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Perspective of Risk Assessment and Management after 5 Years of Fukushima Dai-ichi Accident

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Timeline of Fukushima Dai-ichi Accident and After (1/2) (2011-2015)

- March 11, 2011
  - Fukushima Dai-ichi Accident
- September 19, 2012
  - Establishment of Nuclear Regulatory Authority
- July 8, 2013
  - Enforcement of New Regulatory Requirement
- April 11, 2014
  - Strategic Energy Policy (Cabinet Office)
- May 30, 2014
  - WG Recommendation Report Publication（WG on Industry Voluntary Initiative of Reactor Safety Improvement）
- July 16, 2015
  - Long Term Energy Perspective (Cabinet Office)

Role of Nuclear Energy (April, 2014)

- Nuclear power is an important base-load power source as a low carbon and quasi-domestic energy source, contributing to stability of energy supply-demand structure, on the major premise of ensuring of its safety, because of the perspectives; 1) superiority in stability of energy supply and efficiency, 2) low and stable operational cost and 3) free from GHG emissions during operation.*

*Strategic Energy Plan, Cabinet Office of Japan, April 2014, (Provisional Translation)
http://www.enecho.meti.go.jp/en/category/others/basic_plan/pdf/4th_strategic_energy_plan.pdf

Recommendation of METI WG on Industry Voluntary Initiative of Reactor Safety Improvement (May, 2014)

- Risk Management under the adequate framework
  - Leadership of top management
  - Peer review by JANSI
  - Reciprocal and Cooperative industry's activity based on technical insights
- Reflection of Lessons-Learned from Fukushima Dai-ichi accident
  - Comprehensive PRA (plant-specific)
  - Control of residual risk (Defense-in-depth and PRA)
  - Safety research and its coordination
- Attitude to ingrain the activities in the organizations and individuals
  - Safety culture based on and supported by questioning attitude
  - Operational experience and new findings
  - Involvement of stakeholders
  - Strategic human resource development
  - Overall optimization of safety-related activity

http://www.meti.go.jp/committee/sougouenergy/denryoku_gas/genshiryoku/anzen_wg/report_02.html, (in Japanese)

Long Term Perspective of Energy (July 2015)

- In 2030, dependency on nuclear energy is to be 20-22% (cf. ~30% before 2011). Fraction of the base-load power source, i.e. hydropower, coal and nuclear, etc. will be 56%.

- Long-term Perspective of Energy Supply and Demand of, Cabinet Office of Japan, July, 2015 (in Japanese)
- http://www.meti.go.jp/press/2015/07/20150716004/20150716004.html

Timeline of Fukushima Dai-ichi Accident and After (2/2) (2015-present)

- September 10, 2015
  - Restart Sendai NPP Unit 1
- November 17, 2015
  - Restart Sendai NPP Unit 2
- July 16, 2015
  - Long Term Energy Perspective（Cabinet Office）
- Feb 26, 2016
  - Restart Takahama Unit 3
- Mar 9, 2016
  - Injunction of Takahama 3 and 4 operation (Ohtsu District Court)
- September 7, 2016
  - Restart Ikata Unit 3

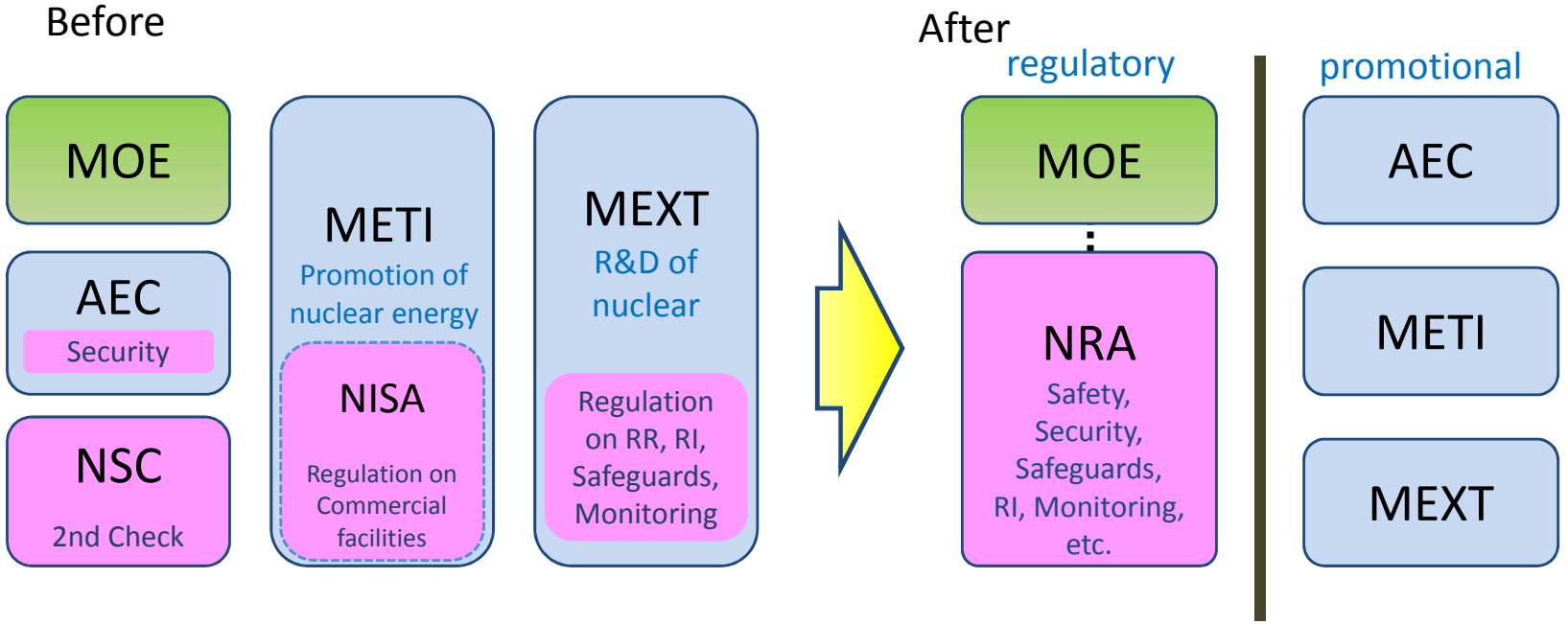
Currently three units (Ikata 3, Sendai 1 &2) are in operation. Sendai will be in refueling outage in 2016.

