Seminar on Nuclear Safety 2012
Jakarta, Indonesia, July 4, 2012

Lessons Learned from Fukushima Accident from the View of Safety Regulation

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C o n t e n t s

What is Nuclear Reactor Safety?

- The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation.(IAEA Safety Standards)
- This standard objective concept of safety should be, therefore, shared among the government and society to peacefully use nuclear reactors.
- Nuclear safety standard should be agreed among stakeholders, such as electric power companies, central and local governments, and general public.
- Nuclear safety is primarily for general public and that for personnel of nuclear utilities is secondary.
- Nuclear safety standard should be mostly based on the newest scientific and technological knowledge.

Benefit and Risk

- **Benefit and risk should be considered in any case, transportation, foods, medicines, for example.**
- **Benefit produced by utilization of nuclear energy is extremely large, but, risk, or safety in another word , is an important issue to be considered.**
- **Severe accident is the state that may cause significant loss of human health and/or life and deteriorate environment, which must be prevented.**
- **Risk brought by utilization of nuclear energy should be minimized within acceptable limit.**

Structure of Safety Guides in Japan

Structure of Safety Guides by Nuclear Safety Commission

- Power Generating Light Water Reactors 【L】
  - Siting (ST)
  - Design (DS)
  - Safety Evaluation (SE)
  - Radiation Exposure Dose Limit Target (RE)
  - Accident Management (AM)
- Research and Development Reactors 【D】
  - Research Reactors (RR)
  - Fast Breeder Reactors (FR)
  - Advanced Thermal Reactors (AT)
  - Nuclear Ship Reactors (NS)
- Fuel Cycle Related Facilities 【F】
  - Fuel Cycle Facilities (FC)
  - Radioactive Waste (RW)
- Thematic (Cross-cutting) Guidance 【T】
  - Dismantling and Decommissioning (DD)
  - Technical Competence (TC)
  - Emergency Preparedness (EP)
  - Environment (EN)

＊ **Information is available at NSC Home Page.**

Regulatory Guides for

Power-generating Light Water Reactors

1. **Site Evaluation**
   site evaluation and application criteria
2. **Design**
   safety design, classification of importance of safety function, seismic design, fire protection, radiation monitoring in accidents, ･･･
3. **Safety Evaluation**
   safety assessment, core thermal design, ECCS performance, reactivity insertion events, decay heat data, ･･･
4. **Radiation Exposure Dose Limit Target**
   annual dose target, evaluation of dose target, radiation monitoring, ･･･
5. **Accident Management**
   accident management for severe accidents

Basic Functions of Safety Assurance

There are three functions for prevention of abnormal operation and failure, progression of abnormal event and escalation to an accident and significant release of radioactive materials to the environment.

1. Shut-down the reactor（Stop fission chain reaction)

   since the core generates large energy and fission products

   e.g. Scram, Boron injection system

2. Cool the reactor core

   since the core is heated by decay heat after the shutdown

   e.g. Emergency Core Cooling System(ECCS)

3. Contain radioactive materials

   since radioactive materials might be released to the environment

   e.g. Containment vessel

Design Basis Events (DBE)

- **Design basis events (DBEs) are the events extracted from <u>internal events</u>, whose causes arise within nuclear reactor facilities, <u>for the consideration of safety design and safety assessment of nuclear reactor facilities</u>.**

- **Adequacy of consideration of <u>natural disasters and man-made external disasters in the design is separately examined</u> based on regulatory guide of reactor safety design.**

- **The subject is how and how much we can and we have to consider natural disasters such as earthquake, tsunami, flood, tornado, etc. and man-made external disasters such as fire, air plain crash, terrorist attack, so on.**

Safety Assessment

Safety evaluation of reactors is to ensure the adequacy of safety design by analyzing a set of design basis events with conservative assumptions and quantitative criteria.

- **Scope to be evaluated is**

1. Abnormal operational transients (AOT)

Anticipated transients caused by malfunction of equipment or miss-operation by operators or external disturbances which might happen during plant life time

2. Accidents

Events beyond AOT which might cause release of radioactive materials to the environment

- **Hypothetical Accident**

Hypothetical condition of release of radioactive materials into the reactor containment with 100 % of noble gases and 50% of iodine in the core is assumed to evaluate the adequacy of the site of reactor installation.

The exposure doses must be less than 0.25 Sv for the whole body and 3 Sv for the thyroid to the inhabitants in the vicinity of the site.

Severe Accident

Definition:

Severe accident is defined as an event, which <u>exceeds the design basis event</u> of the nuclear power plant sufficiently <u>to cause significant damage to the reactor core</u> (OECD/NEA). They are sometimes called "hypothetical beyond-design-basis accidents".

Examples:

Three Mile Island-2 accident (1979, US)
Chernobyl-4 accident (1986, former Soviet Union)
TEPCO's Fukushima Daiichi Accident (2011, Japan)

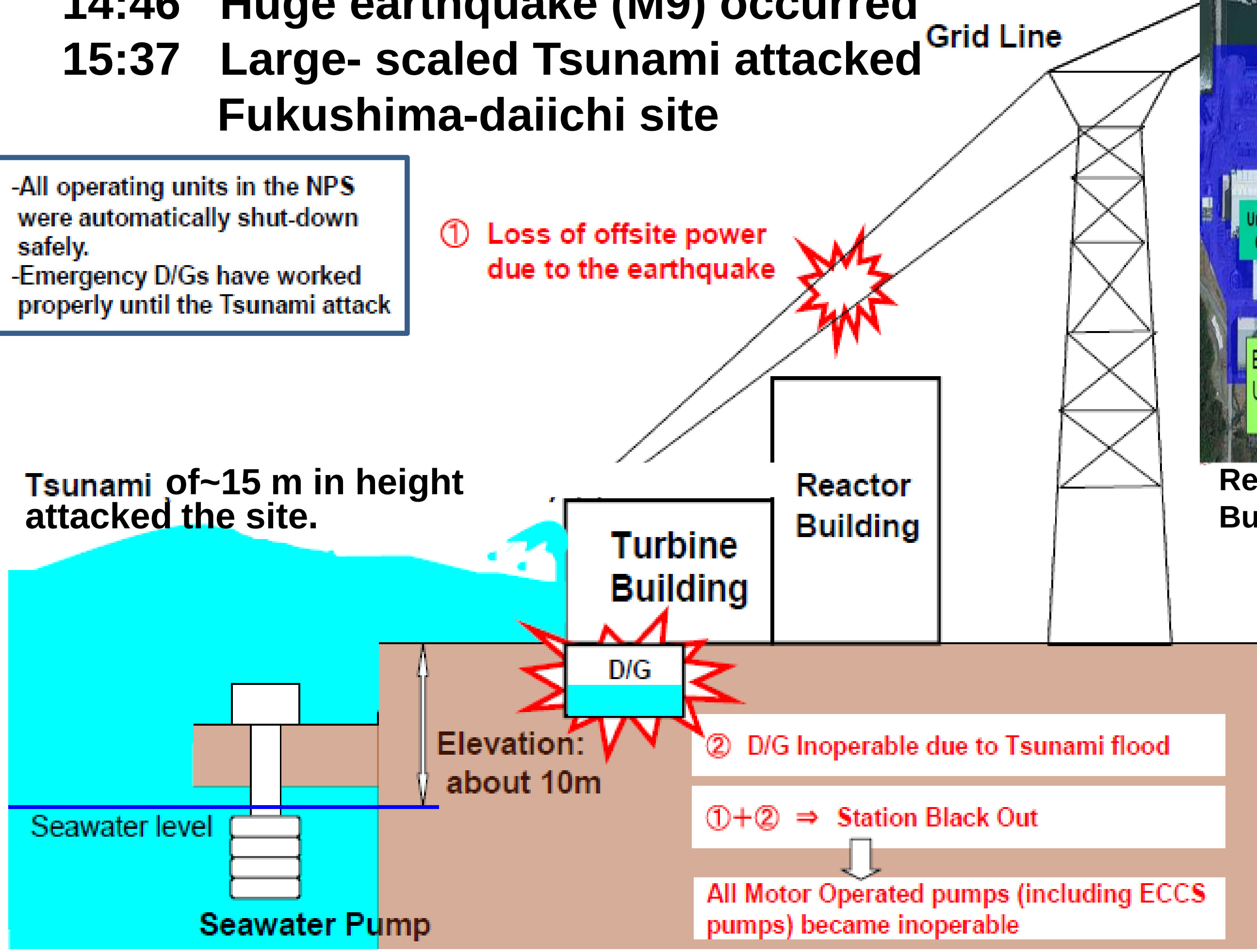
Occurrence and Progression of the Accident at the Fukushima NPPs

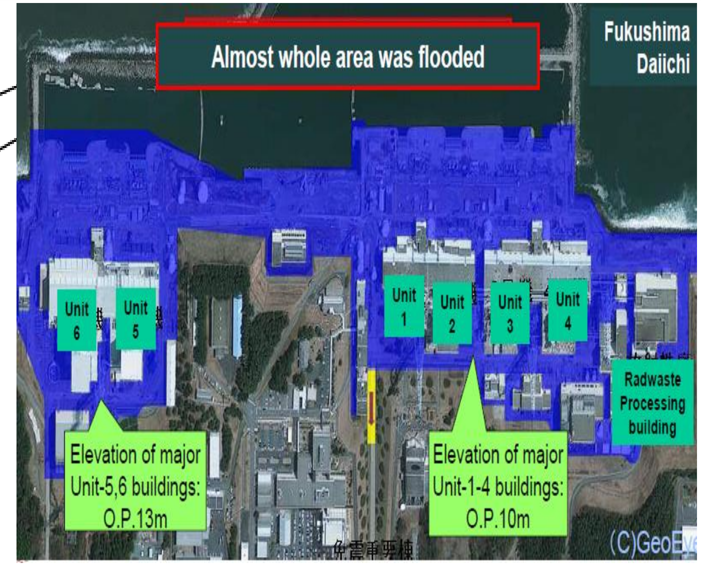
March 11, 2011

14:46 Huge earthquake (M9) occurred

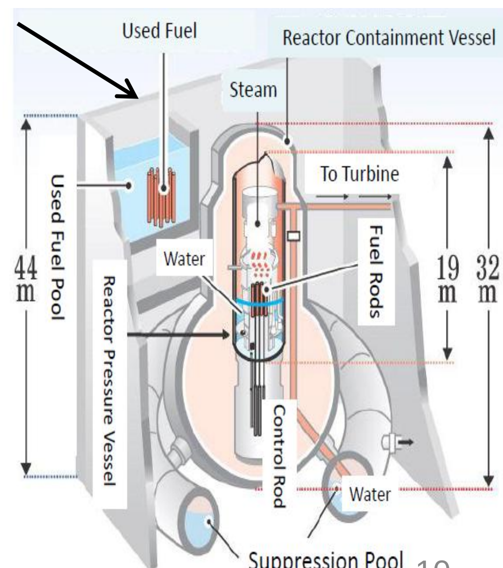
15:37 Large- scaled Tsunami attacked Fukushima-daiichi site

