NRA Nuclear Regulation Authority

Lessons Learned from the Fukushima Dai-ichi Accident and Responses in New Regulatory Requirements

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in the Light of the Accident
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Introduction

- ✓ TEPCO’s Fukushima Dai-ich accident revealed the weakness of the foregone regulatory requirements, e.g.
  - Insufficient design provisions against tsunami,
  - Unpractical management measures under severe accident conditions, and
  - Insufficient provisions for accidents far-exceeding the postulated design conditions.
- ✓ We re-realized the importance of the Defense in Depth (DiD) approach in design and preparations of countermeasures against beyond design basis accidents.
- ✓ We learned from the accident that we must evaluate in advance the potential and consequences of a wide spectrum of internal and external initiators.

This presentation covers;

1. Prevention of SSC (Structures, Systems and Components) failures
2. Measures to prevent CCFs (Common Cause Failures)
3. Prevention of Core Damage
4. Mitigation of Severe Accidents
5. Continuous improvement
6. Use of PRA (Probabilistic Risk Assessment)

1. Prevention of SSC failures

Lessons (1/2)

- ✓ The Fukushima Dai-ichi accident revealed vulnerability of SSCs against extreme loads and conditions caused by some specific internal/external initiators.

- ✓ The past regulations in Japan specified design requirements focusing on random failures of SSCs and the provisions on aseismatic design, although there were conceptual design requirements to cope with all the initiators.

1. Prevention of SSC failures

Lessons (2/2)

- ✓ In Japan, seismic loads were addressed well in the regulations, while less considerations were made for other external hazards including tsunami.
- ✓ As for tsunami, its design-basis heights had been postulated based on the historical records, which covered only 400 years. There was no counter-measures against tsunami with a recurrence period of 1,000 years or more.
- ✓ These facts underscore the need to revisit the regulatory requirements for a wide spectrum of external hazards.

1. Prevention of SSC failures

Response (1/4)

- ✓ Enhancement of safety design requirements.
- ✓ Consideration of all the significant internal/external initiators.
- ✓ Confirmation of general approach for design provisions against the initiators, i.e. (i) identification of potential hazards, (ii) requirement of design against hazards exceeding their respective thresholds for screening, (iii) definition of design basis hazard (DBH), (iv) design requirements to cope with DBH with safety margin, and (v) evaluation of adequacy of safety design.

1. Prevention of SSC failures

Response (2/4)

- ✓ Re-evaluation of external hazards, particularly natural phenomena, based not only on historical data but also on expert judgment to cover very rare events.
- ✓ As for earthquakes, more stringent criteria were prepared for active faults, more precise methods were provided for design-basis ground motions, etc.
- ✓ As for tsunami, design-basis tsunami which exceeds the highest historical record is defined, countermeasures such as coastal levee and watertight doors are required, etc.

1. Prevention of SSC failures

Response (3/4)

- ✓ Development of specific requirements regarding internal fire and flooding.
- ✓ Requirement of countermeasures for extremely aggravated situations, for example, by intentional airplane crash.
- ✓ While many new requirements are developed against both internal and external initiators, the graded approach is applied to determine the necessity of such specific design provisions based on their respective risks.

1. Prevention of SSC failures

Response (4/4)

- ✓ The new requirements aim at "functional" and "performance-based" for providing flexibility in choosing acceptable measures.

- ✓ However, based on recognition that adequate requirements have not been made for fire protection, specific requirements for physical separation of safety systems, fire hazard analysis, etc. are introduced considering current international practices. As well, we need to continue the development and application of fire PRA including data accumulation towards risk-informed regulations.

