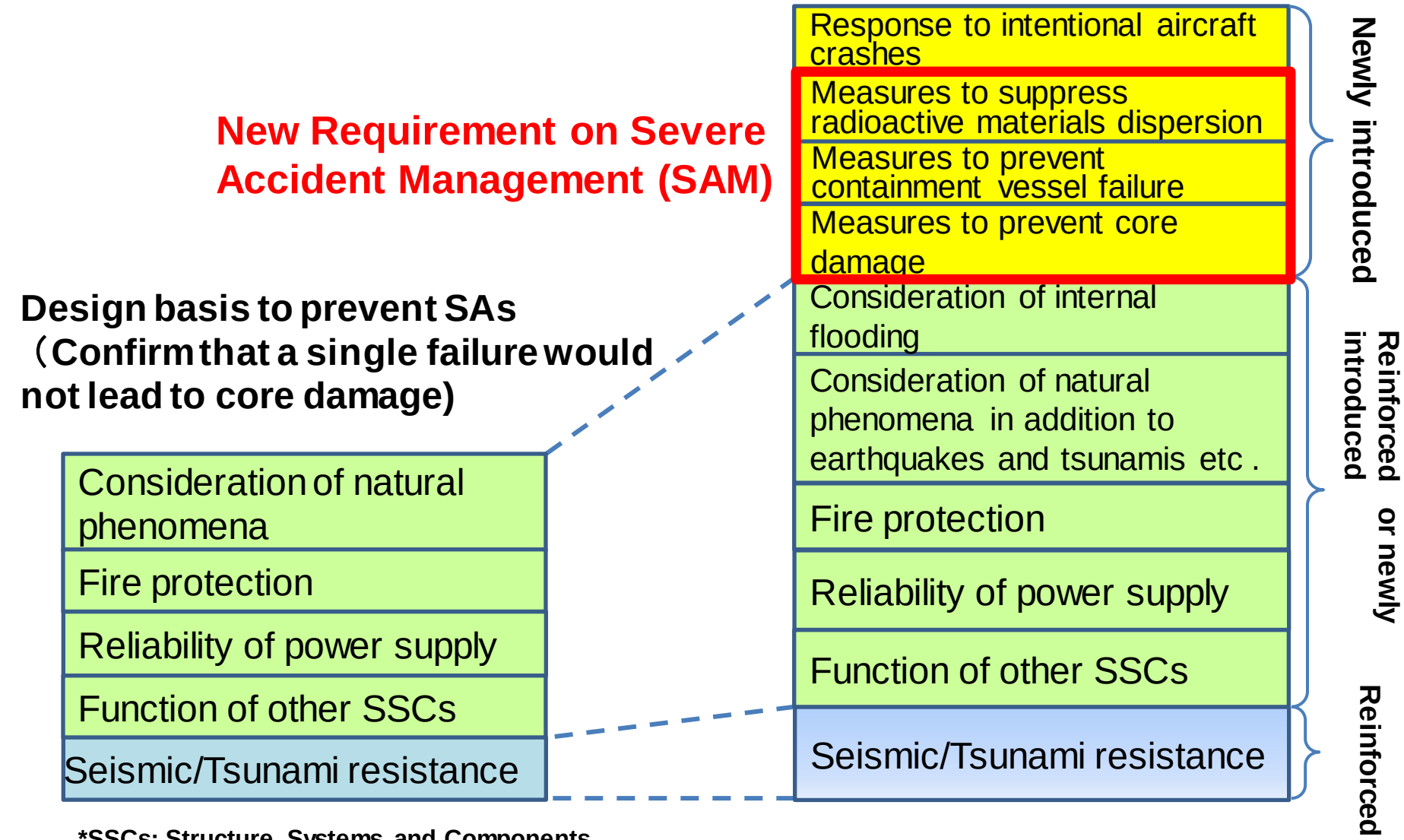
Table of Contents

1. New regulation on NPP

- New regulatory requirements for NPPs came into force in July 2013
- Legally requested measures to prevent and to mitigate severe accidents (SAs)
- Regulation based on the state-of-the-art information
  - Develop new regulatory standards and apply them to existing nuclear facilities (back fitting rule)
- 40-years operation limit for NPPs
  - Legally define the limit to 40years
  - NRA can permit a less-than-20-year extension