Japanese Government Report on Fukushima Dai-ichi Nuclear Accident
- Lessons-Learned in 5 Categories -

- The most important basic principle in securing nuclear safety is “defenses in depth”
- Category 1 (8 Lessons)
  - Strengthen preventive measures against a severe accident.
- Category 2 (7 Lessons)
  - Enhancement of response measures against severe accidents
- Category 3 (7 Lessons)
  - Enhancement of nuclear emergency responses
- Category 4 (5 Lessons)
  - Reinforcement of safety infrastructure
- Category 5 (1 Lesson)
  - Thoroughly instill a safety culture

(1) Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety, The Accident at TEPCO's Fukushima Nuclear Power Stations, June 2011.
(2) Ditto, Second Report, September 2011 (in Japanese)

Independent and Unified Regulatory Authority, Established in Sep. 2012



AEC : Atomic Energy Commission
METI : Ministry of Economy, Trade and Industry
MEXT : Ministry of Education, Culture, Sports, Science and Technology
MOE : Ministry of the Environment
NISA : Nuclear and Industrial Safety Agency (abolished)
NSC : Nuclear Safety Commission (abolished)

NRA, Japan Nuclear Regulation Authority

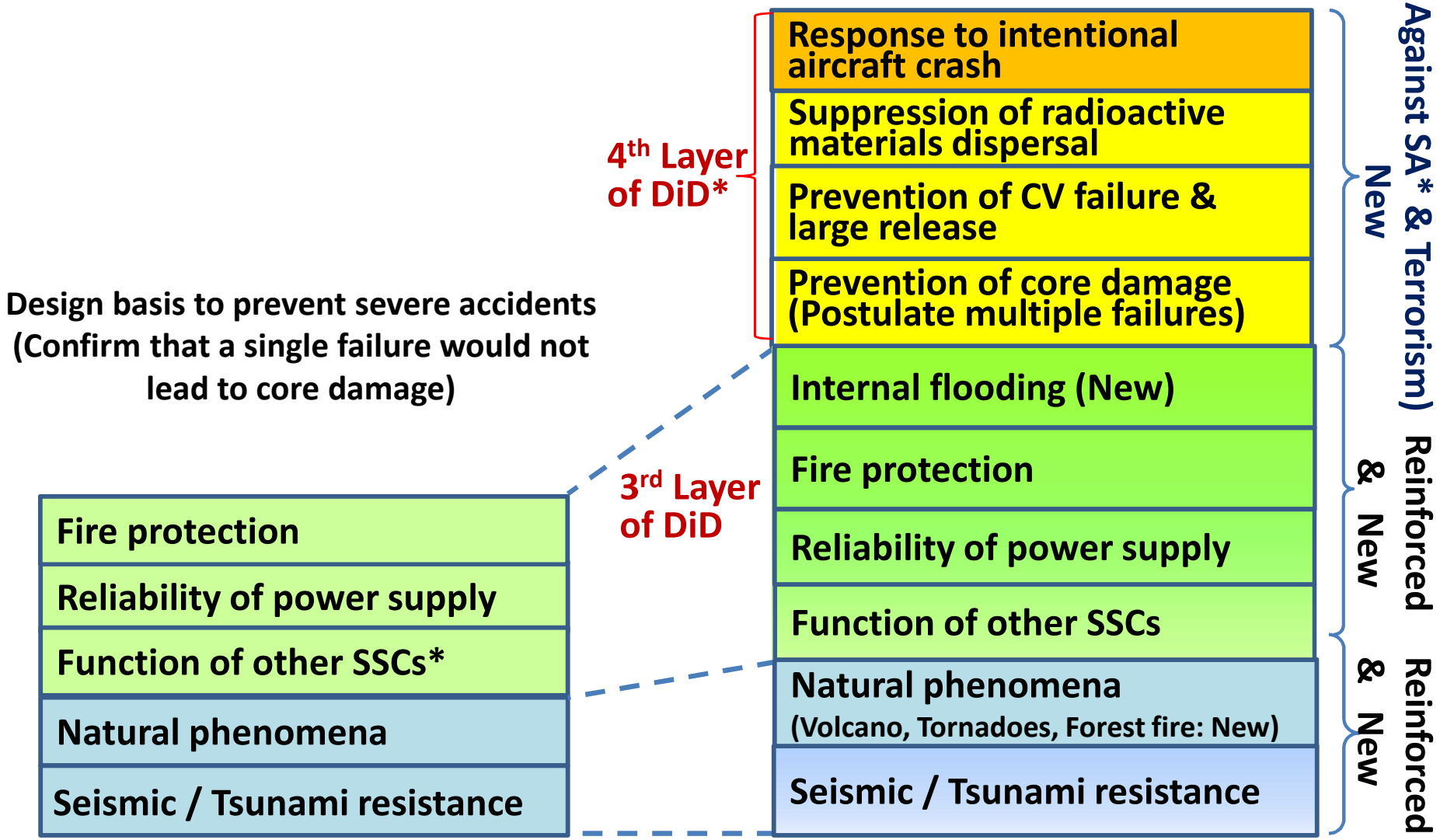
Regulatory promotional

Source: Presentation by Mr. Shimizu, NRA Secretary-General, at the International Conference on Effective Nuclear Regulatory Systems on April 12, 2016, https://www.nsr.go.jp/data/000147733.pdf

