福島原発事故について

Accident in Fukushima Daiichi NPP

Dr. N. Nakae
JNES

2011年12月26日　茨城大学大学院　理工学研究科

本資料は、英国SERCO社、ベルギーSCK･CEN研究所、及び仏国CEAとの技術会議において情報提供のみのためにJNES（中江）が作成したものである。

Contents

Epicenter of the Earthquake

- The earthquake was occurred at 14:46 on March 11, 2011 in Tohoku district where is northern part of Japan.
- Magnitude was 9.0 Mw.
- Epicenter location is 38^{o} 6” north latitude and 142^{o} 51” east longitude, and the depth is 24 km.

source : www.tepco.co.jp

Tsunami After the Earthquake

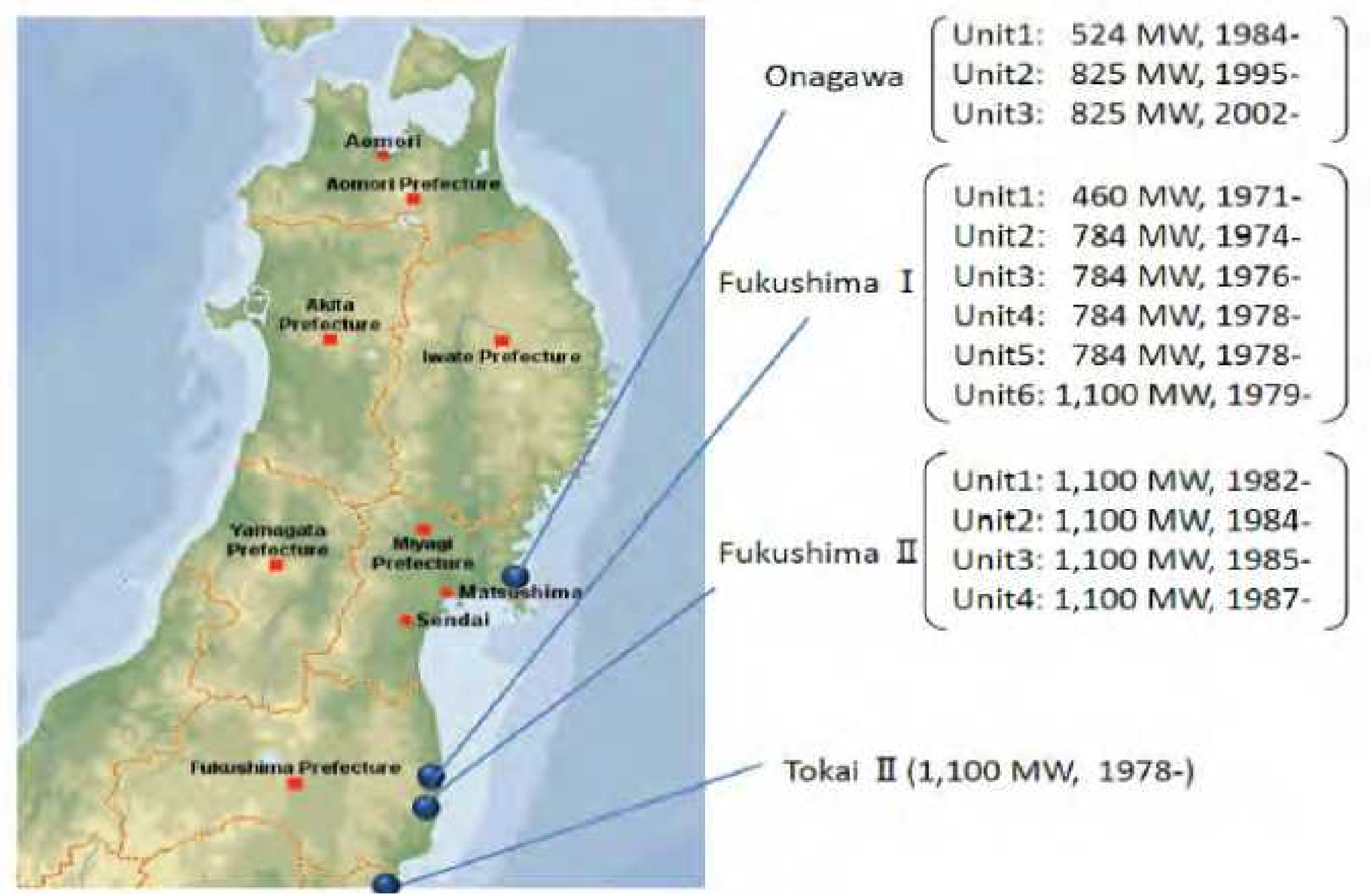
- East coast of northern areas in main island of Japan was seriously damaged due to tsunami.
- As of 24 August, 15,729 peoples are dead and 4,539 people are missing.

source : www.tepco.co.jp

JNES

Nuclear Reactors Near Epicenter of the Earthquake

Location of the Nuclear Installations



source : www.meti.go.jp

Effect of the Earthquake and Tsunami on NPPs

- **11 NPPs were automatically shut down.**
  - Onagawa Unit 1, 2, 3
  - 1F Unit 1, 2, 3
  - 2F Unit 1, 2, 3, 4
  - Tokai Daini

After the automatic shut down, the units of 1-3 at Onagawa NPS, the units 1-4 at 2F have been cold shut down safely. However, the units 1-3 at 1F have been failed to get cold shut down condition.

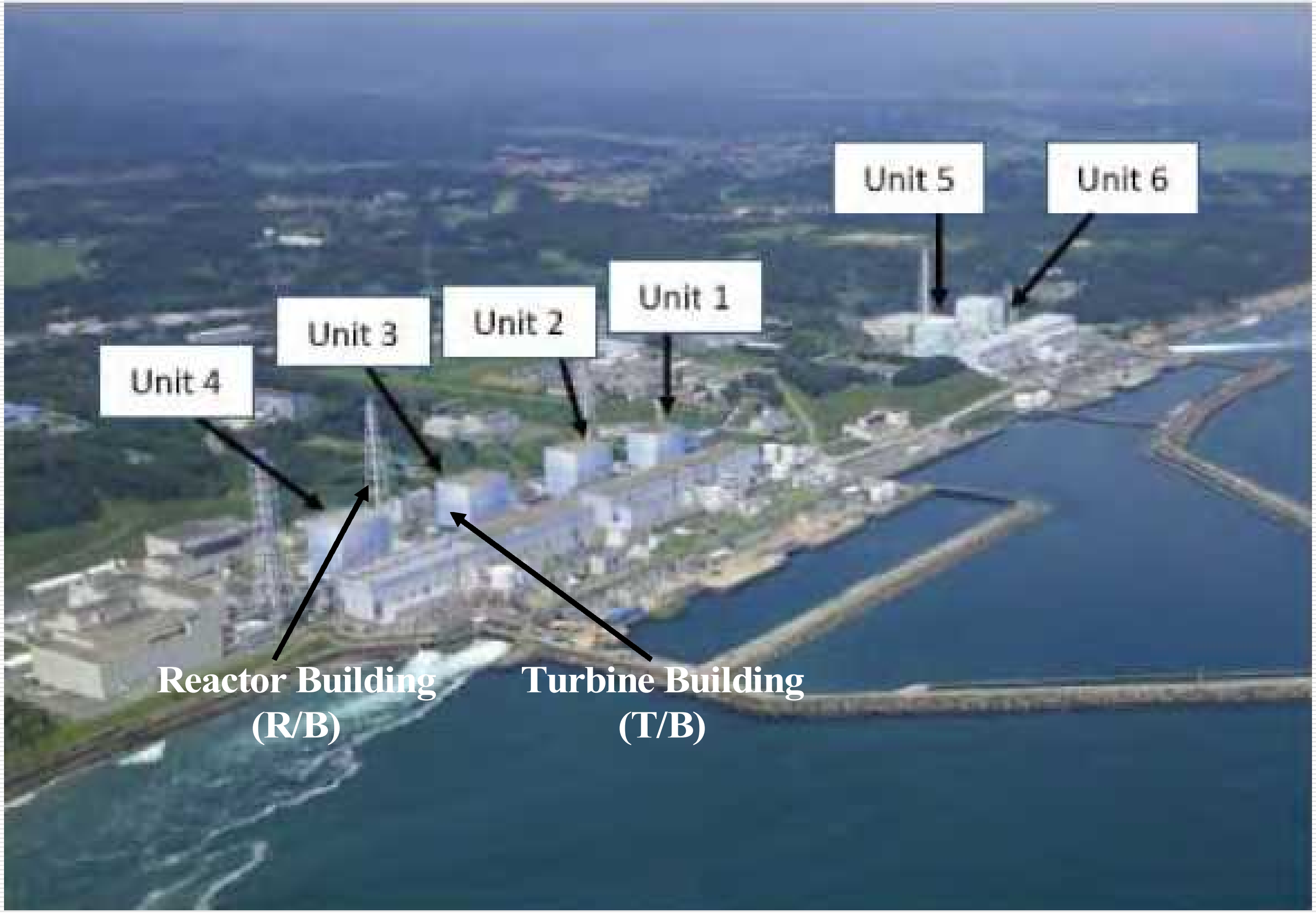
- **3 NPPs were under periodic inspection.**
  - 1F Unit 4, 5, 6

