What should we learn from the severe accident at the Fukushima Dai-ichi Nuclear Power Plant?

Interim Report Summary

BWR

- Team H2O Project -

Revised on December, 21{superscript}st, 2011
The biggest lesson is not the underestimation of the tsunami risk, but the lack of design philosophy to prevent any grave accidents from any threats.

Extracted from **Nuclear Safety Commission of Japan's Design Guidelines** (Supervised by Cabinet Office Nuclear Safety Commission Secretariat)

Part 1 Safety Review Guideline No 27: (Design) In case of power loss:

- There is **no need to consider long-period loss of AC power**, since we **can expect swift restoration of the transmission line** or **restoration of power through the emergency AC power supply system**.

- If the system structure or operational method (i.e. constant backup) of the **emergency AC power-supply is deemed highly reliable**, then **there is no need to take into account any scenario of a complete AC power blackout** in the design of the plant.

Extracted from **Additional Report of Japanese Government to IAEA** (Second Report) September 2011 Nuclear Disaster Response Headquarters

- (First group of lessons learned) The tsunami damage to the plant which is **the cause of the accident**, occurred due to an **underestimation of the height and frequency of the tidal waves**, and that countermeasures against large scale tsunami impacts were insufficient.

- The Central Disaster Prevention Council, in regards to the **prevention plan for tsunami disaster**, proposed fundamental ideas such as to **pursue countermeasures against tsunami by anticipating two categories**, the maximum size and the frequent size. The Nuclear and Industrial Safety Agency started deliberating on design standards for **anticipating appropriate height** and taking into account the period and frequency of recurrence.

**United Nations’ comment** on the Fukushima Dai-ichi nuclear accident (Mainichi Newspaper website, September 15, 2011)

- On September 14th, the UN presented a Summary Report on Nuclear Safety-Security regarding the impact of the Fukushima Dai-ichi Nuclear Plant Accident. The UN criticized Japan for being **“too modest” in its assumptions of such a disaster and severe accidents**, and commented that they were troubled by the safety standards and international emergency crisis response, which were at that point recognized as the international standard.

- In the report, it stated that **“Japan underestimated the possible threats. And all nuclear power plants globally must review their risk assessments against severe accidents”**. and that risk of nuclear power plant accidents must be eliminated through experience and utilization of the latest technologies.

No matter how high we set the estimation, there will always be a possibility of an event that exceeds it.
Safety design for nuclear reactors in the world had shared common design philosophy
– No fundamental question against it had ever been raised in the past.

- 72 Safety Regulations Defined by the United States Atomic Energy Commission
  - Later became the foundation for NRC regulation.
  - Later adopted by other G5 countries.
  - Products introduced to Japan through full-turnkey projects.

- Probability approach applied by Prof. Rasmussen et al. at MIT
  - Severe accidents and natural phenomena with probability of occurrence lower than a specific value, have little effect and risk to the safety of the nuclear reactor and are insignificant enough to ignore.

That is why we need to re-examine the design philosophy – the problem does not lay only in the design conditions such as the ‘estimation of scale’ or the ‘height of the tsunami’.

- No countermeasure exists for events out of scope.
  - Large scale tsunami beyond expectation had hit.
  - Complete power loss was not assumed.
  - Almost all safety devices and ECCS’s assumed that power supply is available.

- Probability theory should not be brought to use on events that have an enormous impact to society.
  - Even if the probability is insignificantly low, if the impact is enormous, the risk is also enormous.
  - Probability % \( \times \) Impact \( \infty \) = \( \infty \)
Specifically, it’s important for us to humbly accept the following two points.

1. **The design philosophy itself was flawed.**
   - After what happened in the Fukushima Dai-ichi Plant, we should stop debating safety issues focusing on “assumptions on the scale of events” such as the height of the tsunami or the magnitude of the earthquake.
   
   - The core design philosophy should be “to maintain power supply and cooling functions on the reactor core, no matter what happens, and how to achieve this.”

2. **The last strong hold “primary containment vessel myth” has been busted.**
   - Until now, there was a belief that “even in an unforeseen event to the reactor core, the containment vessel will contain the radioactive material and will be guaranteed to prevent it from leaking” (= containment vessel myth).
   
   - However, in Fukushima Dai-ichi the core melted down and the molten nuclear fuel rods accumulated at the bottom of the pressure vessel. Then the molten fuel breached through the base of the pressure vessel, and melted through the bottom of the containment vessel, resulting in the leakage of a large amount of radioactively contaminated water and gas outside the containment vessel.
   
   - Furthermore, we have to say that all the operating reactors in Fukushima Dai-ichi, reactor No.1, No.2, and No.3, suffered meltdown and significant damage to their primary containment vessels.
   
   - This means that, in Fukushima Dai-ichi, the containment vessel failed as the “last line of defense.”
The biggest concern in the design (recriticality and LOCA) did NOT occur. Instead, the reactor fell into an unexpected loop after meltdown, resulting in massive hydrogen explosion and leakage of radiation to the external environment.

● The biggest concern in the design of the nuclear reactor was recriticality and pipeline rupture (LOCA: Loss of Coolant Accident).
  - It was feared that a breach of the molten nuclear fuel rods into the containment vessel would result in power excursion followed by a huge explosion, spreading radiation across the environment.
  - It was also feared that an event, such as a major earthquake, would cause a pipeline rupture to the core reactor’s coolant circulation loop.

● In order to prevent this, the nuclear reactors were designed to "shutdown", "cool", and "contain".
  - In case of emergency, the nuclear reactor will be scrammed (emergency shutdown).
  - After the scram, decay heat removal will be constantly implemented to achieve cold shutdown (cool).
  - Even if cold shutdown is failed, the containment vessel will prevent radioactive material from leaking outside with its 2 meter-thick concrete walls (contain).

● All reactors that suffered meltdown in Fukushima Dai-ichi (reactors 1-3) did not result in nuclear excursion. Why?
  - In the process of the meltdown, the boron carbide of the control rods, inserted during the scram, melted and mixed into the fuel. This alleviated the nuclear reaction. Furthermore, the fuel rods that melted through the reactor fell and spread out at the bottom of the wide container. Our theory is that this condition also contributed to the prevention of recriticality.

● However, the meltdown caused a massive amount of hydrogen and fission gas to leak from the containment vessel out into the reactor building, resulting in a hydrogen explosion. This event was not considered in the design of containment vessel.

● Therefore, the containment vessel was not able to ‘contain’ hydrogen and radiation from leaking out.
In Fukushima Dai-ichi reactor 1, not even one of the emergency devices worked during the incident (which mostly can be said also with reactors 2, 3 and 4).

### Countermeasures in design

**Major earthquake**  
⇒ **Scram** (Emergency shutdown). All scrammed successfully in Fukushima Dai-ichi, Dai-ni, Onagawa, Tokai Dai-ni.

**Countermeasures to prevent accidents**
- Backup power (emergency generator, batteries)
- Backup coolant

**Countermeasures to mitigate accidents**
- Emergency Core Cooling System (IC, RCIC, HPCI, boron injection, etc.).
- Containment vessel vent.

**In case of core meltdown (Last line of defense)**
- Containment vessel (2m thick concrete, and 3cm thick metal plate. (100% guaranteed containment in any situation.)