-All operating units in the NPS were automatically shut-down safely.
-Emergency D/Gs have worked properly until the Tsunami attack





Reactor Building

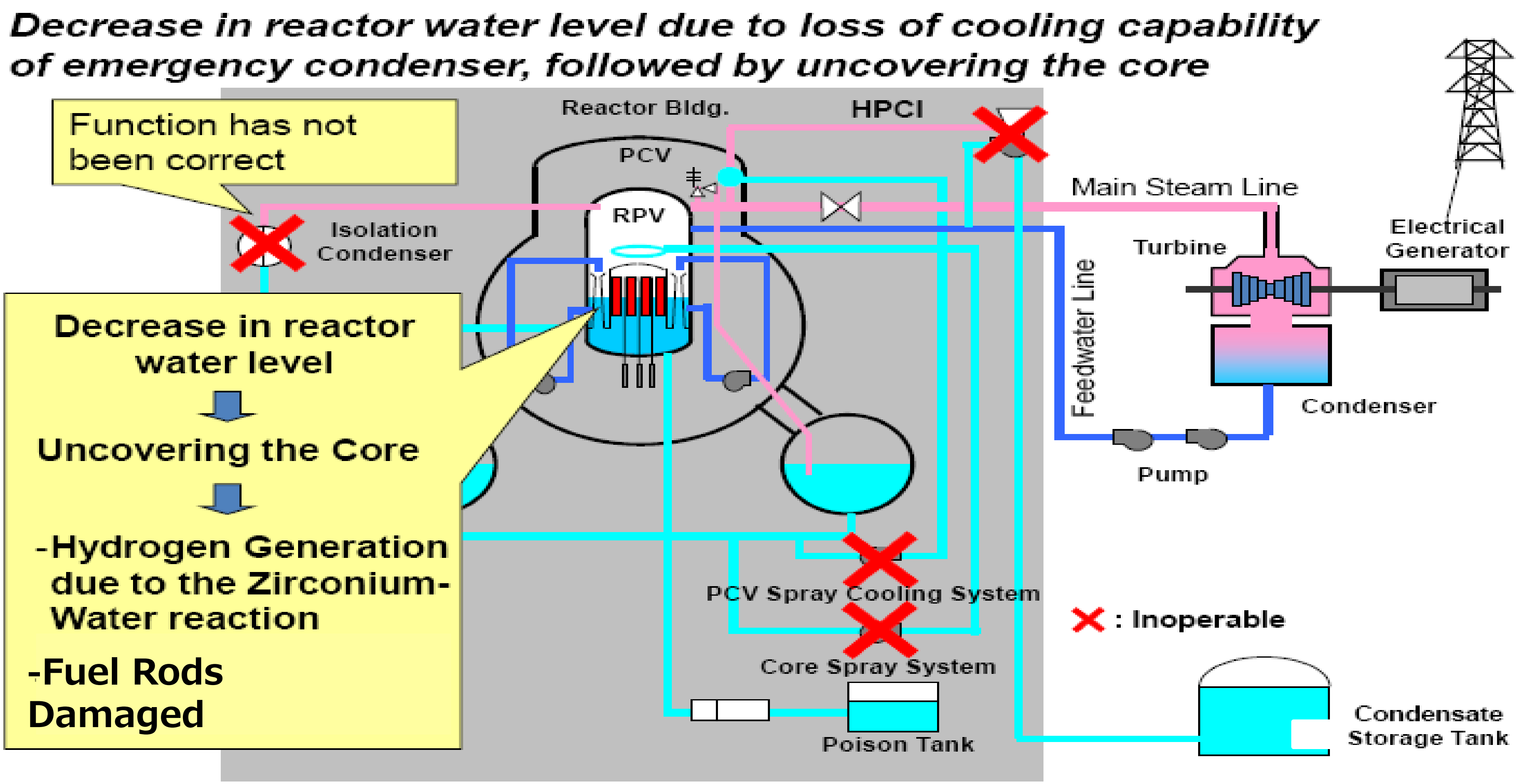


Bird's eye view of Reactor Building

Occurrence and Progression of the Accident at the Fukushima NPPs

Unit 1

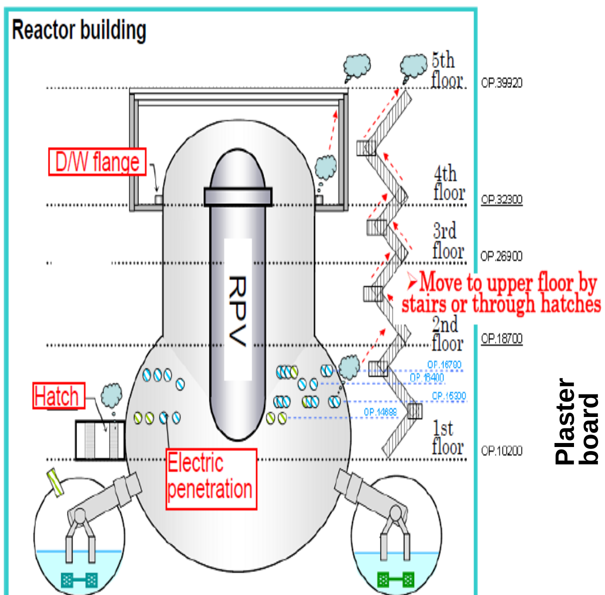
~ 17:00 Fuel rods damaged

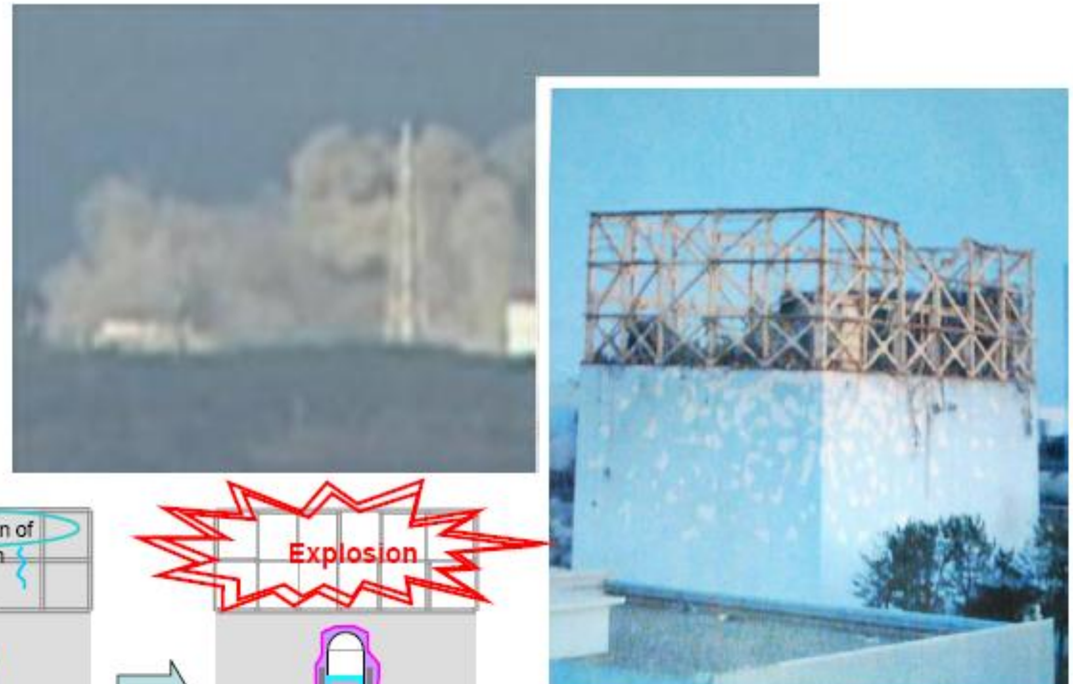


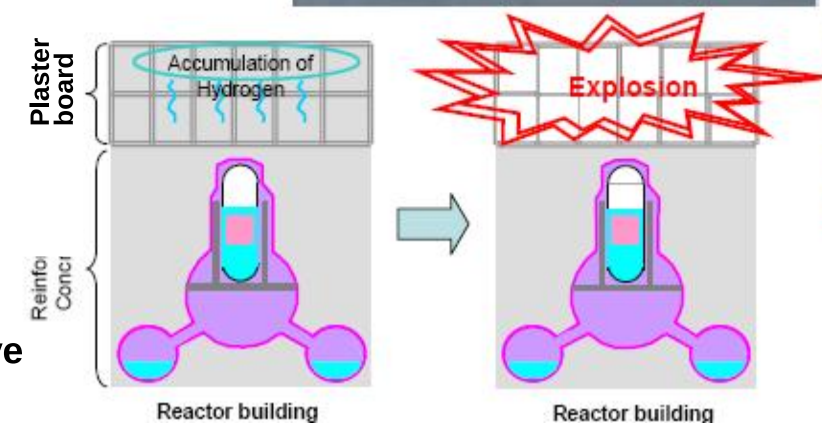
Occurrence and Progression of the Accident at the Fukushima NPPs

March 12 15:36

Hydrogen explosion occurred in the operation floor of R/B and radioactive materials were released into the environment.







Hydrogen is supposed to have leaked through heat affected seals D/W flange, hatch and electric penetrations.

What Brought the Fukushima Severe Accident ?

1. The Nuclear Safety Commission (NSC) decided that measures to prevent severe accidents should be taken as voluntary actions by licensees in 1992.
2. The licensees had not implemented truthful measures for prevention and occurrence of severe accidents. The NISA (Nuclear and Industrial Safety Agency) and NSC admitted the accident management strategies of licensees.
3. Regulatory safety guides are incomplete, specifically, for severe accident condition. Specifically, measures against station black out and flooding are not taken into account.
4. The Act on Special Measures Concerning Nuclear Emergency preparedness(ASMCNE) did not work effectively.
5. Nuclear safety culture have not brought up among licensees and also regulatory bodies.

Accident Management for Severe Accidents at LWRs issued by NSC

1. The NSC judged that safety of nuclear power plants was sufficiently ensured at all stages of design, construction, operation by adopting strict measures based on defense-in-depth philosophy.
2. Therefore, possibility of occurrence of severe accident is so low as not to happen realistically from engineering point of view, and risk of reactor plant is extremely low.
3. Then, accident management (AM) is placed to decrease further this low risk. The NSC strongly recommended that licensees would prepare effective accident management voluntarily and implement it precisely if necessary.

The NSC did not include severe accident as legal requirements, nor pay attention station black-out (SBO) and extremely small volume of BWR Mark1 type containment vessel (CV) resulting in rapid increase of internal pressure in the case of severe accident.

Accident Management Adopted by Licensees

1. **Loss of whole A/C power**
   restoration of external power or emergency diesel generator (D/G)
2. **Failure of reactor scram**
   manual insertion of control rods, manual starting of injection system of boric acid water
3. **Failure of decay heat removal function**
   restoration of residual heat removal system, manual starting of CV spray, installation of CV venting system
4. **Failure of water injection into the core**
   manual starting of HP-ECCS, reactor core isolation cooling system (RCIC), automatic depressurization system(ADS) and LP-ECCS, manual starting of alternative water injection by fire engine

Implementation structure, preparation of implementing manual and practice of education and training must be performed.