1. New regulation on NPP

<Previous Regulatory Requirements> <New Regulatory Requirements >



*SSCs: Structure, Systems and Components

Ref; Enforcement of the New Regulatory Requirements for Commercial Nuclear Power Reactors
http://www.nsr.go.jp/english/e_news/data/13/0912.pdf

1. New regulation on NPP
New Requirements on SAM

- ✓ **Prepare multi-layered protection for "prevention of core damage", "maintaining containment integrity" and "suppression of radioactive materials dispersion"……..**
  - ✓ **Over pressure/Over temperature ; Less than designed value or PCPL (primary containment pressure limit)**
  - ✓ **Hydrogen treatment; H_2 conc. in PCV < 13% (without steam)**
- ✓ **Enhance reliability with permanent systems/equipment and prepare mobile equipment.**
  - ✓ **Redundancy, diversity, independence, dispersion**
- ✓ **Enhance protective measures in spent fuel pool.**
  - ✓ **Water level measurement, alternative water supply,...**
- ✓ **Improve command communication and instrumentation.**
  - ✓ **Reinforced seismic-resistance of on-site emergency response center, improved reliability/durability of communication system,…**

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Ref.: Outline of New Regulatory Requirements For Light Water Nuclear Power Plants (Severe Accident Measures), http://www.nsr.go.jp/english/data/new_regulatory_requirements3.pdf

2. Safety Research Activities in S/NRA/R
Objectives of Safety Research Programs

- **Research on development of evaluation criteria for regulatory standards and requirements**
  - **Technical evaluation criteria for regulatory standards and guidelines on safety review**
  - **Development and maintenance of analysis code etc.**

- **Research on acquisition of technical knowledge necessary for decision making of nuclear safety regulatory actions**
  - **Technical data to increase the accuracy of verification for safety review and inspection etc.**

- **Research on the maintenance and establishment of technical basis**
  - **To maintain technical basis to properly implement regulatory activities in the future.**

See Appendix ; Safety Research Topics conducted by S/NRA/R

2. Safety Research Activities in S/NRA/R
Focused Safety Research Topics

- **Special emphasis on external / internal hazards leading to large scale common cause failure:**
  - **Extreme natural phenomena:**
    - Hazard curves of earthquake/tsunami, fragilities of SSCs , …
  - **PRA methods and models**: External/internal fire and floods, multi-hazards, multi-units, application of level 3 PRA
- **Research on SAs:**
  - **Code development** for SA progression / source terms, …
  - Experiments on **scrubbing**, **seawater injection**, **…**
- **Research on Fukushima Daiichi NPP Accident:**
  - Management of wastes/contaminated water**, …**
- **Other areas:**
  - Decommissioning/waste Disposal, fuel cycle facilities, …

