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

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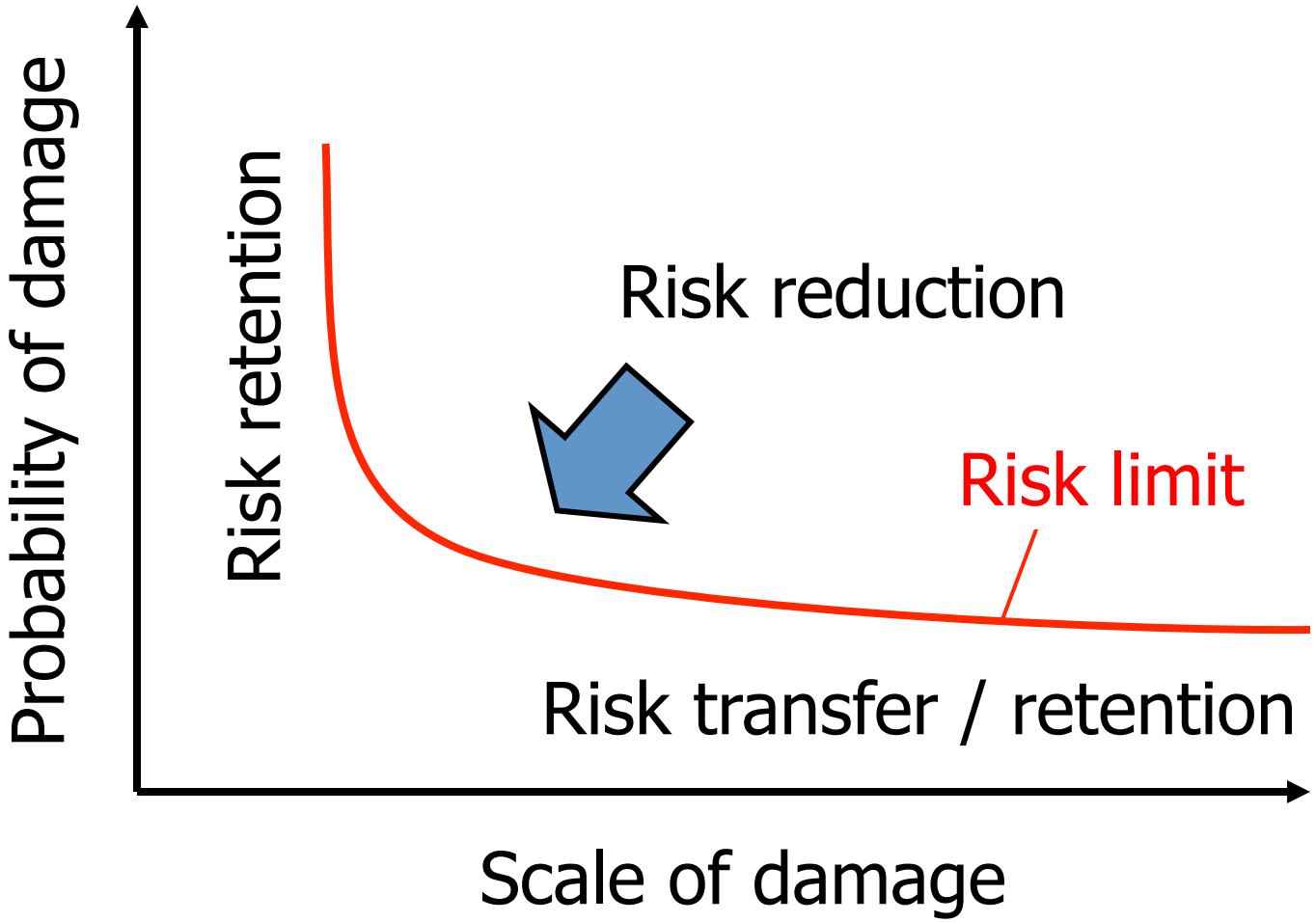
Safety management based on probabilistic concept of risk



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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