External power and D/G could not restore, alternative water injection was delayed due to insufficient preparation and CV venting was incomplete and brought hydrogen explosion. The licensees had not implemented truthful measures and education and training for prevention of severe accidents.

Incompleteness of Regulatory Safety Guide for Severe Accident

1. There are many regulatory safety guides in Japan. Almost of them, however, are applicable to up to Level 3 of defense-in-depth except site evaluation.
2. As for earthquake and tsunami, regulatory guide for reviewing seismic design was revised requiring to consider active faults which have been possibly active up to 120,000 ~130,000 years (50,000 years in the old guide) ago taking into account of serious disasters suffered from the recent earthquakes.
   However, as to tsunami, it states simply as follows; "Safety functions of the Facilities shall not be significantly impaired by tsunami which could be reasonably postulated to hit in a very low probability in the service period of the Facilities".

Incompleteness of Regulatory Safety Guide for Severe Accident

3. There are several incomplete items in regulatory guide for reviewing safety design.
   - No particular considerations are necessary against a long-term total A/C power loss（external and emergency)
   - Diversity is not an indispensable requirement for engineering safety features such as emergency D/G, transportation system of heat to final heat sink. The guide requires multiplicity or diversity and independence.
   - Flammability control system is not aimed at preventing hydrogen combustion inside the reactor building(R/B), but inside C/V.

The regulatory guide does not describe long-term SBO, and no consideration on SBO is a wrong pride caused from the lowest frequency of power stoppage in the world. Simple multiple facilities cause common mode failure in some cases. The CVs in BWRs were filled with nitrogen, re-combiners were provided inside in the CVs which did not function due to loss of electric power. No consideration on installation of flammability control system inside R/B was taken.

Incompleteness of Regulatory Safety Guide for Severe Accident

NSCRG: L-DS-I.0 Regulatory Guide for Reviewing Safety Design of Light Water Nuclear Power Reactor Facilities

Published in August, 1990

The Nuclear Safety Commission of Japan

- **Guideline 27. Design Considerations against Loss of Power**
- The nuclear reactor facilities shall be so designed that safe shutdown and proper cooling of the reactor after shutting down can be ensured in case of a short-term total AC power loss.

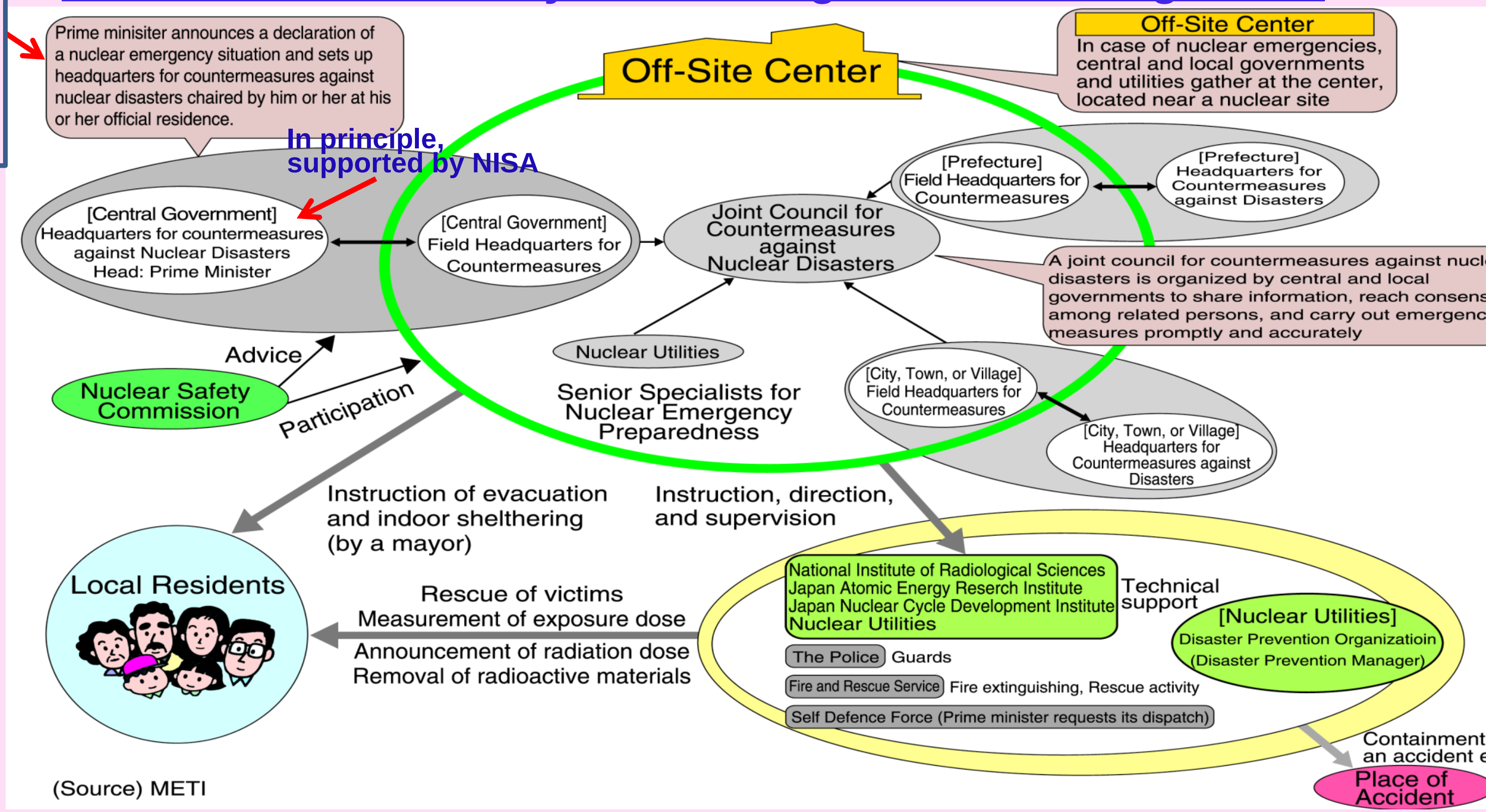
- **Commentary on Guideline 27. Design Considerations against Loss of Power**
- No particular considerations are necessary against a long-term total AC power loss because the repair of troubled power transmission line or emergency AC power system can be expected in such case.
- The assumption of a total AC power loss is not necessary if the emergency AC power system is reliable enough by means of system arrangement or management (such as maintaining the system in operation at all times).

Insufficient Special Actions and Measures during the Severe Accident

Organization structure is settled on the Act on Special Measures Concerning Nuclear Emergency Preparedness (ASMCNE) as below.

Disaster Prevention System during Nuclear Emergencies

Notice of Accidents from Operators: Occurrence of a nuclear emergency



Insufficient Special Actions and Measures during the Severe Accident

1. **The NISA could not support the headquarters** timely and technically gathering necessary information.
2. **There was no qualified technical leader in the headquarters**, then, the Prime Minister who is not a specialist of nuclear engineering established temporarily special headquarters, office not based on the Act, and visited Fukushima site at the early stage of the accident. That brought various confusion. The NSC also could not make adequate technical advice.
3. **Offsite center did not work** due to earthquake disaster and the member could not gather to the center due to earthquake disaster of transportation system.
4. **It was not clear who decided necessary actions** among the site, TEPCO headquarters and Government headquarters.

Lack of Organizational Safety Culture

Safety culture is that assembly of characteristics and attitudes in organizations and individuals which establishes that, as an overriding priority, nuclear plant safety issues receive the attention warranted by their significance. (IAEA /INSAG)

1. The TEPCO had not implemented truthful measures and education and training for prevention of severe accidents.
2. The NISA and NSC did not review sincerely and strictly the measures taken for prevention of severe accident by TEPCO.
3. The NISA had not taken care of workability and reliability of organization structure for nuclear emergency preparedness, although they performed training once a year.

➡ These are lack of organization safety culture, and it is not clear who has these responsibilities.

Lessons Learned from Fukushima Accident (1)

(Report of Japanese Government to the IAEA Ministerial Conference on Nuclear Safety)

Category	Technical Items
1.Strengthen preventive measures against a severe accident	(1) Strengthen measures against earthquake and tsunamis (2) Ensure power supplies (3) Ensure robust cooling functions of reactors and PCVs (4) Ensure robust cooling functions of spent fuel pools (5) Thorough accidents management (AM) measures (6) Response to issues concerning the siting with more than one reactor （7） Consideration of NPS arrangement in basic designs （8） Ensuring the water tightness of essential equipment facilities
2. Enhancement of response measures against severe accidents	（9） Enhancement of measures to prevent hydrogen explosions （10） Enhancement of containment venting system （11） Improvements to the accident response environment （12） Enhancement of the radiation exposure management system at the time of the accident (13) Enhancement of training responding to severe accidents

Lessons Learned from Fukushima Accident (2)

Category	Technical Items
2. Enhancement of response measures against severe accidents	(14) Enhancement of instrumentation to identify of the status of the reactors and PCVs (15) Central control of emergency supplies and equipment and setting up rescue team
3. Enhancement of nuclear emergency responses	(16) Responses to combined emergencies of both large-scale natural disasters and prolonged nuclear accident (17) Reinforcement of environmental monitoring (18) Establishment of a clear division of labor between relevant central and local organizations (19) Enhancement of communication relevant to the accident (20) Enhancement of responses to assistance from other countries and communication to the international community (21) Adequate identification and forecasting of the effect of released radioactive materials (22) Clear definition of widespread evacuation areas and radiological protection guidelines in nuclear emergency

Lessons Learned from Fukushima Accident (3)

Category	Technical Items
4. Reinforcement of safety infrastructure	(23) Reinforcement of safety regulatory bodies (24) Establishment and reinforcement of legal structures, criteria and guidelines (25) Human resources for nuclear safety and nuclear emergency preparedness and responses (26) Ensuring the independence and diversity of safety systems (27) Effective use of probabilistic safety assessment (PSA) in risk management
5. Thoroughly instill a safety culture	(28) Thoroughly instill a safety culture

Items with ○ are deeply concerned with safety regulation.

Lessons Learned from Fukushima Accident (4)

(1) Strengthen measures against earthquake and tsunamis

Measures against earthquake is already described.
Regarding tsunamis, from the viewpoint of preventing a severe accident, Japan will assume appropriate frequency and adequate height of tsunamis in consideration of a sufficient recurrence period for attaining a safety goal, although the design against tsunamis has been performed based on tsunami folklore and indelible traces of tsunami. Japan will perform a safety design of structures, etc. to prevent the impact of flooding of the site caused by tsunamis of adequately assumed heights, in consideration of the destructive power of tsunamis together with watertight design for protection of important equipments .