3. Overview of Research on SAs

Objective and Outcome for Research on SA

Major Objectives

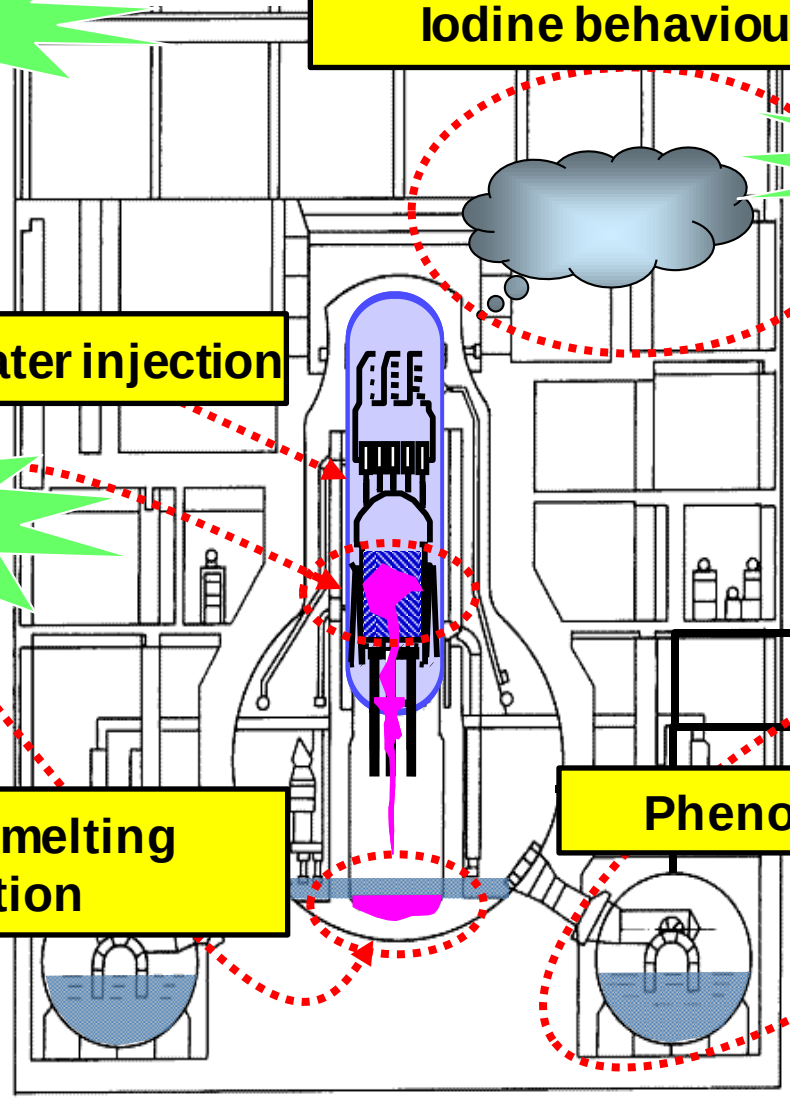
- To develop and improve analysis code, and to promote experiments for the decrease of the uncertainties of SA phenomena.
- To understand SA phenomena or progression that may occur under potential accident conditions and to investigate new measures to mitigate SAs based on the up-to-date scientific and technical knowledge.
- To contribute to international collaboration by participating in international Joint research projects to study the common subjects.

Outcomes

- Proposal for development of the regulatory standard or guideline related to SA for NPPs.
- Confirmation of the effectiveness of proposed licensing actions for preventing SA.

3. Overview of Research on SAs

SA Subjects based on Fukushima Daiichi NPP Accident



Core Cooling

- Was Long Term Seawater Injection Harmful to Heat Removal ?

Effective of Seawater injection

Iodine behaviours

Source Term

- Uncertainty in Source Term (Iodine) ?

Core Degradation

- Detailed Core Melting and Debris Formation ?

Behavior of Core melting and debris formation

Phenomena of Pool scrubbing

Source Term

- How was S/P Scrubbing under High Temperature and Depressurization ?

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3. Overview of Research on SAs
SA Safety Research Plan by S/NRA/R

- **Near term experimental subjects**
  - **Pool scrubbing test** ; Study on scrubbing under saturated water conditions taking into account flashing accompanied by venting.
  - **Seawater injection test** ; Study on the influence on fuel/debris cooling by seawater/boric acid injection
  - **Inorganic iodine behaviours test ;** Study on pH dependence of inorganic Iodine behaviors
- **Mid & long term experimental subjects**
  - **Core melting and debris formation test** ; Study on evaluation method of ex-vessel debris coolability by cavity injection strategy

- **Development of SA code based on the results of experiments (According to the progress of experiments)**
  - SA analysis code for plant system behaviour
  - Mechanistic SA analysis code for core melting and debris formation