More stringent criteria for active faults

→ Active faults with activities later than the Late Pleistocene (later than 120,000-130,000 years ago) shall be considered for seismic design

Activities in the Middle Pleistocene (later than 400,000 years ago) must be further investigated if needed

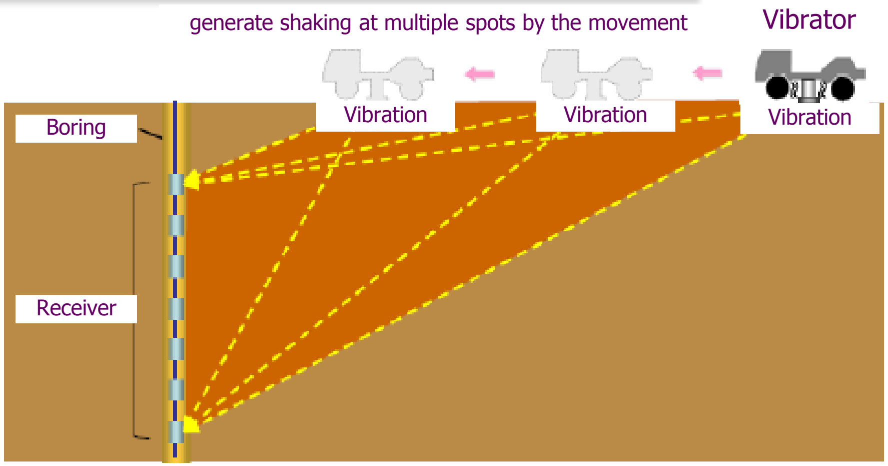
More precise methods to define design basis seismic ground motion

→ 3D observation of underground structure of the site

Clarification of requirements for “displacement and deformation” in addition to the seismic ground motion

→ Structures and buildings important to safety which belong to Seismic Class S shall not be constructed on the exposure of active faults

Example of geophysical exploration



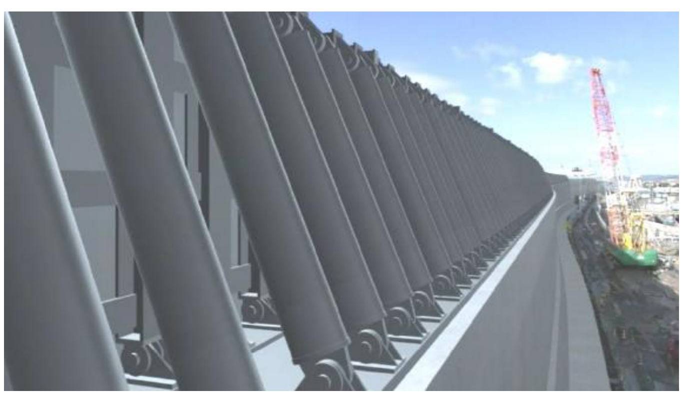
The underground structure is explored by generating a vibration by vibrator and analyzing the signals received in a borehole.

Accurate Evaluation Method on Earthquake and Tsunami; Particularly Enhanced Tsunami Measures

More stringent Standards on Tsunami	⇨ Define "Design Basis Tsunami" that exceeds the largest in the historical records, and require to take protective measures, such as breakwater wall against the design basis tsunami
Enlarged Application of Aseismatic Design	⇨ The highest class of aseismatic design is applied to SSCs for tsunami protective measures

Examples of tsunami measures (multiple protective measures)

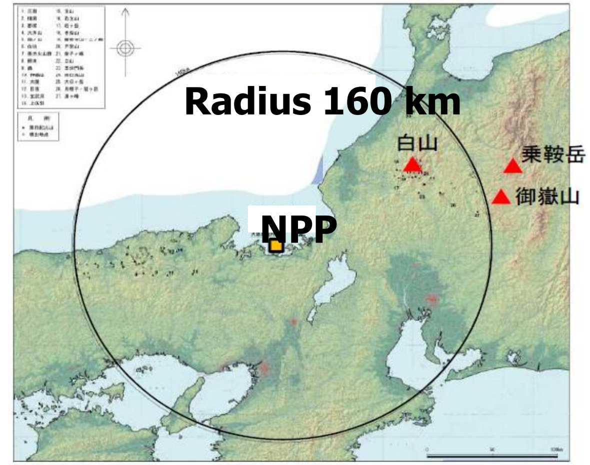
○ Breakwater Wall
(prevent inundation to the site)



○ Watertight Door (Tsunami Gate)
(prevent water penetration into the building)

Guides for Evaluating Impacts of Volcanic Phenomena

- Identifying all sources of volcanic activity within 160 km.
- Estimating the possibility that "severe volcanic phenomena exceeding design-basis postulations" would attack the site during the plant life.
- Even if the possibility is small, it is required to conduct the monitoring of volcanic activities and to improve the preparedness against volcanic emergency, such as reactor shutdown, fuel unloading, etc.