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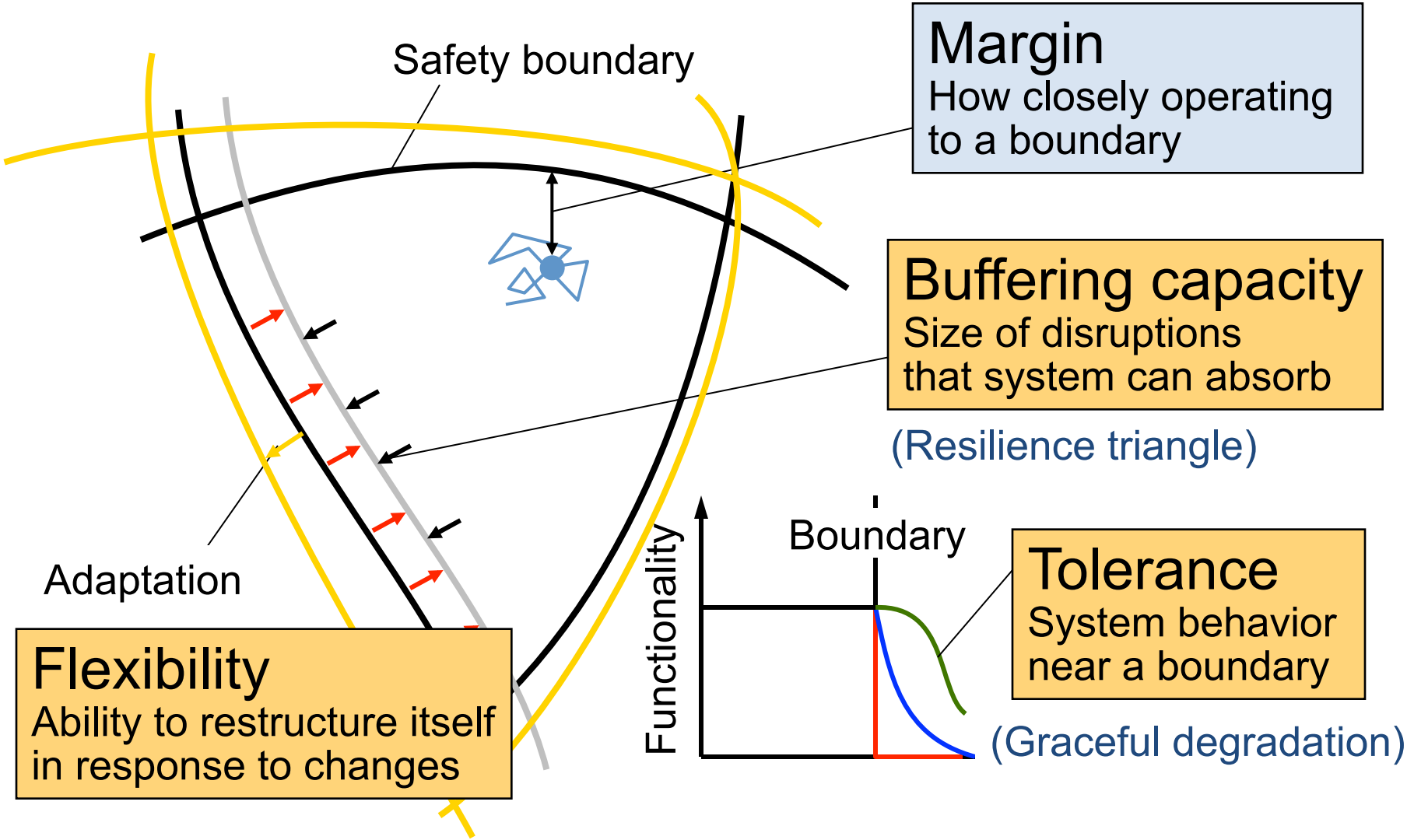
Essential characteristics of resilience



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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