New Regulatory Requirement

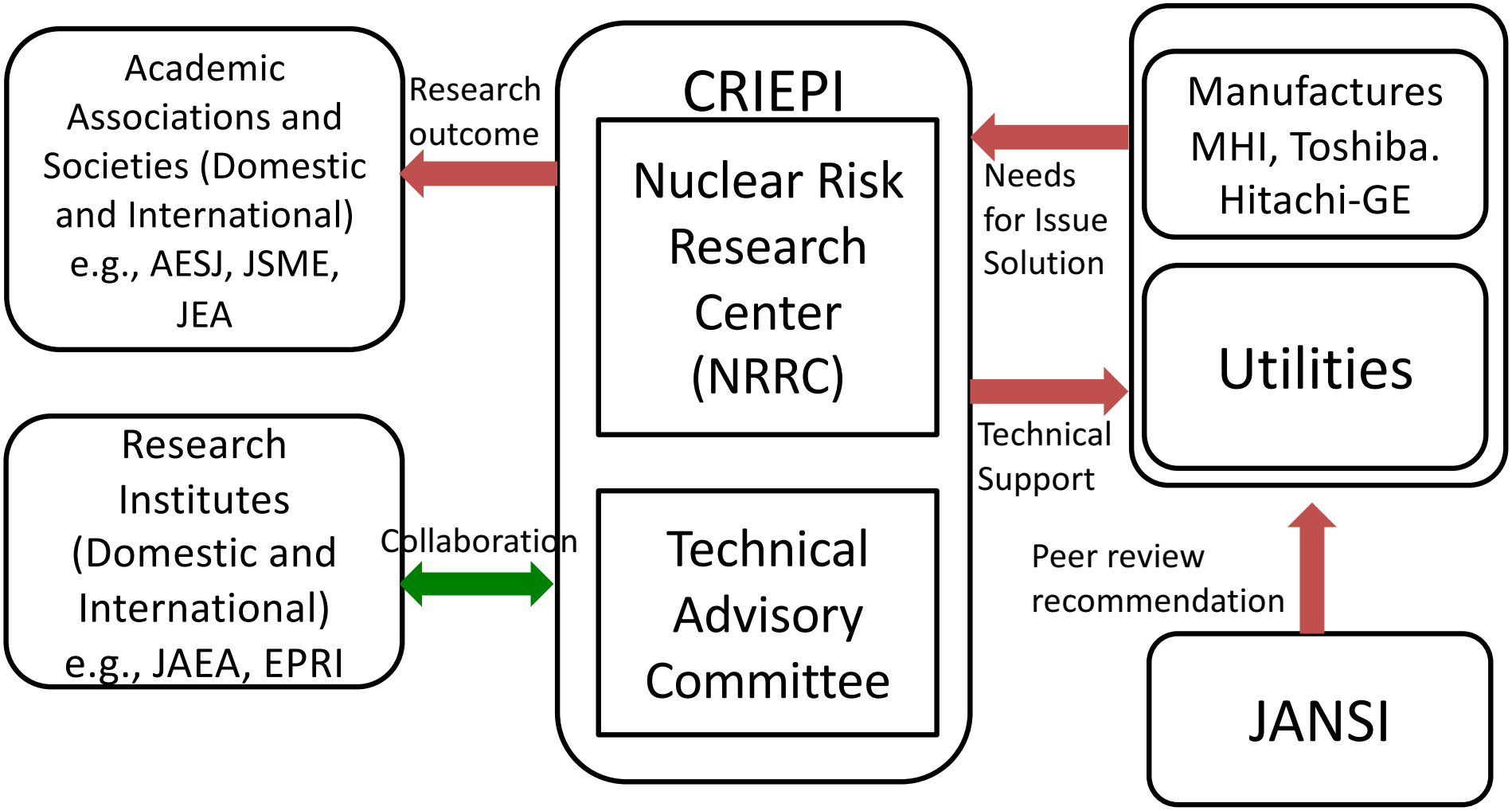
<Previous requirement>

<New requirement>



Source: Presentation by Mr. Shimizu, NRA Secretary-General, at the International Conference on Effective Nuclear Regulatory Systems on April 12, 2016, https://www.nsr.go.jp/data/000147733.pdf