Spent fuels stored in the SFP at the units 5 and 6 have been cooled safely. However, those at unit 4 have not been cooled.

source : www.meti.go.jp

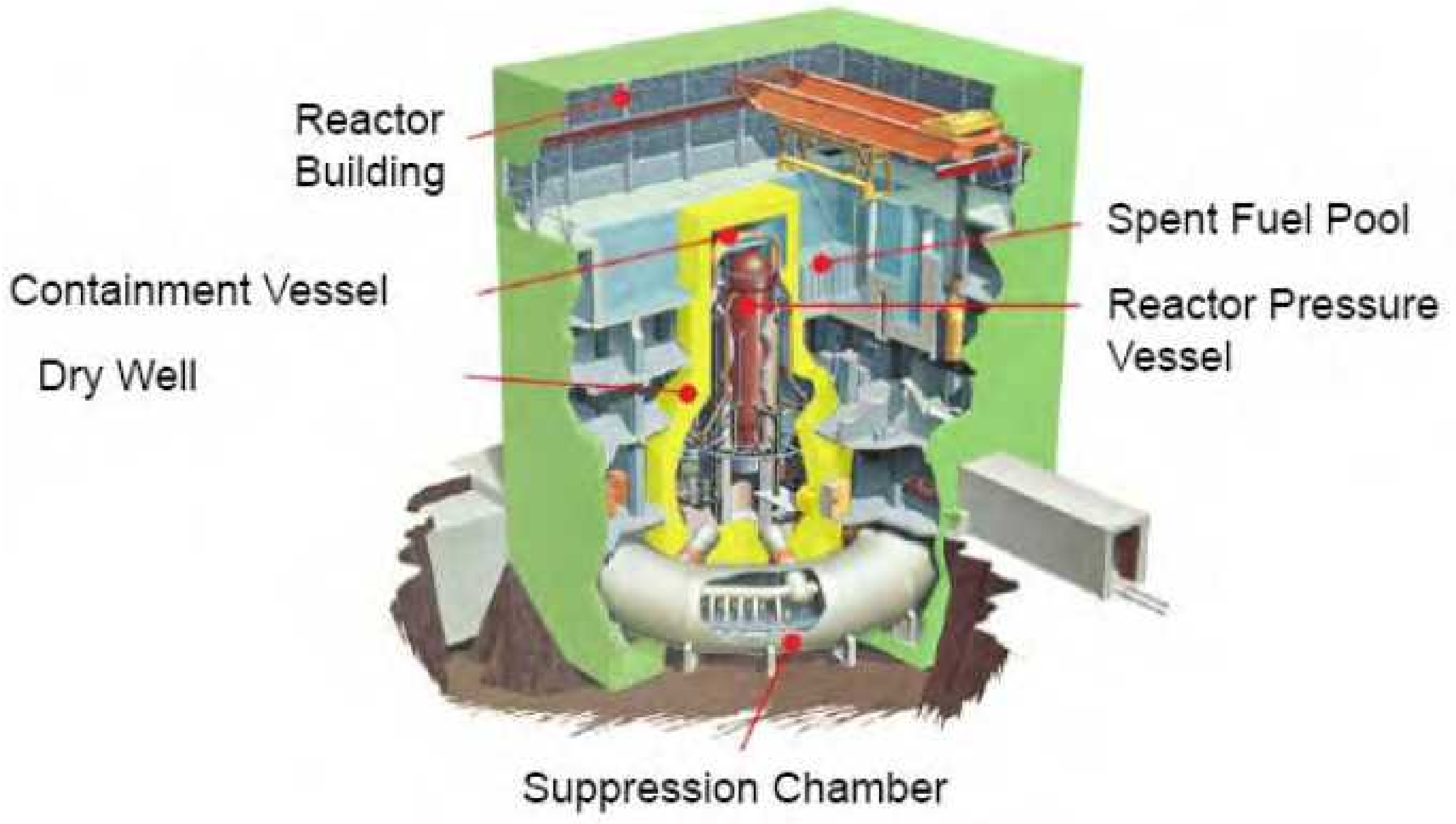
JNES

Location of Fukushima Daiichi (1F) NPPs



source : www.tepco.co.jp

Overview of Mark-I Type BWR (1F1-4)



source :USNRC Technical Training Center

JNES

Main Parameters of 1F NPPs

	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
Type	BWR-3	BWR-4	BWR-4	BWR-4	BWR-4	BWR-5
Containment Vessel (CV) Model	Mark-1	Mark-1	Mark-1	Mark-1	Mark-1	Mark-2
Electric Output (MWe)	460	784	784	784	784	1100
Max. Pressure of RPV (MPa)	8.24	8.24	8.24	8.24	8.62	8.62
Max. Temperature of RPV (°C)	300	300	300	300	302	302
Max. Pressure of CV (MPa)	0.43	0.38	0.38	0.38	0.38	0.28
Max. Temperature of CV (°C)	140	140	140	140	138	171 (D/W) 105 (S/C)
Fuel Type Loaded in the Core	8x8, 9x9	9x9	9x9	9x9	9x9	9x9
No. of Fuel Assembly Loaded	400	548	548*		548	764
No. of Fuel Assembly in SFP	392	615	566	1535	994	940
Commercial Operation	03/1971	07/1974	03/1976	10/1978	04/1978	10/1979
No. of Emergency DG	2	2	2	2	2	3**

* Thirty two (32) fuel assemblies are MOX fuel.

** One emergency DG is air-cooled.

source :Application document of license for establishment of NPP

JNES

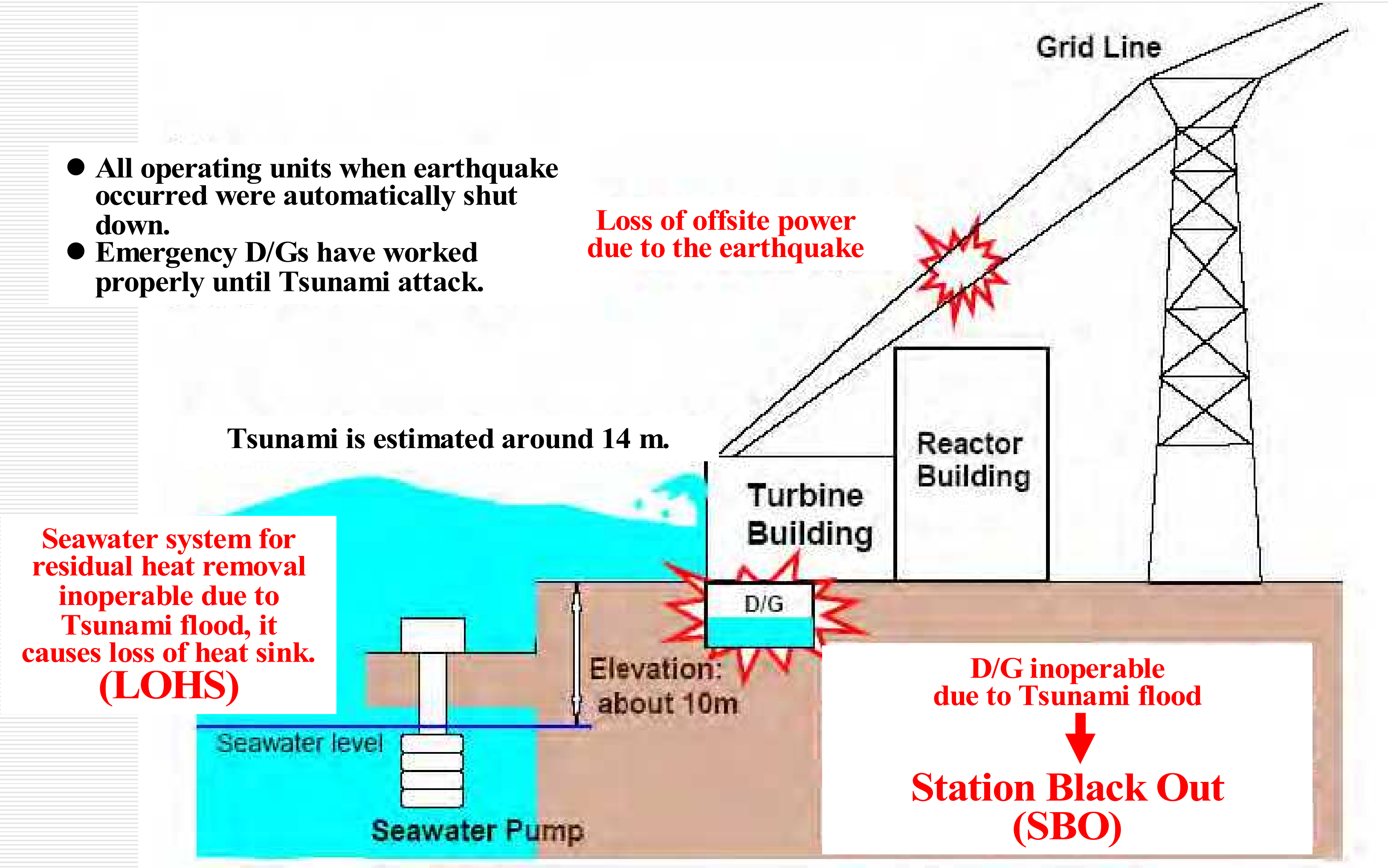
Plant Status of 1F NPPs Just Before Accident

