Fukushima-Daiichi NPP Accident

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Lessons Learned from the Accident

- People and the environment should be protected by risk of radiation
- Nuclear Safety should be based on the Defense-in-Depth Concept
  - Accident Management should be re-checked with serious viewpoints
  - Complete station blackout should be prevented in any conditions
  - Alternate AC and DC system should be prepared
  - To recover Loss of ultimate heat sink, backup components should be prepared
  - Air-cooled System should be considered for cooling diversity
  - Filtered Vent might be useful to protect environment
- Kaizen from the experience should be most important to keep the nuclear safety

IAEA Safety Fundamentals (SF-1)

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

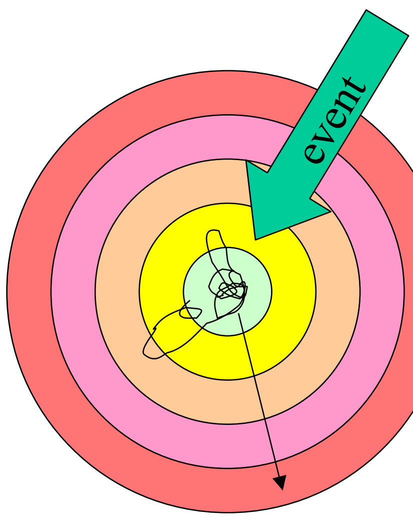
Principle 1: Responsibility for safety
Principle 2: Role of government
Principle 3: Leadership and management for safety
Principle 4: Justification of facilities and activities
Principle 5: Optimization of protection
Principle 6: Limitation of risks to individuals
Principle 7: Protection of present and future generations
Principle 8: Prevention of accidents
Principle 9: Emergency preparedness and response
Principle 10: Protective actions to reduce existing or unregulated radiation risks

http://www-pub.iaea.org/MTCD/publications/PDF/Pub1273_web.pdf

IAEA Safety of Nuclear Power Plant (NS-R-1)

Defense-in-Depth Concept

1. Prevent deviations from normal operation
2. Prevent from escalating to accident
3. Prevent core damage or significant off site release
4. Mitigate the consequence of accident
5. Mitigate radiological consequence



5 layer of DiD

IAEA Safety of Nuclear Power Plant (NS-R-1)

Defense-in-Depth Concept

1. Prevent deviations from normal operation	Design, Operation, Maintenance,…
2. Prevent from escalating to accident	Anticipated Transient Accident
3. Prevent core damage or significant off site release	Design Basis Accident
4. Mitigate the consequence of accident	Sever Accident
5. Mitigate radiological consequence	Emergency response

IAEA Safety of Nuclear Power Plant (NS-R-1)

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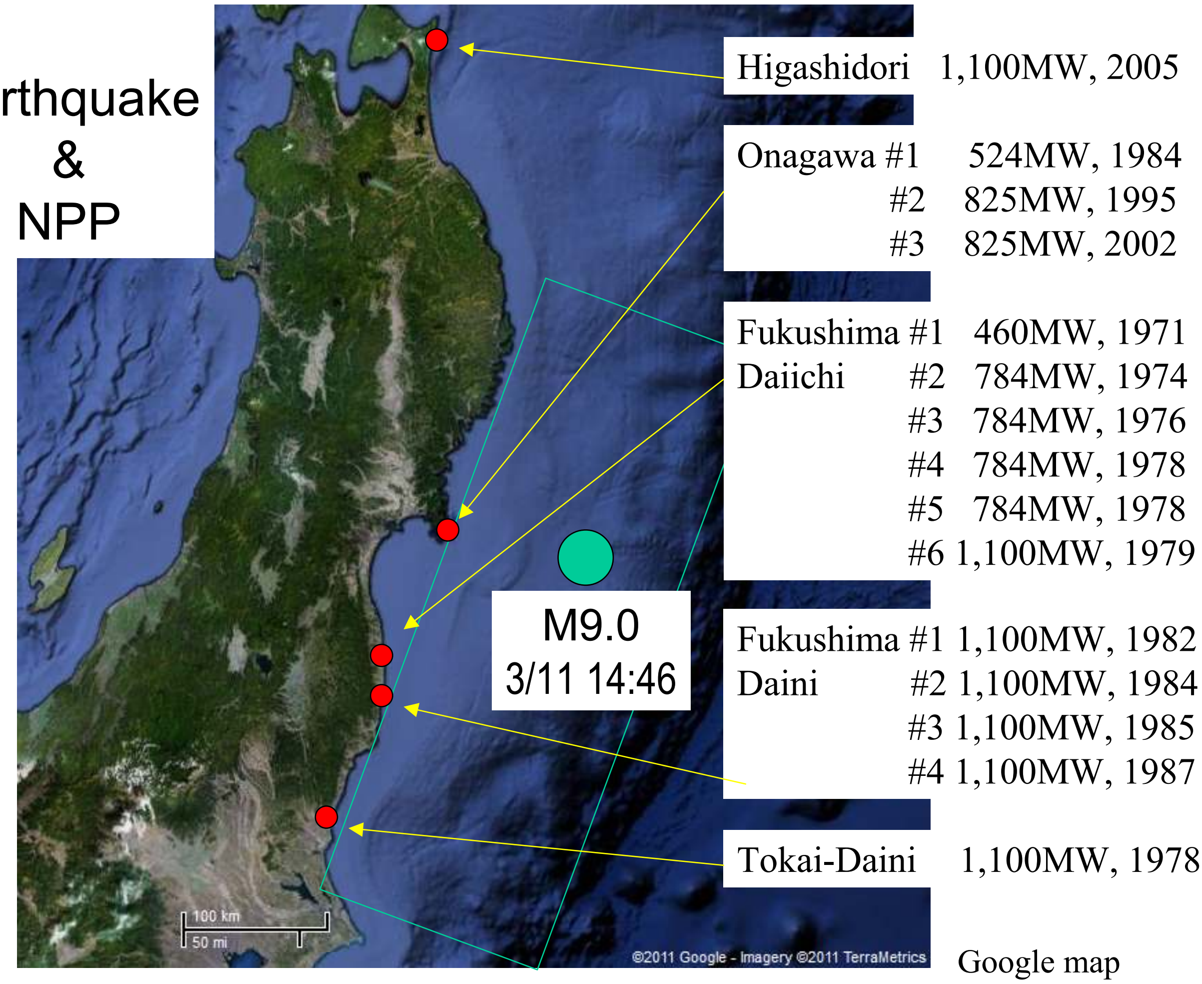
Earthquake & NPP