### Design: Power supply available out of scope

- **Power**
  - External power supply  
    - Reactor 1: All 6 lines lost from the earthquake
    - Reactor 2: All lost from the tsunami
    - Reactor 3: Only 1 / 5 good
    - Reactor 4: 2 / 2 good
    - Reactor 5 & 6: All lost from the tsunami
    - Reactor 6: 4 / 4 good

  - Emergency generator  
    - Reactor 1: All lost from the tsunami
    - Reactor 2: 2 / 2 good
    - Reactor 3: 1 / 5 good
    - Reactor 4: 4 / 4 good

  - DC power supply  
    - Reactor 1: All lost from the tsunami
    - Reactor 2: 2 / 2 good
    - Reactor 3: 1 / 5 good
    - Reactor 4: 4 / 4 good

  - Power supply vehicle  
    - Reactor 1: Only unit lost in explosion during an attempt to connect it to No.1
    - Reactor 2: Used to run sea water pump

- **High Pressure Cooling ECCS, etc.**
  - HPCI / HPCS
    - Reactor 1: Failed to function
    - Reactor 2: After DC power depleted
  
  - IC / RCIC
    - Reactor 1: Failed after operating (Reactor 2, failed after 3 days)
    - Reactor 2: After DC power depleted

  - SLC  
    - Reactor 1: Due to power loss
  
  - CRD  
    - Reactor 1: Due to power loss

- **Low Pressure Cooling ECCS, etc.**
  - FP  
    - Reactor 1: FP pump did not work
    - Reactor 2: Power loss

  - MUWC / MUWP  
    - Reactor 1: Power supply and motor flooded

  - CCSW / RSW / RHRS etc.  
    - Reactor 1: Power supply and motors flooded by the tsunami

### Summary

- Reactor No.1, 3, and 4 = Hydrogen explosion  
  - Reactor 2 = Damaged containment vessel

The reactor went into an unexpected loop (not part of the design), which probability theory neglected, making itself incapable of preventing the meltdown and hydrogen explosion.
Safety design of both the power supply and ultimate heat-sink was too focused on multiplicity, and lacked diversity.

In Fukushima Dai-ichi

- Reactor No. 1
  - All of the two DC power sources (batteries) were placed in the basement of the turbine building.
  - 2 emergency generators (DG) were:
    - both placed in the basement of the turbine building.
    - both seawater cooling type, so their cooling systems were all placed at the sea side.
  - Similar (sets of) safety measures were implemented at the other reactors as well.

- Placed in the same area
- Equipment with same specifications
- Operated from the same power source
- The same above applies to other plants

- All failed to function for the “same reason”.
- Without diversification, it will be difficult to eliminate risks, even if the number of measures are increased.
The fundamental safety philosophy should be that “power, cooling function, and water sources must be secured in any situation”. The safety principles should have 3 layers, normal, emergency, and extreme emergency.

**Normal**
- Power
  - External power supply
  - Backup generator (DG)
  - DC power supply (battery)
- Cooling function
  - High-pressure coolant system (RCIC, HPCI etc.)
  - Ventilation
  - Low-pressure coolant system (RHR etc.)

**Emergency**
- Secure water and power by creating seawater intake tunnel, and connecting it to a vertical pipeline from a power hub set on an elevated area (see page 9).
- In case the regular measures fail, on-site emergency power and cooling systems work.
  - Backup battery
  - Power supply vehicle (AC& DC)
  - Emergency DG vehicle
  - Cable, Power panel, etc.
  - Water pump, etc.
- Executed by the electric power company.

**Extreme Emergency**
- Supply power from off-site by helicopters etc.
- Supply water from a nearby water source such as a river, lake, pond, etc.
- Collaboration by different parties (power company, government, and Self Defense Forces, etc.)
  - Secure access route to the plant, etc.

**Diversity and multiplicity**
- Countermeasures with different principles (diversity)
- Increase number of countermeasures (multiplicity)
- Hot standby and cold standby (Speed)
- Regular / Backup (role)
- On-site and off-site (location)
- Electric power company and its alliance with government (Main responsibility)
Example of emergency countermeasure: Create seawater intake tunnel leading to the mountain for sufficient elevation. Plug in on-site emergency pumps and batteries to provide cooling function.

If required, transport necessary equipment (power sources, pumps, etc.), by helicopter to the inlet (in case of extreme emergency)
Lessons learned from Fukushima Dai-ichi: Events overwhelmingly beyond the design philosophy had occurred.

- Ordeals far beyond the design philosophy of the nuclear reactor
  - Long-term power outage (AC&DC).
  - Without the cooling system, the core reactor started meltdown within an extremely short period of time.
  - Zirconium oxidation caused hydrogen buildup.
  - No system to vent the hydrogen resulted in a massive explosion.

- None of the emergency safety devices functioned (all due to prolonged power loss)
  - IC, ECCS, boric acid insertion, emergency gas treatment.

- Even with such a strong earthquake and tsunami, cold-shutdown could have been achieved if just one emergency power supply was secured
  - Fukushima Dai-ichi Reactors 5 and 6 (only one backup generator for the cooling system was working)
  - Fukushima Dai-ni Reactors 1 – 4 (2 units for Reactor 3, and 1 unit backup generator for Reactor 4 were working)

- Major events that hindered recovery action on site, or significantly damaged functions of the reactor
  - Critical devices were stored in the basements and completely flooded.
    - Emergency generators (AC)
    - Batteries (DC)
  - Cooling system pumps and motors at the shoreline were damaged or submerged by the tsunami.
  - Unable to secure coolant for the water cooling emergency generators.
  - Unable to control ventilation from the outside.
  - Power panels for connecting external power were flooded.
  - Difficulty in connecting power vehicles to the panels, most of which were submerged and not functioning.
Ordeal far beyond the design philosophy of the nuclear reactor – Events totally unexpected in the original design, or events expected but on an unforeseeable scale have occurred.

<table>
<thead>
<tr>
<th>Crucial Events at Fukushima Dai-ichi No. 1 – 4</th>
<th>Design Philosophy</th>
<th>Reality</th>
<th>Implications</th>
</tr>
</thead>
</table>
| Prolonged outage of all DC and AC power       | • Even if station-blackout occurs, power can be quickly restored before causing any serious problems.  
• The emergency DG can be used as backup until external power is restored.  
• DC power will last for at least 8 hours.  
• Even if DC power drains down, it can be extended by recharging from AC power source. | • External AC power supply and emergency DG were not restored before the hydrogen explosion.  
• Almost all DC power was submerged by the tsunami.  
• The flooded DC batteries were un-rechargeable. | • AC power shortage lasted longer than what was estimated in the design.  
• Instant loss of all DC power supply from the flood was not expected. |
| With complete loss of cooling functions, core meltdown occurred within a very short period of time. | • The core reactor’s high pressure cooling function is run by DC power.  
• DC power will not drain right away.  
• Thus, even if station-blackout occurs, the reactor’s water level, temperature, and pressure can be controlled with the high pressure cooling system until AC power is restored. | • DC power supply drained instantly, and the high pressure cooling system stopped working simultaneously (Reactor 1).  
• Water level of the nuclear reactor dropped, and core meltdown occurred in a very short time.  
• Although the timing of the fuel damage was predicted, power and pumps were not restored in time. | • Loss of power and cooling function lasted longer than anticipated in the design.  
• No manual to restore power and cooling function under harsh conditions, such as in complete darkness and amid rubble. |
| Zirconium oxidation built up massive hydrogen. | • Hydrogen can be brought down below the inflammable level by injecting nitrogen in the containment vessel and activating the flammability control system.  
• Radioactive materials can be contained within the vessel even while operating ventilation. | • Core damage caused hydrogen buildup.  
• Hydrogen leaked into the containment vessel through the Safety Relief Valve (SRV).  
• Increased pressure and temperature in the containment vessel caused the hydrogen to leak into the reactor building through the vent line, and accumulated in the upper floor. Flammability control system did not work.  
• The hydrogen level reached the combustion threshold and resulted in a massive explosion.  
• On-site personnel were not aware of the risks of hydrogen explosion. | • Hydrogen leak to the reactor building and explosion were not considered in the design.  
• Thus, no hydrogen detection system in the building.  
• No system to release the hydrogen outside.  
• No manual to deal with this type of hydrogen explosion. |
| No system to release the hydrogen, which resulted in a massive explosion. | • Therefore, hydrogen will not leak into the reactor building nor accumulate. If ever there is a leak, flammability control system can be applied.  
• This prevents hydrogen explosion caused by leak to the reactor building. | | |
Long-term power outage (DC&AC) occurred – While design philosophy assumed “in case of Station Blackout, AC power would be quickly restored, and DC will last for at least 8 hours”.