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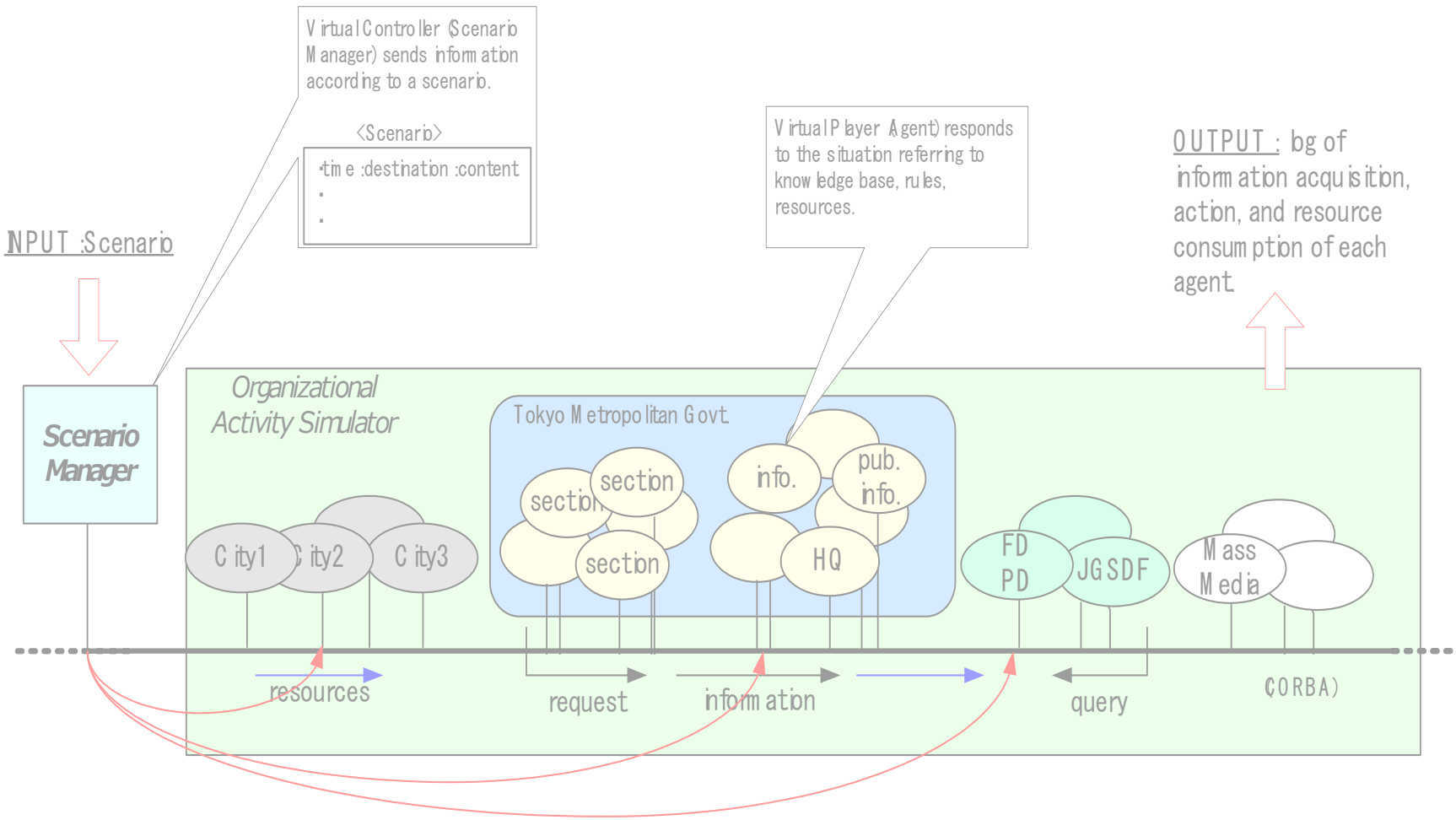
Simulation of organizational emergency response



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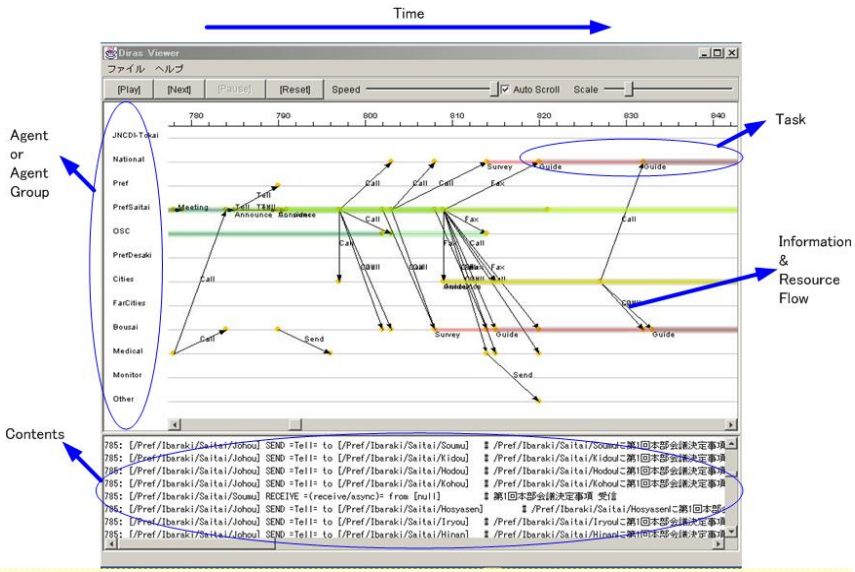
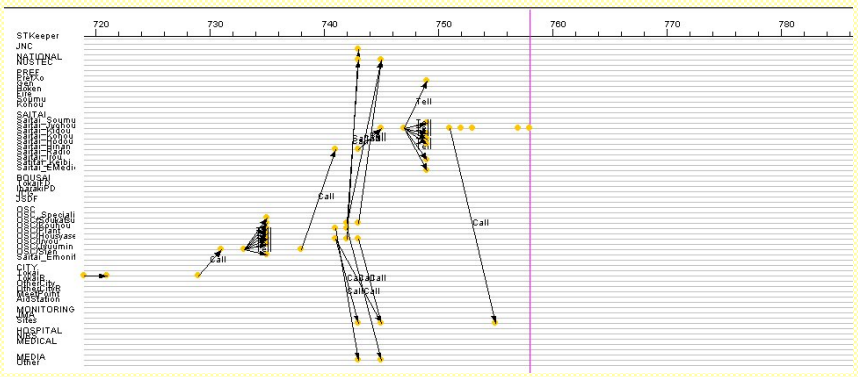
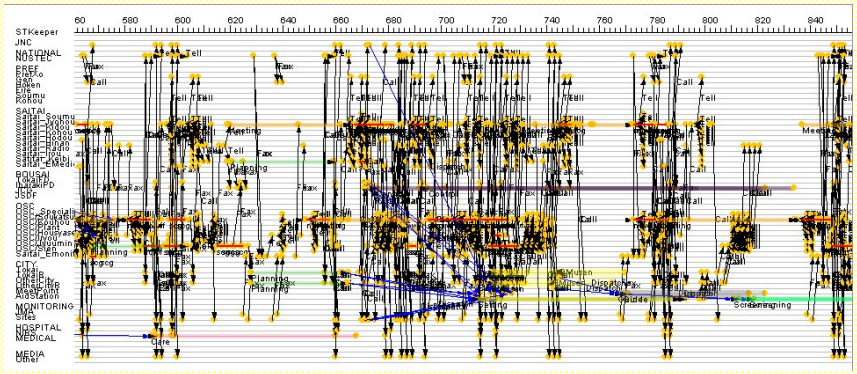
Task and communication