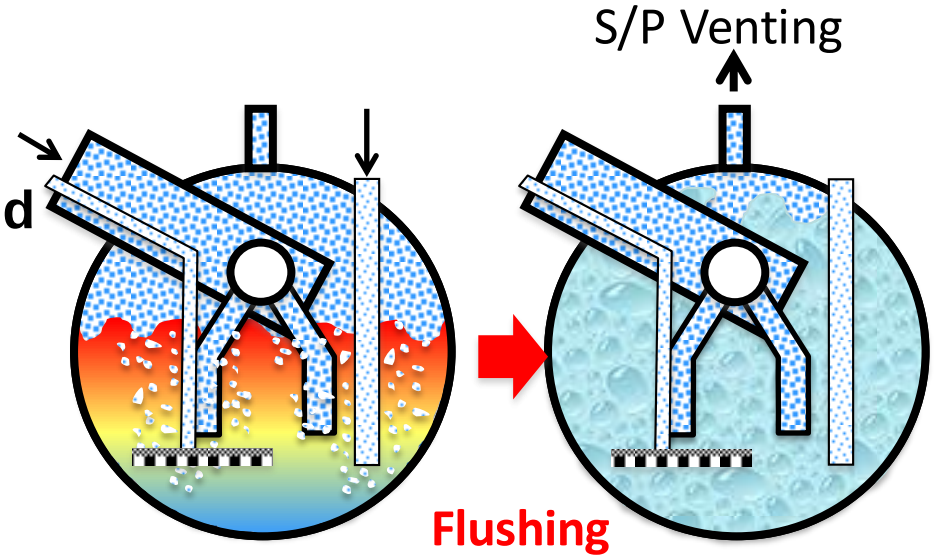
4. Example of Research Activity
Pool Scrubbing Test (1/2)

Background

- Rapid decompression due to venting might cause saturated boiling over a wide range in S/P and degrade scrubbing effect on reducing the release of radioactive materials in the case that S/P temperature keeps high for a long period.
- This process is still controversial subject, however, clarifying this phenomenon is crucial in determining the source term.

Objective

- To clarify aerosol physics and two-phase fluid dynamics taking into account flashing accompanied by venting for improving AM measures.

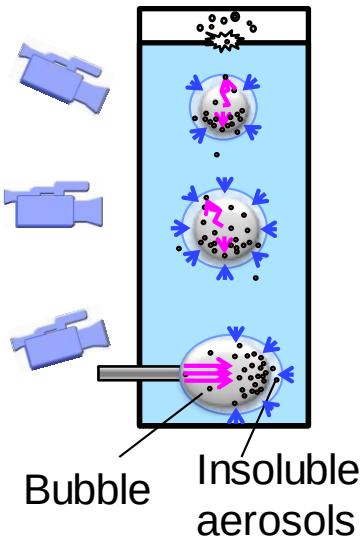


Flashing accompanied by venting

4. Example of Research Activity
Pool Scrubbing Test (2/2)

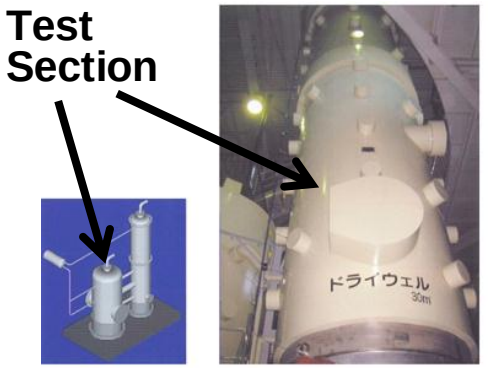
Small Scale Test

- Perform systematic parametric studies to separate underlying mechanisms.
- High resolution instrumentation including visualization



Large Scale Test

- Large scale tank with the pool depth equivalent to that of BWR plants.
- Obtaining data that can be easily scaled up to the actual plant conditions.