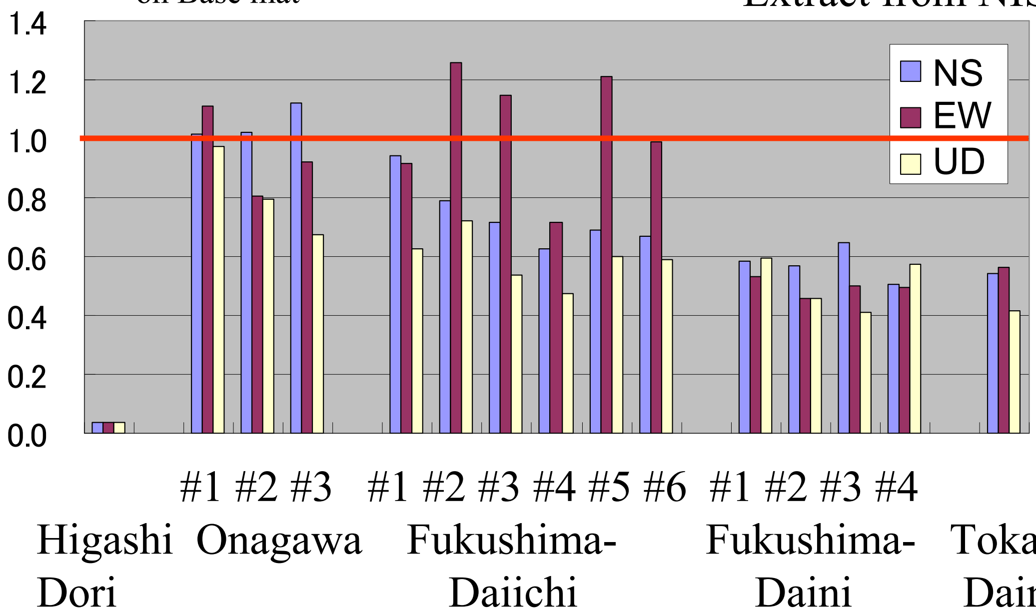


Google map

Ratio of Measured Maximum Acceleration to Seismic Design Acceleration (Ss)

on Base mat

Extract from NISA HP



Important Components have no damage

Seismic Design worked well, under current knowledge

Status of NPPs after Earthquake

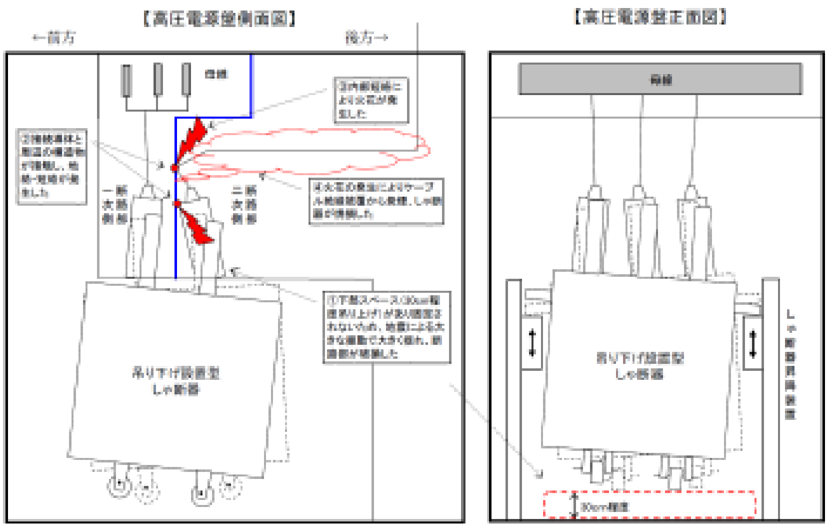
		Operation	DiD1	DiD2
Onagawa	#1	Full-power	Shut-down	non-emerg. M/C Fire
	#2	Start-up	Shut-down	
	#3	Full-power	Shut-down	
Fukushima Daiichi	#1	Full-power	Shut-down	Offsite Power lost
	#2	Full-power	Shut-down	Offsite Power lost
	#3	Full-power	Shut-down	Offsite Power lost
	#4	Outage		Offsite Power lost
	#5	Outage		Offsite Power lost
	#6	Outage		Offsite Power lost
Fukushima Daini	#1	Full-power	Shut-down	
	#2	Full-power	Shut-down	
	#3	Full-power	Shut-down	
	#4	Full-power	Shut-down	
Tokai-Daini		Full-power	Shut-down	Offsite Power lost

Onagawa after Earthquake

No damage for Class-S System Structure & Component (SSC)

