How the Fukushima Daiichi accident changed (or not) the nuclear safety fundamentals?

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Anatomy of Fukushima

- Lack of defense-in-depth against tsunamis
  - Seawalls of an insufficient height
  - Safety-relevant equipment under the ground level
  - Insufficient backups for station blackout

- Unpreparedness for consequence mitigation
  - Efforts after JCO were ineffective
Safety management based on probabilistic concept of risk

Probability of damage

Risk retention

Risk transfer / retention

Risk reduction

Risk limit

Scale of damage
Enhancement of defense-in-depth

- Reevaluation of the maximum scale of earthquakes and tsunamis
- Installation of watertight structures and countermeasures against submerging
- Reinforcement of emergency power supply
- Reinforcement of emergency water supply including that for spent fuel pits
- Prevention of reactor containment vessel damage, e.g., installation of filtered containment venting
- Preventing dispersion of radioactivity
Essential characteristics of resilience

- **Margin**
  - How closely operating to a boundary

- **Buffering capacity**
  - Size of disruptions that system can absorb
  (Resilience triangle)

- **Tolerance**
  - System behavior near a boundary
  (Graceful degradation)

- **Flexibility**
  - Ability to restructure itself in response to changes

- **Safety boundary**

- **Functionality**

- **Adaptation**

Changes after *Fukushima*

- Preparedness for all-hazards and multiple disasters
  - Natural disasters other than seismic motion
  - Aircraft crashes, terrorists’ attacks, pandemic, etc.

- Administration of emergency response
  - Information sharing between different organizations
  - Agent-based organizational design, bio-inspired design of complex social systems
Simulation of organizational emergency response

INPUT: Scenario

Scenario Manager

OUTPUT: bg of information acquisition, action, and resource consumption of each agent
Task and communication

Information transfer

all activities

emergency medical activities
Resilience enhancement measures

Margin
- Conventional safety design
- Redundancy
- Fail safe & fool proof
- Risk-informed management

Tolerance
- Margin beyond design basis
- Accident management
- Nuclear disaster prevention

Buffering capacity
- Nuclear disaster prevention
- Restoration
- Decontamination
- Compensation

Flexibility
- Incident management
- Living PSA
- Technological back-fits
- Organizational restructuring
### 3 categories of unsafe events (1)

| Manifestation                          | Category 1                                   | Category 2                                      | Category 3                                      |
|----------------------------------------|----------------------------------------------|-------------------------------------------------|-------------------------------------------------|
| Work accidents or single failures      | Systemic or organizational accidents         | Design basis events or anticipated incidents   |
| Frequency                              | Relatively high                              | Extremely low                                   | Very low                                        |
| Scale of damage                        | Local and limited                            | Medium ~ devastating                            | Devastating                                     |
| Primary victims                        | Interested people                            | Interested people Third party                   | Interested people and/or third party            |
| Complexity of scenarios                | Simple                                       | Complicated and non-linear                      | Complicated but linear                          |

*(Furuta, 2001)*
## 3 categories of unsafe events (2)

|                      | Category 1                          | Category 2                      | Category 3                      |
|----------------------|-------------------------------------|---------------------------------|---------------------------------|
| Variety of scenarios | Diverse but classifiable            | Extremely diverse               | Limited and finite              |
| Quantitative risk    | Statistically possible              | Impossible                      | Theoretically possible          |
| assessment           |                                     |                                 |                                 |
| Safety goal          | ALARP                               | ALARP                           | Absolute risk limit             |
| Countermeasures      | Quality assurance & work management | Systems approach                | Engineered safety features      |
| Trade-off with       | Compatible                          | Partly compatible               | Conflicting                     |
| economy              |                                     |                                 |                                 |
| Status in nuclear    | Already resolved                    | Resilience?                     | Already resolved                |
| industry             |                                     |                                 |                                 |

(Furuta, 2001)
Conclusion

• The very basis of nuclear safety, defense-in-depth, has not changed after *Fukushima*.

• Enhancement of NPPs resilience
  – Preparedness for all-hazards and multiple disasters
  – Importance of administration of emergency response
  – Efforts targeting at Category 2 unsafe events