Unit 1	Unit 2	Unit 3	Unit 4	Unit 5	Unit 6
in Operation	in Operation	in Operation	Refueling Outage	Refueling Outage	Refueling Outage
460MWe	784MWe	784MWe	0MWe	0MWe	0MWe
Spent Fuel Pool 1	Spent Fuel Pool 2	Spent Fuel Pool 3	Spent Fuel Pool 4	Spent Fuel Pool 5	Spent Fuel Pool 6
in normal Operation	in normal Operation	in normal Operation	All fuel assemblies in the R/C were transferred to SFP.	in normal Operation	in normal Operation

source : www.tepco.co.jp

Effects caused by the Earthquake and Tsunami

- All operating units when earthquake occurred were automatically shut down.
- Emergency D/Gs have worked properly until Tsunami attack.



source : www.tepco.co.jp

Summary of the Accident with Units 1-3 at 1F

	1F1	1F2	1F3
SBO	15:37 (Mar.11)	15:41 (Mar.11)	15:38 (Mar.11)
LOHS	same as above	same as above	same as above
Water Injection into Reactor Core	05:46 (Mar.12) freshwater	19:54 (Mar.14) seawater	13:12 (Mar.13) seawater
C/V Vent	14:30 (Mar.12)	try but fail	8:41 (Mar.13)
Hydrogen Explosion	15:36 (Mar.12)	after 6:00(Mar.15) at S/C	11:01 (Mar.14)
Fuel Melting	about 17:00 (Mar.11) 100%	about 18:00 (Mar.14) 100%	about 8:00 (Mar.13) 50%

source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety

JNES

Causes of the Different Behavior in Units 1-3

	1F1	1F2	1F3
Hydrogen Explosion	15:36 (Mar.12)	after 6:00 (Mar.15) at S/C	11:01 (Mar.14)
Fuel Melting	about 17:00 (Mar.11) 100%	about 18:00 (Mar.14) 100%	about 8:00 (Mar.13) 50%
Kinds of ECCS	IC	RCIC	RCIC HPCI
Operational State of ECCS	Startup of IC at 14:52 Mar. 11	Startup of RCIC at 14:50 Mar. 11 Stop of RCIC at 13:25 Mar.14	Startup of RCIC at 15:05 Mar. 11 Stop of RCIC at 11:36 Mar. 12 Startup of HPCI at 12:35 Mar. 12 Stop of HPCI at 02:42 Mar. 13
Ventilation of R/B	not be functioned	blowout panel broken due to explosion at 1F3	not be functioned

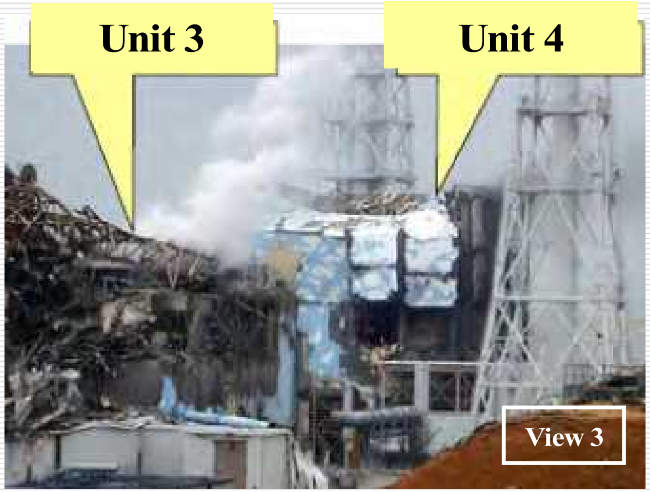
source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety

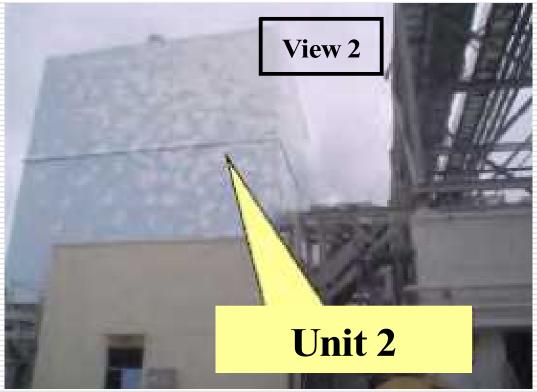
Summary of the Accident with Unit 4 at 1F

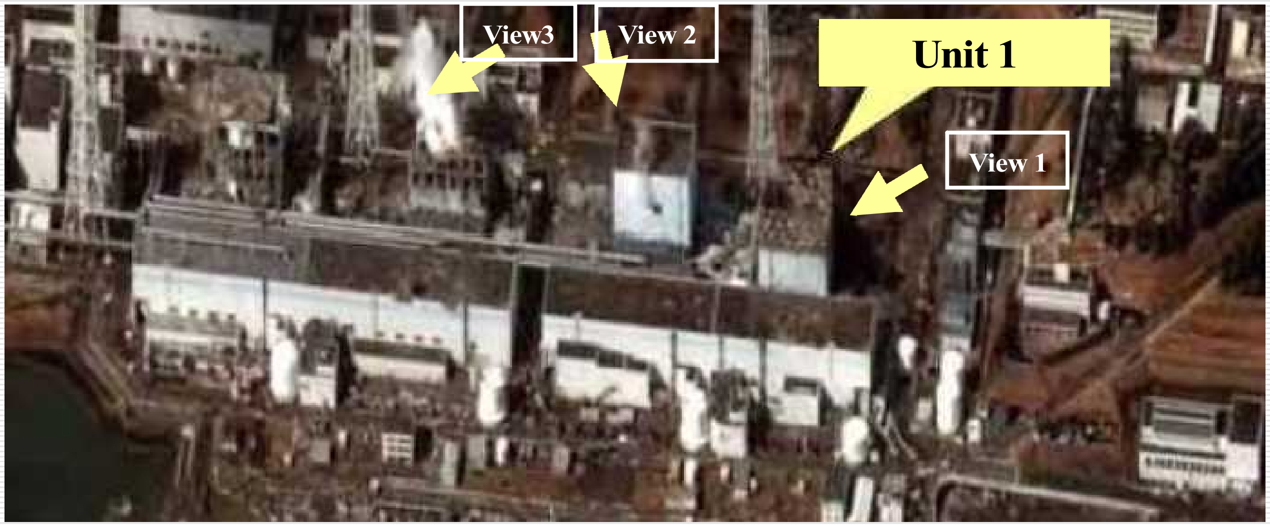
	Spent Fuel Pool in 1F4	
SBO	15:38 (Mar.11)	Spent fuel pool cooling system in 1F4 did not work due to SBO. Vaporization of SFP water occurred and water level decreased. Water may be supplied from the reactor core through cannel.
Hydrogen Explosion	about 6:00 (Mar.15)	Hydrogen production is not taken in 1F4, and it may come from 1F3.
Fuel Failure	Failure?	Fuel assemblies stored in the SFP were observed, also the activity of water in the pool was analyzed. Fuel failure may not be occurred.

source : www.tepco.co.jp

Photograph of 1F1-4 After Exposure







source : www.tepco.co.jp and www.digitalglobe.com

Water Discharge by Concrete Pumping Vehicle

source : www.tepco.co.jp

Why Severe Accident Occurred?