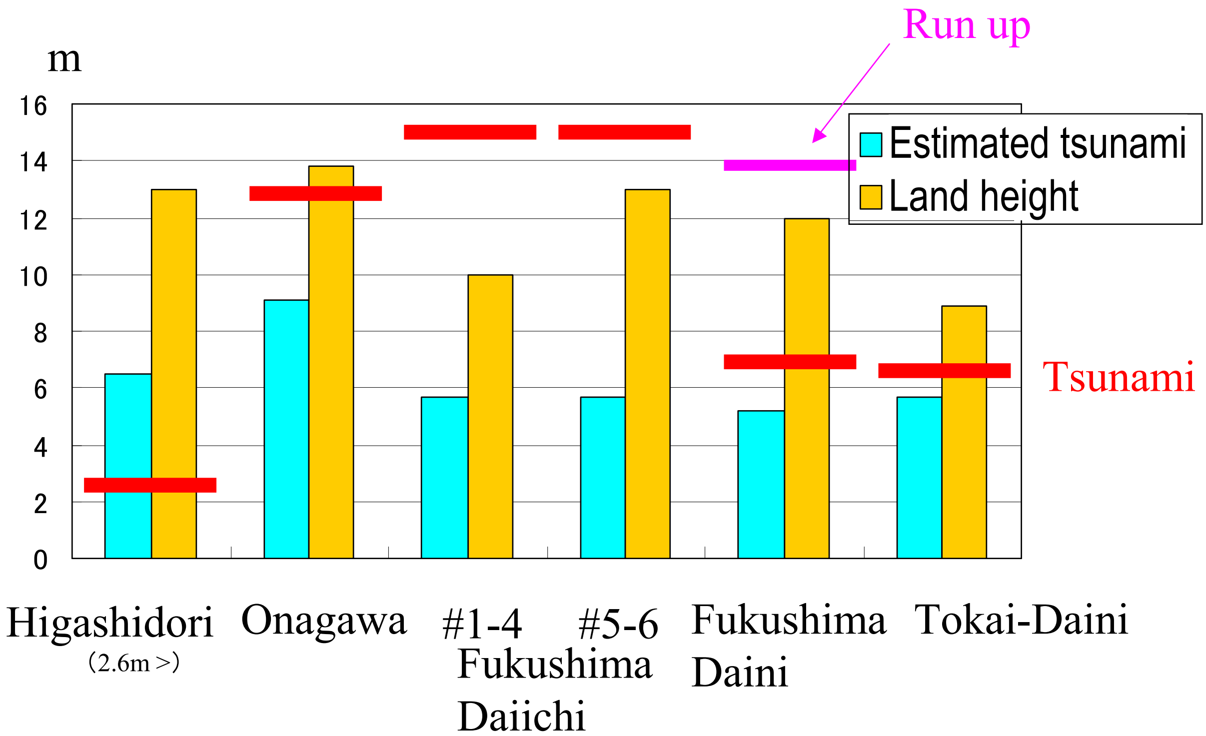
A few damages for Class-B & C SSC

Non-emergent M/C for Unit #1 had a fire



www.tohoku-epco.co.jp/news/atom/1183294_1065.html

Tsunami height



Design against Tsunami was failed, causing Accidents

Status of NPPs after Tsunami

		DiD3	DiD4(AM)	DiD5(Emergency)
Onagawa	#1			
	#2	2D/G×		
	#3			
Fukushima Daiichi	#1		SBO, LUHS	Core Damage, Hydr. Exp.
	#2		SBO, LUHS	Core Damage
	#3		SBO, LUHS	Core Damage, Hydr. Exp.
	#4		SBO, LUHS	Hydr. Exp.
	#5		SBO, LUHS	
	#6		LUHS	
Fukushima Daini	#1		LUHS	
	#2		LUHS	
	#3			
	#4		LUHS	
Tokai-Daini		1D/G×		

IAEA Safety of Nuclear Power Plant (NS-R-1)

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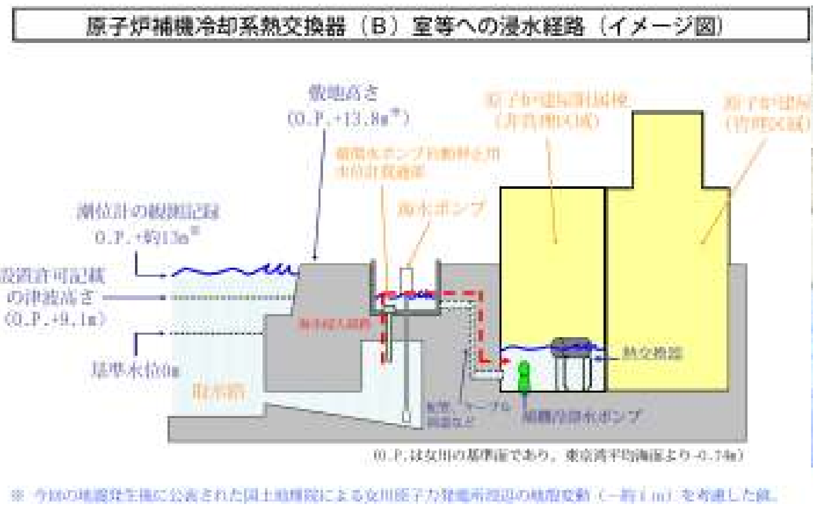
Onagawa

- Sea water leakage to Unit #2 Reactor Bldg.
  - Plant height (14.8m – 1m) is higher than tsunami (13m)
  - Sea water flew into Pump(B) area. Water level meter box seal is too weak to protect the pressure.
  - Sea water leaked to Reactor Bldg. through pipe/cable trench, resulting in the 2 D/G stop by flooding.