Height: 10 m
Diameter: 2 m
Volume: 30 m^3

Max. Pressure > 1MPa
Max. Temperature > 200 ℃

Items	2012	2013	2014	2015	2016	2017	2018～
Scrubbing Test • Small Scale Test • Large Scale Test			→	→	→	→	
Modeling, SA Code Improvement				→	→	→	

4. Example of Research Activity
Seawater Injection Test（1/2）

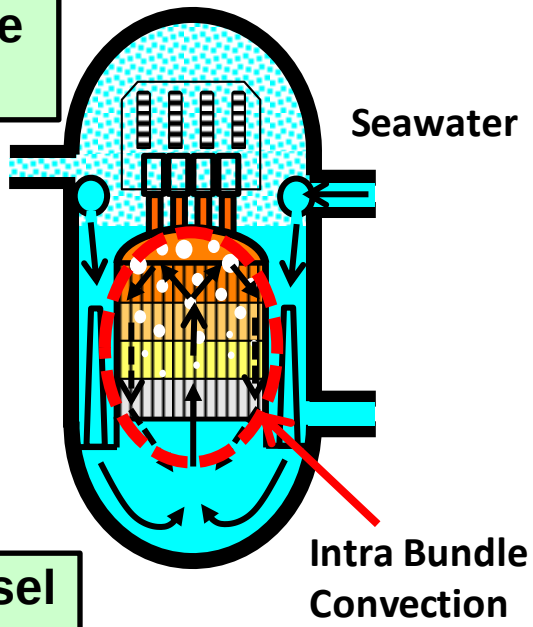
Background

- Seawater is regarded as one of alternative water source in the accident management (AM) in Japan.
- It is important to understand how long and how much seawater injection can continue to reactor pressure vessels (BWRs or PWRs) without losing the cooling effect.

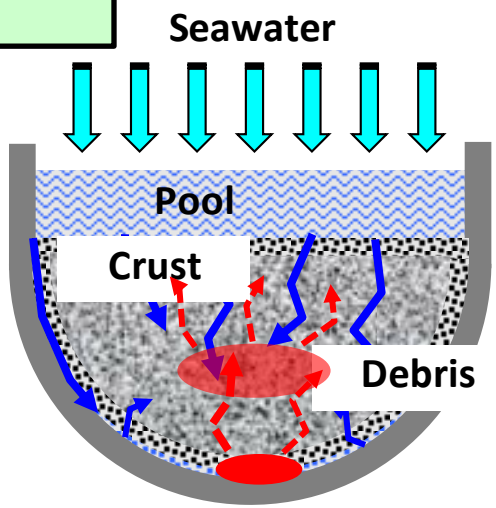
Objective

- To identify the salt and boric acid crystallization/precipitation characteristics and its influence on fuel/debris cooling such as flow blockage for improving AM measures.