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<tbody>
<tr>
<td><strong>External AC power</strong></td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>△ Only 1/4 lines worked</td>
<td>△ Only 1/5 lines worked</td>
<td>× All 2 lines lost from the earthquake</td>
</tr>
<tr>
<td><strong>Backup diesel generator</strong></td>
<td>×</td>
<td>Lost all from the tsunami</td>
<td>Only 1/5 was working</td>
<td>Only 1/5 was working</td>
<td>Only 1/5 was working</td>
<td>○ Reactor 1 &amp; 2: none worked</td>
<td>○ Reactor 1 &amp; 3: all working</td>
<td>○ 2/3 working</td>
</tr>
<tr>
<td><strong>DC power supply</strong></td>
<td>×</td>
<td>2/2 working</td>
<td>4/4 working</td>
<td>8/8 working</td>
<td>6/6 working</td>
<td>Not required since external power supply or emergency generator was working.</td>
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</tr>
<tr>
<td><strong>Power supply vehicle</strong></td>
<td>×</td>
<td>Used to power sea-line pump</td>
<td>Power partially restored by power supply vehicle</td>
<td>Not required since external power supply or emergency generator was working.</td>
<td></td>
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</tr>
<tr>
<td><strong>Restoration of external power</strong></td>
<td>×</td>
<td>Not restored before the hydrogen explosion</td>
<td>Not restored before cold shutdown</td>
<td>At least one external power source was available right after the earthquake and Tsunami.</td>
<td>○ 154kV backup power restored on March 13 at 19:37.</td>
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</tbody>
</table>

Power loss lasted longer than expected in the design.
At Fukushima Dai-ichi Reactor 1, complete loss of all coolant systems, due to total power loss, had rapidly led to core-meltdown. Core damage is estimated to have started 2 to 3 hours after Tsunami.

### Lessons learned from Fukushima Dai-ichi...Design Philosophy...Cooling System...

#### Core damage start (Analysis)
- 3/11 18:46
- 3/14 19:46
- 3/13 8:46

**Hydrogen Explosion (or damage)**

- On halt Reactor 4 hydrogen explosion (Backflow from Rct 3)
- Operating => cold shutdown

#### Dai-ichi Reactor 1: All cooling functions were lost simultaneously.
- No other option but to supply water to the reactor with only one fire truck.

Core was damaged a few hours after the loss of cooling functions followed by exposure of fuel rods.
In reactor 1 with no coolant functionality, core meltdown caused the cladding tube around the fuel rods to oxidize and built up a massive amount of hydrogen.

Mechanism of hydrogen generation

- Without power and cooling, the core’s temperature and pressure surged. This lowered the water level in the core and eventually caused the fuel rods to be exposed above the coolant water.

- As the temperature in the core increased, the cladding tube around the fuel rods (zirconium alloy) started melting and oxidizing at approximately 900°C, which raised core temperature further.

- The chemical reaction between the molten cladding tubes (zirconium) and oxygen in the steam in the pressure vessel produced a massive amount of hydrogen (zirconium-water reaction).

- According to TEPCO’s simulation, in Reactors 1, 2 and 3, with the water level down and the fuel rods exposed, core damage (melting of fuel) possibly started in about 2 hours after the exposure of the fuel rods.

Simulated time to core damage

(From the timing of earthquake) Fukushima Dai-ichi Reactor 1 Reactor 2 Reactor 2 Reactor 3 Reactor 3

Core exposure started:

- Approx. 3 hrs
  - March 11 17:46
- Approx. 4 hrs
  - March 11 18:46
- Approx. 15 hrs
  - March 12 05:46

Core damage started:

- Approx. 75 hrs
  - March 14 17:46
- Approx. 77 hrs
  - March 14 19:46
- Approx. 109 hrs
  - March 16 03:46

Damage to containment vessel occurred:

- Approc. 40 hrs
  - March 13 06:46
- Approc. 42 hrs
  - March 13 08:46
- Approc. 66 hrs
  - March 14 08:46

Note: Source May 23, 2011 Tokyo Electric Power Company Corp. “Analysis and effect evaluation of the records on operations and accidents at Fukushima Dai-ichi Nuclear Power Plant in Tohoku Region Pacific Coast Earthquake”

- Date of analysis: May 16, 2011
- Method: Used the gathered information on condition of the equipment and plant operation when the earthquake first occurred as input for simulation information, and analyzed.
- Software: Accident Analysis Code (MAAP = Modular Accident Analysis Program)
The reactor building had no system to “detect” or “release” hydrogen, resulting in a massive explosion. ※Emergency gas treatment system did not function because of the power outage.
Even with such a strong earthquake and tsunami, cold-shutdown could have been achieved if even a single emergency power supply were secured; Fukushima Dai-ichi (Rctrs 5 & 6), Tokai Dai-ni, Fukushima Dai-ni, etc. These reactors lost almost all external power, but were able to achieve cold shutdown with the surviving (one or two) emergency generators. (Note: Frontline (RHR pump) has to be working as well)

<table>
<thead>
<tr>
<th>Power Supply Type</th>
<th>Reactor 1</th>
<th>Reactor 2</th>
<th>Reactor 3</th>
<th>Reactor 4</th>
<th>Reactor 5 &amp; 6</th>
<th>Reactor 1 &amp; 2</th>
<th>Reactor 3</th>
<th>Reactor 4</th>
<th>Reactor 1 &amp; 3</th>
<th>Reactor 2</th>
<th>Reactor 3 &amp; 4</th>
<th>Tokai Dai-ni</th>
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<tbody>
<tr>
<td>External AC power supply</td>
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<tr>
<td>Emergency generator</td>
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<tr>
<td>DC power supply (A type, B type)</td>
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<td>2/2 working</td>
<td>×</td>
<td>4/4 working</td>
<td>×</td>
<td>8/8 working</td>
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<td>6/6 working</td>
<td>2/2 working</td>
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<tr>
<td>HPCS (IC/RCIC, etc.)</td>
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<tr>
<td>LPCS (MUWC/MUWP, etc.)</td>
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<td>LPCS seawater pump (CCSW/RSW/RHRS, etc.)</td>
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</tbody>
</table>

Core damage / Hydrogen explosion (or damage)

Cold shutdown achieved
Lessons Learned from Fukushima Dai-ichi...Importance of power supplies... (Continued...) Chronology to cold shutdown or hydrogen explosion.

<table>
<thead>
<tr>
<th>Date</th>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011/3/11</td>
<td>In operation</td>
<td>In operation</td>
<td>In operation</td>
<td>In operation</td>
</tr>
<tr>
<td>2011/3/12</td>
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<td>2011/3/13</td>
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<td>2011/3/14</td>
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<td>2011/3/15</td>
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<td>2011/3/16</td>
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<td>2011/3/17</td>
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<td>2011/3/18</td>
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Critical devices, such as emergency power supplies (AC) and batteries (DC), were stored in basements and completely flooded.

- The greater the height difference between the tsunami and the altitude of the plant, the greater the damage
  => Dai-ichi No 1-4: 5.5m, No 5, 6: 1.5m. Onagawa: 0m. Tokai Dai-ni: -2.6m
- These power supplies placed in areas much lower than the tsunami crest were disabled.

### Lessons Learned from Fukushima Dai-ichi...Placement...

<table>
<thead>
<tr>
<th>Height of flood (Main building area)</th>
<th>Dai-ichi Rctr1</th>
<th>Reactor 2</th>
<th>Reactor 3</th>
<th>Reactor 4</th>
<th>Reactors 5 &amp; 6</th>
<th>Fukushima Dai-ni</th>
<th>Onagawa</th>
<th>Tokai Dai-ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>O.P. 15.5m (T.P. = O.P.+0.727m)</td>
<td>O.P.14.5m</td>
<td>O.P.14.5m</td>
<td>O.P.13m</td>
<td>O.P.13m</td>
<td>O.P.13m</td>
<td>O.P.13m</td>
<td>H.P.6.3m</td>
<td>H.P.8.9m</td>
</tr>
<tr>
<td>O.P. 10m</td>
<td>O.P.13m</td>
<td>O.P.12m</td>
<td>O.P.13.8m</td>
<td>H.P.8.9m</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Altitude (Main building)