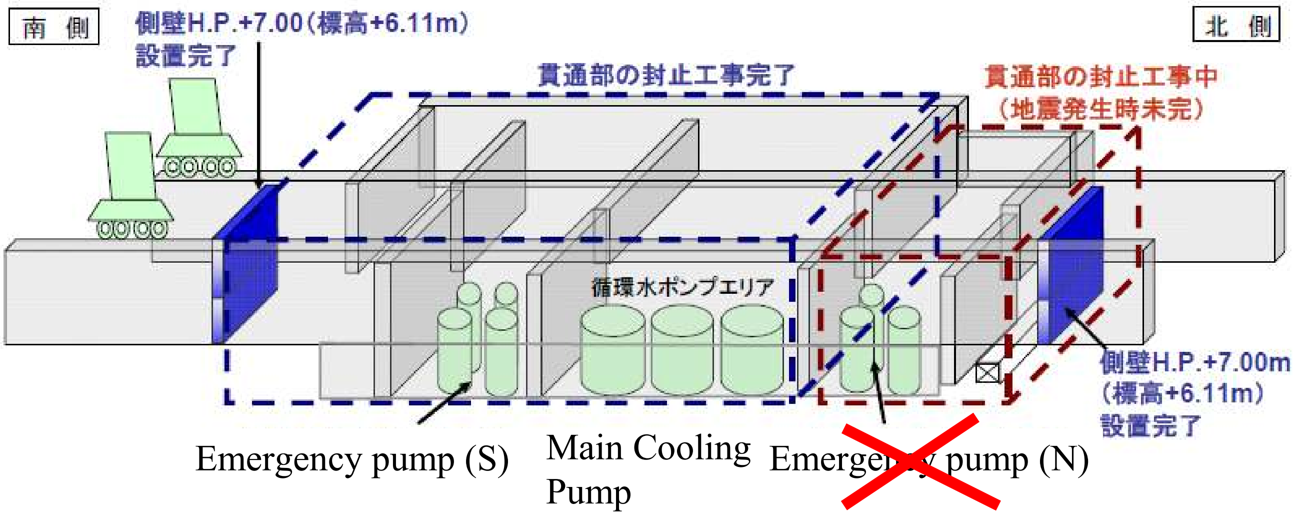


水位計収納箱から海水が流入（対策前）

www.tohoku-epco.co.jp/news/atom/1183294_1065.html

Tokai-Daini

www.meti.go.jp/press/2011/04/20110407003/20110407003.pdf



Tsunami (6.3m) < Protect Wall (7.0m)

Sea water leakage through cable pit
(Sealing was not enough)

IAEA Safety of Nuclear Power Plant (NS-R-1)

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Status of Fukushima Daiichi after Tsunami

	#1	#2	#3	#4	#5	#6
Offsite Power	×	×	×	×	×	×
Emergency D/G A/C: Air-cooled *: cooling pump flooding	× ×	× × A/C	× ×	× × A/C	× * × *	× * ○ A/C × *
M/C (Emergency)	×	×	×	×	×	3/3
M/C (non-Emrg.)	×	×	×	×	×	×
P/C (Emergency)	×	2/3	×	2/3	×	3/3
P/C (non-Emrg.)	×	2/4	×	2/2	2/4	×
DC battery	×	×	○	×	○	○
Seawater Pump	×	×	×	×	×	×

Status of Fukushima Daini after Tsunami

	#1	#2	#3	#4
Offsite Power	○	○	○	○
Emergency D/G A/C: Air-cooled *: cooling pump flooding	× × ×	× * × * × *	× * ○ ○	× * × * ○
M/C (Emergency)	1/3	○	○	○
M/C (non-Emrg.)	○	○	○	○
P/C (Emergency)	1/3	2/3	2/3	2/3
P/C (non-Emrg.)	6/7	4/5	7/7	4/5
DC battery	○	○	○	○
Seawater Pump	×	×	1/2	×

Status of Onagawa & Tokai-Daini after Tsunami

	Onagawa			Tokai-Daini
	#1	#2	#3	
Offsite Power	○	○	○	×
Emergency D/G A/C: Air-cooled *: cooling pump flooding	○ ○ ○	○ × ×	○ ○ ○	○ ○ ×*
M/C (Emergency)	○	○	○	○
M/C (non-Emrg.)	×	○	○	○
P/C (Emergency)	○	○	○	○
P/C (non-Emrg.)	○	○	○	○
DC battery	○	○	○	○
Seawater Pump	○	○	○	○

Taiwan Maanshan NPP Unit #1
Station Blackout (SBO) on March 18, 2001

0:45 Loss of 2 Offsite Power Line
Damage of A-BUS
Failure of B-D/G Startup

0:57 RCIC start to cooling reactor

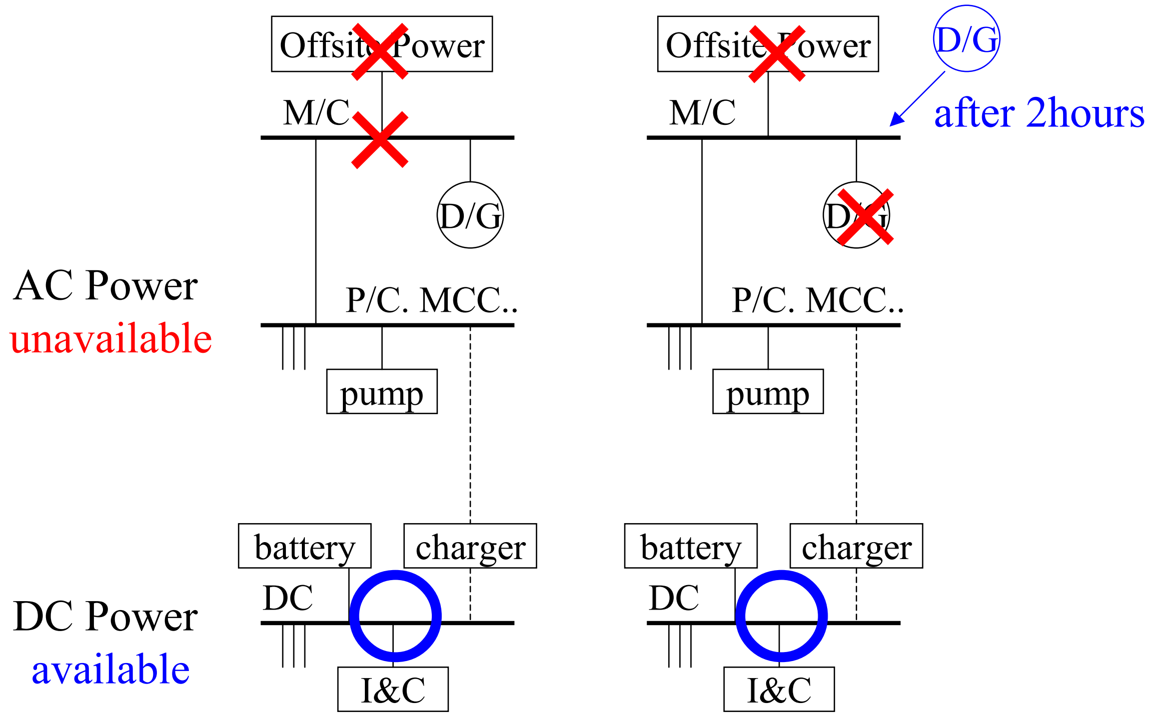
2:54 Swing-D/G (5th) was connected to B-BUS