(2) Ensure power supplies

Reflecting the failure to secure the necessary power supply, it is important to secure a power supply at sites for a longer time set forth as a goal even in severe circumstances of emergencies, through the diversification of power supply sources by preparing various emergency power supply sources such as air-cooled diesel generators, gas turbine generators, etc., deploying power –supply vehicles and so on, as well as equipping switchboards, etc. with high environmental tolerance and generators for battery charging, and so on.

Lessons Learned from Fukushima Accident (5)

(3),(4) Ensure robust cooling functions of reactors and PCVs , and spent fuel pools

Reflecting on the failure to cool reactors and PCVs, robust alternative cooling functions for reactors and PCVs by securing alternative final heat sinks for a durable time. This will be pursued through such means as diversifying alternative water injection functions, diversifying and increasing sources for injection water, introducing air-cooling systems, and natural circulation cooling systems.

As for spent fuel pools, robust cooling measures will be alternative cooling functions such as a natural circulation cooling system or air-cooling system.

(5)Thorough accidents management (AM) measures

It is discussed later.

(8)Ensuring the water tightness of essential equipment facilities

The water tightness of essential equipment facilities such as component cooling seawater pumps, emergency diesel generators, switchboards, etc. must be ensured by installing watertight doors in consideration of the destructive power of tsunamis and floods, blocking flooding routes such as pipes, and installing drain pumps, etc.

Lessons Learned from Fukushima Accident (6)

（9）Enhancement of measures to prevent hydrogen explosion

Hydrogen explosion must be prevented by installing of flammability control systems in the reactor buildings as well as PCVs or top venting system in RBs. The penetrations at PCVs must be also sealed with heat –resistant materials.

(10) Enhancement of containment venting system

Operability and independence of the containment venting system should be ensured together with strengthening its function of removing released radioactive materials.

(14) Enhancement of instrumentation to identify the status of the reactors and PCVs

It is very important to provide and enhance the instrumentation of reactors and PCVs, etc. such as water level, temperature, pressure, amounts of released radioactive materials, etc. even in the wake of severe accidents to obtain important information to identify how the accident is developing.

(24) Establishment and reinforcement of legal structures, criteria and guidelines

It is clear, however, Japan did not pay attention to new findings and knowledge proposed by US NRC on SBO.

(26) Ensuring the independence and diversity of safety systems

It is already pointed out.

Lessons Learned from Fukushima Accident (7)

The fundamental safety objective is to protect people and the environment from harmful effects of ionizing radiation.

→ **"Out of supposition" accident is not admitted.**

→ **In principle, "evacuation free" in any kind of reactor accidents should be maintained.**

1. Fukushima severe accident is sometimes said to be "Out of supposition" accident because the extremely huge earthquake and subsequent large-scaled tsunami could not be supposed. However, massive release of radioactive materials into the environment can not be permitted. That is fundamental philosophy of reactor safety objective.
   The NISA instructed all the reactor licensees to take urgent actions to implement emergency safety measures for prevention of tsunami-induced severe accidents on March 30, and subsequently for addressing such specific aspects of severe accidents as hydrogen explosion risk on June 7. The NISA has completed its review of the licensee actions.

Lessons Learned from Fukushima Accident (8)

Safety Measures for Prevention of Tsunami-induced Severe Accidents

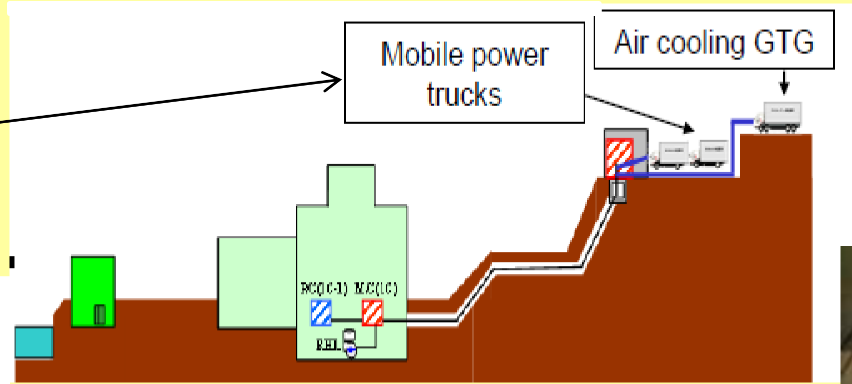
Phase	Urgent measures Short-term	Fundamental measures Mid, long-term
Expected time of completion	Finished	1〜3 years
Target (requirement level, scope)	Prevention of failure of fuel and spent fuel in case of loss of ①A/C power, ② Sea-water cooling function and ③Cooling function of spent fuel storage pool	Prevention of occurrence of disaster caused by tsunami considered its height based on 3.11 earthquake and tsunami
Examples of definite measures	【Equipment, installation】 ・Mobile power trucks （for cooling of reactor and spent fuel storage pool) ・Fire engine （to supply cooling water) ・Fire hose (to secure water supply roots) 【Arrangement of implementing manual】 【Training based on implementing manual】	【Equipment, installation】 ・Embankment ・Water tight doors in R/B, etc. ・Other necessary equipments ・Air –cooled D/G ・ Reserved electro motors for sea-water pumps

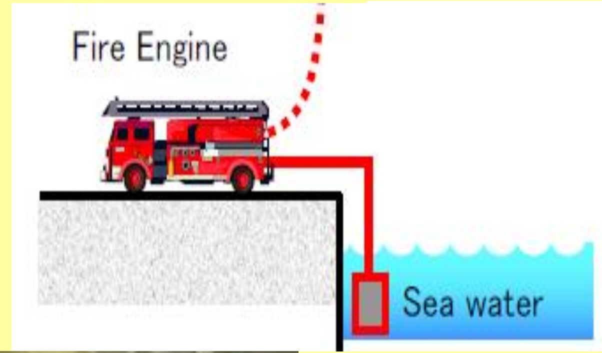
（By NISA）

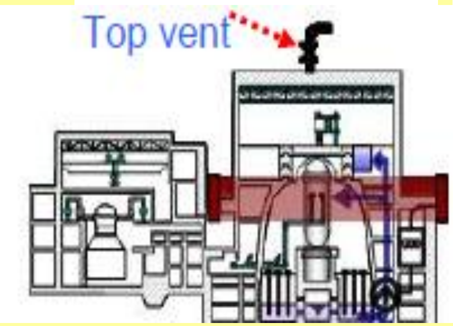
Lessons Learned from Fukushima Accident (9)

Various equipments and installations

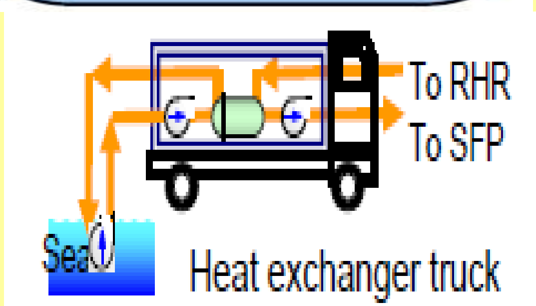
Mobile power trucks





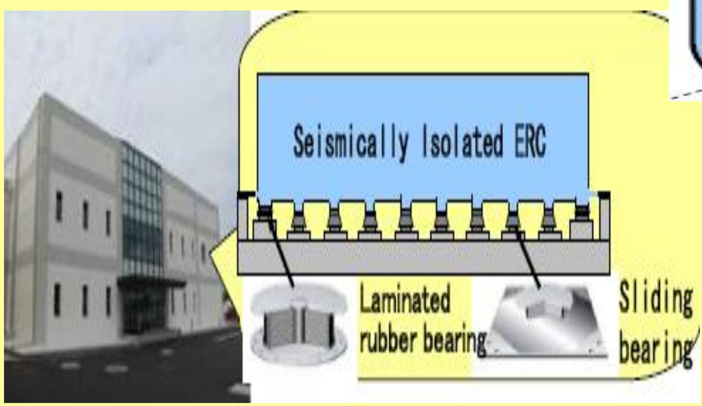


Hydrogen Vent from R/B

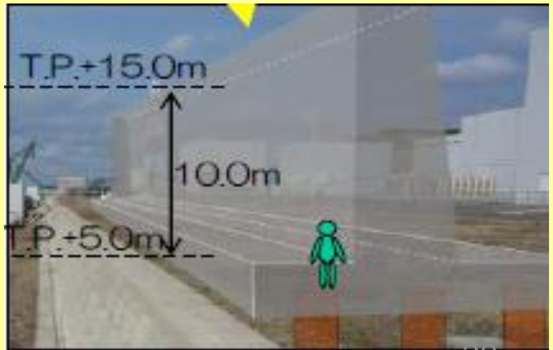


Watertight Door

Penetration sealed with silicon rubber



Emergency Response Center in Robust Building



Embankment

Lessons Learned from Fukushima Accident (10)

2. Reactor safety regulation and requirements should be expanded to include the prevention of occurrence of severe accidents and mitigation of consequences, which is Level 4 of the Defense-in-Depth as defined by the IAEA-INSAG.

Defense-in-Depth and Regulation

Defense-in-Depth Level	Present	To be revised
1. Prevent any occurrence of abnormal events	○	○
2. Prevent from extending and developing into an accident	○	○
3. Prevent the abnormal release of radioactive materials to the environment	○	○
4. Prevent and mitigate the consequence of severe accident	△ Voluntary actions	○
5. Mitigate radiation exposure of the public	△ Insufficient	○

Lessons Learned from Fukushima Accident (11)

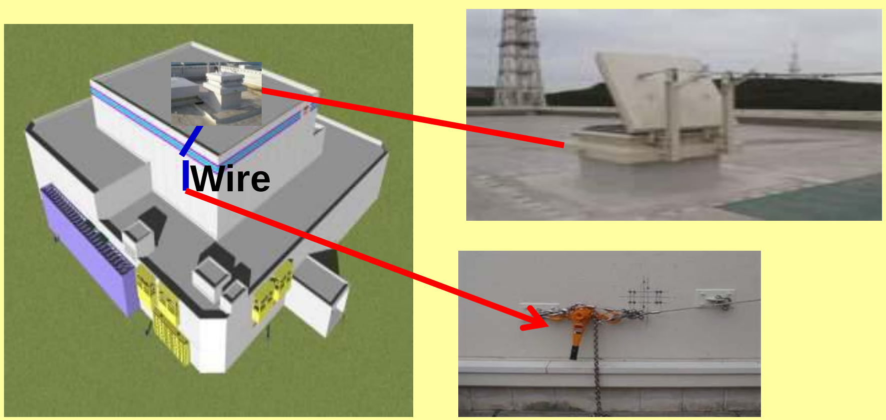
3. Safety assessments for preventing severe accidents and mitigating the consequences aim to properly ascertain risks of nuclear power reactors and seek measures to effectively control them.

Defense measures up to Level 3 should be enhanced in accordance with sequences leading to accidents due to earthquake, tsunami, eruption of a volcano, tornado or other natural disaster, airplane crash, fire, or terrorist attack, etc. So, these accidents should be included in design basis events. (personal view, It is necessary to be discussed further.)