<table>
<thead>
<tr>
<th>Emergency generator elevation</th>
<th>Dai-ichi Rctr1</th>
<th>Reactor 2</th>
<th>Reactor 3</th>
<th>Reactor 4</th>
<th>Reactors 5 &amp; 6</th>
<th>Fukushima Dai-ni</th>
<th>Onagawa</th>
<th>Tokai Dai-ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>O.P. 4.9m(A) O.P.2m(B)</td>
<td>O.P.19m(A)</td>
<td>O.P.19m(A)</td>
<td>O.P.19m(A)</td>
<td>O.P.19m(A)</td>
<td>Reactor 5</td>
<td>O.P.0m</td>
<td>O.P.0.5m</td>
<td>O.P.14m</td>
</tr>
<tr>
<td>O.P. 10.2m(A/B)</td>
<td>O.P.10.2m(B)</td>
<td>O.P.10.2m(B)</td>
<td>O.P.5.8m(A/H)</td>
<td>O.P.13.2m(B)</td>
<td>Reactor 6</td>
<td>O.P.0m</td>
<td>O.P.0.5m</td>
<td>O.P.14m</td>
</tr>
<tr>
<td>(Air cool)</td>
<td>(Air cool)</td>
<td>(Air cool)</td>
<td>(Air cool)</td>
<td>(Air cool)</td>
<td></td>
<td>(No. 1  4 A/B/H)</td>
<td>(No. 2/3 A/B/H)</td>
<td></td>
</tr>
</tbody>
</table>

### DC mother board elevation (A) and (B) type

<table>
<thead>
<tr>
<th>Emergency generator elevation</th>
<th>Dai-ichi Rctr1</th>
<th>Reactor 2</th>
<th>Reactor 3</th>
<th>Reactor 4</th>
<th>Reactors 5 &amp; 6</th>
<th>Fukushima Dai-ni</th>
<th>Onagawa</th>
<th>Tokai Dai-ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>O.P. 4.9m</td>
<td>O.P.19m</td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
<td>Same (No. 5 &amp; 6)</td>
<td>Control bldg 2F (No 1 &amp; 2)</td>
<td>Control bldg 1F (No 1)</td>
<td>Outer B1F</td>
</tr>
<tr>
<td>2m</td>
<td>6.5m</td>
<td>1.9m</td>
<td>1.9m</td>
<td>9.5m</td>
<td>18m/12.2m</td>
<td>9.5m (no. 1A/B)</td>
<td>7m (no. 2A/B)</td>
<td>9.1m</td>
</tr>
<tr>
<td>B1 F</td>
<td>O.P.9.5m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H.P.9.1m</td>
</tr>
<tr>
<td>Same</td>
<td>Same</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### DC power supply lost?

- Emergency generator lost?
  - Lost from flood
  - A: Lost from flood
  - B: Power panel lost from flood
  - Reactor 6: 1 unit OK
  - 2 units OK

- DC power supply lost?
  - Malfunction from flood
  - Lost from flood
  - Working

### Note
- O.P.: Onahama Port Construction Reference Plane
- T.P.: Tokyo bay standard sea level
- H.P.: Hitachi Bay Construction Reference Plane
- Accounted in -1m of slide-down by earthquake

- O.P.: Onagawa Reference Plane
- O.P.: 1m of slide-down by earthquake

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On-shore motors and pumps for main cooling system malfunctioned due to tsunami – Of 13 emergency generators in Dai-ichi, all but one (air cooling type) malfunctioned. Water-cooling DG with cooling devices at the coastal side were especially vulnerable.

**Loss of functions of emergency generators**

- Total of 24 emergency generators malfunctioned. The loss of cooling function is 1.5 times higher than loss of generator itself (= more orange than pink).
  - Flooded generator (or power panel): 9 cases (pink)
  - Cooling system malfunction (motor, pump, etc.): 15 cases (orange)

- **This is especially so when looking at Fukushima Dai-ichi Reactors 5 & 6 and Dai-ni, which had relatively little flooding in the reactor building.**
  - Dai-ichi Reactors 5 & 6: 4/4 cooling systems on the coast lost.

- **Emergency generators for cooling system installed near the coast are vulnerable to tsunami, even with no damage to the generator unit.**
  - The only generator that survived in Fukushima Dai-ichi (Reactor 6) was an air cooling type. It had no cooling device on the coast.
Workers were unable to secure coolant for the water-cooling type emergency generators.

<table>
<thead>
<tr>
<th>Availability of coolant for emergency generator</th>
<th>Dai-ichi Reactor 1</th>
<th>Dai-ichi Reactor 2</th>
<th>Dai-ichi Reactor 3</th>
<th>Dai-ichi Reactor 4</th>
<th>Dai-ichi Reactors 5 &amp; 6</th>
<th>Fukushima Dai-ni</th>
<th>Onagawa</th>
<th>Tokai Dai-ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lost (Seawater coolant)</td>
<td>×</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Only one air cooling type unit was working (Reactor 6).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remaining 4 units all failed (seawater cooling type)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Unable to recover</td>
<td>×</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>After restoring the damaged A type seawater pump for reactor 6, type A generators started operating.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Type B seawater cooling system for all reactors restored through maintenance checkup, motor replacement, and temporary power connection.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Precondition is that related power panels, power bus-line and other supply routes are working.
Unable to perform ventilation from the outside – Workers spent too much time preparing the vent line and failed to execute ventilation.

Result of ventilation

<table>
<thead>
<tr>
<th>Equipment Type</th>
<th>Reactor 1</th>
<th>Reactor 2</th>
<th>Reactor 3</th>
<th>Reactor 4</th>
<th>Dai-ichi Reactor 5 &amp; 6</th>
<th>Fukushima Dai-ichi</th>
<th>Onaga, Tokai Dai-ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>W/W vent</td>
<td>Succeeded in opening the vent valve but hydrogen explosion occurred right after.</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td></td>
<td>Vent line constructed but unable to hold the necessary pressure to open rupture disc.</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
<tr>
<td>D/W vent</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
<td>×</td>
</tr>
</tbody>
</table>

Cautions:
- Was not able to operate the ventilation appropriately. On top of power outage, multiple obstacles such as darkness, transmission problems, parameter loss, frequent aftershocks, increasing radiation, rubble, etc., made it impossible. Manual operation of ventilation was also extremely difficult.
- As a result, failed to operate the ventilation at the right time.

Right after the tsunami, Reactor 1 lost all functions for coolant injection and PCV ventilation...

...Then tried to manually open the valve at basement but gave up as radiation level increased.
(Later succeeded by using the improvised compressor)

Succeeded in manual release
Abandoned manual release due to high radiation level
### Dai-ichi Reactors 1 - 4, with power panels to external power flooded, failed cold shutdown.

- Almost all of the crucial panels, such as M/C and P/C, malfunctioned in reactors 1-4 which eventually exploded.
- Especially, all of the power panels were lost at reactors 1 and 3.

#### Fusion Dai-ichi

<table>
<thead>
<tr>
<th>Unit</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
<th>Unit 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG 1A</td>
<td>×</td>
<td>DG 2A</td>
<td>√</td>
<td>DG 4A</td>
<td>×</td>
</tr>
<tr>
<td>DG 1B</td>
<td>×</td>
<td>DG 3A</td>
<td>×</td>
<td>DG 5A (×)</td>
<td>×</td>
</tr>
<tr>
<td>DG 1C</td>
<td>×</td>
<td>DG 4A</td>
<td>×</td>
<td>DG 6A (×)</td>
<td>×</td>
</tr>
<tr>
<td>DG 2A</td>
<td>×</td>
<td>DG 2B</td>
<td>×</td>
<td>DG 3B (×)</td>
<td>√</td>
</tr>
</tbody>
</table>

#### Power Grid A

<table>
<thead>
<tr>
<th>Unit</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
<th>Unit 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/C 1A</td>
<td>×</td>
<td>M/C 2A</td>
<td>×</td>
<td>M/C 4A</td>
<td>×</td>
</tr>
<tr>
<td>M/C 1B</td>
<td>×</td>
<td>M/C 2B</td>
<td>×</td>
<td>M/C 4B</td>
<td>×</td>
</tr>
<tr>
<td>M/C 1C</td>
<td>×</td>
<td>M/C 2C</td>
<td>×</td>
<td>M/C 4C</td>
<td>×</td>
</tr>
</tbody>
</table>