Station Blackout → ~2 hours → Recovery

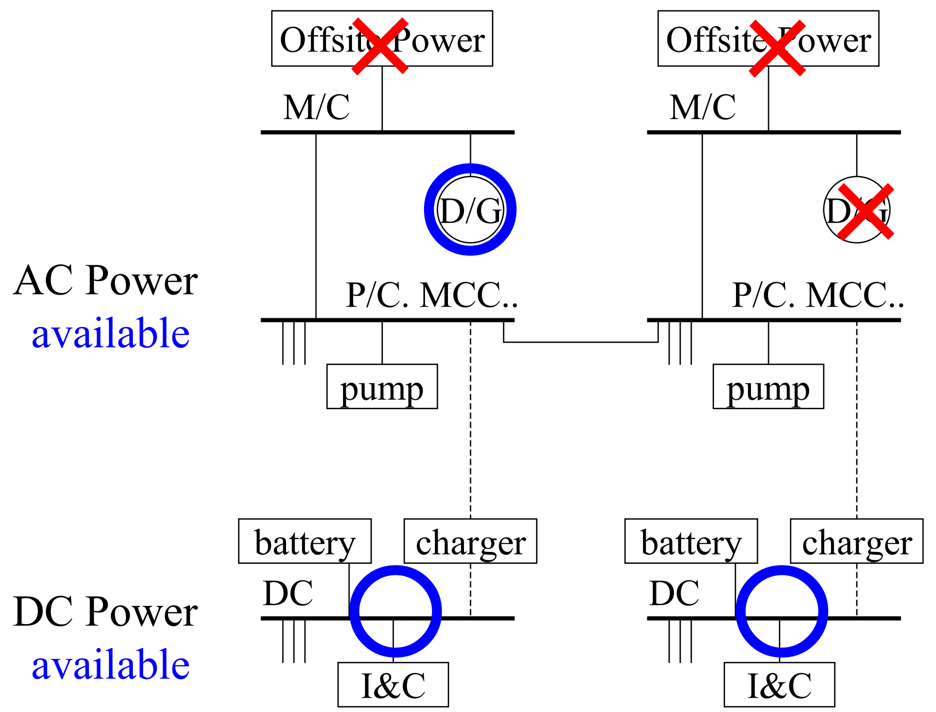
SBO does happen even D/G were available, if M/C and/or BUS have been lost.
M/C and/or BUS are very important.