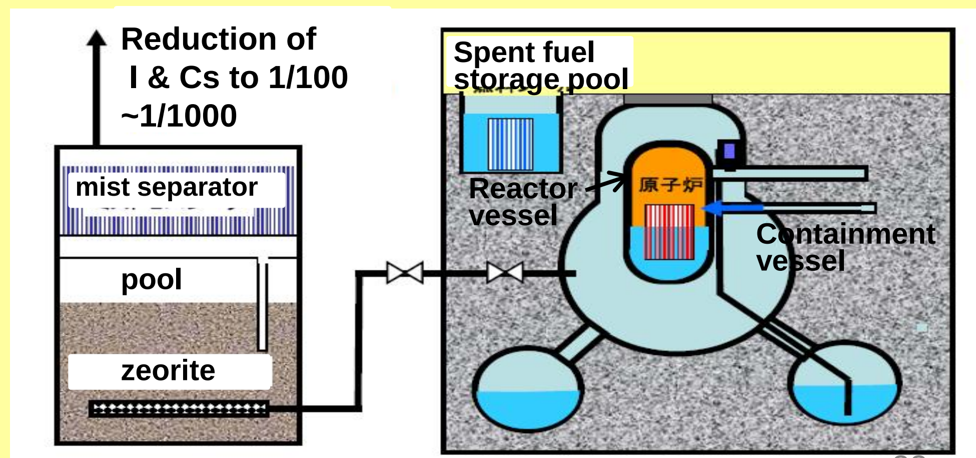
We never forget that an accident will not occur in accordance with the scenarios previously assumed. In this sense, measures to station blackout and failure of residual heat removal system including loss of final heat sink are extremely important.

Lessons Learned from Fukushima Accident (12)

4. Various regulatory guides established so far in Japan should be revised to reconstruct total safety of Nuclear Power Reactors (NPR). Major points are as follows.
   - **Seismic design**: seismic design principle (exceeded design acceleration), detailed design philosophy to tsunami
   - **Safety design**: revised and additional description to severe accident, station blackout, loss of ultimate heat sink, spent fuel storage pool cooling, diversification of engineering safety features, hydrogen explosion, CV over-pressurization, monitoring of reactor system at SBO, etc.
   - **Safety evaluation**: severe accident



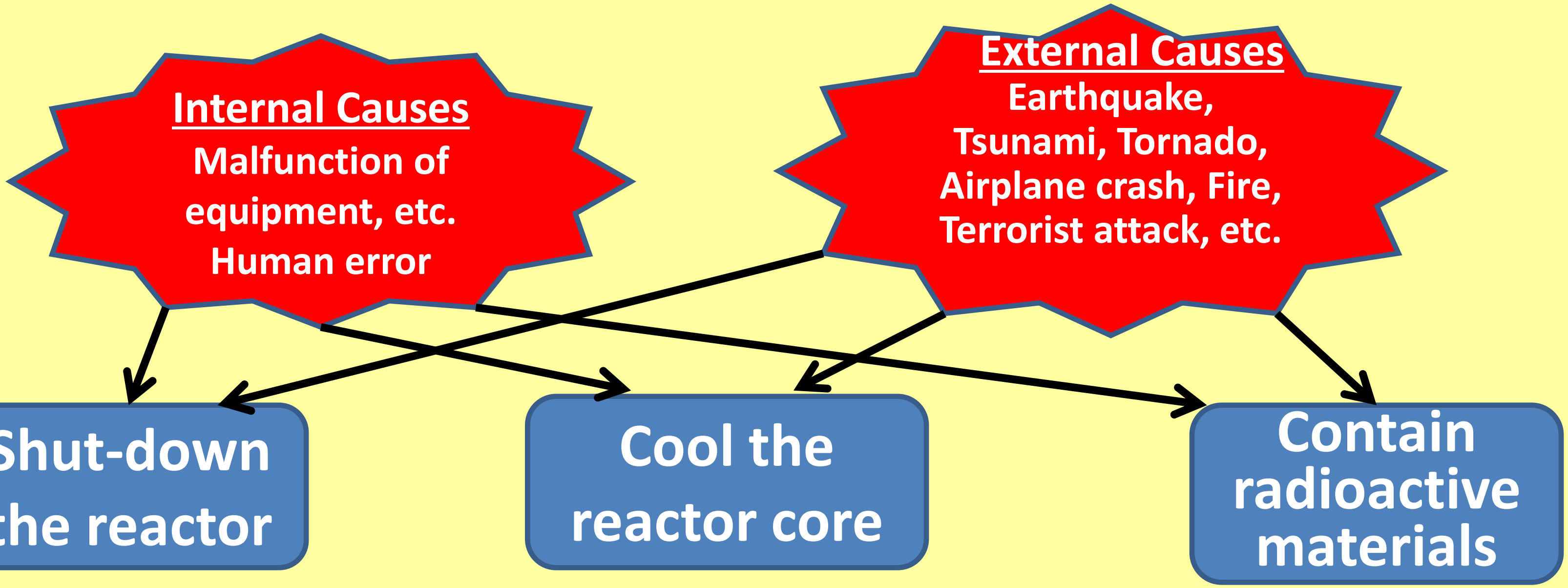
R/B top venting



Filtered vent system

Lessons Learned from Fukushima Accident (13)

The basic concept of safety assurance of nuclear reactors is how to maintain three functions of "Shut-down the reactor", " Cool the reactor core" and "Contain radioactive materials", "Cool spent fuel" as well against any incident and accident induced by any internal or external cause.(personal view)



- Insertion of control rods
- Feed of boric acid water
- Altenate measure

- ECCS
- Measure against SBO
- Diversification of system
- Natural convection, etc.

- CV over-pressure
- Hydrogen explosion
- Measure against melt through of molten fuel, etc.

Lessons Learned from Fukushima Accident (14)

5. Leaders in safety matters has to be demonstrated at the highest levels in an organization. Safety has to be achieved and maintained by means of an effective management system. (IAEA Safety Standard)

   The government including the NISA and the NSC could not deal properly with the nuclear emergency in Fukushima severe accident.
   Japan is going to establish new Nuclear Regulatory Commission (JNRC, tentative name) by integrating functions of the NISA and the NSC.

   The JNRC must be independent of the government, maintain transparency and independent decision of personal affairs and budget, furthermore, construct a group of qualified experts. Qualified experts are essentially necessary for safety review in license of new nuclear power plant, inspection of construction and operation stages of the plants, etc. as well as proper actions to nuclear emergency situation.
   The chairman of the JNRC has leadership and is responsible for all safety matters including nuclear emergency preparedness.

Lessons Learned from Fukushima Accident (15)

6. Arrangements for Emergency Preparedness and Response must be planned and prepared with scrupulous care considering that large-scale natural disasters may bring serious damage in social infrastructures.

   The government headquarters, JNRC, off-site center and the concerned utility must prevent a severe accident and mitigate consequence when it occurs with all their might even in such a case. They also must determine evacuation area, restriction of intake of foods and drinking water, so on , asking opinions of specialists in confused situation.

   A building needed for implementation of practical action should be seismically isolated and filtered if necessary and equipped with communication system by satellite and helicopters, etc.
   Preparation of back-up building might be another solution.

Lessons Learned from Fukushima Accident (16)

7. All those involved in nuclear energy should be equipped with a safety culture recognizing their duty and responsibility. Without a safety culture, there will be no continual improvement of nuclear safety.

   Reflecting on the current accident, the nuclear operators whose organization and individuals have primary responsibility for securing safety should do their best to introduce appropriate measures for improving safety, when they are not confident that risks concerning the public safety of the plant low.

   Organizations or individuals involved in national nuclear regulations, as those who are responsible for ensuring the nuclear safety of the public, should keep not leaving any doubts in terms of safety in a responsive and prompt manner.

Summary

1. The fundamental nuclear reactor safety objective is to protect people and the environment from harmful effects of ionizing radiation. In this sense, "Out of supposition" accident is not admitted in any case.
2. In this sense, countermeasures to station blackout and failure of residual heat removal system including loss of final heat sink are extremely important.
3. Defense countermeasures should be enhanced in accordance with sequences leading to accidents due to earthquake, tsunami, eruption of a volcano, tornado, flood or other natural disaster, airplane crash, fire, or terrorist attack, etc.
4. Reactor safety regulation and requirements should be expanded to include the prevention of occurrence of severe accidents and mitigation of consequences, which is Level 4 of the Defense-in-Depth.

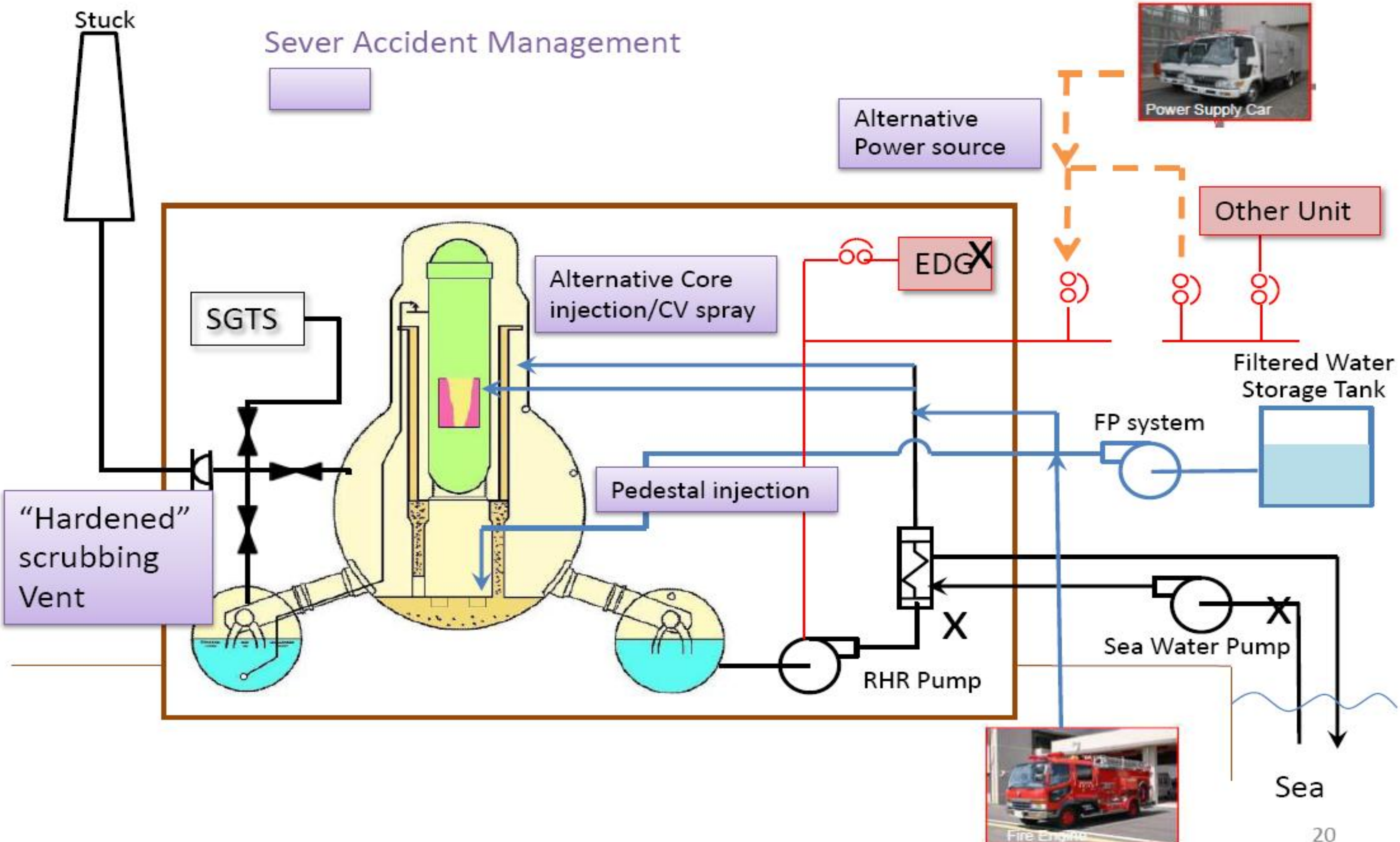
Summary

5. Various regulatory guides established so far in Japan should be revised to reconstruct total safety of nuclear power reactors.
6. Nuclear regulatory commission should be a group of qualified experts, and independent of the government and to have independent decision of personal affairs and budget, besides, maintain transparency. The commission should improve disaster prevention systems during nuclear emergency.
7. All those involved in nuclear energy should be equipped with a safety culture recognizing their duty and responsibility.