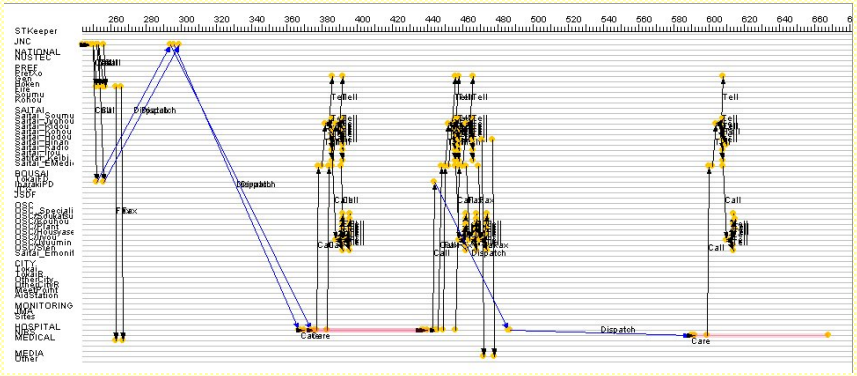




Information transfer



all activities



emergency medical activities

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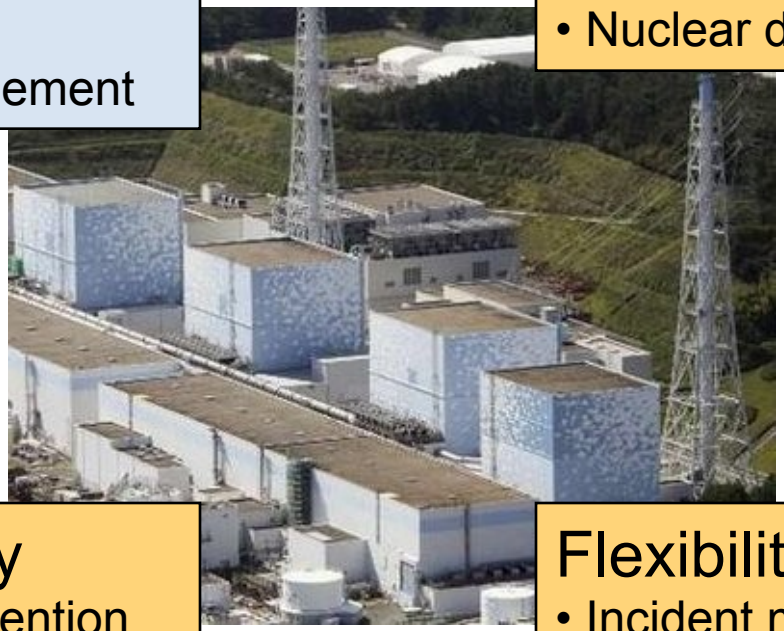
Resilience enhancement measures

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

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3 categories of unsafe events (1)

	Category 1	Category 2	Category 3
Manifestation	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)

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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 assessment	Statistically possible	Impossible	Theoretically possible
Safety goal	ALARP	ALARP	Absolute risk limit
Countermeasures	Quality assurance & work management	Systems approach	Engineered safety features
Trade-off with economy	Compatible	Partly compatible	Conflicting
Status in nuclear industry	Already resolved	Resilience?	Already resolved

(Furuta, 2001)

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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

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