The event should be considered to improve safety

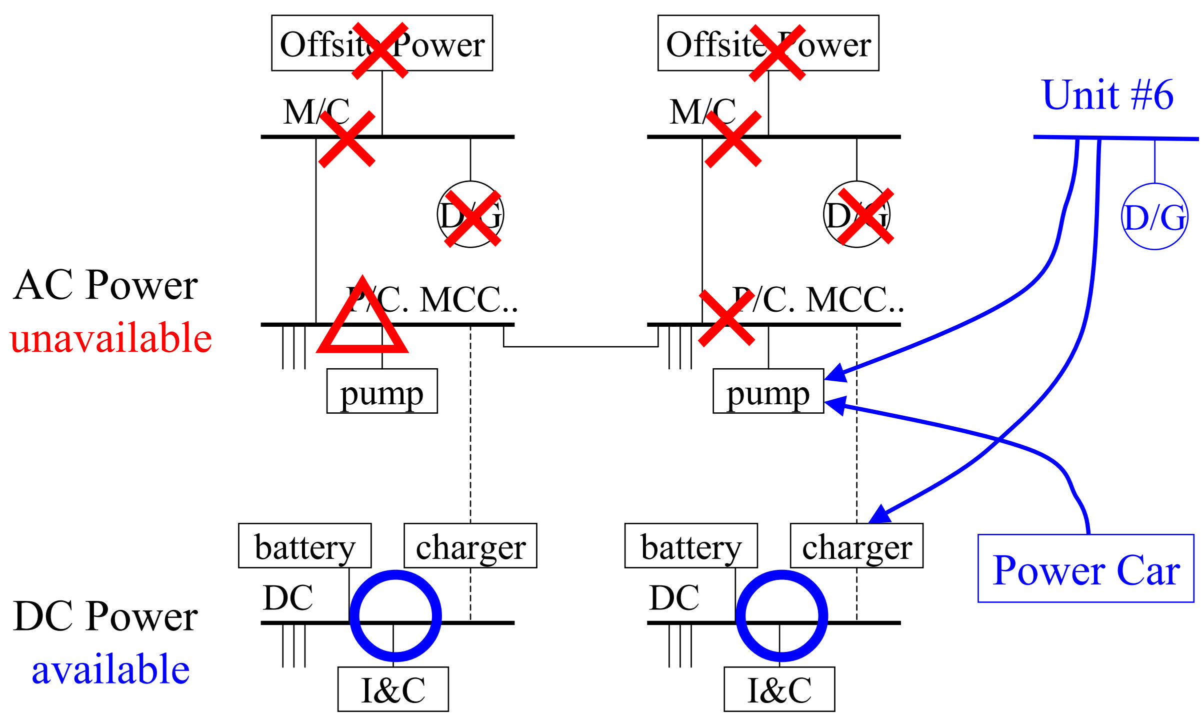
Taiwan Maanshan



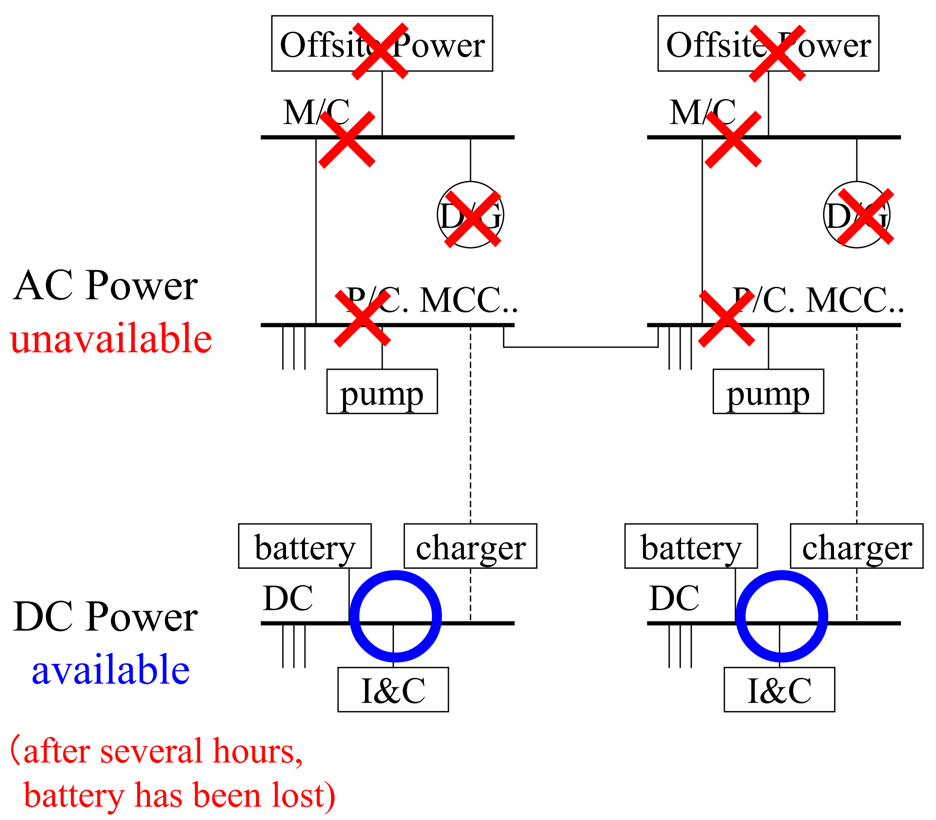
Fukushima Daiichi Unit 6



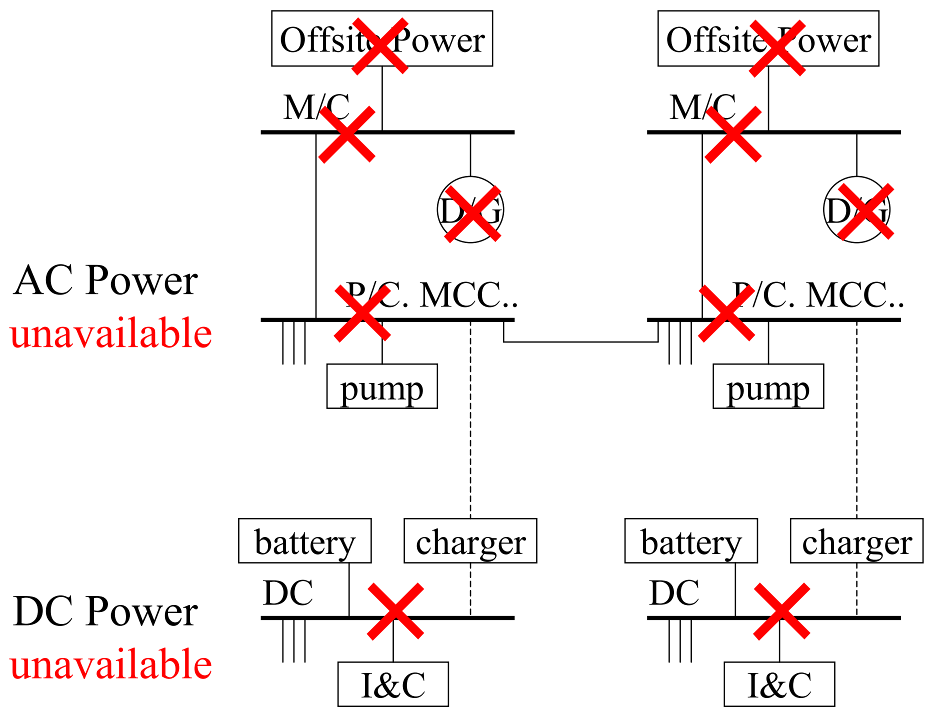
Fukushima Daiichi Unit 5



Fukushima Daiichi Unit 3



Fukushima Daiichi Unit 1