New Framework of Industry's Voluntary Safety Initiative



Air Photo Service（March 20, 2011）

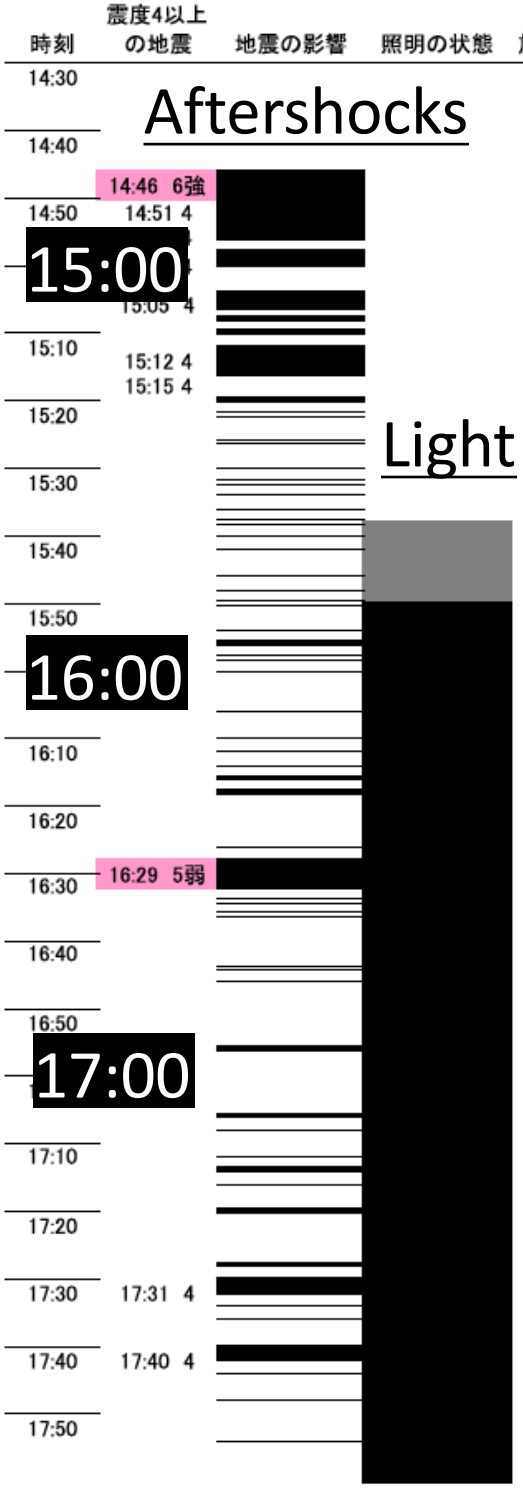
Dr. Kurokawa's View

The National Diet of Fukushima Nuclear Accident Independent Investigation Commission (NAIIC)

- The root causes of the accident were in the organizational and regulatory systems that supported faulty rationales for decisions and actions. The accident was "manmade";
- There were organizational problems that limited an effective emergency response in the utility such as insufficient level of knowledge, training, equipment inspection and emergency procedures related to severe accidents;
- The nuclear power plant operator did not fulfill its ultimate responsibility for the safety of his facility, relying on the regulators taking final responsibility. This relationship weakened the pursuance of minimizing risk in line with the principle of as low as reasonably practicable (ALARP);
- Laws and regulations related to nuclear safety have only been revised as stopgap measures when an accident happened: the latest technological findings from international sources have not been reflected in existing nuclear energy laws and regulations. What must be admitted is that this disaster was 'Made in Japan'; and
- Recommended fundamental reforms of both the structure of the electric power industry and the structure of the related government and regulatory agencies as well as their operation processes, the elimination of insular attitude, in particular.

Testimonies of Accident Witness (1) Initiation of Nightmare

- After this (around when the tsunami arrived), power lights began to flick, and then I saw they all turned off.
- The emergency power was shut off, and all of the lights on the MCR panel started to turn off. I did not know what happened however I couldn't figure out that it was caused by a tsunami.
- My fear were confirmed when operator was running into the MCR and yelling we're being flooded with sea water.



14:46 Earthquake

Many aftershocks

15:27 Tsunami

Blackout

Tsunami alarms

In darkness
No communication

Complete darkness

Habitability/Accessibility

17:41 Sunset

Radioactivity Level

17 : 50 Increased in RB

21 : 51 High in RB

22:00 Power Vehicle

Testimonies of Accident Witness (3)
Confirming Equipment Performance in Darkness

- The ERC at the power station asked me in the MCR to confirm the operating of RCIC. However that was not easy. Normally it only takes a few minutes. However it required 45 minutes to an hour because fastening a self-contained air unit tool 10 to 15 minutes, performing in the field took 30 minutes, returning to the MCR, taking off all the equipment, and going back to the MCR for the report.
- It would not have taken as long if we had some communication measures. Aftershocks were continued, and there was still the possibility of another tsunami would arrive.

Self-contained air unit

Working in the darkness
-Taken the service building entrance from inside.
- The floor was cluttered with objects

Availability of Electrical Equipment Operator Identified in Evening of March 11

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Offsite Power	X (0/6/7)	X (0/6/7)	X (0/6/7)	X (0/6/7)	X (0/6/7)	X (0/6/7)
Metal Clad	X	X	X	X	X	Δ
	X	X	X	X	X	O
	NA	X	NA	X	NA	Δ
Power Center	X	Δ	X	-	X	Δ
	X	Δ	X	Δ	X	O
	NA	X	NA	X	NA	O
Emergency DG	X	X	X	X	X	X
	X	X	X	X	X	O
	NA	NA	NA	NA	NA	X
DC Battery	X	X	O	X	O	O
	X	X	O	X	O	O

X: Not available (submerged/spray) Δ: Not available (no power feed)

O: Available NA: Not applicable

Monitored by the Assistant Shift Supervisor

The supervisor at the desk monitored plant data and information wearing a full face mask in the total darkness

Checking Instrument Gauges in the total darkness with only a flashlight to depend on

Temporary Instrument Power

Temporary batteries were connected to power control room instrument due to loss of power

Installing Temporary Power

Workers who are not working for electrical system were called out to manually lay the power cables

Power Recovery of Unit 2 and Alternative Cooling of Unit 1 & 2

- Obstacles on Access Routes
  - Fire hoses caused detour for access. After the explosion, debris and damaged fire engines become additional obstacles.