#### Power Grid B

<table>
<thead>
<tr>
<th>Unit</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
<th>Unit 5</th>
<th>Unit 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>M/C 1A</td>
<td>×</td>
<td>M/C 2A</td>
<td>×</td>
<td>M/C 4A</td>
<td>×</td>
</tr>
<tr>
<td>M/C 1B</td>
<td>×</td>
<td>M/C 2B</td>
<td>×</td>
<td>M/C 4B</td>
<td>×</td>
</tr>
<tr>
<td>M/C 1C</td>
<td>×</td>
<td>M/C 2C</td>
<td>×</td>
<td>M/C 4C</td>
<td>×</td>
</tr>
</tbody>
</table>

### Fukushina Dai-ni

<table>
<thead>
<tr>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
<th>Unit 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG 1A</td>
<td>×</td>
<td>DG 2A</td>
<td>×</td>
</tr>
<tr>
<td>DG 1B</td>
<td>×</td>
<td>DG 2B</td>
<td>×</td>
</tr>
</tbody>
</table>

### Onagawa (Tohoku Electric Power Co)

<table>
<thead>
<tr>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG A</td>
<td>○</td>
<td>HPSG 1</td>
</tr>
<tr>
<td>DG B</td>
<td>○</td>
<td>HPSG 2</td>
</tr>
</tbody>
</table>

### Tokai Dai-ni

<table>
<thead>
<tr>
<th>Unit 1</th>
<th>Unit 2</th>
<th>Unit 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG A</td>
<td>○</td>
<td>HPSG 1</td>
</tr>
<tr>
<td>DG B</td>
<td>○</td>
<td>HPSG 2</td>
</tr>
</tbody>
</table>

---

Loss of functions below were based on the estimation by the project:
- Onagawa’s M/C, P/C, and Tokai Dai-ni’s P/C electrical panel 4/5 lines were lost due to earthquake.
- Both lines were lost due to earthquake.

Information on DC power of system-H was omitted.

4/5 lines were lost due to earthquake (Matsushima Main line 1L Only 275 kV survived)

Both lines were lost due to earthquake (Onagawa DC line H survived, 125 kV line 100 kV survived other than 1L)

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Information on DC power of system-H was omitted.

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Both lines were lost due to earthquake (Onagawa DC line H survived, 125 kV line 100 kV survived other than 1L)

---

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With almost no working panels for the power supply vehicles to connect to, it was very difficult to supply power.

Power supply vehicle arrangements

- Power supply vehicle arrived right after the tsunami (High voltage vehicle)
  - March 11 approx. 22:00  First group arrives with one unit.
  - March 12 approx. 01:20  4 units arrive (total 5 units)
  - March 12 approx. 03:00  7 units arrive (total 12 units)

- Same as above (Low voltage vehicle)
  - March 11 approx. 23:30  2 units from Self Defense Force
  - March 12 approx. 07:00  3 more units arrive

Difficulty with connection

- Few power supply vehicles were rounded up by dawn of March 12.
- However, there was trouble connecting them as very few power panels (M/C, P/C) were working due to tsunami as well as time was consumed in identifying working ones.
- Furthermore, factors such as rubble, aftershocks, transmission problems, insufficient heavy equipment, hindered the set-up of lines to connect vehicles.
- All the preparations made for restoring power in Fukushima Dai-ichi Reactor 2 had to start from scratch when Reactor 1 exploded.
## Specific measures/Guidelines

### Secure power
(Without power supplies, cooling function to the reactor will instantly stop)

**Secure external AC power supply**
- Ensure water seal and pressure resistance, or place in elevated areas.
- Improve earthquake resistance of external power supply and multiplicity of power supply routes. Allow versatility of power within the wider region.

**Secure emergency diesel generator (DG)**
- Ensure water seal and pressure resistance, or place in elevated areas.
- Reinforce the capability to share DG power supplies: All DG to be shared by all reactors (i.e. multiplexing). DG at Reactor 6 was shared with Reactor 5, but not so with Reactors 1-4.
- Add more air-cooling and gas turbine types of DG (Only the air cool type survived as it did not need seawater pump and circulation.)
- Place gasoline and diesel tanks on elevated areas.
- Activate DG automatically during earthquake scram.

**Secure AC power**
- Ensure water seal and pressure resistance, or place in elevated area.
- Versatile AC power supply (versatility between M/C and P/C)
- Reinforcement of power supply vehicles
  - Add on-site units, add more units, review locations
  - Add different types of vehicles: DC, AC, AC & DC mixed, with generator, with DG, etc.
- Enable air transport of power supply vehicles and other backup power supplies (set up helipad on the premises or rooftop)
- Store power cables and tools for working on terminals in appropriate places.
- Set up multiple hubs for connecting power supply vehicles to power panels, and improve water resistance.

**Secure DC power supply**
- Ensure water seal and pressure resistance, or place in elevated area.
- Upgrade DC power capacity (from 8 hours to 24 hours or above).
- Designate mobile battery vehicles in case a disaster renders the DC power supplies useless.

---

**Note)** Compared with instructions from NISA
- Black text = exists
- Red text = does not exist
Summary of countermeasures - 2

Secure cooling functions (Without the cooling function, core will melt down in a matter of hours. Meltdown triggers hydrogen buildup.)

- Ensure water source: secure source and means of water supply from multiple sources such as water tanks, water reservoir, lakes, rivers, sea, etc.
- Secure the necessary number of fire trucks and fire hoses. Set in elevated areas.
- Install multiple hubs for fire truck hoses.
- Secure water seal and pressure resistance of high- and low-pressure cooling systems, or place in elevated areas.
- Secure water seal and pressure resistance of facilities and buildings near the sea.
- Prepare motor cleaning devices and parts.
- Must have alternative core cooling system, which drives on an independent set of coolant, power, and water-injection systems.
- Implement feed-and-breed systems via wet-well vent (to secure heat sink until cold shutdown).
- Prepare portable underwater pumps.

Monitoring of spent fuel pool

- Strengthen the system to thoroughly monitor temperature and water level (both hard and soft).

Secure control room functions

- It is important to secure monitoring systems. Prepare backup batteries so that measuring instruments can be monitored during power outage.
- Maintenance and upgrade of central control room.
- Proper storage of protective suits, masks, dosimeters, etc for workers.

Secure ventilation

- Reexamine the logic of the ventilation system (its effectiveness was unclear) and design philosophy of rupture disc.
- Reconsider the location of the vent line valve (focus on operability).
- Considering the rupture disc didn’t open, review the method for opening/closing its valve (change the method).
- Consider installing multiple measures to reduce pressure within the core (consider a system that doesn’t rely on SR valve which is run by DC power).
- Prepare temporary power source and gas tanks so that vent line can be set up swiftly during power outage.
- Prepare batteries near/in the central control room to open and close SR valve to relieve core-pressure.
## Summary of countermeasures - 3

### To prevent a hydrogen explosion
- Reinforce the containment vessel’s sealing functions: Reevaluate the sealing materials used for PCV head flanges, electric cable routing, hatches, etc, and improve the resistance against high temperature and pressure.
- In case of massive hydrogen buildup, install measures to reduce its density in an enclosed space;
  - Install hydrogen detectors in the enclosed space (transmit signal using own power source or by RF).
  - Ensure filling of nitrogen into the containment vessel during ventilation.
- Install canopy to ventilate hydrogen (remote control + manual operation + absorption filter for fission gas)

### Enrich disaster and accident manual (AM)
- Redesign of AM: How long (hours) should the water and power supply last? How to arrange off-site support while supplies last? In order to achieve this, perform the following:
  - Set quantitative values on how long water and power supplies will last, and create corresponding manuals.
  - Define operational manual to supply alternative power/water and equipment, and to set them up on-site in order to ensure completion within specified life expectancy.
  - Implement periodic training to verify that the above tasks can be executed within the necessary period of time. (including extreme conditions such as night time, holidays, simultaneous accidents on all reactor units, etc.)

### Reinforcement of infrastructure
- Assemble operators to the power plant after an earthquake, assign emergency supporting staff. (Assemble within a specified time. Set an alternative assembly location in case of large scale disaster (i.e. - beyond 100 yd in US ))
- Secure access to the plant (reinforce roads, bridges, etc.)
- Improve accessibility to and from the plant in case of earthquake and tsunami:
  - Reinforce the main road (include measures against liquefaction).
  - Secure appropriate amount of heavy machinery, and drivers for clearing up rubble.
  - Secure routes suitable for earthquake and tsunami situation (Construct passage or path that will not crack or liquefy, and has no manholes.)
  - Set up gasoline tanks.
- Communication among operators, restoration team, emergency response office, and central control room were cut off. This made it impossible to report in a timely manner. Means and equipment for communication during an emergency must be secured.