Pyroclastic flows
at Mayon Volcano Philippines, 1984

http://en.wikipedia.org/wiki/File:Pyroclastic_flows_at_Mayon_Volcano.jpg

2. Measures to prevent CCFs

Lessons (1/2)

- ✓ In the Fukushima Dai-ichi accident, emergency diesel generators (EDGs) and station butteries lost their functions simultaneously due to the tsunami since they were located on the floors at similar elevations. This fact highlights the necessity of enhanced physical separation for safety-related systems/components.

- ✓ Although all the water-cooled EDGs were damaged by tsunami directly or indirectly, one air-cooled EDG survived and supplied power to both Units 5 and 6 because it was located at a higher elevation. The turbine driven RCIC worked under the SBO situation at Units 2/3 and delayed accident progressions. These imply the importance of diversity of systems.

2. Measures to prevent CCFs

Lessons (2/2)

- ✓ Loss of station batteries resulted in loss of control room functions including instrument, closure of isolation valves in isolation condenser (IC), unavailability of reactor depressurization, loss of control of reactor core isolation cooling and high pressure injection systems, inoperability of containment venting, etc. The fact underlines the need to prepare alternative DC power sources.

- ✓ Electrical power system is essential to actuate and control the safety-related systems including the control room and its loss might lead to common cause failures of safety-related systems. Accordingly, the diversity should be improved to secure the plant safety.

2. Measures to prevent CCFs
Response (1/2)

- ✓ Extend design-basis events strengthen protective measures against natural phenomena and others which may lead to common cause failure
- ✓ Due consideration to ensure diversity and independence (shift of emphasis from "redundancy centered")
- ✓ Diversity of operating mechanisms

Examples:
Diesel Generator and Gas Turbine Generator
Motor Driven Pump and Diesel Driven Pump

2. Measures to prevent CCFs

Response (2/2)

✓ Physical Separation

Safety-related system trains shall be

- located at different elevations and/or different areas,
- compartmentalized by installing bulkhead, or
- distanced enough from each other.

Mobile equipment shall be

- stored in different locations, which are not easily affected by external initiators including terrorisms, and
- easily and surely connectable to the target system by preparing spatially-dispersed multiple connecting ports.

3. Prevention of Core Damage

Lessons (1/2)

- ✓ There was no provision against prolonged station blackout (SBO) and prolonged loss of ultimate heat sink (LUHS).

- ✓ The duration of loss of offsite power, 30 minutes, was assumed based on the operating experience in Japan, which showed high reliability and short-term restoration of offsite power and high reliability of EDGs. As well, the interconnection of safety busbars between units was incorporated into accident management (AM) procedures on an industries' voluntary basis.

- ✓ For the ultimate heat sink, the hardened venting system together with alternative water injection was prepared as one of the voluntary based AM measures.

3. Prevention of Core Damage

Lessons (2/2)

- As a result, SBO and LUHS were considered a highly unlikely scenario, leading to lack of further discussions on these scenarios.

- Although the regulation had applied the single failure criterion to the safety analysis of design-basis accidents over years, the Fukushima Dai-ichi accident suggested that multiple failures due to specific initiators must be considered more seriously in the licensing bases and/or safety cases.

- The regulation should specify the requirements on AM measures as a licensing basis and licensees should prepare the sophisticated AM measures and procedures in consideration of multiple failures.

