東京大学
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Continuous Improvement of Nuclear Safety based on Lessons Learned from Fukushima Accident and Safety Research Cooperation

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Fukushima Accident

- **The TEPCO's Fukushima Dai-ichi accident was caused by external events; earthquake and tsunami.**
- While the earthquake caused damage at external power supply, there is no evidence so far that it produced to the plants mechanical and structural damage.
  - Although one cannot deny any impact by the earthquake, it is considered that the majority of the damage was caused by the tsunami.
- **Protection against external hazards must be enhanced according to the "Defense-in-Depth" concept**, which is believed to be valid even after the accident.
- Safety regulatory system pre-existed in Japan was not strong enough to enforce the necessary upgrades in protections against external hazards and against resulting severe accidents.

AESJ/NSD Report on Fukushima Accident

- The Nuclear Safety Division of the Atomic Energy Society of Japan **(AESJ/NSD)** issued the "Report of Seminars to Investigate the Accident at the Fukushima Dai-ichi Nuclear Power Station – What were wrong? What should be done from now on?" (March, 2013)

- **AESJ/NSD** pointed out major issues which are highly related with the **Defense-in-Depth against external events.**
  - Insufficient design provision against tsunami,
  - No practical accident management (AM) under actually-generated environments during the accident, and
  - Insufficient provision for accidents far-exceeded from the postulated design condition.

(1) Insufficient Design Provision against Tsunami

- Postulated tsunami, which was decided with the method developed by the Civil Engineering Society of Japan based on the historical tsunami records, was not high enough.
- We cannot define design basis hazard (DBH) only from historical records. Cooperation is needed between nuclear safety professionals and natural phenomena experts.
- Safety requirements against various initiators, e.g. volcano, internal fire and internal flooding, are needed.

(2) No Practical Accident Management

- Some accident management operations were not successfully implemented under the actual conditions produced by:
  - Natural phenomena including after shocks and repetitive tsunami attacks, and
  - Severe accident phenomena including hydrogen explosion at reactor buildings and high radiation level.
- Licensees and regulators must examine whether AM operations are really carried out with high reliability taking various effects by natural phenomena and severe accident conditions into account.

(3) Far-exceeded from the Postulated Design Condition

- There was no effective mitigation feature under accident conditions far beyond the postulated design condition.
- It revealed the weakness of the nuclear facilities against extreme natural hazards.
- Some provisions, including mobile devices, are needed against unexpected accident conditions.

Summary of Lessons Learned

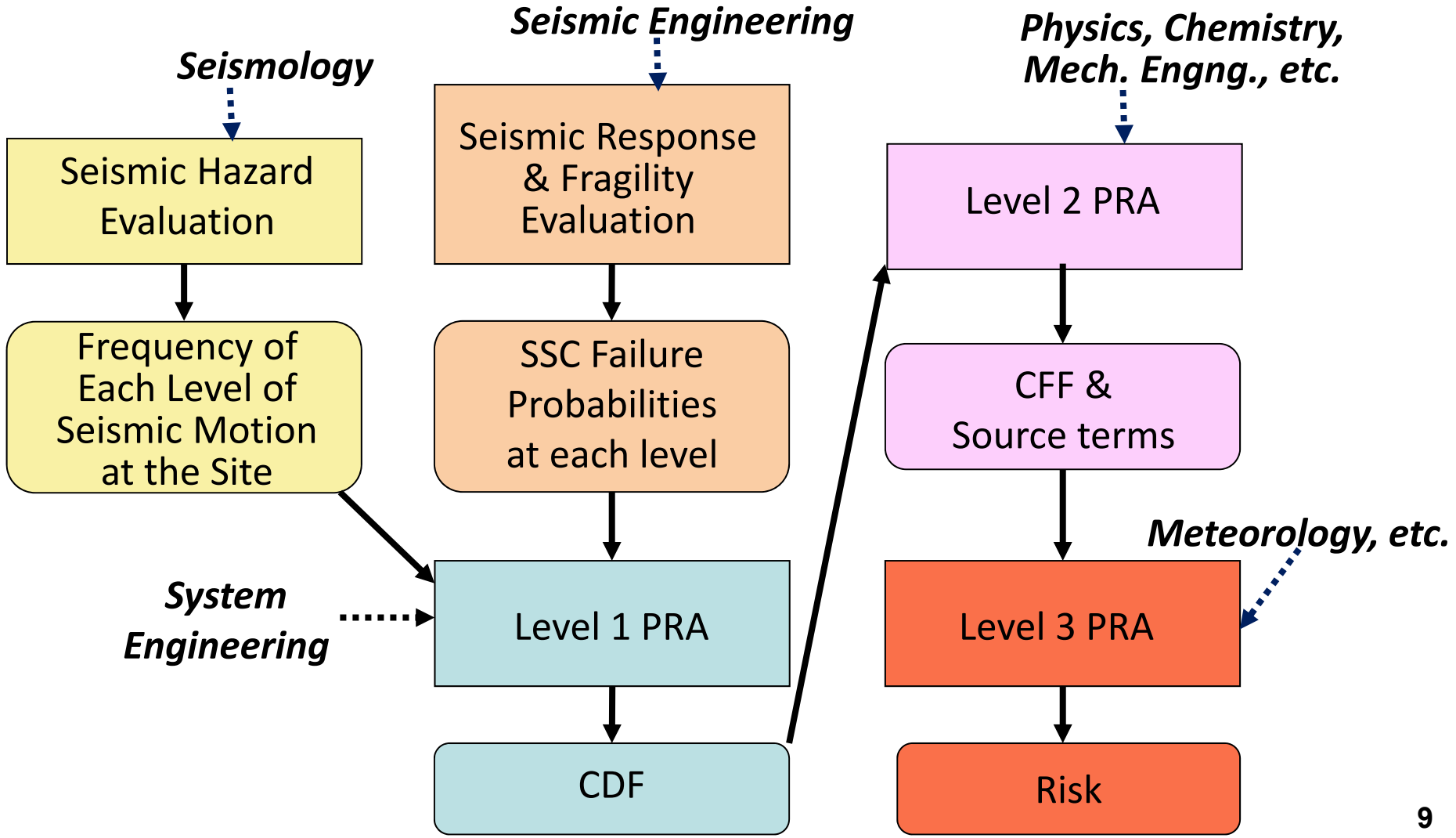
- **Estimation of external hazard** has large uncertainty.
  - Deficiency in Defense-in-Depth protection caused Fukushima accident.
  - Diversity and flexibility are important for these measures.