Direct Cause

- Tsunami continued by earthquake caused SBO and LOHS.
- SBO and LOHS are direct causes of severe accident.

Design and Construction

- The countermeasure against tsunami attack was not enough to prevent SBO and LOHS.
- There are flaws in the guideline of safety design, especially on SBO.

PSA and Stress Test

- PSA or PRA has been actively performed, but the scope is not enough to cover wide range of accident scenario.
- Stress test has not been done.

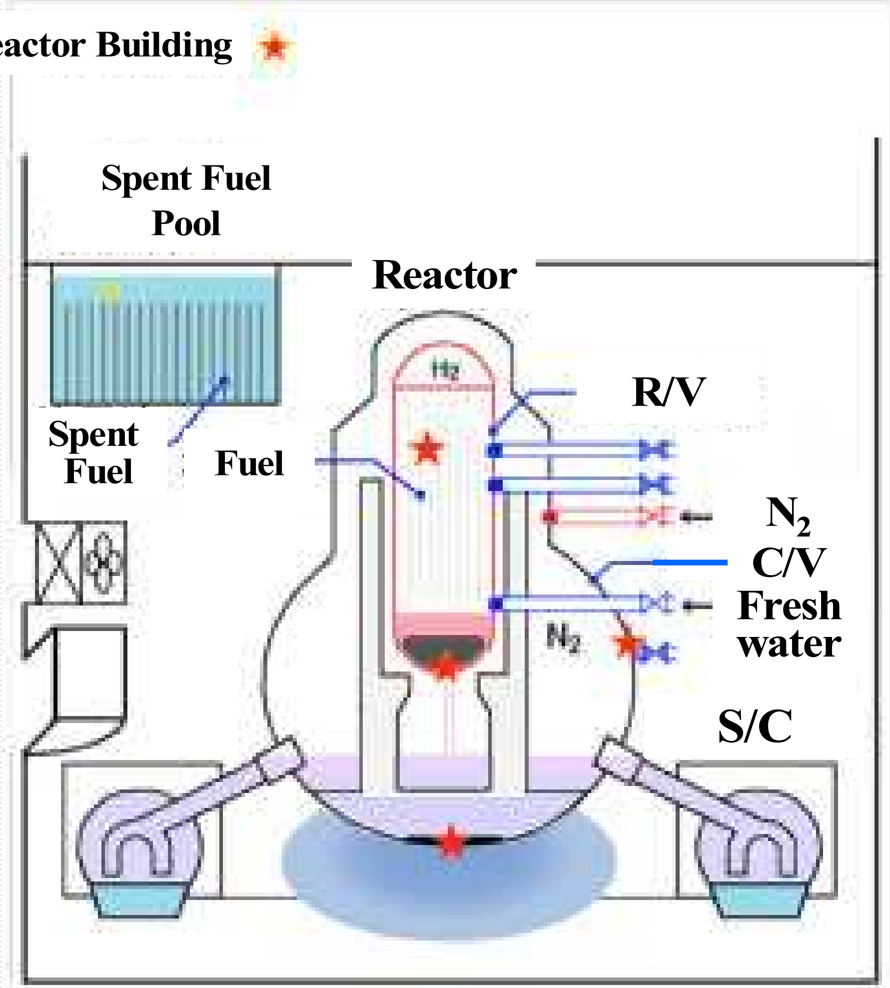
Mind and Education

- The occurrence of real severe accident is not in the right mind frame by persons concerned with nuclear engineering.
- The education of operators is not enough against protection of severe accident.

source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety

JNES

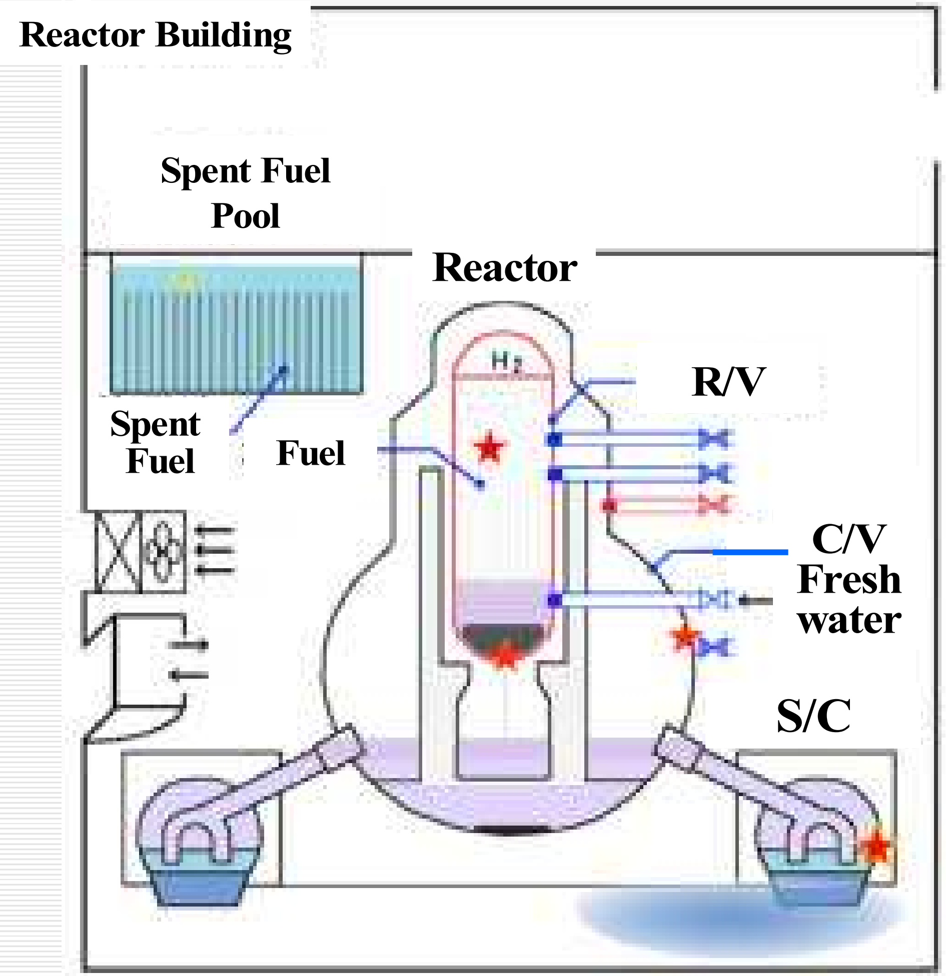
Status of 1F1 As of 24 August 2011



Plant Parameters	1F1
Temperature at feed water nozzle (ºC)	91.2
Reactor Pressure (MPa g)	0.017
Reactor Coolant Level (mm)	down scale
Temperature in Spent Fuel Pool (ºC)	29.0