3. Prevention of Core Damage

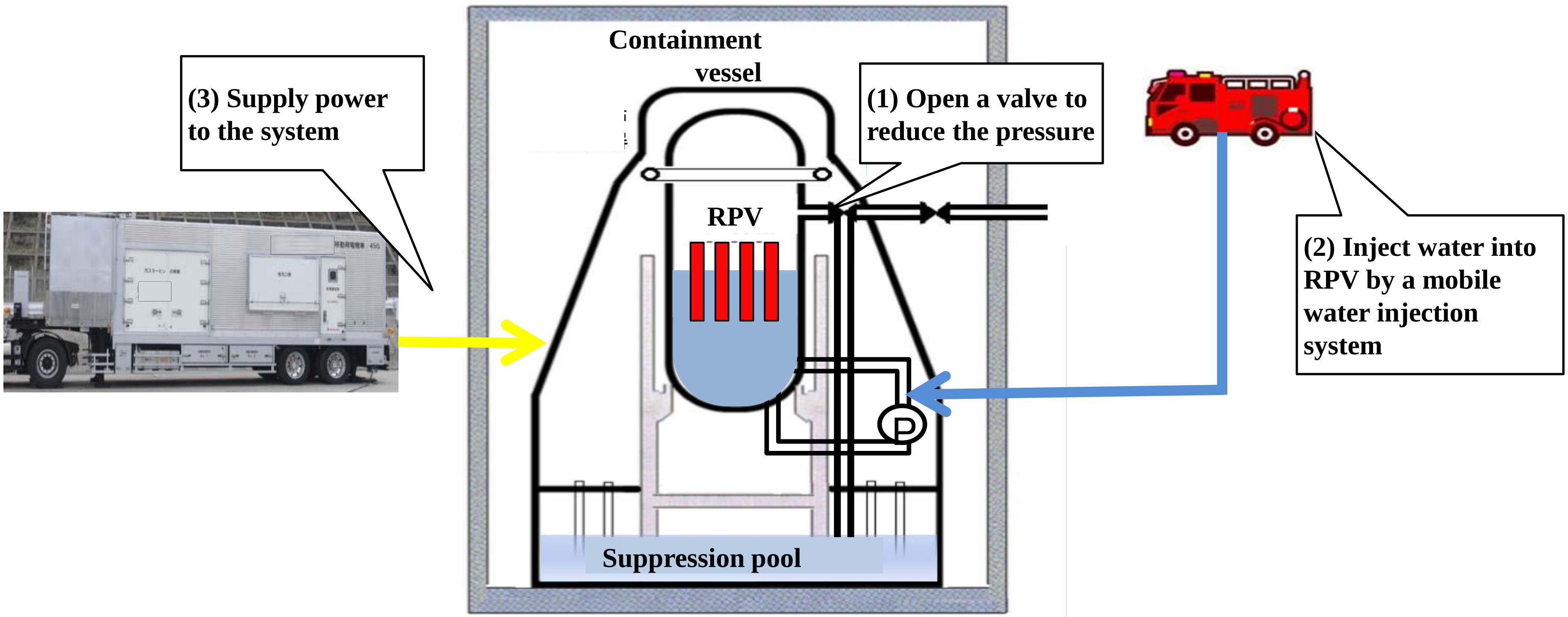
Response

- In the new requirements by NRA, the definitions of some DBAs were changed. Design provisions are now required against prolonged SBO and LUHS.
- Also required are provisions against some beyond design-basis accidents (b-DBAs) involving multiple failures, including anticipated transient without scram (ATWS), loss of core cooling, and loss of reactor depressurization.
- The new regulations require the licensees to validate the effectiveness of countermeasures against b-DBAs.

Prevention of Core Damage due to Multiple Failures

- ✓ Assume loss of safety functions due to common cause,
- ✓ Require alternative measures to prevent core damage
  - Ex.1 Open a safety-relief valve with mobile battery and/or compressor
  - Ex.2 Inject water into the RPV with mobile pumping unit
  - Ex.3 Supply power from ground power unit (GPU) during SBO

<Examples of measures>



4. Mitigation of Severe Accident

Lessons (1/2)

- ✓ In 1990s, a series of AM measures were prepared at individual NPPs in Japan on a licensees' voluntary basis to improve the plant safety.
- ✓ However, these AM measures mainly focused on the prevention of core damage and a few mitigation measures, such as molten core cooling, had been implemented so far.
- ✓ In the Fukushima Dai-ichi accident, many attempts to take AM measures were unsuccessful under the aggravated plant conditions, such as loss of power, loss of control air, aftershocks, and high radiation.