Leadership and Management for Safety

- Conclusion 2 *
  - Given the extreme circumstances of this accident the local management of the accident has been conducted in the best way possible and following Fundamental Safety Principle 3.

- Principle 3: Leadership and management for safety **

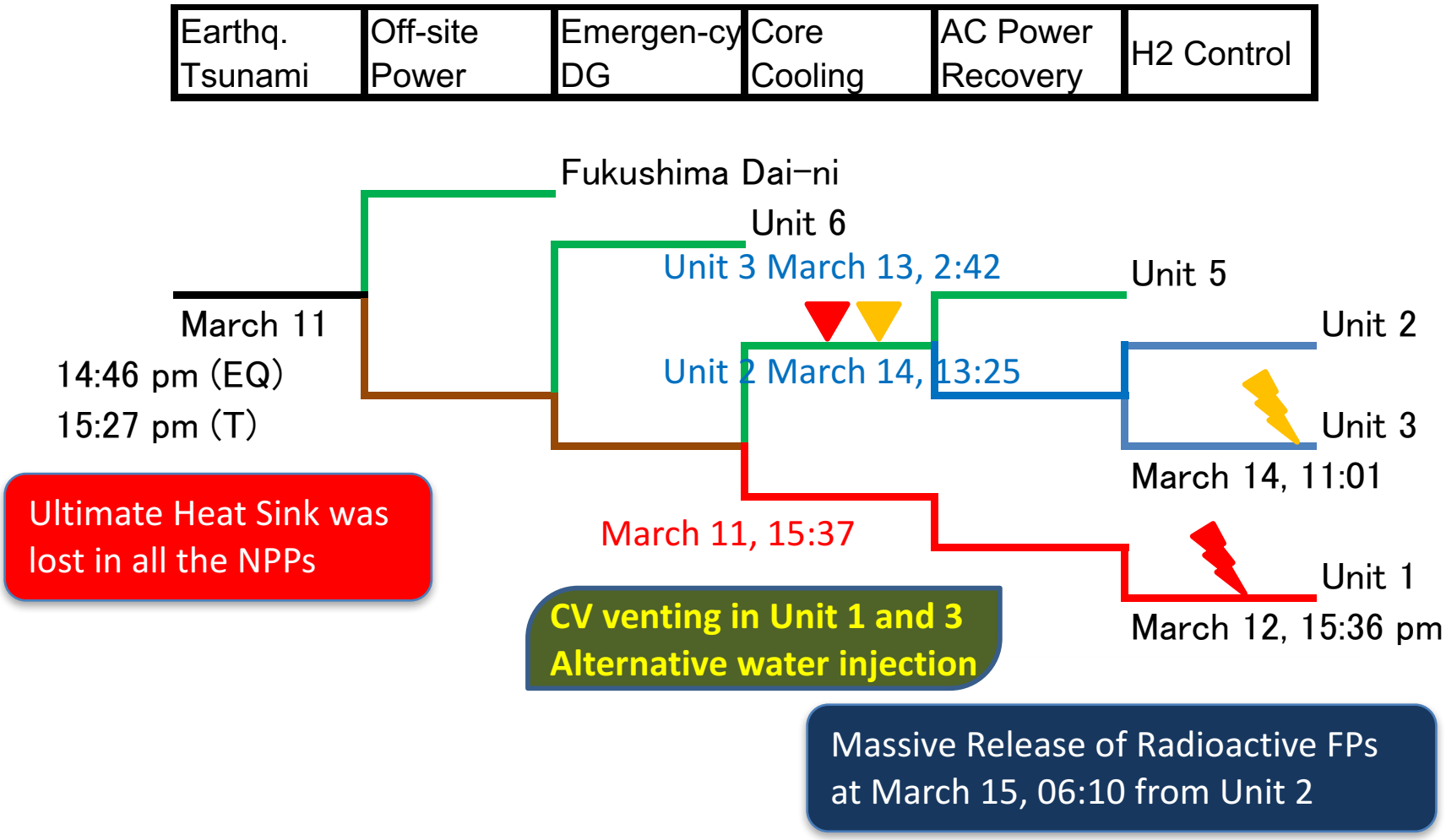
* IAEA International Fact Finding Expert Mission of the Fukushima Dai-ichi NPP Accident Following the Great East JAPAN Earthquake and Tsunami, Report to the IAEA Member States, Tokyo, Fukushima Dai-ichi NPP, Fukushima Dai-ni NPP and Tokai Dai-ni NPP, Japan, June 2011