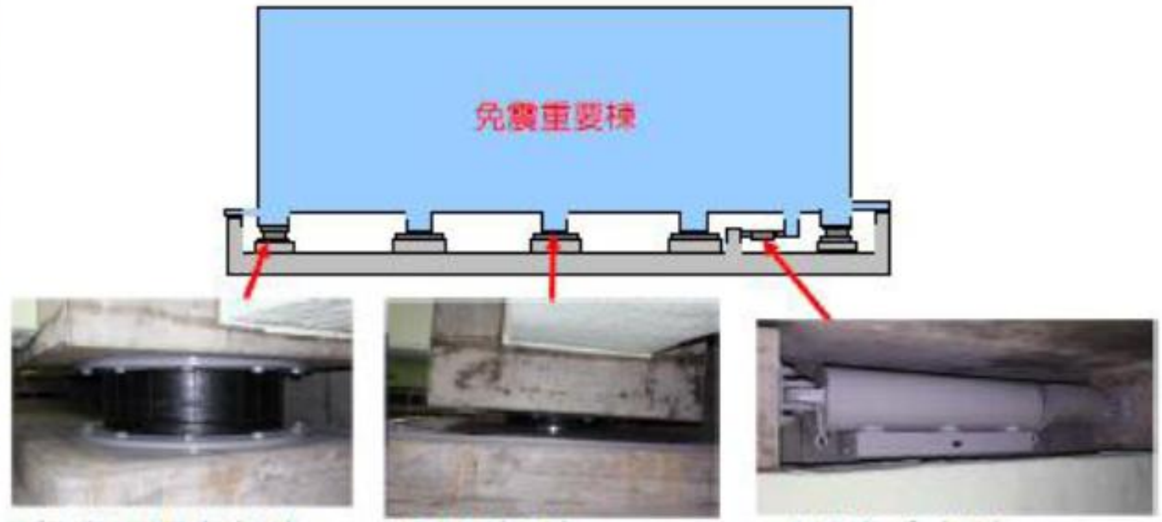
"Fukushima" should become a symbol of recovery from nuclear accident and contribute to construct the highest level of nuclear power reactor safety !

Thank you very much for your kind attention.

What SAM (Severe Accident Management) was in place?



Onsite ERC by TEPCO: seismic isolation structure

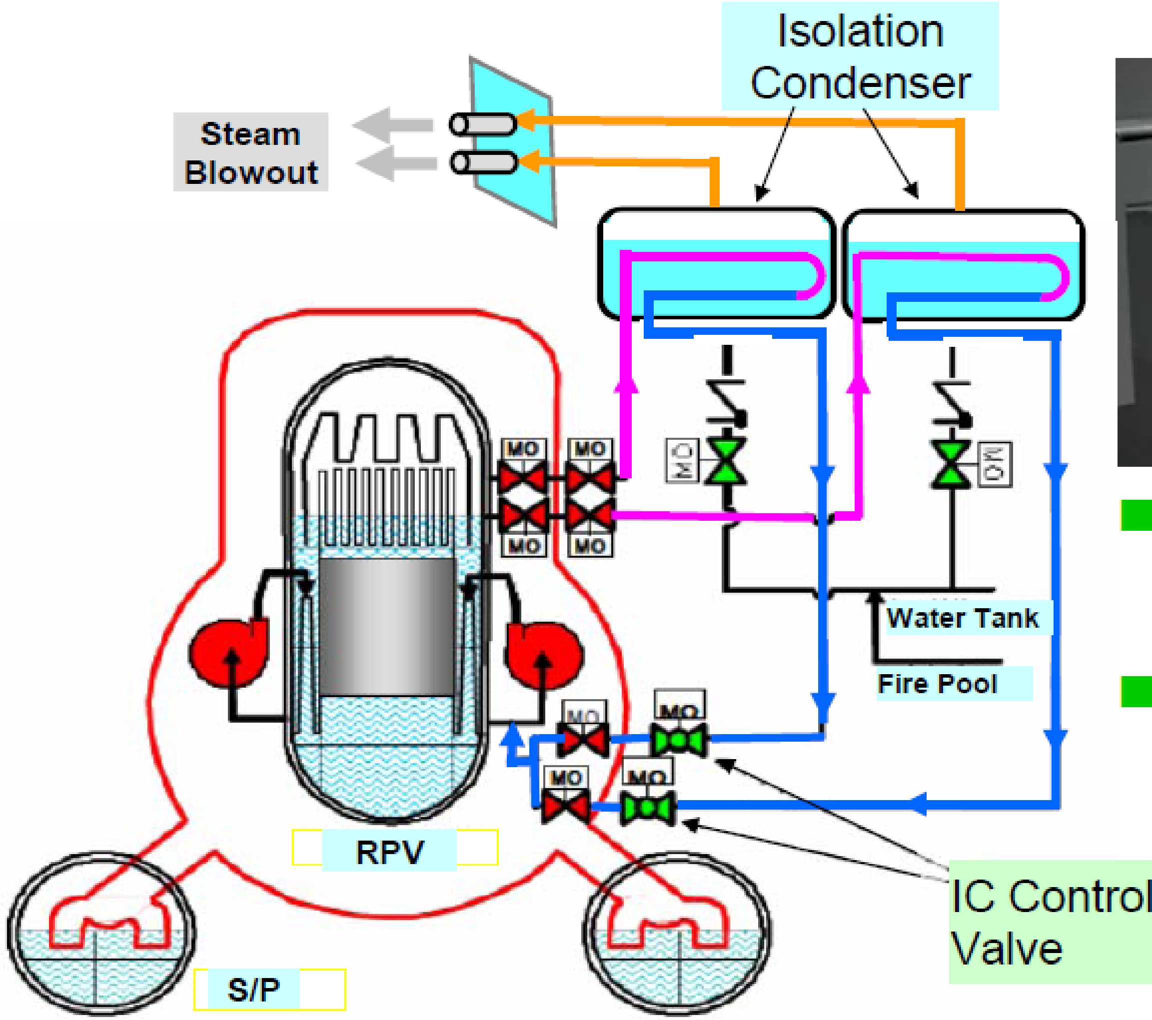


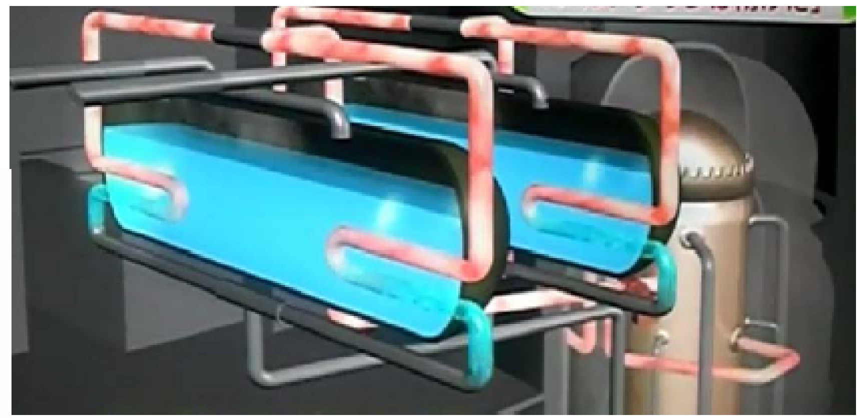
SBO in Fukushima Daiichi NPPs

	#1	#2	#3	#4	#5	#6
DG	A:NG B:NG (T/B B1)	A:NG (B1) B:OK (FP/B 1F)	A:NG B:NG (T/B B1)	A:NG (T/B B1) B:OK (FP/B 1F)	A:OK->NG B:OK->NG (T/B B1) Water Cooling	A:OK->NG (R/B B1) Water Cooling B:OK (DG/B 1F)
Metal-Crad Swich	NG (T/B B1)	NG (T/B B1)	NG (T/B B1)	NG (T/B B1)	NG (T/B B1)	Barely (R/B B2F)
Power Center	NG (T/B B1)	Barely (T/B B1)	NG (T/B B1)	Barely (T/B 1F)	Barely (T/B 2F)	Barely (R/B B2F)
DC Buttery	NG (C/B B1)	NG (C/B B1)	OK (T/B BM1)	NG (C/B B1)	OK (T/B BM1)	OK (T/B BM1)
ECCS RCIC	HPCI:NG IC:OK(FC)	NG RCIC:OK	HPCI:OK RCIC:OK	(No Fuels in RPV)	—	HPCS:OK (R/B B1)

ICs in unit #1 were tripped by FC

- Loss of battery power for main control room caused the fail-close action to MO isolation valves to cutoff the IC. It was a fail-dangerous system.
- If the IC continue to operate, the accident would be terminated soon.