4. Mitigation of Severe Accident

Lessons (2/2)

- ✓ The Fukushima Dai-ichi accident brought to light the necessity of implementing AM measures for mitigating severe accident and radiological consequences as well as those for preventing core damage.

- ✓ Considering the extremely severe natural hazards and terrorisms, the flexibility should be incorporated into the design and implementation of AM measures. Also, plant personnel should be well trained so that they could execute the AM procedures under the aggravated conditions in a timely manner.

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4. Mitigation of Severe Accident

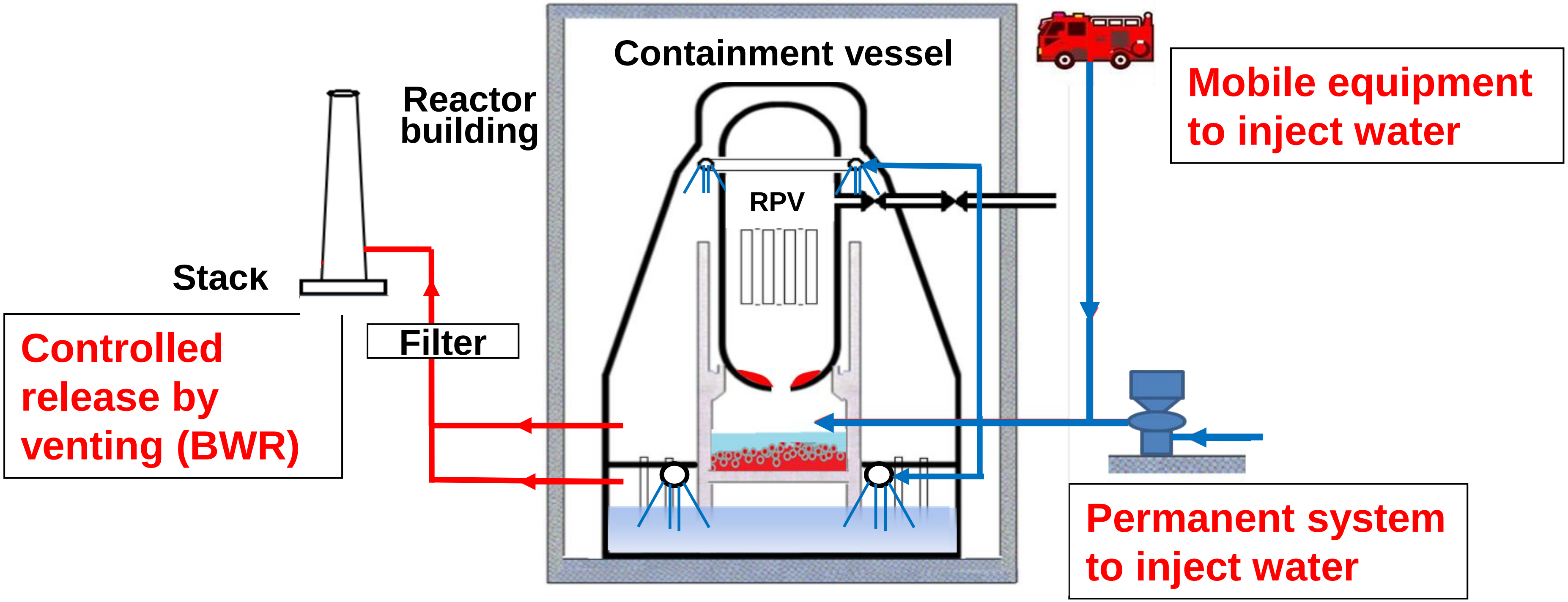
Response

- ✓ The new regulations require the licensees to design and implement AM measures for mitigating severe accident conditions.
- ✓ The effectiveness and feasibility of AM measures is strictly examined in licensing processes.
- ✓ Containment depressurization system, such as filtered venting system, shall be installed to prevent the containment failure due to over-pressurization and to minimize the radioactive consequences.