** Fundamental Safety Principles, Safety Fundamentals SF-1, IAEA, 2006

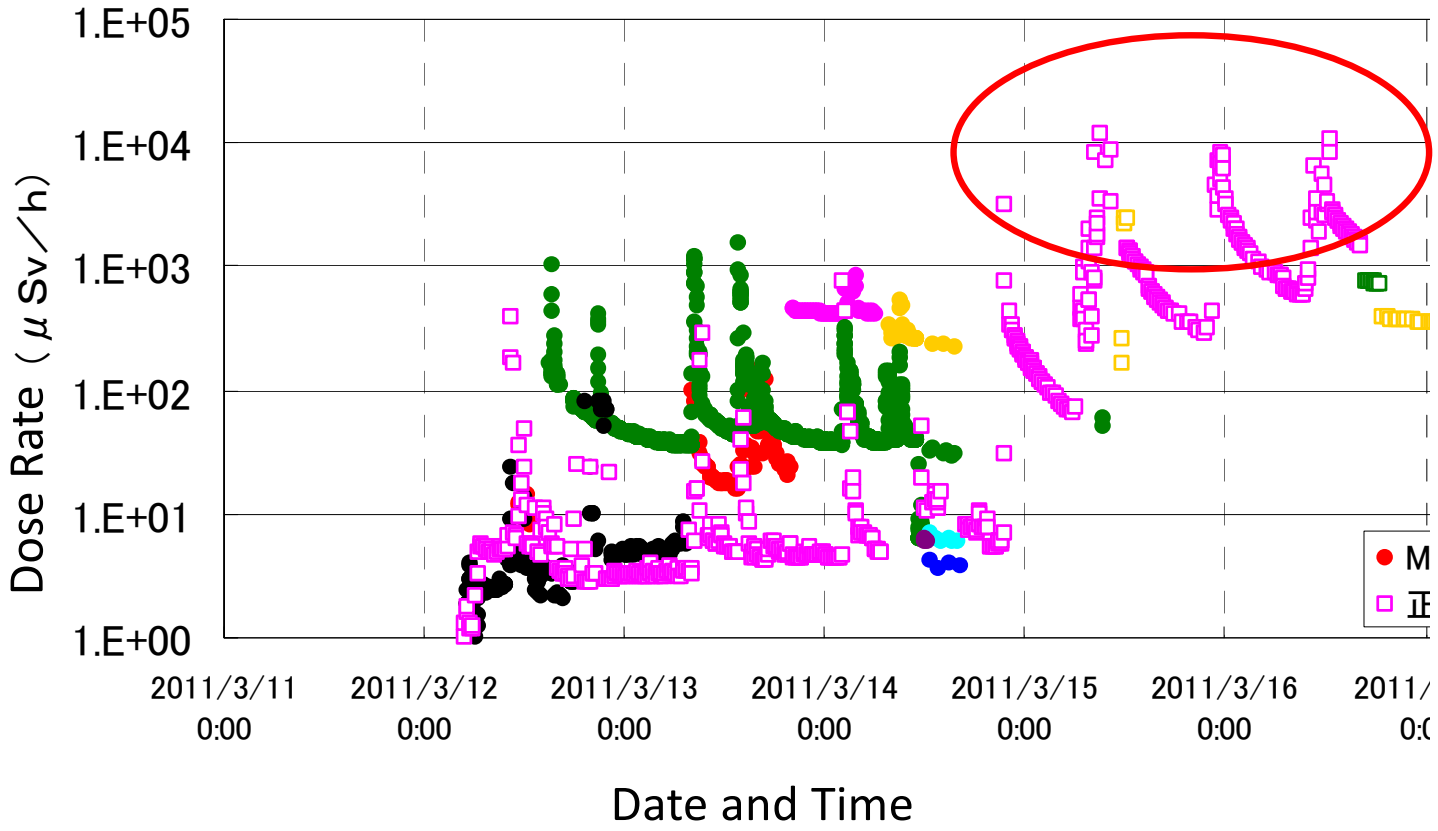
Major Events

- March 11, 14:46pm Earthquake, LOSP
- March 11, 15:27pm~ Tsunami, SBO
- Unit 1
  - March 11, 15:37pm IC stopped operation
  - March 12, 15:36pm H_2 explosion
- Unit 2
  - March 14, 13:25pm RCIC stopped operation
  - March 15, 6:10am FP large release
- Unit 3
  - March 13, 2:42am HPCI intentionally stopped
  - March 14, 11:01am H_2 explosion

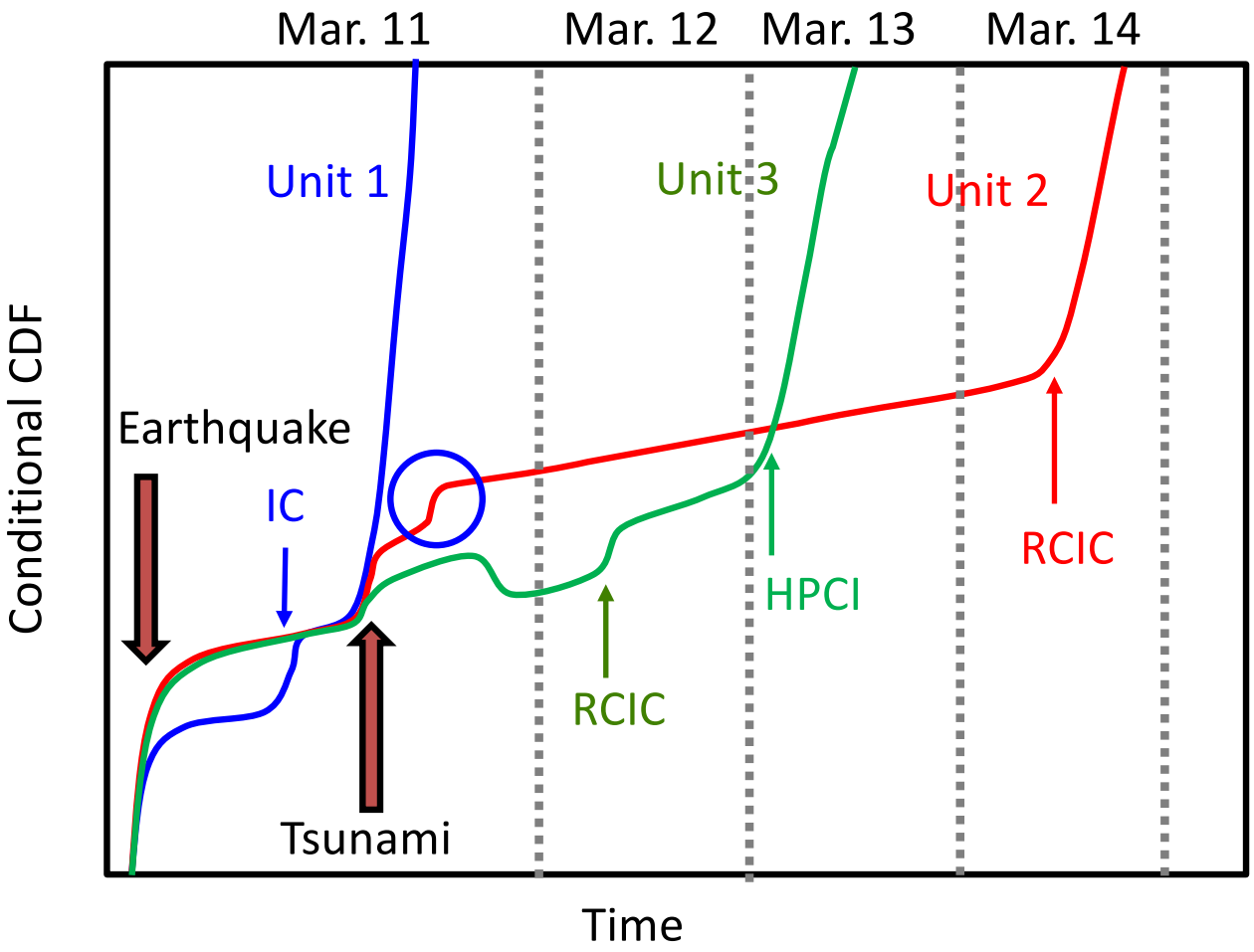
Accident Progression at Fukushima Dai-ichi NPS