source : www.tepco.co.jp and fukumitsu.xii.jp/syu_f/FukushimaGenpatsu_1.html

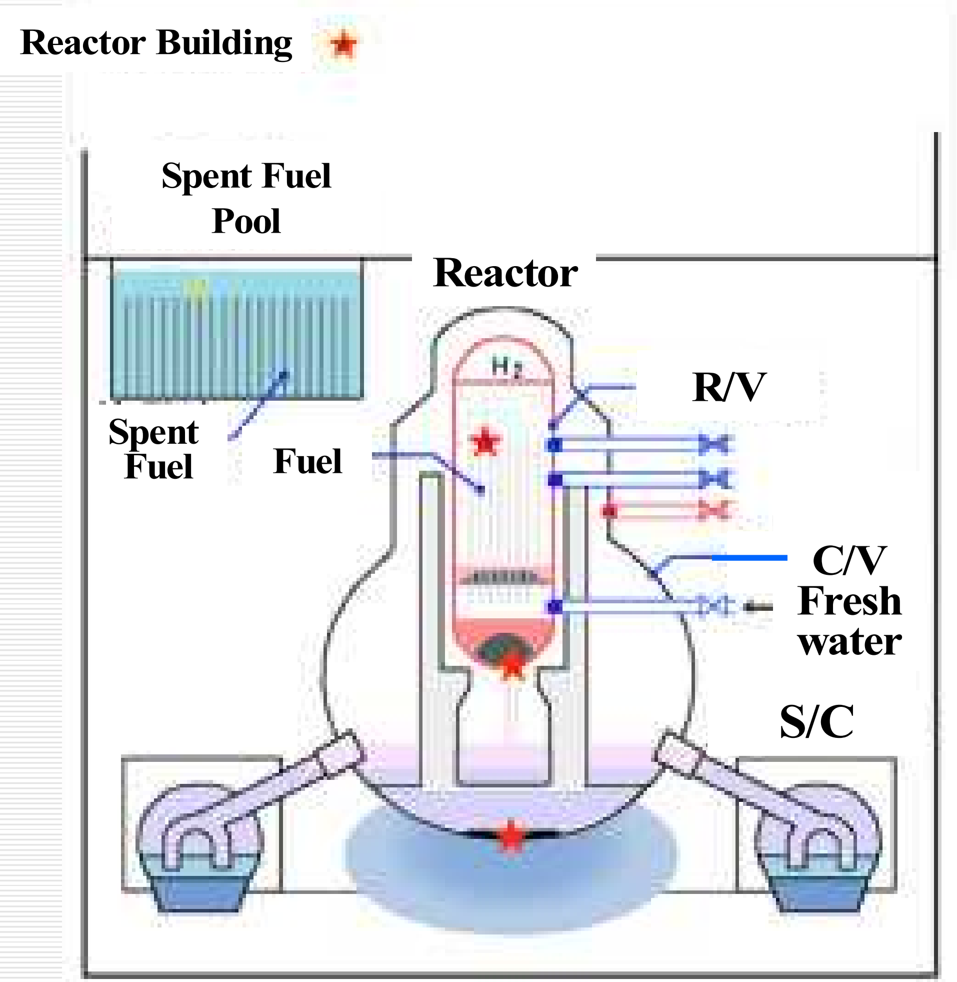
Status of 1F2 As of 24 August 2011



Plant Parameters	1F2
Temperature at feed water nozzle (ºC)	106.8
Reactor Pressure (MPa g)	0.012
Reactor Coolant Level (mm)	-1850
Temperature in Spent Fuel Pool (ºC)	34.0

source : www.tepco.co.jp and fukumitsu.xii.jp/syu_f/FukushimaGenpatsu_1.html

Status of 1F3 As of 24 August 2011

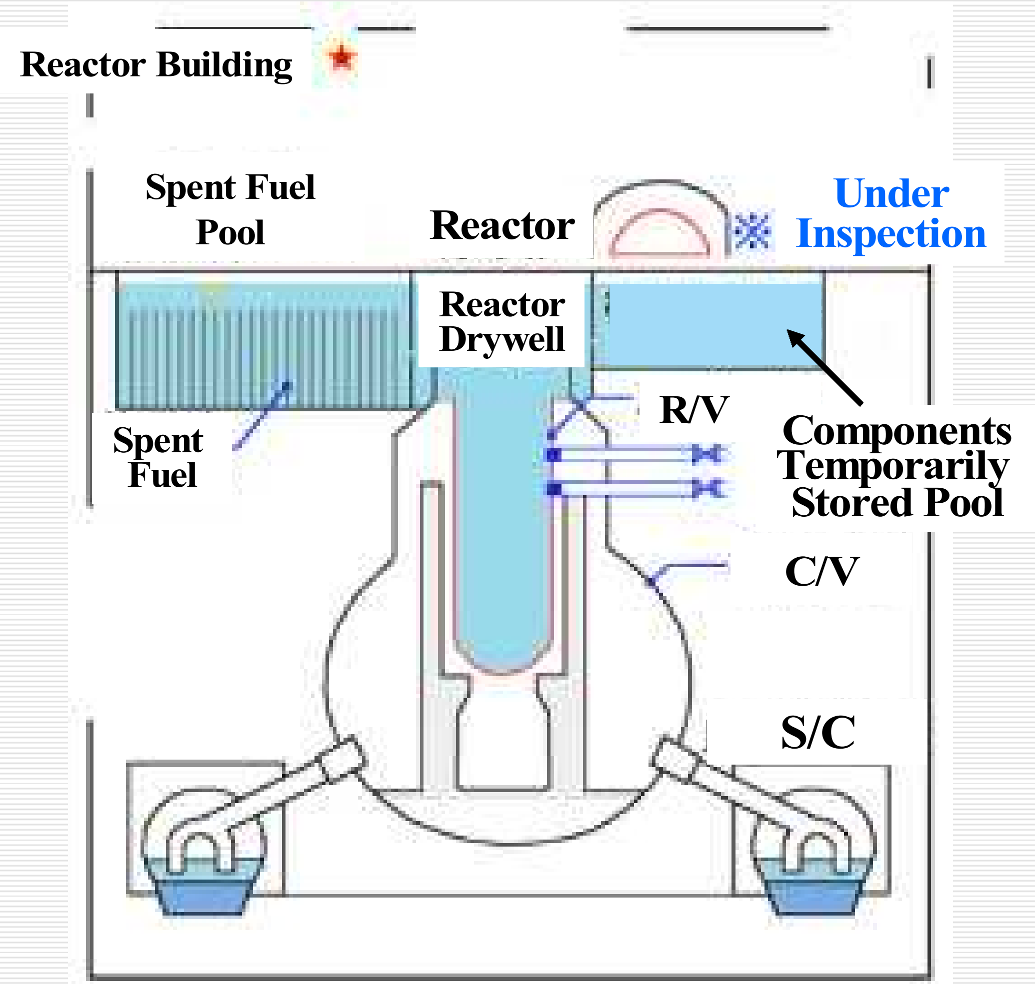


Plant Parameters	1F3
Temperature at feed water nozzle (°C)	112.0
Reactor Pressure (MPa g)	-0.183
Reactor Coolant Level (mm)	-1750
Temperature in Spent Fuel Pool (°C)	31.6

source : www.tepco.co.jp and fukumitsu.xii.jp/syu_f/FukushimaGenpatsu_1.html

JNES

Status of 1F4 As of 24 August 2011



Plant Parameters	1F4
Temperature at feed water nozzle (ºC)	-
Reactor Pressure (MPa)	-
Reactor Coolant Level (mm)	-
Temperature in Spent Fuel Pool (ºC)	40

source : www.tepco.co.jp and fukumitsu.xii.jp/syu_f/FukushimaGenpatsu_1.html

Treatment of Contaminated Water

- A large amount of fresh and sea water were discharged into reactor cores of 1F1-3, and SFP of 1F4.
- These water contaminated by radioactive materials were free to diffuse from R/C or SFP to R/B.
- Contaminated water existed in R/B was recovered into special tank and a fraction of it was leaked from R/B into sea water.
- Very low activated water was released from the tank to sea.
- Some of it is recycled for cooling R/C and SFP by use of newly equipped system. Then, cooling system is changed from once through system to closed recycle system.

source : www.tepco.co.jp

JNES

Release of Radioactive Materials to the Sea

Events	Results
Leakage from 1F2 (Apr. 2 - Apr. 6)	On April 2, it was discovered that highly contaminated water was flowing into the sea water through the crack on the lateral surface of the pit. Total discharged amount of the radioactive was assumed to be approximately $4.7\text{x}10^{15}$ Bq.
Discharge to the sea (Apr. 4 - Apr. 10)	In order to secure capability for highly contaminated water, TEPCO discharged low level radioactive water into sea water. Total discharged amount was presumed to be approximately $1.5\text{x}10^{11}$ Bq.
Leakage from 1F3 (May 11)	On May 11, TEPCO confirmed the outflow from a pit near Channel of 1F3 into the sea. Total amount can be estimated to be $2.0\text{x}10^{13}$ Bq.