Prevention of Containment Failure

- ✓ Assume severe core damage,
- ✓ Require alternative measures for
  - cooling and depressurizing the containment,
  - reducing radioactive materials in the containment,
  - cooling molten core in the pedestal,
  - preventing hydrogen explosion, etc.

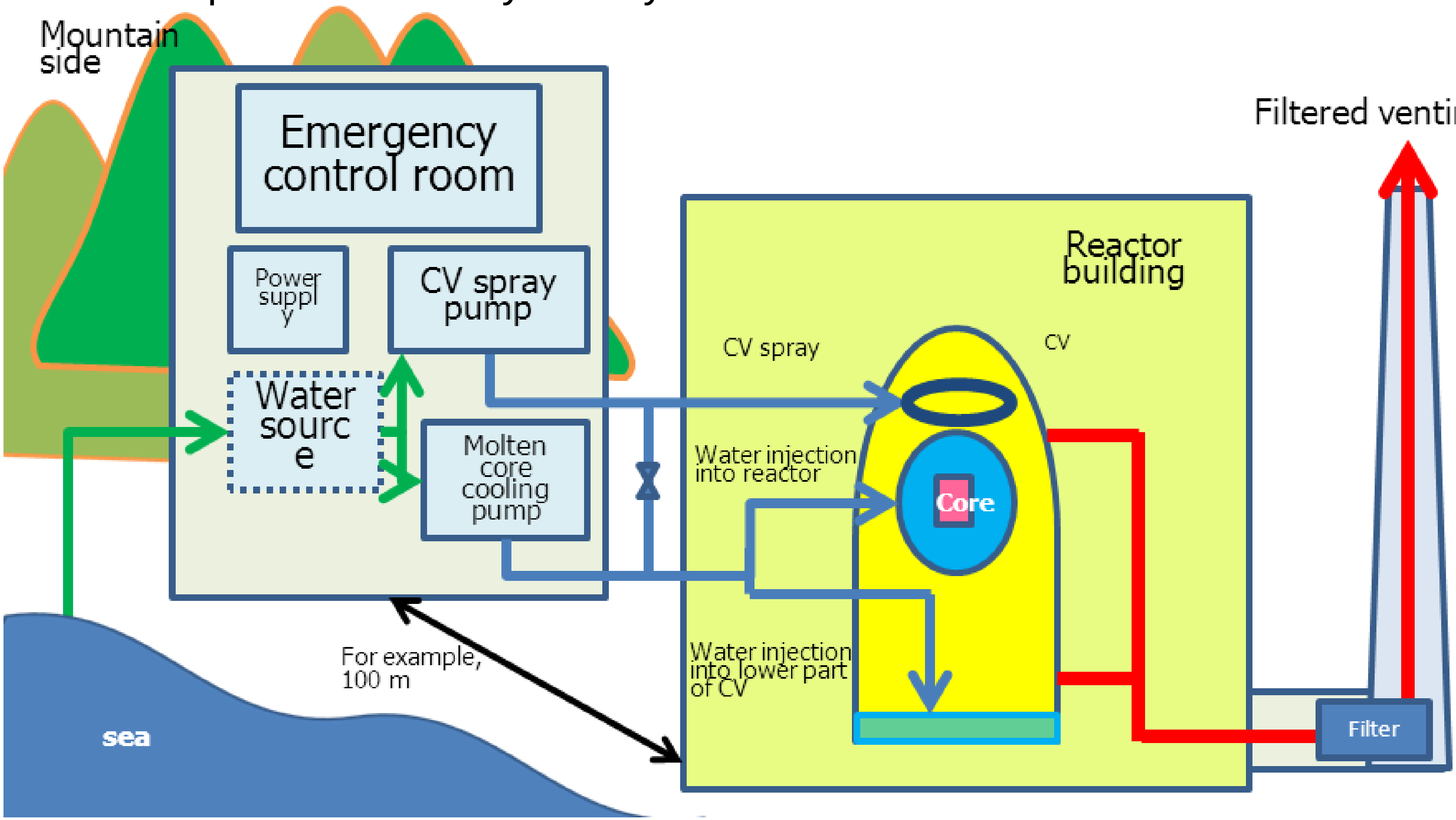
<Examples of measures>



Measures against Intentional Aircraft Crash, etc.