Monitoring Data at Fukushima Daiichi Nuclear Power Site

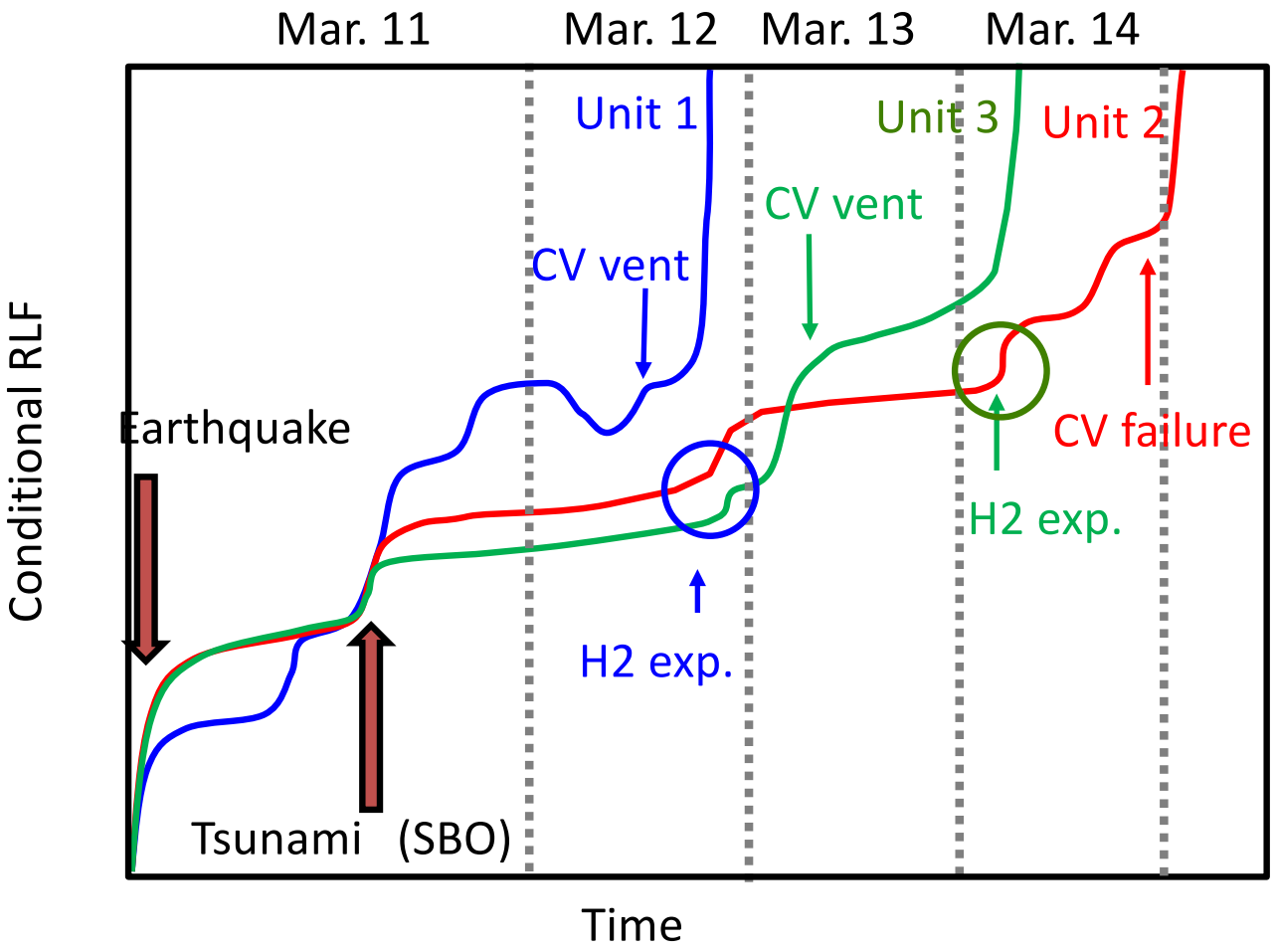


Dynamic Risk Profile and Multi-Unit Effect
Core Damage Frequency



SBO: Station Blackout, PCV: Primary Containment Vessel

Dynamic Risk Profile and Multi-Unit Effect
Large Release Frequency



SBO: Station Blackout, PCV: Primary Containment Vessel

Keywords

- Safety goal
  - NSC report on the safety goal was not endorsed (2003)
- ALARP (As low as reasonably practicable)
  - “How reasonable is reasonable enough?”
- Safety Culture
  - Lack of questioning and learning attitude