- **Elimination of cliff-edge effect** is essential for external initiators.
  - Diversity and flexibility are important for these measures.

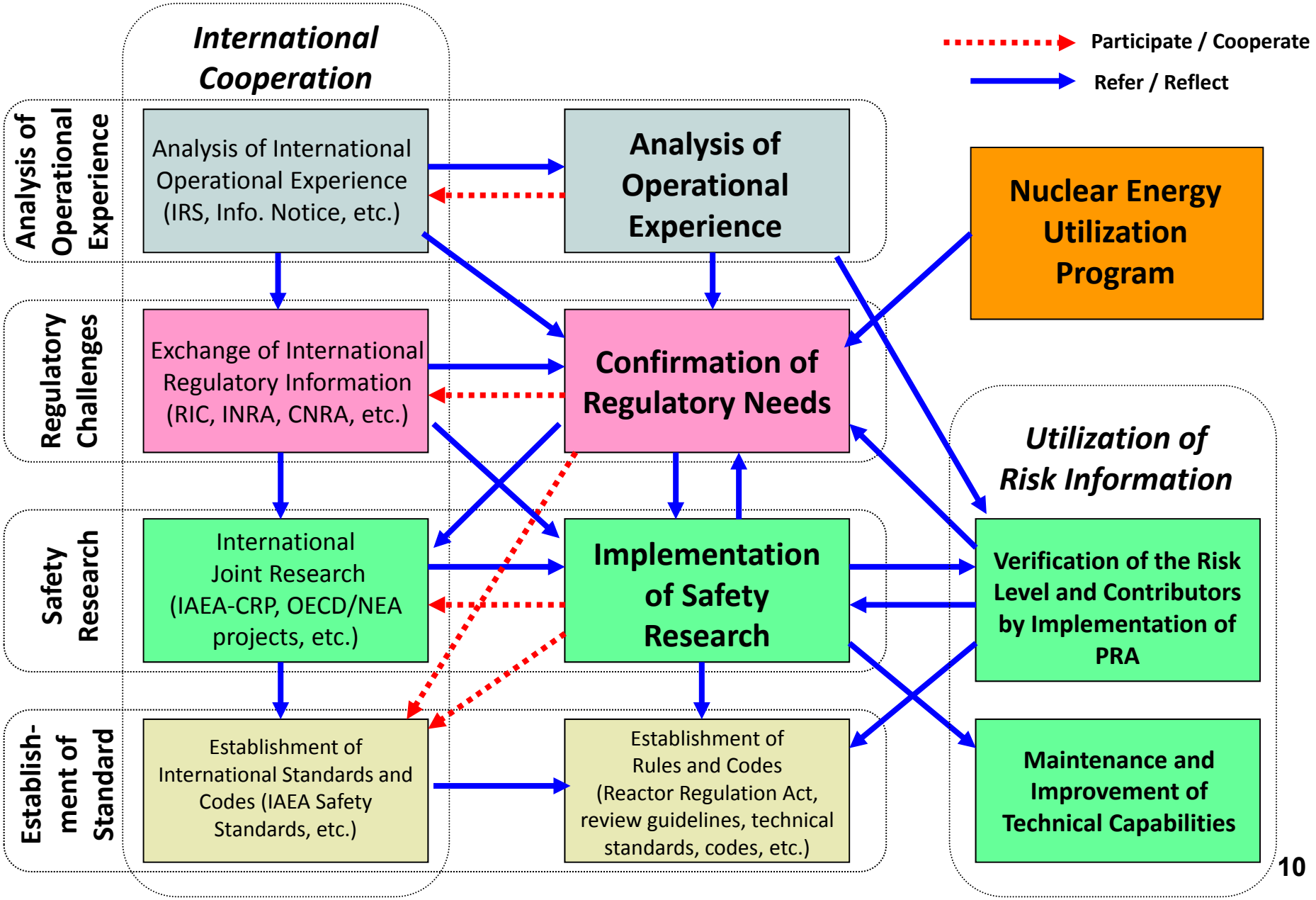
- **Effectiveness of safety measures can be evaluated using PRA** (Probabilistic Risk Assessment).