Specialized Safety Facility is similar to the "bunkered system" in European countries.

Specialized Safety Facility



Mitigation of Radioactive Dispersion

- ✓ Assume the containment failure,
- ✓ Require outdoor water spraying equipment and/or reactor building spray system to mitigate radioactive dispersion from the reactor building.

Water-spraying with a large scale bubble water cannon system

(Pictures cited) Fire fighting white paper, 2011 edition, http://www.fdma.go.jp/html/hakusho/h23/h23/html/2-1-3b-3_2.html

Alternative Cooling of Spent Fuel Pool (SFP)

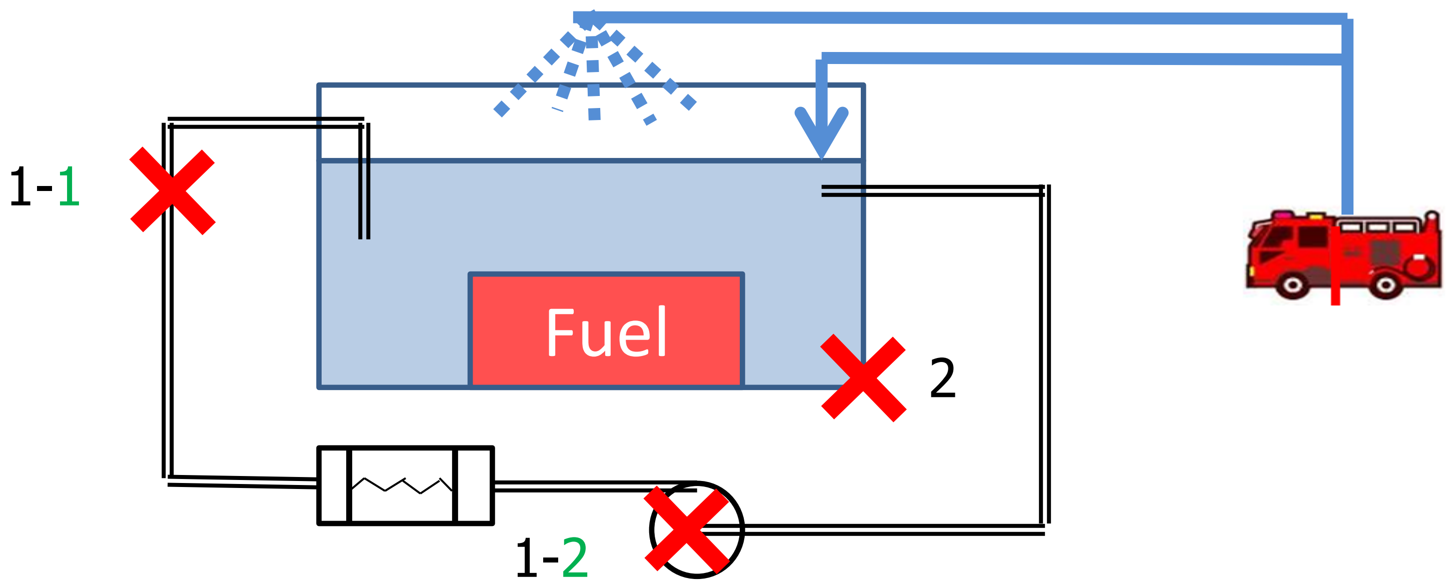
1-1 Assume draindown of water inventory due to pipe break followed by failure of siphon breaker,

1-2 Assume loss of cooling or makeup function,

✓ Require alternative makeup equipment to maintain water level and to keep radiation shielding function.

2 Assume loss of water inventory due to the structural failure of SFP,

✓ Require equipment to mitigate fuel damaging and radioactive release.



5. Continuous Improvement

Lessons

- ✓ Before the Fukushima Dai-ichi accident, licensees had re-evaluated tsunami height and some of them reinforced the protection against tsunami. As a result, some NPPs could be brought into a safe shutdown although they were hit by very high tsunami. This shows the importance of "Continuous Improvement".