The Three Mile Island Unit 2 Accident

U.S.NRC, NUREG/BR-0518, No Undue Risk: *Regulating the Safety of Operating Nuclear Power Plants*, June 2014

Figure 3: The accident at Three Mile Island in March 1979 marked a turning point in the regulation of operating reactors. It led to a greater focus by the NRC on severe accidents, human factors, and the use of new accident-assessment tools.

TMI-2 Lessons… Japanese Response

- U.S.NRC expands the meaning of defense-in-depth to address matters other than design and hardware
  - A strategy that employs successive levels of defense and safety measures in the design, construction, and operation to ensure appropriate barriers, controls, and personnel are in place to prevent, contain, and mitigate exposure to radioactive material
- Three Mile Island was a troubling indication that determinism did not address all of the credible threats to plant safety.
- Japanese regulation had insisted on prevention strategy and deterministic approach
  - Aversion of nuclear risk and uncertainties
  - Insistence on complacency of safety

Why ALARP?
Paradox in Safety Goals (Okrent, 1987)

- The NRC has adopted a group of policy positions on safety goals, backfitting and severe accident that may prove to be incompatible with one another.
- Reducing core melt frequency or the frequency of a large release of radioactive material to the environment may involve expenditures that do not fit the cost-benefit procedures of the backfitting rules.

David Okrent, The Safety Goals of the U.S. Nuclear Regulatory Commission, Science Vol 236, 1987

Discussions on Safety Goal in Japan

- Interim Report on Safety Goal was published in Dec. 2003 from the Special Committee on Safety Goal, chaired by Prof. Kondo under Nuclear Safety Commission (NSC).
- The report was discussed in the NSC but not approved
- The ex-Chairman of the NSC, Dr. Matsuura looks back the discussion in NRRC Symposium in 2015*
  - There was criticism from experts (members of Special Committee on Safety Goal under NSC):
    - Not appropriate to use fatality for engineering goal
    - Safety goal based on probability is not understood nor accepted by society/public
- Since then, the safety goal has not been openly discussed

* Nuclear Risk Research Center Symposium, Tokyo, Sep. 2, 2015, http://criepi.denken.or.jp/jp/nrrc/event/pdf/sympo2015_outline.pdf

Safety Goals

- NSC Safety goal Committee*
  - Safety goal has to be established in relation to the social risk level; it should be continuously discussed and updated according to the scale of nuclear activities and social risk level.
  - Considering the intrinsic uncertainty in risk, we need to pursue strategy and approach in peer review and effective risk-informed decision making process more reasonable.
  - Safety goal is to be accepted and respected from the society overall. Essential point is to continue dialogue with society about the purpose, contents, application of the safety goal at every stage.
- George Apostolakis**
  - Safety goal is not criterion but a kind of guideline. It is meaningful and worthwhile only if the safety goal is effectively utilized for decision making process for the necessity of further risk reduction. PRA spotlights truly significant things in view of reactor safety.

* Interim Report on Safety Goal, Nuclear Safety Commission, 2003

** Nuclear Risk Research Center Symposium, Tokyo, Sep. 2, 2015

Sendai Nuclear Power Station, Unit 1 and Unit 2 The Fukuoka High Court, April 6, 2016

- However, it is impossible under the current level of science and technology to ensure the perfect safety such that radioactive materials are released under no circumstances.
- We have no option but to make a judgement with regard to the safety to be achieved and ensured on the basis of social convention or common wisdom, in other words, the acceptable safety level or acceptable risk level.
- As to the volcanic effect, the regulatory guide relies on the premise that a super volcanic eruption is forseeable. However one have to say prediction of possibility, time and magnitude of eruption is difficult even with the most recent scientific knowledge. (…snip...) Natural disaster risk of high consequence low frequency is not considered in regulations unless the occurrence potential is claimed with some certainty. It is a reflection of the socially accepted opinion that the risk of this kind is supposed to be negligible and acceptable.

Open Issues (Lessons-Learned)

- Category 4: Reinforcement of safety infrastructure
  27. Effective use of probabilistic safety assessment (PSA) in risk management
- Category 5: Safety Culture
  28. Thoroughly instill a safety culture

- The decision by Fukuoka High Court implies
  - "No undue risk" in comparison to "other risks"
  - Social receptiveness of safety goal, and
  - ALARP principle

Conclusions

- Use nuclear as a base-load power (20—22% in 2030)
- Regulatory reform, industry safety initiative, activities in academia…
- But….No benefit from nuclear yet

- Nuclear safety objective
  - Right risk management only with right safety objective
- Risk insights
  - Dynamic and interactive PRA for site
- Operational experience
  - Problem finding and reasonable solution
- Leadership and good management supported by safety culture
  - Crossroads exist for accident prevention, mitigation and termination