Experts Cooperation for Probabilistic Risk Assessment

Example for Seismic PRA



Safety Research and Cooperation

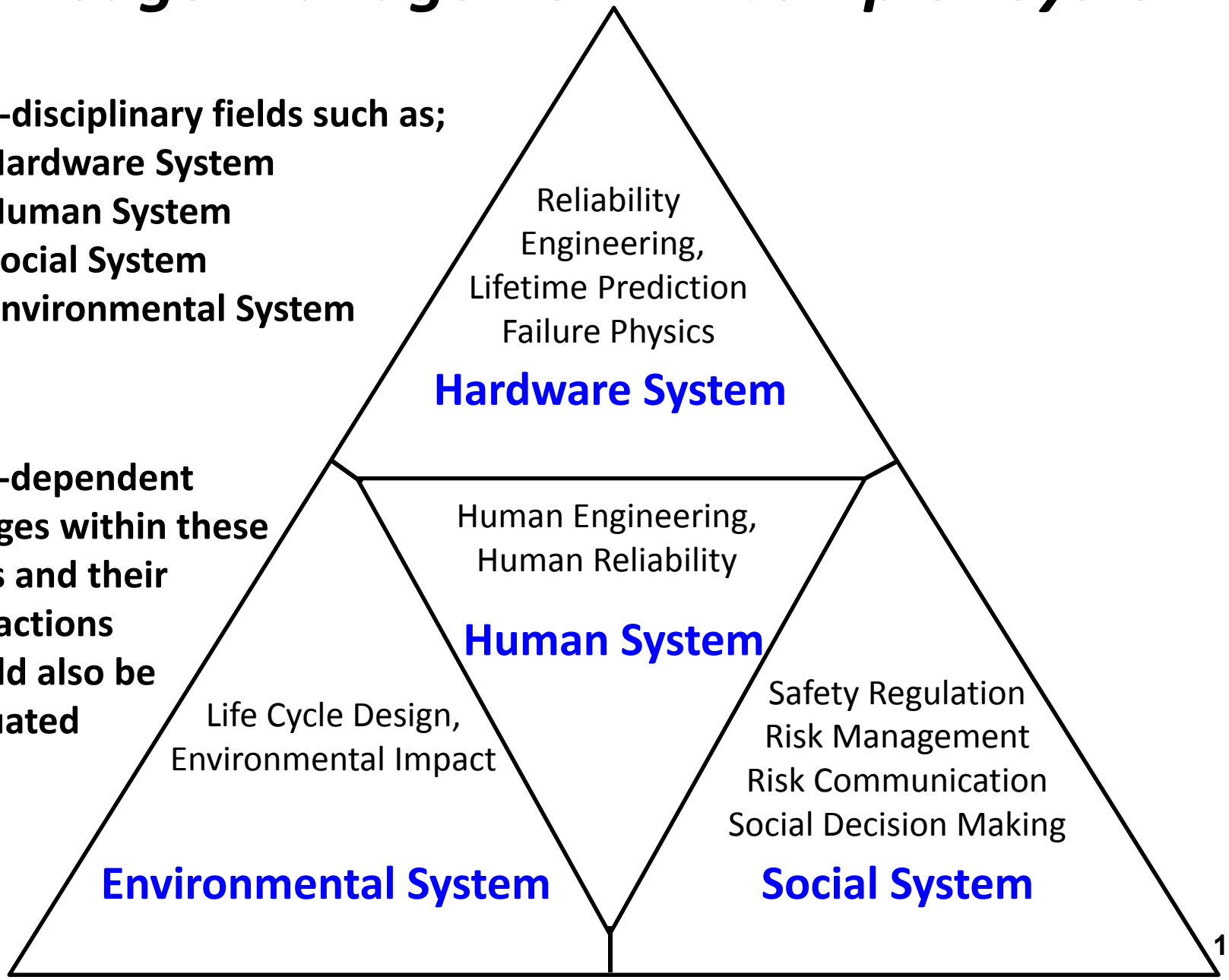