source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety

JNES

Amount of Radioactive Materials Discharged

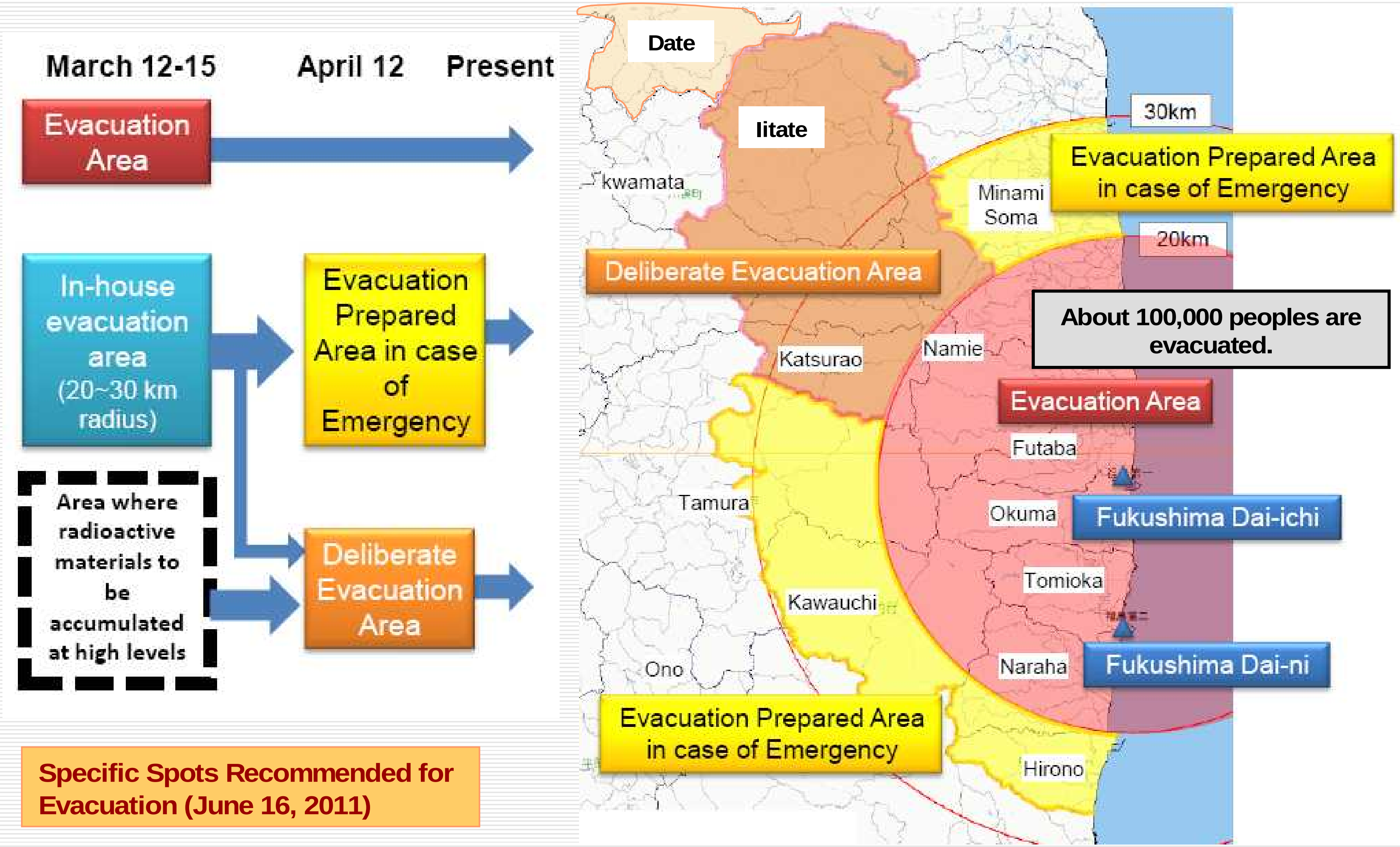
	I-131	Cs-137
Amount of RM discharged to the atmosphere (Bq)	1.6×10^{17}	1.5×10^{16}

	Noble gases	Iodine	Other nuclides
Release Rate (%) at 1F1	100	1	less than 1
Release Rate (%) at 1F2	100	0.4-7	Te:0.4-3 Ce:0.3-6
Release Rate (%) at 1F3	100	0.4-0.8	0.3-0.6

analyzed by use of MELCOR code

source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety

Evacuation of Neighborhoods



source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety

JNES

INES Rating

NISA issued provisional INES ratings, based on "What is known" at the time.

Timing	INES Ratings	Criteria
March 11	Level 3 for 1F1, 2 and 3 Level 3 for 2F1, 2 and 4	Defense in Depth
March 12	Level 4 for 1F1	Radiological Barriers and Control
March 18	Level 5 for 1F1, 2 and 3 Level 3 for 1F4	Radiological Barriers and Control Defense in Depth
April 12	Level 7 for 1F NPS	People and Environment

Official rating will be done after cause and countermeasures are identified.

source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety

Current Status of Nuclear Energy Policy

- Chubu EPC is requested to stop all Hamaoka NPPs due to political reason.
- It is proposed that renewable energies should be developed instead of nuclear energy.
- Restart of NPPs whose periodic inspection has been finished or will be started is uncertain though two step stress test is scheduled on NPPs.
- If this situation is continued, all NPPs will be stopped.
- Development of nuclear fuel cycle including FBR is also uncertain.
- Political parties and politicians in Japan have different policies on utilization nuclear energy in future.

source :news paper and so on

Current Status of NPP in Japan As of 25 August

EC	Plant	Status	EC	Plant	Status	EC	Plant	Status
Hokkaido EPCO	Tomari-1	PI	TEPCO	K-1	PI	KEPCO	Takahama-1	PI
	Tomari-2	PI		K-2	SD		Takahama-2	OP
	Tomari-3	OP		K-3	SD		Takahama-3	OP
Tohoku EPCO	Higashi-dori	SD		K-4	SD		Takahama-4	PI
	Onagawa-1	SD		K-5	OP	Chugoku EPCO	Shimane-1	PI
	Onagawa-2	SD		K-6	OP		Shimane-2	OP
	Onagawa-3	SD		K-7	PI	Shikoku EPCO	Ikata-1	OP
Hokuriku EPCO	Shika-1	SD	Chubu EPCO	Hamaoka-1	DC		Ikata-2	OP
	Shika-2	PI		Hamaoka-2	DC		Ikata-3	PI
TEPCO	1F-1	SD		Hamaoka-3	PI	Kyushu EPCO	Genkai-1	OP
	1F-2	SD		Hamaoka-4	SD		Genkai-2	PI
	1F-3	SD		Hamaoka-5	SD		Genkai-3	PI
	1F-4	SD	KEPCO	Mihama-1	PI		Genkai-4	OP
	1F-5	SD		Mihama-2	OP		Sendai-1	PI
	1F-6	SD		Mihama-3	PI		Sendai-2	OP
	2F-1	SD		Ooi-1	PI	JAPC	Tokai-1	DC
	2F-2	SD		Ooi-2	OP		Tokai-2	PI
	2F-3	SD		Ooi-3	PI		Tsuruga-1	PI
	2F-4	SD		Ooi-4	PI		Tsuruga-2	SD

OP: Operation (13) PI: Periodic Inspection (20) SD: Shutdown (21) DC: Decommissioning (3)

Lessons Learned From 1F Accident (1)

1. Appropriate DBAs

- Appropriate consideration for natural hazards by design
- Design basis tsunami height 5.7 m against 15 m of actual tsunami height

2. Robustness in responding to BDBAs such as SBO for long duration and LOHS

- Appropriate design philosophy to sustain safety function against common cause failures brought by natural hazards
  - Only 1 air cooled DG, which is located on the ground level, was survived
  - All the sea water pumps were located slightly above the design tsunami height and they were with no protection against water
- Appropriate AM measures for both prevention and mitigation of severe accidents
  - No AMs for SFP cooling and H_2 control in the R/B
  - No AMs training under severe conditions for multi-units under continuous aftershocks

source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety

Lessons Learned From 1F Accident (2)

3. Difficult situation for Post Severe Accident Recovery

- Warning for aftershocks and subsequent tsunami
- High radiation in working area
- Massive radioactive debris everywhere within the site

4. Emergency Preparedness and Responses

- Evacuation zone
- Function of off-site center
- Communication
- Radiation monitoring

source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety

Statement of AEC on July 19, 2011

- **Atomic Energy Commission in Japan (AEC) found out the following facts from 1F NPP accident.**
  - **To arise skepticism toward adequacy of design basis tsunami height and DBEs**
  - **To know inadequacy in defense in depth approaches**
  - **To occur severe accident whose scale is much bigger than those expected in nuclear policy**
  - **To find out problems in crisis-control structure in and out of NPP**

- **AEC takes the following actions.**
  - **To ask for strengthening safety measures of NPP**
  - **To set up basic strategy for future nuclear energy research, development and utilization within 2011 JFY based on atomic energy basic law**

Original statement of AEC (Fundamental Policy Concerning Budget Estimation of Nuclear in JFY of 2012) was published in Japanese and translated into English by JNES.

source : www.aec.go.jp

JNES

Accident in Fukushima Daiichi NPP

Thank you very much for your attention!