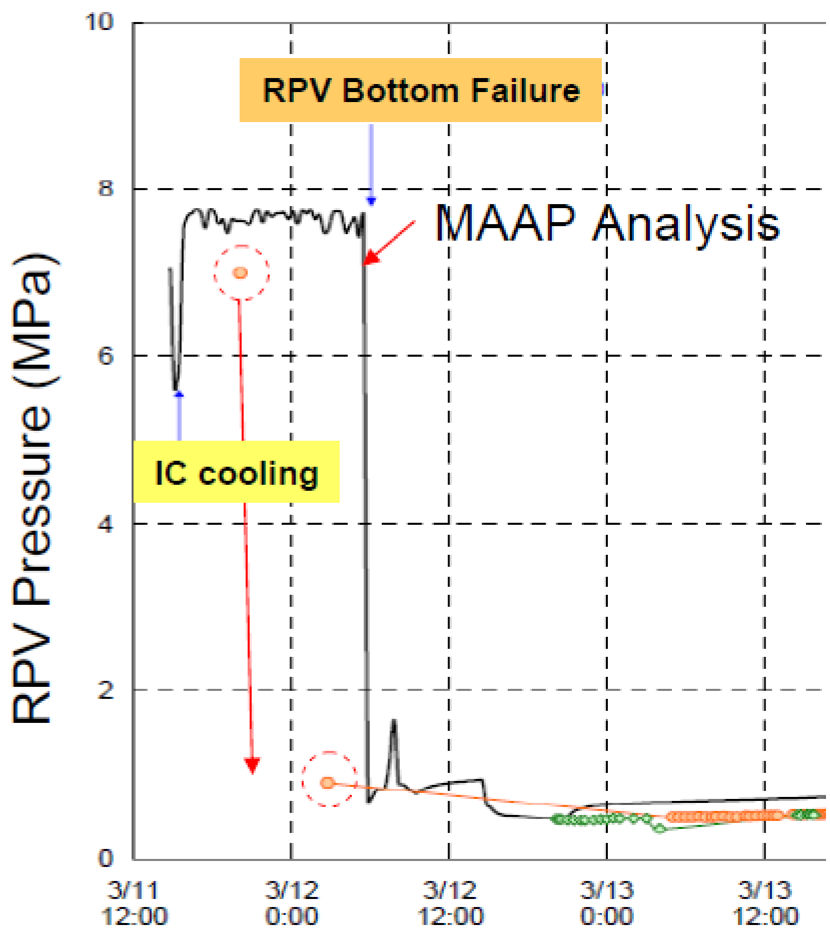


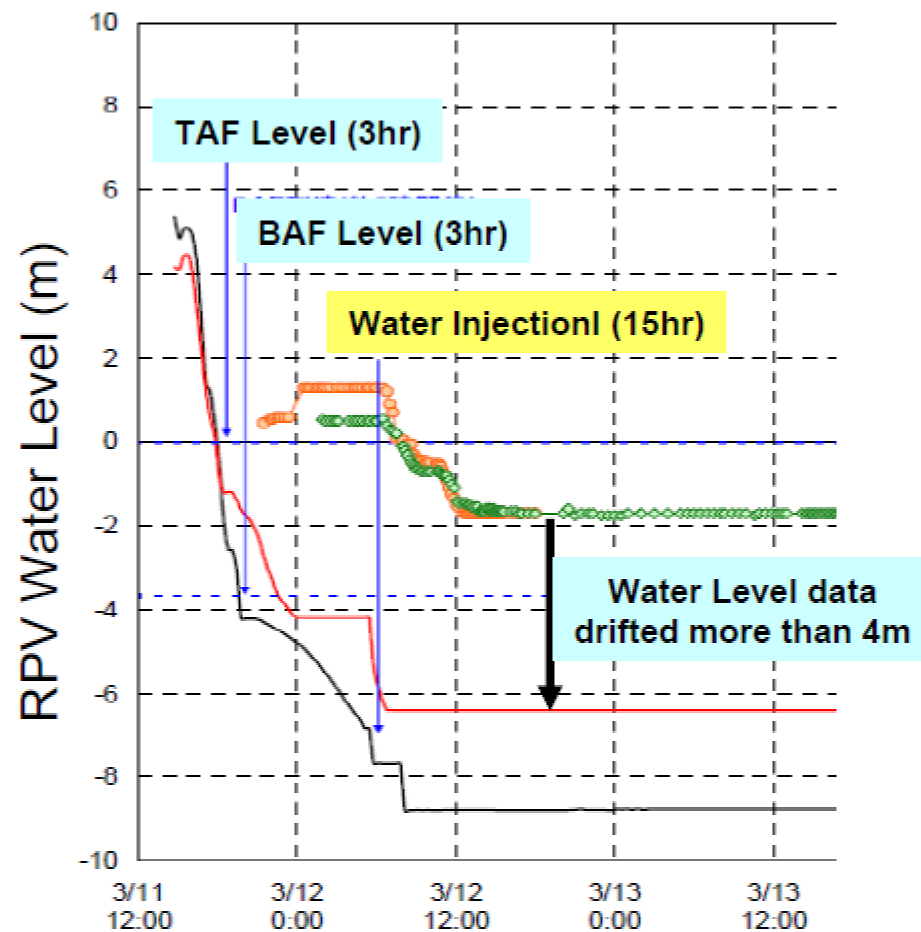


- RCIC steam turbine also stopped by loss of battery power in Unit #2 and #3.
- S/P temperature and pressure were so high that AM water injection took a lot of times.

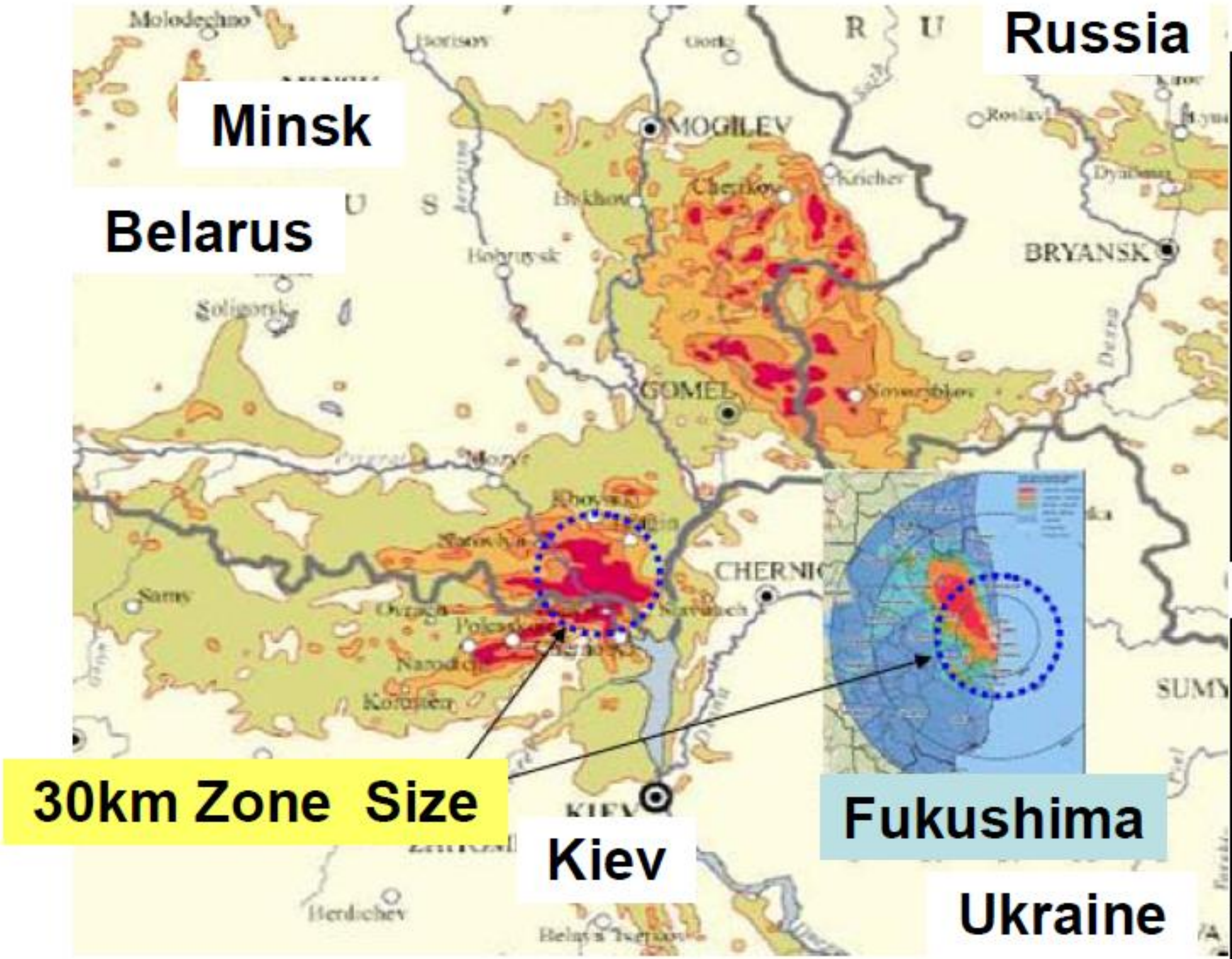
Pressure and Water Level in #1 RPV

- Analysis results show the RPV depressurization started before RPV bottom failure. It might be caused through melted TIP tubes in the core.
- Water level measurement was drifted by the loss of water in a reference leg by high-temperature superheated core. It should be supplied water to the leg.