### Specific measures/ Guidelines

<table>
<thead>
<tr>
<th>Power Supply</th>
<th>Cooling function</th>
<th>Control Room function</th>
<th>Ventilation function</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Prevention against hydrogen explosion</strong></td>
<td><strong>Disaster and accident manual/infrastructure</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Compared with instructions from NISA
- Black text = exists
- Red text = does not exist

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26
"Regarding the reoperation of the plant, what happened at Fukushima Dai-ichi, including decision making, has to be examined. Computer simulation that hasn’t taken this into account is unsubstantiated" – Governor of Niigata Pref(*). Izumida (*) re: Another nuclear power plant location.

Governor Izumida’s comment (extracted from regular briefing on Sep 14th)

- Q: What do you think about the government’s announcement regarding the IAEA’s participation in the evaluation of the stress test?
- O: Governor: It isn’t enough. What happened in the Fukushima Dai-ichi isn’t just about the mechanisms and equipment. The decision making mechanism must be evaluated as well. We need to consider questions such as, when should the decision to pour seawater have been made? who should have made the decision? can someone really make such a decision knowing that he/she is disposing of a plant worth hundreds of billions of yen?

Was there really nothing that could have been done to prevent the release of a massive amount of radiation? It was pointed out in IAEA ‘s report that the prime minister was intervening too much with the site. Considering this, there isn’t much point in conducting stress test without reviewing the decision making mechanism, like who’s responsible for what.

If you ask me if there really is any point in computer simulations, without even verifying if there was a pipeline rupture, that is solely based on past knowledge and perception, and then having the IAEA review it, I'd say that it may be better than doing nothing at all, but it’s really nothing more than that.

What it means
- Prevention measures must be made from both the technical and organizational aspects.
- Technical aspect: Inspect Fukushima Dai-ichi (back from design philosophy), and identify lessons learned and countermeasures.
- Organizational aspect: Establish an organization to implement the countermeasures, and clarify the requirement for the decision-making mechanism.
  - Redesign the decision-making mechanism to prioritize prevention of recurrence as top priority.
  - Design the organizational structure and identify the roles for the implementation of the countermeasures (Power company, National Government, Local Government)
- Reinforce training: Practical training necessary for countermeasures and organizations (that were established based on the lessons learned) to be effective.
  - Training program simulating the accident in Fukushima Dai-ichi.
  - Plan and practice program, and improve the results.
  - Case study around the world.

In addition to technical measures, accident management systems for local participation in terms of decision-making, organization, and training are required.
In order to achieve that, it is very important to incorporate the following missions in the design of Accident Management.

- **Safety Priority**
  - To protect human life and promote safety culture, create a system that prioritizes “safety of plant” and “safety of local community” above all.
  - Hydrogen explosion and radiation leaks must be prevented at all cost. (Never Fukushima again.)

- **Real time information sharing NW**
  - Provide network that allows real-time and transparent information sharing during severe accidents (or risks).
  - Create a system that notify the status once the accident mode is on, and that allows information sharing and discussion regarding the progress of the accident.

- **Local participation**
  - System that allows local bodies to share information and make decisions on the safety of the area.
  - Enrich human resources of the local administration such as nuclear power specialists and consultants.
  - Impel and reinforce training.

- **Transparent and swift decision making**
  - Design an organization and authority where proper and transparent governance works.
    - Plant safety: The site (plant head or shift manager) is the chief decision maker.
    - Local safety: The local government can share information from the plant in real-time to make final decisions.
    - Decision-making process should be transparent and should not be delayed or diverted due to external influences.

- **Proper training to secure safety**
  - To guarantee the items above, AM (accident management) procedure manual and countermeasures have been defined appropriately.
  - Select qualified personnel for executing the manual.
  - Selected personnel will undergo necessary training.
  - Periodic evaluation on these procedures, personnel, and training shall be conducted from a neutral point of view (possibly a third party)
For severe accidents that require prompt action, there needs to be a real-time network that enables all the stakeholders to share information and participate in discussion.

Current situation (Article 10 in case of accident)

- **On-site Emergency Headquarter (at Earthquake shelter)**
  - Surrounding cities, towns, and villages
  - Police, fire department, coast guard

- **Off-site Emergency Headquarter (at Headquarters of TEPCO)**
  - Related departments within power company
  - Related parties of Ministry of Education
  - Cabinet Secretariat, Cabinet Office

- **Nuclear Emergency Preparedness Div of NISA at METI (Minister of METI)**
  - Communication other than with government bodies are mainly one-directional through phone, FAX and mail.
  - Limited information sharing:
    - Communication difficulties during power outage and transmission problems.
    - Local government pointed out that information on the accident provided to them was insufficient (partly because they were using public lines).

- **Real-time (limited):** Real-time TV conference available between the power plan and Head Office.
- **Bi-directional (partial):** Communication other than with government bodies are mainly one-directional through phone, FAX and mail.

Future

- **Overall Emergency Headquarters (Power company)**
- **Emergency Headquarters (Central government)**
- **Emergency Headquarters (Prefecture)**
- **Emergency Headquarters (City/Town/Village)**

- **Individual Plant’s Central control room**
- **Local Emergency Headquarters (Earthquake shelter)**
- **Off-site center**

- **System that enables the network to simultaneously connects related stakeholders and plants, and help real-time information sharing, meetings, and decision making.**
  - Stakeholders: Plant, power company’s headquarter, government, prefecture and city/state/province of the plant.
  - Function: Share information and hold conference regarding plant status, countermeasures, local safety, evacuation, etc.
  - Let stakeholders know that AM (accident management) mode is on, and share the progress of events.
  - Help transparent and prompt decision-making with all the information shared.
  - Prevent information from leaking.

- **It will be too late to consult with the head office when the accident passes a critical point.**
Ensure plant safety: Front line (Plant Head and Unit Manager) shall have absolute authority, and must govern the plant with accident prevention and containment as top priority – equivalent to airline’s “air-traffic controller” and “pilot”, or manufacturing’s “CEO” and “Chief Engineer”.

### Power Company's Head Office and Plant: Separation of Safety from Business

- **Power plant**: Decisions and actions with top priorities on accident prevention and safety. On this issue, it should be independent from management.
- **Head office**: Entrust the site to “plant safety”. Provides logistical support to the plant.

### Plant Head and Shift Manager: Act as ‘Traffic Controller’ and ‘Pilot’.

- **Plant Head (= Traffic Controller)**:
  - Provide instructions to the shift manager in the event not defined in the Accident Procedure (AM Manual).
  - Has absolute authority and responsibility over the safety and accident prevention of all reactors in the plant.
- **Shift Manager (= Pilot)**:
  - Has absolute authority over the plant’s safety on events and operations defined in the AM manual.
  - Shares information to stakeholders when in AM mode.

In order to achieve this mission, Plant Head and Unit Managers should go through stricter qualification and trainings, and receive appropriate rewards.
We must aim for a decision-making system where the local officials can make decisions on “the safety of the citizens” as a local autonomy.

The accident from the local government’s viewpoint

- Overwhelmed with incomplete and erroneous information.
- Delayed information (status of the accident, evacuation, etc.)
- Contents of the information were confusing.
- It was confusing who had authority to make decisions (accident response, evacuation, etc.)
- The local governments had no authority to participate in decision-making, so were positioned like “victims”.

Ideal role of local government

- **Decision-making**: On local safety and evacuation, the head of local government should have full understanding of the situation and discuss with plant’s head before making any final decision.
- **Training**: Head of local government should receive constant training to develop good judgment skills.
- **Information sharing**: Information needed to make decisions shall be provided directly from the plant rather than from the central government or head office of power company.
- **Network**: There is a network to conduct these missions.
- **Decision standards**: Basis on the roles and responsibilities of the national and local government is explicitly defined.

(Three Mile Island accident in US: One of the reasons the power company was able to build a good relationship with the local government/community was because they involved the locals in the operations/trainings of the plant after the accident.)