Knowledge Management in Complex System

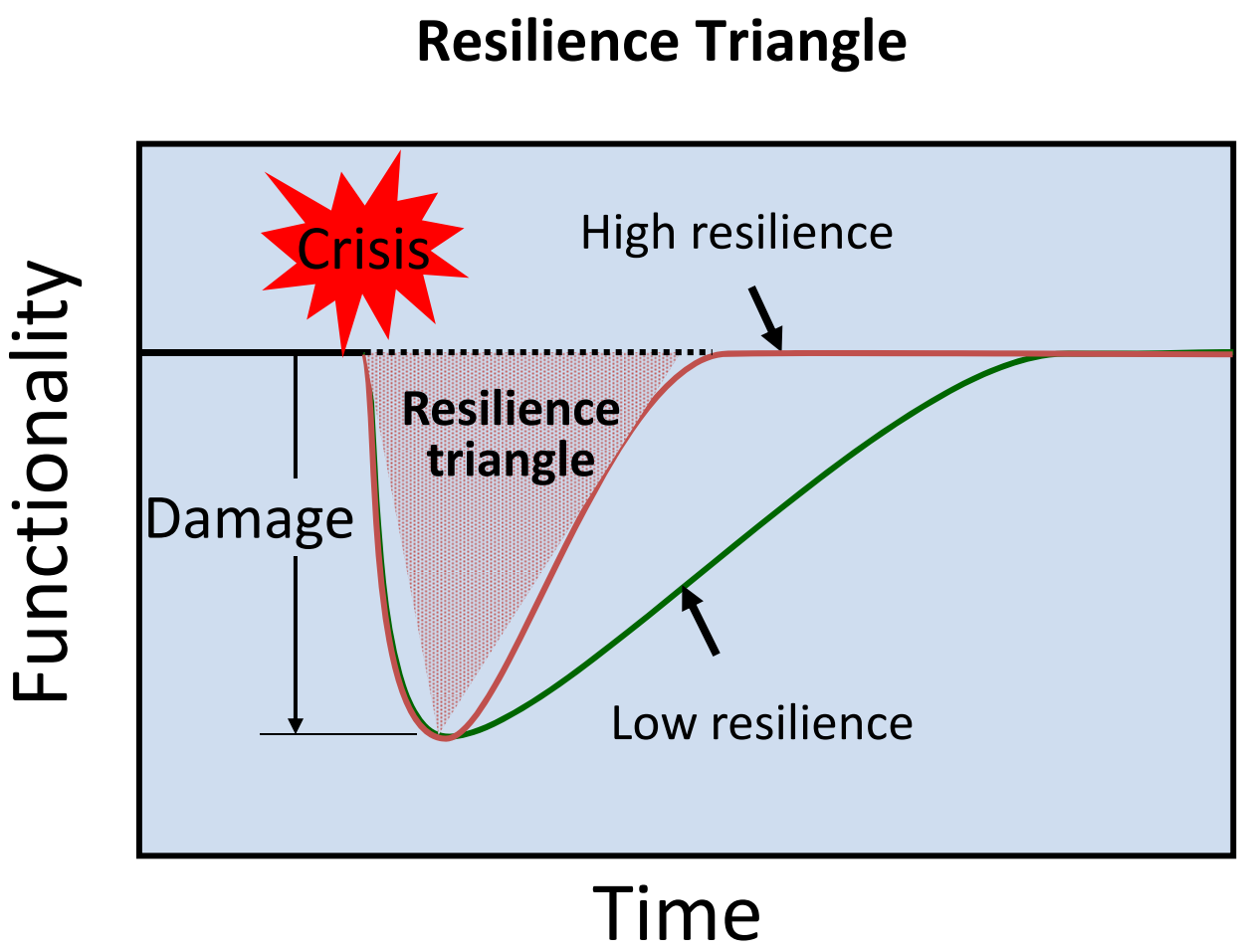
Multi-disciplinary fields such as;