- ✓ On the other hand, the regulatory requirements on tsunami were not reviewed over years before the Fukushima Dai-ichi accident. This implies lack of "Continuous Improvement" in regulation.

5. Continuous Improvement

Response (1/2)

- ✓ The amended "Reactor Regulation Act" stipulates licensees' responsibility for "safety improvement" and requires licensees to conduct "self-assessment for safety improvement" periodically.
- ✓ This framework strongly encourages licensees' initiatives towards continuous improvement of safety by requesting licensees to prepare the final safety analysis report which provides "as-built" or "as-is" plant description and to update it when major design modifications or procedural changes take place.

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5. Continuous Improvement

Response (2/2)

- ✓ Licensees are also requested to carry out the periodic safety review (PSR) to incorporate the state-of-the-art knowledge into the plant design, operation and maintenance activities.
- ✓ In addition, it is required to conduct level 1 and 2 PRAs for both internal and external events including hazard re-evaluation to demonstrate the effectiveness of the plant modifications.

Contents of Self-Assessment Report for Safety Improvement

1. "As-built" or "as-is" plant description and compliance with requirements (Establishment of "license basis")

2. Voluntary efforts for safety improvement
   - Policy and plan on continuous improvement of safety
   - Survey on feedback of operating experience and state-of-the-art knowledge, and plant walkdown
   - Additional actions taken
   - External review (e.g. IAEA OSART mission)
3. Effectiveness of voluntary efforts demonstrated by
   - Level 1 and 2 PRA for internal and external events
   - Safety margin analysis (e.g. stress test)
4. Comprehensive self-assessment of overall plant safety

6. Use of PRA

Lessons

- ✓ The importance of PRA is different for different initiator. The priority should be determined according to risk profile (a relative importance of each initiator).
- ✓ While random failure (internal event) and fire are dominant initiators in U.S., individual plant examination for external events (IPEEE) were done there. While natural hazards are thought to be dominant initiators in Japan, the IPEEE were not done. PRAs for external initiators had not been carried out in Japan where they are most needed.
- ✓ Although PRAs for external initiators have relatively large uncertainties, implementations of those PRA could avoid our "thought-stopping" at least and may provide technical insights regarding relative importance of SSCs, etc.

6. Use of PRA

Response

- ✓ In the new regulatory framework, licensees are requested to conduct the plant-specific level 1 and 2 PRAs for both internal and external events as voluntary initiatives.
- ✓ Using the plant-specific PRA, licensees shall identify the severe accident scenarios and classify them into several groups. Also, licensees shall check the adequacy and sufficiency of AM measures by conducting deterministic analysis for each scenario.
- ✓ Licensees shall analyze all the “generic severe accident sequence groups” and “generic containment failure modes” that were defined by the NRA regardless of the results from the plant-specific PRAs.

Closing Remarks (1/2)

- ✓ In the light of the Fukushima Dai-ichi accident, the NRA developed the new design requirements and established the new regulatory framework to ensure the NPP safety.
- ✓ The new requirements aim at primarily;
  - changing the definition of DBAs by including prolonged station blackout and loss of ultimate heat sink,
  - enhancing the prevention measures against common cause failures, in particular due to external hazards, by strengthening the diversity/independence,
  - enhancing the prevention of core damage by preparing alternative measures with use of mobile equipment, and
  - enhancing the mitigation measures against severe accident to eliminate a large radioactive release from the containment and to minimize the radioactive consequences by mobile and immobile equipment.

Closing Remarks (2/2)

- ✓ The new regulatory framework encourages licensees' initiatives towards continuous improvement of safety and requests licensees to:
  - conduct "self-assessment for safety improvement" periodically,
  - prepare and update the final safety analysis report which provides "as-built" or "as-is" plant description, and
  - carry out PSR and plant-specific level 1 and 2 PRAs for both internal and external initiators to demonstrate the effectiveness of the plant modifications.
- ✓ In-depth discussions in international community are essential regarding, for example, the DiD concept applied to protections against specific external initiators.

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