Principle is to “Operate the plant safely with the locals”.
In order to achieve that, the local government should strengthen human resources, such as by hiring a senior officer (CATO) with expertise on nuclear technology. (*Chief Atomic Technology Officer)

**Future direction (vision)**

- **Mission of CATO**
  - **Qualifications:** If the local governor deems that he/she will have difficulty in handling issues on the nuclear power plant accident, which require technical knowledge and expertise, he/she should assign a CATO, who is responsible for the technology and safety of the nuclear power plant.
    - To maintain neutrality, CATO candidates should have no previous affiliation with the power company or the government.
    - This is only subject to areas with nuclear power plants.
  - **Role of CATO:** To have meetings and share information with the power company, government, administrative agencies, emergency headquarters. To advise to the governor.

For example, Niigata Prefecture introduced a new post, “Crisis Manager”, who manages risks related to the nuclear power plants. - Expenses including training should be shouldered by the central government.
From now on, we need to manage accidents in 3 categories and establish its own AM structure.

<table>
<thead>
<tr>
<th>Accident Category</th>
<th>Examples</th>
<th>Information NW</th>
<th>Responsibility of “Plant Safety”</th>
<th>Responsibility of “Local Safety”</th>
<th>Responsibility within government</th>
</tr>
</thead>
</table>
| Accident           | - Core reactor scram + external power outage + activation of emergency generator (DG)  
                    | - Fukushima Dai-ichi Reactor 6, Tokai Dai-ni, etc.                     | ON             | - Defined in AM = Shift Manager               | - Plant shares information directly with local government.  
                    |                                                                           |                | - Not defined in AM = Plant Head              | - Local government makes final decision to evacuate.  
                    |                                                                           |                |                                                | - Central government provides logistical support and agreement.  
                    |                                                                           |                |                                                |                                | Ministry of Environment        |
| Severe Accident    | - Reactor scram + complete power outage (DG unavailable)               | ON             | - Same as above                               | - Same as above                               |                                | Ministry of Environment        |
|                    | - Fukushima Dai-ichi Reactor 5                                          |                |                                                |                                                |                                |                                |
| Grave Accident     | - Complete loss of power and cooling function                           | ON             | - Same as above                               |                                                | - Central government has authority to make decisions  
                    | - Core meltdown, increasing risk of radioactive leakage                 |                |                                                | - Central government, after consulting with local government, shall make overall decisions for national defense/national interest.  
                    | - Fukushima Dai-ichi Reactors 1 - 4                                     |                |                                                |                                | Office of Prime Minister       |
|                    | - Terrorist attack                                                      |                |                                                |                                                |                                |                                |

When the situation reaches extreme level, the central government will take control in order to protect national safety and interests.
For example, as to Fukushima Dai-ichi Reactors 1 – 3, wasn’t there a need to judge the level and stage of accidents and determine the appropriate actions?

Criteria of Severe Accident (SAM) and Grave Accident (GAM) (illustration)

- Availability of power (External power, Emergency DG, Battery, etc.)
  - Should be able to comprehend the availability of all power sources so that it can be checked instantly.

- Availability of HPCS functions.
  Possibility of malfunction and estimated timing.

- Status of the core reactor and risk of meltdown based on the overall availability and conditions of the power and cooling functions.

- Looking at the chronology of Fukushima Dai-ichi Reactors 1 – 3, power outage + HPCS malfunction resulted in meltdown and radioactive leakage. (+ Hydrogen explosion on Reactors 1 & 3)

- When expected to lose power and cooling functions, the probability of GAM is very high.
Government announced level 4 on March 12, level 5 on March 18, and level 7 on April 12. However, were these really appropriate? (level, timing, frequency, and key message)

**Facts and References**

- **The event in Fukushima was the first to ever pass level 5 since the establishment of the International Nuclear Event Scale (INES) in 1989.** There was no precedence of an ongoing event to be declared on such a scale.
  - Chernobyl (April 26, 1986 - Level 7) and Three Mile Island (March 28, 1979 - Level 5) were scaled in years after the events.

- **On March 12 15:36, the hydrogen explosion occurred in Dai-ichi Reactor 1.** At that point it should have already met the criterion of **level 5**.
  - Level 5 = Severe damage to the nuclear reactor core or radiation protection vessels. Requires planned emergency action.

- **“The primary purpose of the INES Scale is to facilitate communication and understanding … on the safety significance of events.”**
  “INES is a tool for promptly communicating to the public in consistent terms the safety significance of reported nuclear incidents….” (Extracted from official site of INES)

- **The “impact on people and environment” criterion in Levels 6 and 7 is highly subject to interpretation.**
  - **Level 7:** more than several tens of thousands of tera-becquerels (TBq) => stochastic health effects over a wide area, perhaps involving more than one country, long-term environmental contamination, and sheltering and evacuation is necessary.
  - **Level 6:** thousands to tens of thousands of TBq => sheltering and evacuation is likely.
  - Level 5: hundreds to thousands of TBq => Localized sheltering and/or evacuation may be likely.

- **Compared to Chernobyl, the amount of radiation in Fukushima Dai-ichi is around 10%.**
  - Chernobyl = 5.2 million TBq, Fukushima Dai-ichi = 370,000 TBq (NISA), 630,000 TBq (NSC)

**Issues and Lessons**

- **Was it really necessary to declare the scale 3 times while the accident was in-progress?** (issue with international response?)

- Learning from the experience in Fukushima, there needs to be specific guideline in how to declare the scale for progressing accidents.

- In hindsight, the question remains whether the level 4 declared on March 12 23:00 was a technical mistake.

- Why was level 7 declared on April 12, one month after explosion of Dai-ichi Reactors 1 to 4, not right after three explosions?

- The accident was still expanding, so instead of just indicating the scale, shouldn’t it have focused on providing more precise and clear-cut explanations regarding the “impact on people and environment”?

- **The radiation level of Fukushima does fit the level 7 criterion but in terms of “impact on people and environment”, which is the original purpose of the scale, the impact is much smaller than Chernobyl. It seems that level 6 (or a level between 6 and 7) is more appropriate in this case.**

- Further discussions should be made to review INES criteria based on what was learned in the Fukushima Dai-ichi Accident and aim for improvement, especially the criteria for Level 6 and 7 (or modify into detailed scale).
Was the message to the public appropriate? Wasn’t there a gap between what’s stated and what actually happened? Doesn’t it add anxiety to the local and international society?

Press Conference with the Chief Cabinet Secretary (Sources from various news articles from the web; March 12 onwards)

**March 12 18:00 (Reactor 1 after the explosion)**

- “Does it mean there was no damage to the nuclear reactor? Has it been confirmed?” => I would like to answer that once we have clarified the details, including final confirmation of facts and analysis of the cause.
- “Does the government expect the hydrogen explosion and radiation leak?” => We are handling this matter while expecting the worst. This accident, when it occurred, was within the scope of our expectations.... Comments that give out a false sense of alarm or security must not be made.

**March 13 (Regarding Reactor 1 and 3)**

- 8:00: In regards to Reactor 1, we have confirmed that the filling of seawater is working well as it would with the pump. …we can logically conclude that the core is now filled with seawater, or at least filled to a level that covers the fuel rods.
- 8:00: (regarding reactor 3) …By this ventilation and water injection with the pump, we should be able to manage, secure and control the situation, although there will be some level of radioactive materials in the gas it will have no effect on the health, and will insure nuclear reactor safety.
- 8:00: “At what time will the filling of seawater end?” => Even if we’re done pouring water into the pressure tank and core reactor, we’d also like to fill-up the containment vessel …if we continue filling the pressure tank, it will overflow, meaning the water will be going outside, so we would like to continue filling it with water.
- 11:00: (regarding Reactor 3) ….water pump stopped functioning…. It is presumed that water level on the fuel rods dropped, exposing the top of the fuel rods. Because of this, the safety valve of the pressure tank opened and the pressure in the nuclear reactor dropped. Pumping of water started at 9:08. At 9:25 we mixed boric acid to increase the safety even more.
- 11:00 “What is the status on the exposed fuel rods in Reactor 1?” => We believe that water have been filled, so it’s no longer exposed.
- 11:00: “Does it mean that core meltdown occurred in Reactor 1?” => There is a possibility. Although we can’t confirm, since of course we can’t see inside the reactor, it is very likely so we are handling the situation with the assumption that it did occur.
- 11:00: “Reactor 1 exploded soon after the ventilation. What about reactor 3?” => This time we were able to properly inject the water and to set up the vent.
- 11:00: “Have you already prepared what to do in case Reactor 1 can’t no longer be filled with seawater?” => We believe that, although it was at the last moment, we were able to fill the reactor with seawater before the problem got any bigger. For the other reactors, we’d like to do the same and be prepared at all times.