JNES

Support Documentation

Accident in Fukushima Daiichi NPP

for an information purpose only

Dr. N. Nakae

JNES

JNES

Contents

1. Radiation Exposure (engaged person)
2. Radiation Exposure (peripheral people)
3. Amount of Radioactive Materials Discharged
4. Integrated Dose at Reading Points
5. Road Map of Recovery Plan
6. Emergency Safety Precaution
7. Conducting Stress Tests
8. Careful Thinking of Nuclear Energy

JNES

Radiation Exposure (engaged person)

Dose limit	100 mSv→250 mSv		
	March	April	May
Total number of engaged persons	3,538	3,254	4,772
Average radiation dose (mSv)	23.1	4.2	1.85
Number of the persons whose dose exceeds 100 mSv	111	0	0
Number of the persons whose dose exceeds 250 mSv	6	0	0

source : www.tepco.co.jp

JNES

Radiation Exposure (peripheral people)

Radiation dose level No. of screening people (As of 21 August 2011)	no harmful effect 219,743 persons
Radiation dose level on childhood thyroid No. of screening infants (As of 30 March 2011)	no harmful effect 1080

source :wwwcms.pref.fukushima.jp
www.nsc.go.jp

Amount of Radioactive Materials Discharged

	Fukushima Daiichi NPS		Chernobyl	TMI
	NISA	NSC		
I-131 (a)	1.3×10^{17}	1.5×10^{17}	1.8×10^{18}	5.6×10^{11}
Cs-137	6.1×10^{15}	1.2×10^{16}	8.5×10^{16}	negligible
Reduced Iodine (b)	2.4×10^{17}	4.8×10^{17}	3.4×10^{18}	negligible
(a) + (b)	3.7×10^{17}	6.3×10^{17}	5.2×10^{18}	5.6×10^{11}

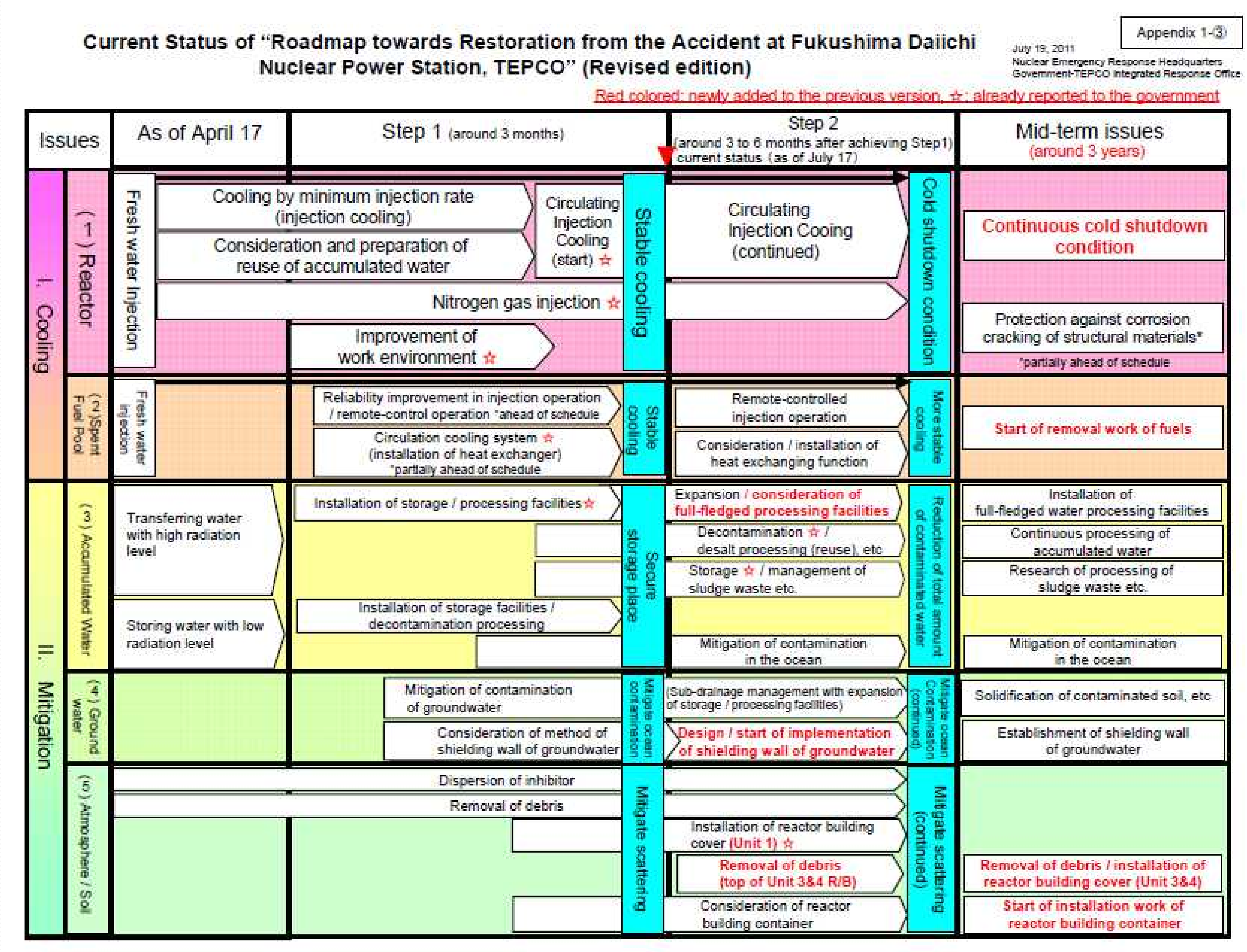
source : Report of the Japanese Government to IAEA Ministerial Conference on Nuclear Safety
T. Watarai, Y. Inoue, F. Masuda, J. of the Atomic Energy Society of Japan, Vol.32,No.4 (1990)

Integrated Dose at Reading Points

source :http://radioactivity.mext.go.jp/

JNES

Road Map of Recovery Plan



source :www.meti.go.jp

Emergency Safety Precaution

- **Nuclear and Industrial Safety Agency (NISA) called for the emergency safety precaution on 30 March, 2011.**
- **The emergency safety caution consists of the following six items.**

① **Implementing the emergency inspections of equipments and facilities to ensure the readiness for tsunami induced emergencies.**

② **Implementing a review of the Emergency Preparedness Plan and conducting drills with the assumption that all alternating current power sources, seawater cooling function and Spent Fuel Pool cooling function have been lost.**

③ **Ensuring the alternative power sources that can supply necessary power in a timely manner when both on-site power and emergency power supply are lost.**

④ **Preparing for the measures to recover heat removal function in a timely manner with the assumption of loss of seawater system facility or its function.**

⑤ **Implementing the measures to supply coolant water to Spent Fuel Pools in timely manner when cooling function for the pools and usual on-site water supply to the pools are lost.**

⑥ **Implementing necessary measures taking into account the structural configuration of each NPS site**