Comparison between Chernobyl and Fukushima



Released FP		
	Cher-nobyl	Fuku-shima
Cs,I	1	1/13
Total	1	1/50

Core thermal output		
TMI-2	Cher-nobyl	Fuku-shima
1	100	~0.01

Power supply of Unit 1-4 @ 1F after Tsunami

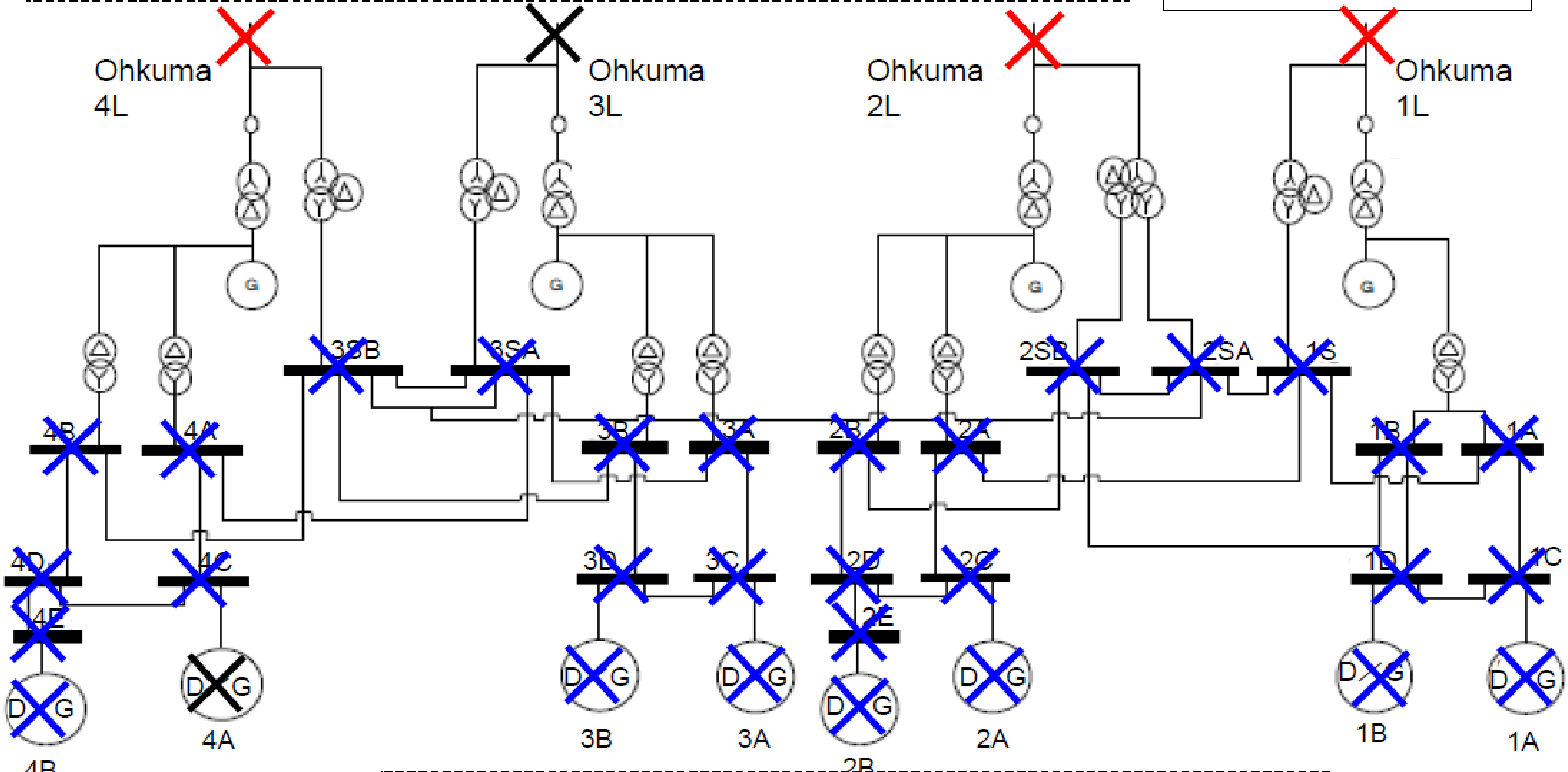
Okuma Line 1L, 2L: Receiving circuit breaker damaged in earthquake

Okuma Line 3L: Renovation work in progress

Okuma Line 4L: Circuit breaker shutdown by protection relay activation

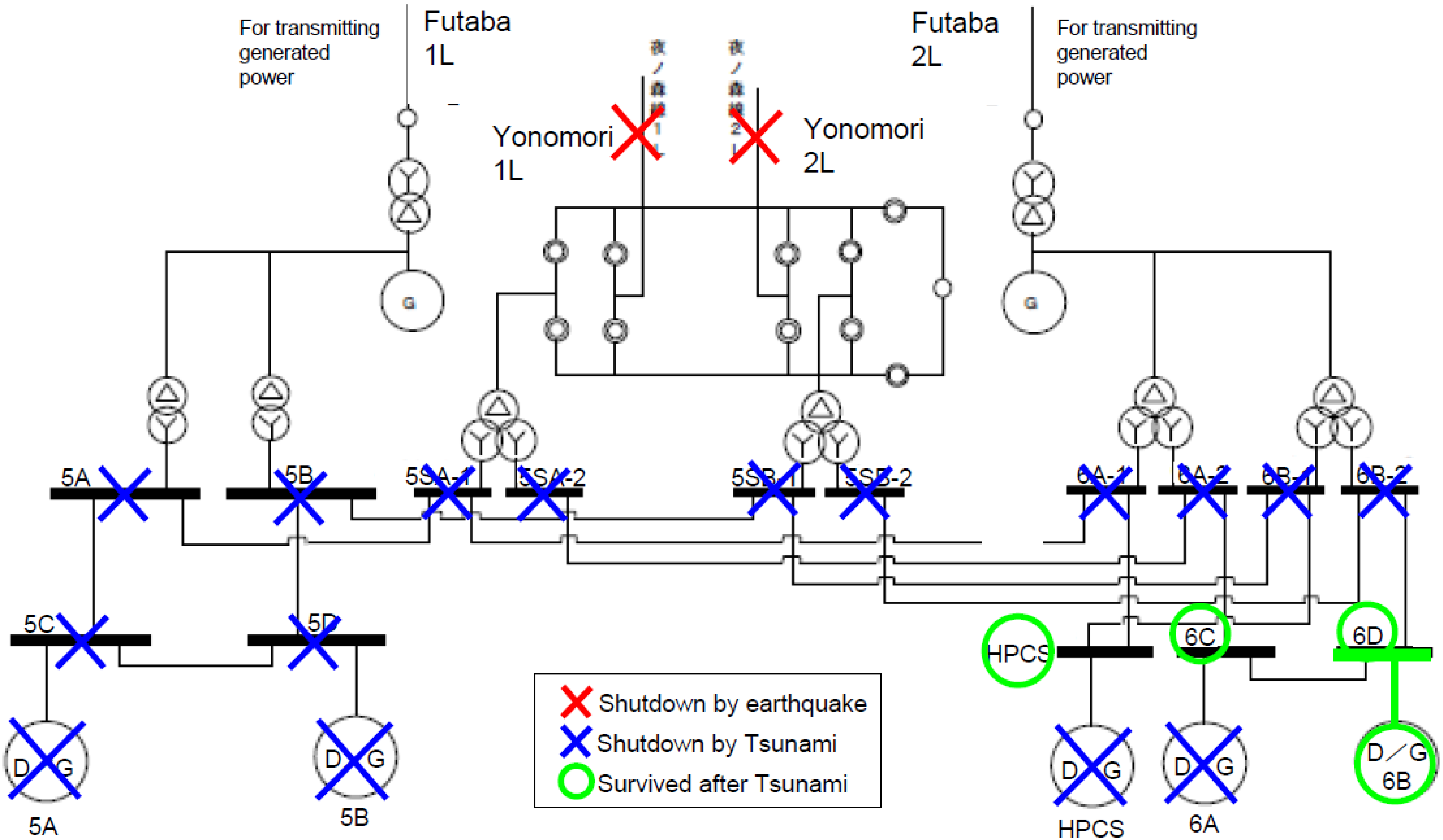
Shutdown by earthquake

Shutdown by Tsunami



The DG lost the function due to either "M/C failure," "loss of sea water system," or "DG main unit failure."

Power supply of Unit 5/6 @ 1F after Tsunami



Major Activities at 1F
~Factors disturbing the recovery work (inside the building) ~

Scram response

Deteriorated operability due to the tsunami

Preparations for water injection

Preparations for venting

Water injection started

Venting

Due to lack of power sources, initial recovery activities had to be conducted in complete darkness, without any instrumentation, and without most communications means.

Work in complete darkness. Many scattered objects were also on the floor.

Connected temporary batteries to recover instrumentations.

Major Activities at 1F
~ Factors disturbing the Primary Containment Vessel Venting Operation

Scram response

Deteriorated operability due to the tsunami

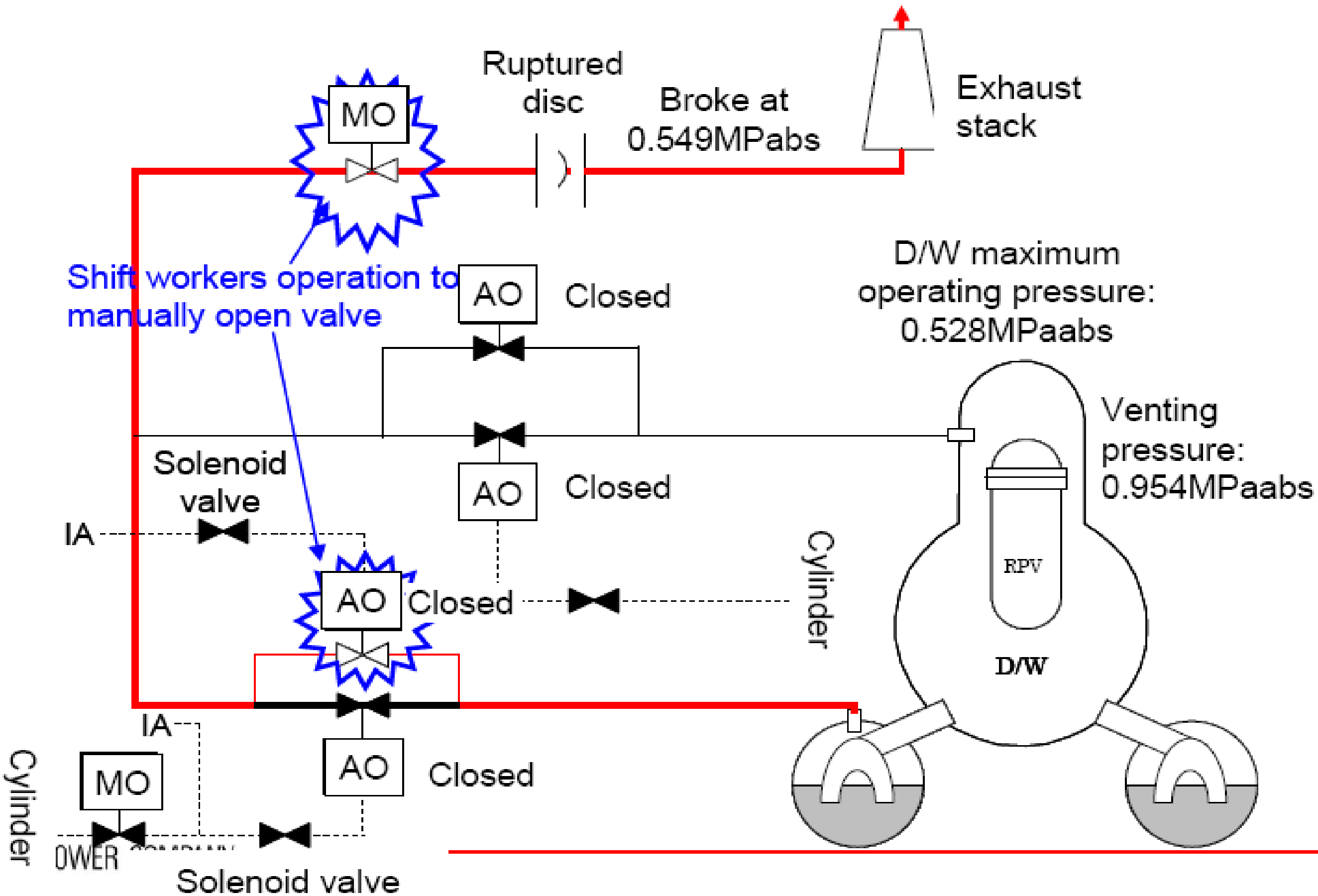
Preparations for water injection

Preparations for venting

Water injection started

Venting

- No power source for the MO-valve ➡ Manual operation
- No power source to the solenoid valve ➡ Engine driven generator
- Low IA pressure to actuate the AO-valve ➡ Engine driven air compressor
- High radiation level in R/B



Self-contained breathing apparatus

Hydrogen Explosions at Units 1 and 3 R/B

- Hydrogen is supposed to have leaked through heat affected seals on the D/W flange, hatch and electric penetrations.