Issues & lessons learned

- When should public statements be made?
- Was the hydrogen explosion really anticipated?

- What was the basis for the methods used for the vent and water injection when planning and executing it?
- Didn’t they anticipate severe damage of pressure vessel and water to leak to the containment vessel?
- At this point, did they prepare the way to restore power and to cool the core in reactor 3?
- Was the countermeasure to explosion in reactor 3 really prepared?
The government’s safety guideline has been incorrect – “No need to consider long-term loss of power.”

Nuclear Safety Commission's Design Guidelines
(Supervised by Cabinet Office Nuclear Safety Commission Secretariat)

Section 1: Safety Review Guideline No. 27 “In case of power loss"

● Nuclear reactors and facilities should be **able to safely stop and secure cooling function in case of a short-term loss of all AC** power.

(Explanation)

● There is **no need to consider long-period loss of AC power**, since we can **expect swift restoration of the transmission line** or **restoration of power through the emergency AC power supply** system.

● If the system structure or operational method (i.e. constant backup) of the emergency AC power-supply system is deemed highly reliable, then there is **no need to take into account any scenario of a complete AC power blackout in the design of the plant**.

Facts at Fukushima Dai-ichi

● Transmission line was not restored before hydrogen explosion.

● Emergency AC power supply system malfunctioned due to the tsunami and was not restored before the hydrogen explosion.

● Not only the AC power, but also the DC power supply were completely lost for a long period.

● Due to the complete loss of all AC and DC power for a long period, key functions such as parameter-control at the central operation room, cooling, and water-injection were all lost.

It is necessary to verify why and who is responsible for this guideline, and completely redesign the atomic energy administration, as known for its back-scratching structure.
It is imperative to provide clear safety guidelines for long-term power loss. For example, if it is over 24 hours, off-site support shall be provided, and if within 24 hours, the on-site team has to deal with it.

Length of AC power outage

<table>
<thead>
<tr>
<th>Guideline</th>
<th>24 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Prepare on-site plan and safety measures that can prevent core damage for at least 24 hours for any type of power loss.</td>
<td>● For power loss over 24 hours, off-site support and actions shall be made.</td>
</tr>
<tr>
<td>Main player</td>
<td>Power company and central government</td>
</tr>
<tr>
<td>● Power company</td>
<td>Must accomplish off-site support within 24 hours.</td>
</tr>
<tr>
<td>Power supply</td>
<td></td>
</tr>
<tr>
<td>● Secure power supply on-site for at least 24 hours.</td>
<td></td>
</tr>
</tbody>
</table>

● In US, boundary between on-site and off-site response is 72 hours for NRC and 24 hours for INPO.
● For example, USA has a special unit that is intensively trained to work in radiation-contaminated areas (e.g. Fort Leonard Wood Chemical Biological Radioactive Unit).
● Japan should have a similar special unit as well.
## Future education and training should include ‘lessons learned from Fukushima Dai-ichi’.

<table>
<thead>
<tr>
<th>Important items for the education and training programs (Example)</th>
</tr>
</thead>
<tbody>
<tr>
<td>● <strong>Practical training under extreme conditions such as in Fukushima Dai-ichi Reactor 1</strong></td>
</tr>
<tr>
<td>• Complete power outage, loss of cooling function, darkness, aftershocks, high radiation, insufficient materials, and telecommunication problems.</td>
</tr>
<tr>
<td>• Risk of core damage and hydrogen build-up in a couple of hours from the stop of cooling system.</td>
</tr>
<tr>
<td>• (Furthermore) Severe accident during holidays, night, bad weather, fire, and road blocks (simultaneously).</td>
</tr>
<tr>
<td>• Emphasis on the absolute prevention of a hydrogen explosion under any circumstances.</td>
</tr>
<tr>
<td>● <strong>Practical training to supply alternative power source and cooling system to the plant (for example) “within 2 hours” during complete power outage</strong></td>
</tr>
<tr>
<td>• Prepare and store the requirements. (Define the type and quantity of power/water sources and equipments to meet the necessary time of cooling.)</td>
</tr>
<tr>
<td>• Actual operation to carry and set up alternative systems such as power supply, coolant, water-injection, carry-on batteries on-site.</td>
</tr>
<tr>
<td>• Organize and operate supply chains for emergency equipment (at the plant, at the head office, etc.)</td>
</tr>
<tr>
<td>● <strong>Set specific indicators/goals/periods in each training and check its proficiency level.</strong></td>
</tr>
<tr>
<td>• Example: Provide X amount of power/water supply within Y hours. Complete task A within B hours, etc.</td>
</tr>
<tr>
<td>● <strong>Practical training not only for the power company, but together with the central and local government and related stakeholders.</strong></td>
</tr>
<tr>
<td>● <strong>Share and pass down the experience and lessons learned from Fukushima Dai-ichi with all power companies in Japan and the world.</strong></td>
</tr>
</tbody>
</table>
List of the main sources and references

**Tokyo Electric Power Company (from website)**
- Fukushima Dai-ichi Reactors 1 – 6 plant-related parameters (water level, pressure, temperature, monitored data).
- Effect of the Tohoku earthquake and tsunami on nuclear power plant and current situation. (May 16 2011)
- Report on the responding action based on the report on the damage on power equipment in the vicinity of Fukushima Dai-ichi nuclear power plant. (May 23 2011)
- Analysis and evaluation based on operations and accident records in Fukushima Dai-ichi nuclear power plant during the 2011 Tohoku earthquake. (May 23 2011)
- Effects of the earthquake and tsunami on the Fukushima Dai-chi and Dai-ni nuclear power plants. (May 24 2011)
- Chronology of seawater injection at Fukushima Dai-ichi nuclear power plant Reactor 1. (May 26 2011)
- The research result on the effects of tsunami by the 2011 Tohoku earthquake to Fukushima Dai-ichi and Dai-ni nuclear power plants. (May 27 2011)
- Recovery status on Fukushima Dai-ichi and Dai-ni nuclear power plants. (August 10, 2011)
- Effects on the nuclear reactor facilities at Fukushima Dai-ni nuclear power plant from the 2011 Tohoku earthquake. (August 8, 2011)
- Effects on the nuclear reactor facilities at Fukushima Dai-ichi nuclear power plant from the 2011 Tohoku earthquake. (September 9, 2011)
- Analysis on the explosion of nuclear reactor building in Fukushima Dai-ichi nuclear power plant. (October 21, 2011)

**Nuclear and Industrial Safety Agency (from website)**
- Examination standards for verifying implementation of emergency safety measures. (May 6, 2011)
- Examination standards for verifying implementation of safety measures against severe accidents. (June 18, 2011)
- Security of external power source in nuclear power plants and reprocessing plants. (April 15, 2011)
- Additional report from the Japanese government to IAEA - The accident at Tokyo Electric Power Company Fukushima nuclear power plants (2nd report). (September 11, 2011)
- Comparison of Fukushima Dai-ichi nuclear power plant with other power plants. (June 24, 2011)

**Tohoku Electric Power Company (from website)**
- Situation of Onagawa nuclear power plant during the 2011 Tohoku earthquake and tsunami. (May 30, 2011)

**Japan Atomic Power Company (from website)**
- Effect of the 2011 Tohoku earthquake on Tokai Dai-ni power plant reactor facilities. (September 2, 2011)
Note) The translation of this report has been done by a limited number of staff and within a limited period of time. If there are any discrepancies between this translation and the original Japanese report, please refer to the Japanese report for clarifications.

The project would like to extend its special thanks to the following people for their great support in this translation work:

Mr. Kenjiro Ishikawa
Ms. Jewel Naruse
Ms. Seiko Toyama
Mr. Curtis Hoffmann
Ms. Keiko Sato