Effect to core cooling



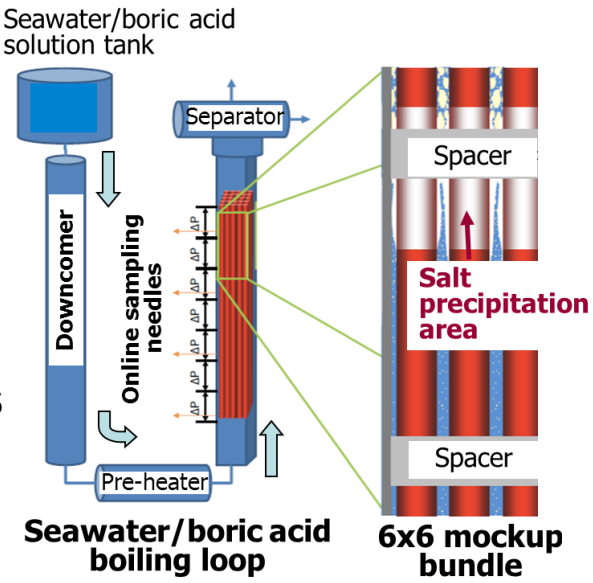
Effect to vessel cooling



4. Example of Research Activity
Seawater Injection Test （2/2）

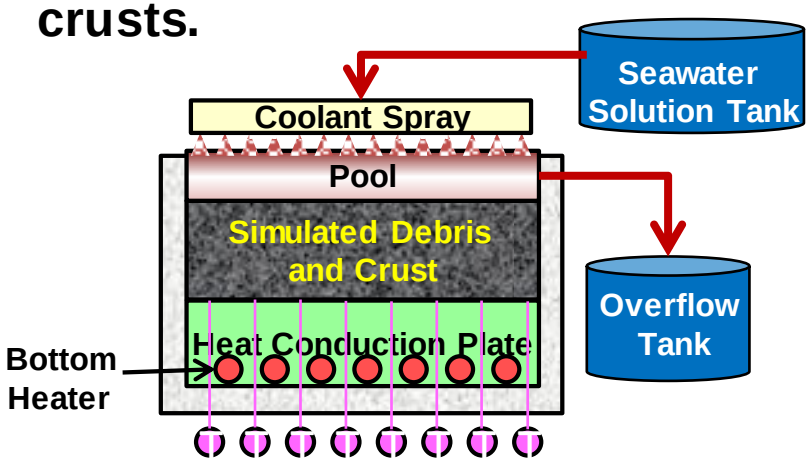
☐ Fuel Bundle Test

- Monitor formation process of precipitation by X-ray CT
- Observe influences on the heat removal by mockup of BWRs fuel bundle



☐ Debris Bed Test

Observe influences on the heat removal of debris bed in the lower head by several mock up crusts.



Items	2012	2013	2014	2015	2016	2017	2018～
Bundle Test	→	→	→	→	→		
Debris bed Test		→	→	→	→		
Development of Heat Transfer Models			→	→	→	→	→

5. Summary

- After Fukushima Daiichi NPP Accident, severe accident research program is placed on one of important research activities in NRA
- S/NRA/R established R&D plan to decrease the uncertainties of SA phenomena and has conducted a part of it in near term experiments,
  - Near term experimental subjects are in progress on schedule.
  - Analysis models will be developed and improved based on these experimental data contributing to the reduction of uncertainly of SA analysis result.
  - The detail of results on experiments and analysis will be addressed in a timely manner.
- S/NRA/R participates in the several international cooperative projects continuously to resolve the remaining issues on SA phenomena and to develop and improve the analytical codes.

Summary of Safety Research in NRA

Appendix

Categories	Safety Research Topics/Subjects
1. Nuclear Reactor	Safety analysis and code development
	Thermal-hydraulic phenomena during accidents at LWRs
	Sever accidents
	Regulatory criteria for fuel
	Aging technical evaluation and extension of operation limit
	Management of water chemistry/quality
2. Fukushima Daiichi	Management of radioactive wastes including liquid wastes
	Transportation of damaged spent fuel
3. Internal or External Hazards	Evaluation of design basis earthquake and assessment of seismic ground motion/land slides
	Evaluation of design basis tsunami and probabilistic tsunami hazard
	Structural integrity assessment for earthquake and tsunami
	Research on volcano eruption for new regulatory requirements
	Evaluation techniques for fire protection
	Risk evaluation for internal and external hazards leading to common cause failure
4. Nuclear Fuel Cycle	Evaluation techniques for interim storage and transportation of radioactive materials
	Assessment for aging management for fuel reprocessing facilities
5. Backend	Methods for verification of clearance
	Evaluation techniques for safety review of underground waste disposal
6. Emergency Response	There's no specific topic at the moment. It needs to maintain technical capabilities.
7. Physical Protection	
8. Radiation Protection and Monitoring	
9. Cross-cutting Issues	Human and organizational factors
	Criticality assessment of spent fuel
	Maintaining technical competence/expertise