- **Hardware System**
- **Human System**
- **Social System**
- **Environmental System**

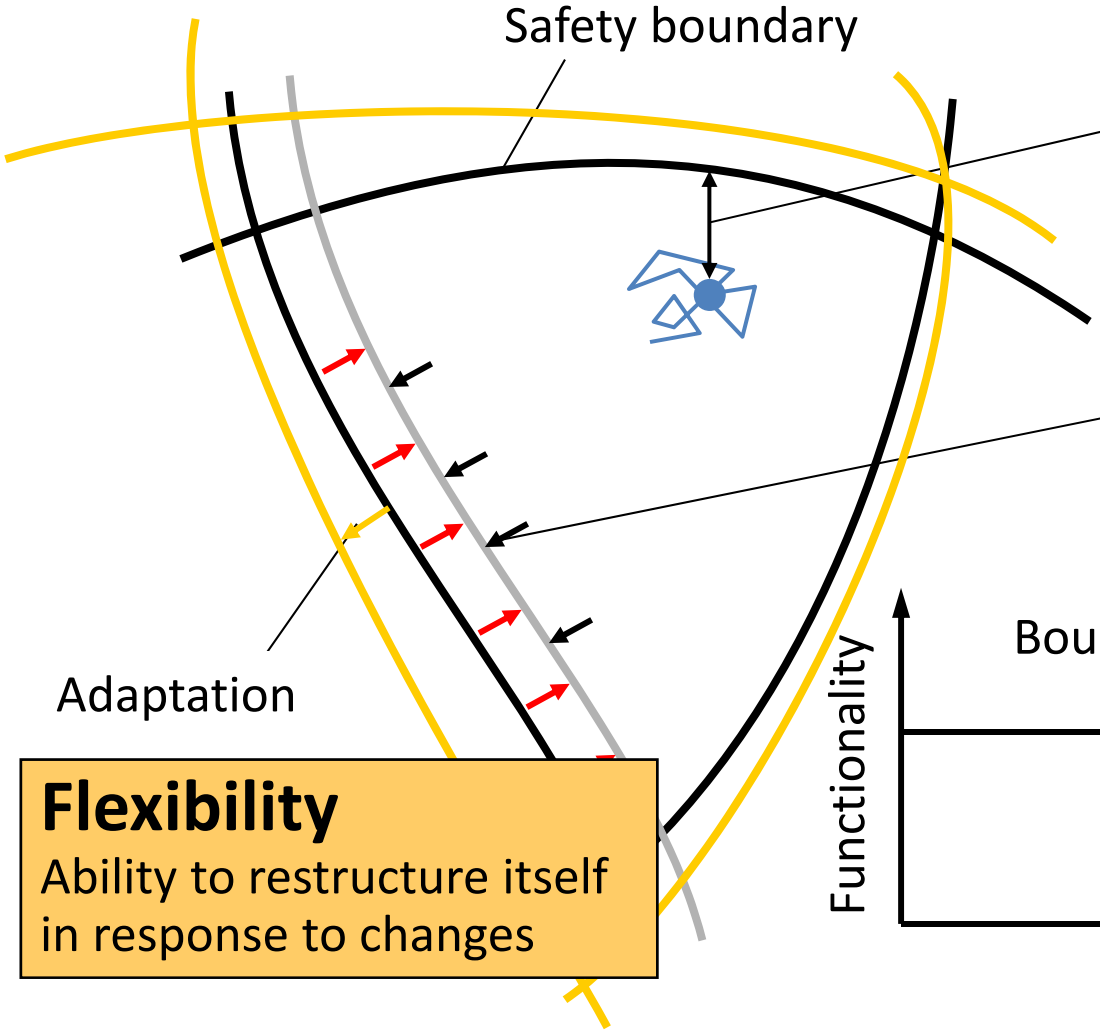
Time-dependent changes within these fields and their interactions should also be evaluated



Measure of Resilience in Complex Systems



Essential Characteristics of Resilience



Margin
How closely operating to a boundary

Buffering Capacity
Size of disruptions that system can absorb

(Resilience triangle)

Flexibility
Ability to restructure itself in response to changes

Tolerance
System behavior near a boundary

(Graceful degradation)

Summary

- *The Defense-in-Depth Concept*
- *Continuous Improvement of Nuclear Safety and Radiation Protection with Graded Approach based on Probabilistic Risk Assessment*
- *Collaborative Work with Nuclear and Non-nuclear Experts*
- *Nuclear Safety as Multi-disciplinary Approach*
- *Resilience Engineering*

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Thank you very much for your attention