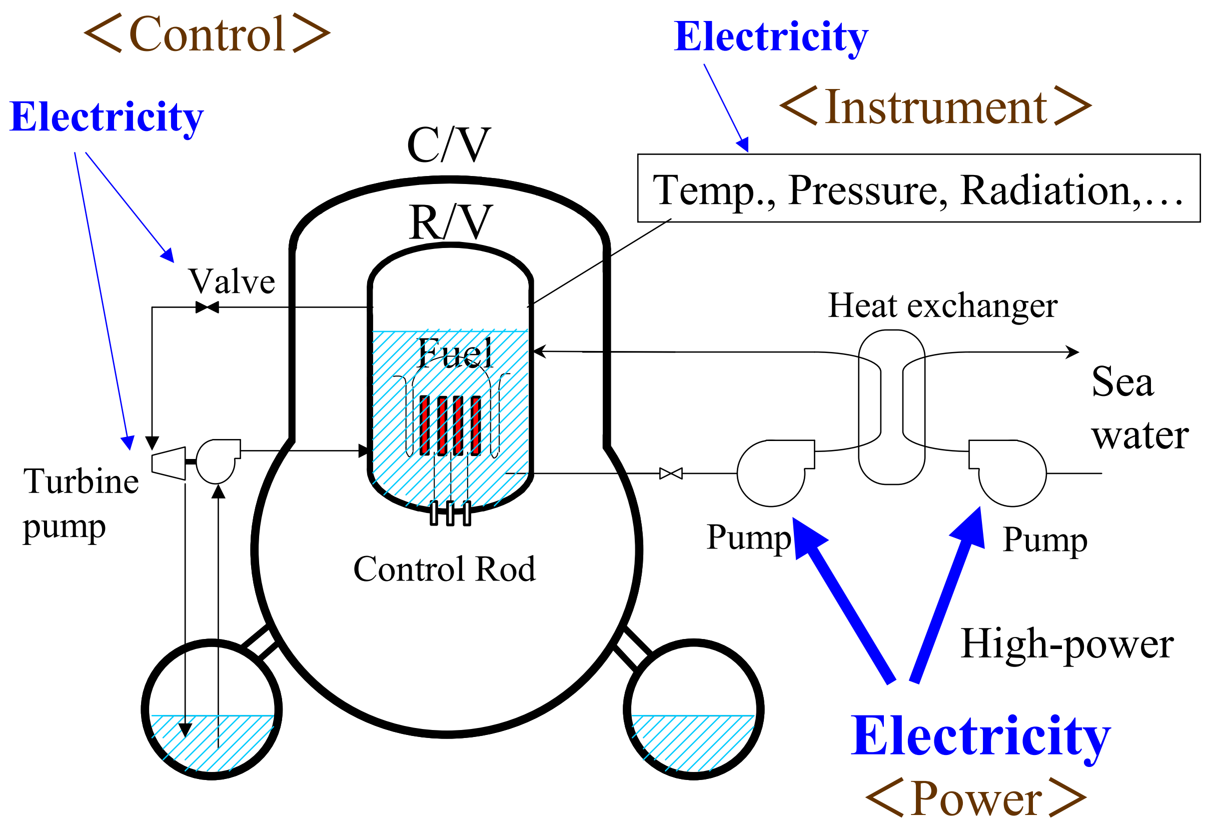


SBO classifications

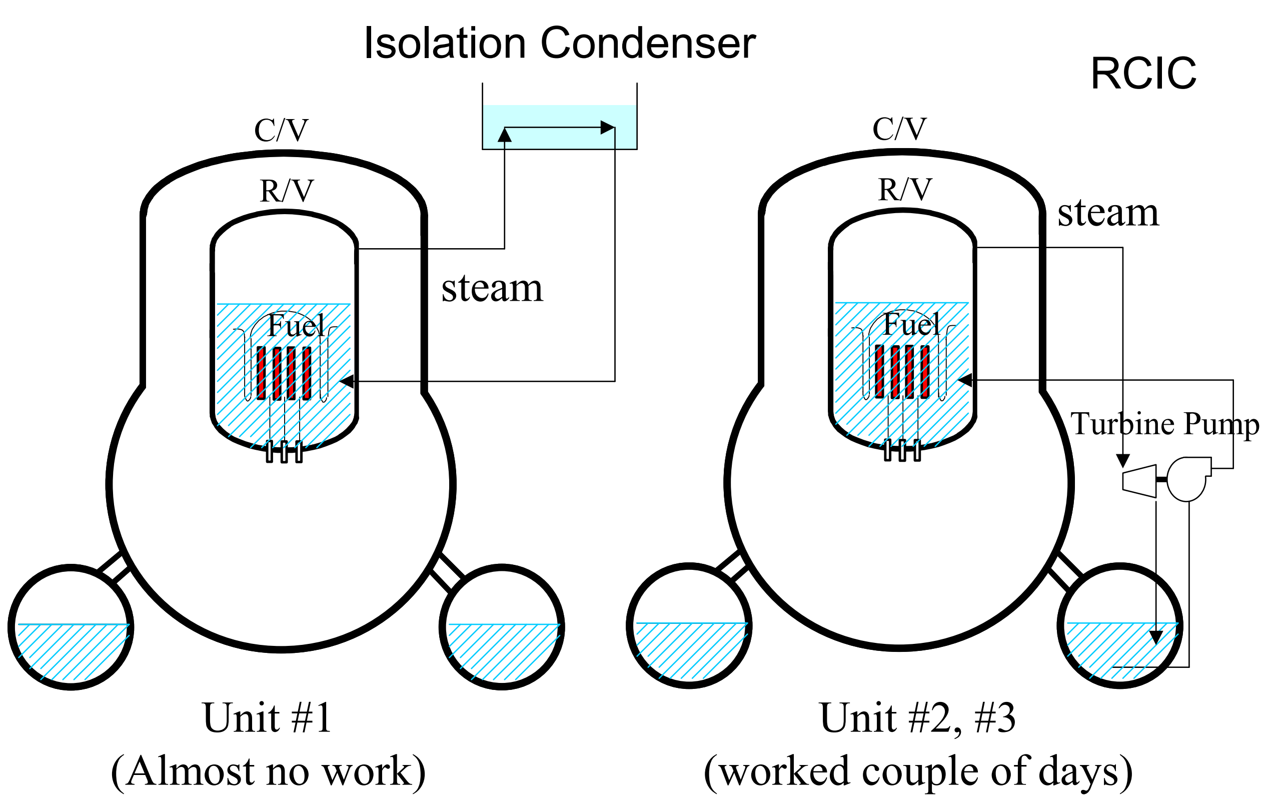
Offsite power	Emrg. D/G	M/C & BUS	DC battery	countermeasures
×	×	○	○	Alternate AC (Swing D/G)
×	×	×	○	Alternate M/C Battery Charger Backup Cabling
×	×	×	×	Backup Battery Backup Charger Backup Instrument