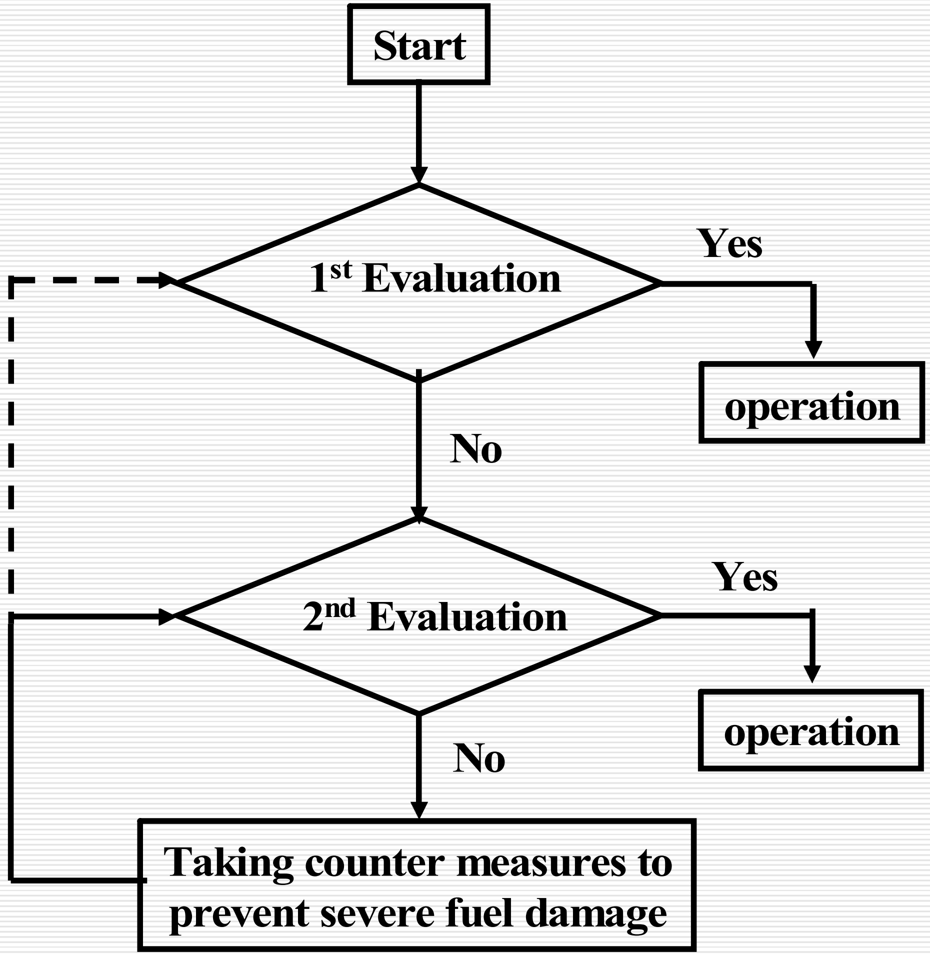
source :News Release from NISA on March 30, 2011

Conducting Stress Tests

	First Round Evaluation	Second Round Evaluation
Intended Events	**Natural Hazard** Earthquake, Tsunami, Overlapping **Loss of Safety Functions** Electric Power Supply, Final Heat Sink, **Severe Accident Management**	**Natural Hazard** Earthquake, Tsunami, Overlapping **Loss of Safety Functions** Electric Power Supply, Final Heat Sink, Overlapping **Severe Accident Management**
Contents	To evaluate safety margin for hypothetical events (beyond design basis accident, BDBA) To check if evaluation results are satisfied with acceptable values To confirm that NPP has a certain level of safety margin	To evaluate safety margin for hypothetical events (beyond design basis accident, BDBA) To identify cliff edge for severe damage of fuel To examine measures to prevent severe fuel damage
Remarks	Japan Original Apply to NPP under inspection	Correspond to European Stress Test Apply to NPP under operation

source : www.meti.go.jp

Conducting Stress Tests (Flow Sheet)



source :N. Nakae, private communication

Careful Thinking of Nuclear Energy

- Processing the Accident of Fukushima Daiichi Nuclear Power Plants

- Safety Improvement of Existing Nuclear Power Plants

- Procession of the Development of Nuclear Fuel Cycle including LMFBR

source :N. Nakae, private communication

JNES

Processing the Accident of 1F NPPs

(1) Radiation Exposure of General Public living in the Vicinity

① Careful Follow-up of the Effect on Health of General Public Received Radiation Dose

② Designing Criteria of Dose Limit for Severe Accident in Order to Control Radiation Exposure of the Workers and the People in the Surrounding Area Based on the Reporting by ICRP

③ Explanation of the Background of the Criteria done by the Government

(2) Recovery of Environment Contamination

① Assurance of the Period of Evacuation and Safety of the Environment when they come back again

② Returning Evacuated Peoples Back to Original Places as soon as possible

③ Cleaning Contaminated Soil, Building, Plants and others up

(3) Treatment and Disposal of NPPs Damaged

① Handling and Reprocessing of Fuels Stored in Damaged Core and SFP

② Decommissioning Damaged NPPs Including Environment Clean-up

source :N. Nakae, private communication

JNES

Safety Improvement of Existing NPPs

- **Review of Guides** of Safety Design, Safety Assessment, Site Evaluating, Severe Accident (SA), its related Accident Management (AM), Radiation Dose Limit, and Evacuation
- **Review of Safety Design** such as Water Proof of Components, Electric Power Supply, Multiple and Multiplicity of Safety Protection System, Monitoring of Plant Parameters, Seismic, and Tsunami
- **Review of Safety Assessment** such as External Events, especially Natural Hazard such as Earthquake and Tsunami
- **Review of Site Evaluating** in relation with Severe Accident (SA) in view point of Determining Source Term and Method of Evaluating Dose Effect on the Public and Environment
- **Extraction of Systematic Fuel Failure Modes** in SA and Taking into Account of Corresponding AM
- **Reflection of the Result of Reviewing AM and Stress Test** in Education and Training of Operators also in Checking and Testing Safety Protection System

source :N. Nakae, private communication

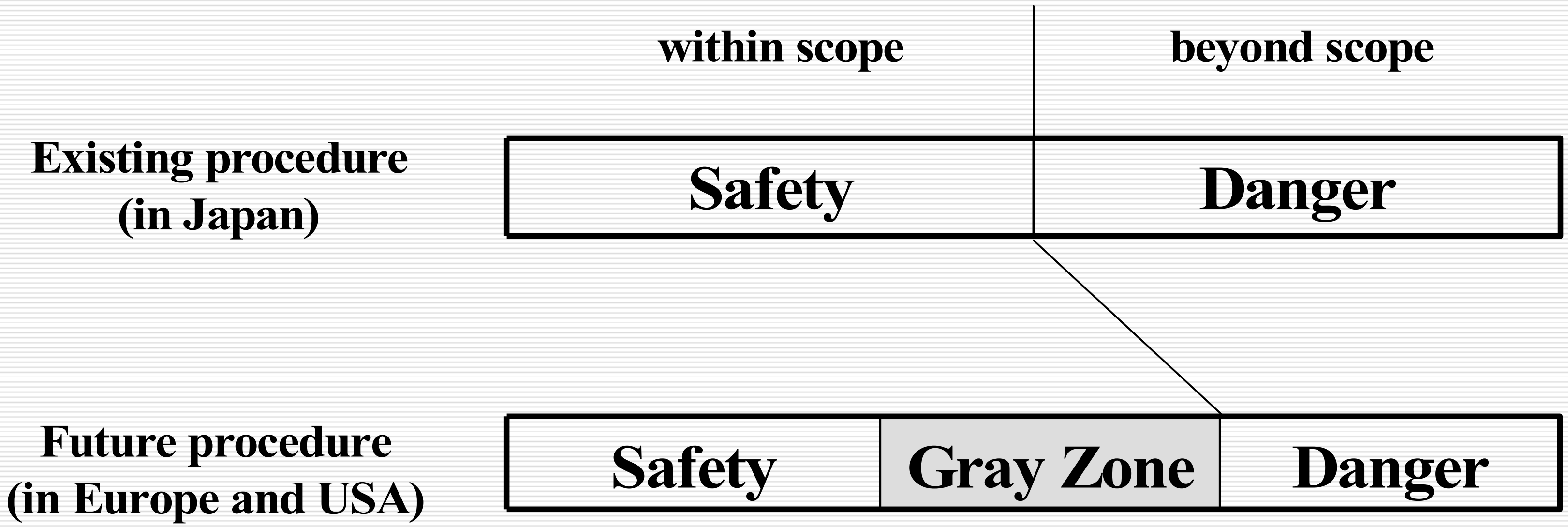
Procession of the Development of NFC

- Technology of Reprocessing Contributes to Handling and Treatment of Fuels in Damaged Core and Spent fuel Pool
- Technology of High Level Waste Disposal Contributes to Recovery of Environment Contamination
- Improvement of Safety of LMFBR contributes to strengthening of Safety of Existing Nuclear Power Plants
- Achievement of Nuclear Fuel Cycle Including LMFBR Contributes to Realizing Sustainable Social World of Friendly Earth Environment

source :N. Nakae, private communication

Background

An approach taking into account for concept of risk shall be needed in safety licensing of nuclear facilities.



JNES

Why Needs To Introduce Concept of Risk?

Gray zone might exist in safety licensing of nuclear facilities.