Possibility

Design Basis — Accident Management



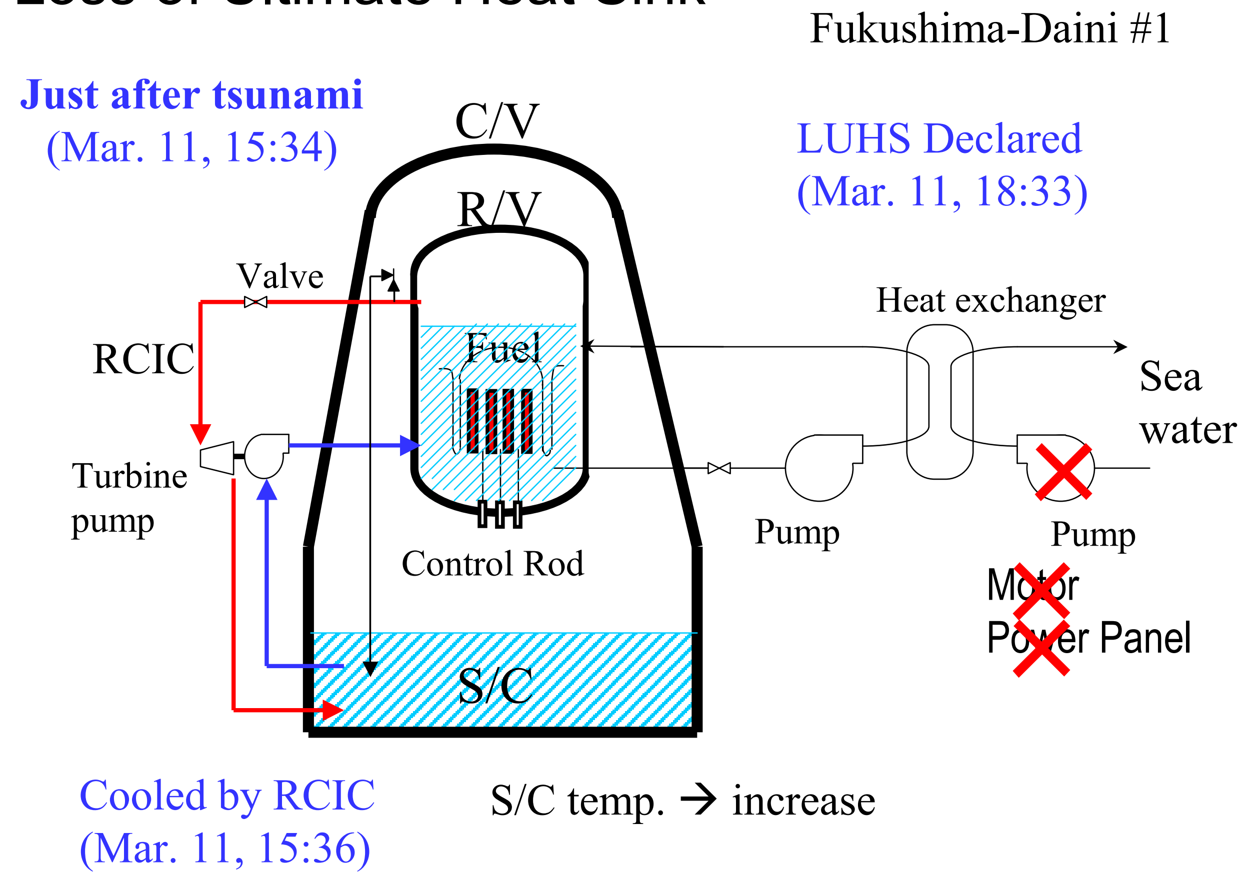
Cooling System without Electricity (Fukushima-Daiichi)



Summary for Station Blackout

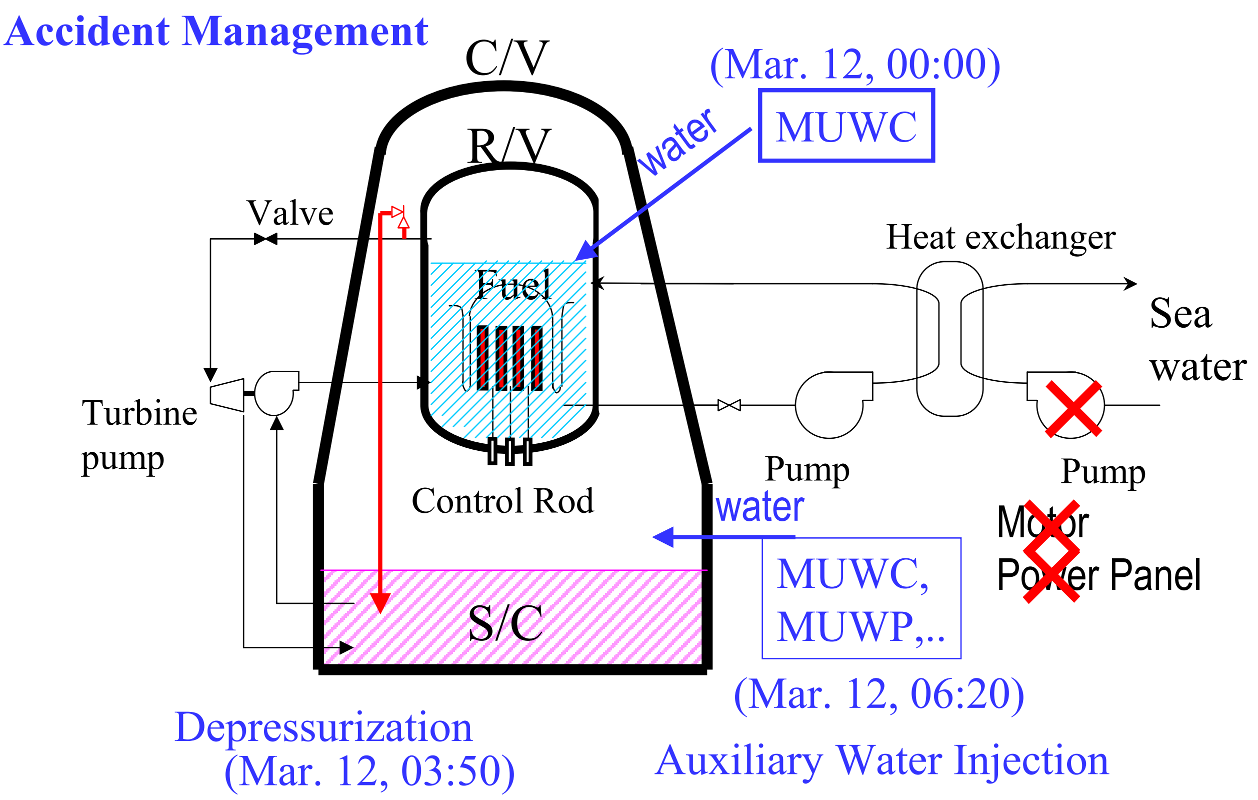
1. Emergency Power Source should have diversity, independency and multiplicities.
2. Simple SBO should be considered as design basis accident (DB). Alternate AC power source should be prepared to reduce SBO risk.
3. Loss of BUS and loss of DC have to be considered as design extension condition (DEC).
4. I&C needs few power, comparing pumps.
   Backup DC battery might be useful for sever accident management.
5. Waterproof should be perfectly applied for preventing common cause failure of Electric Systems

Loss of Ultimate Heat Sink



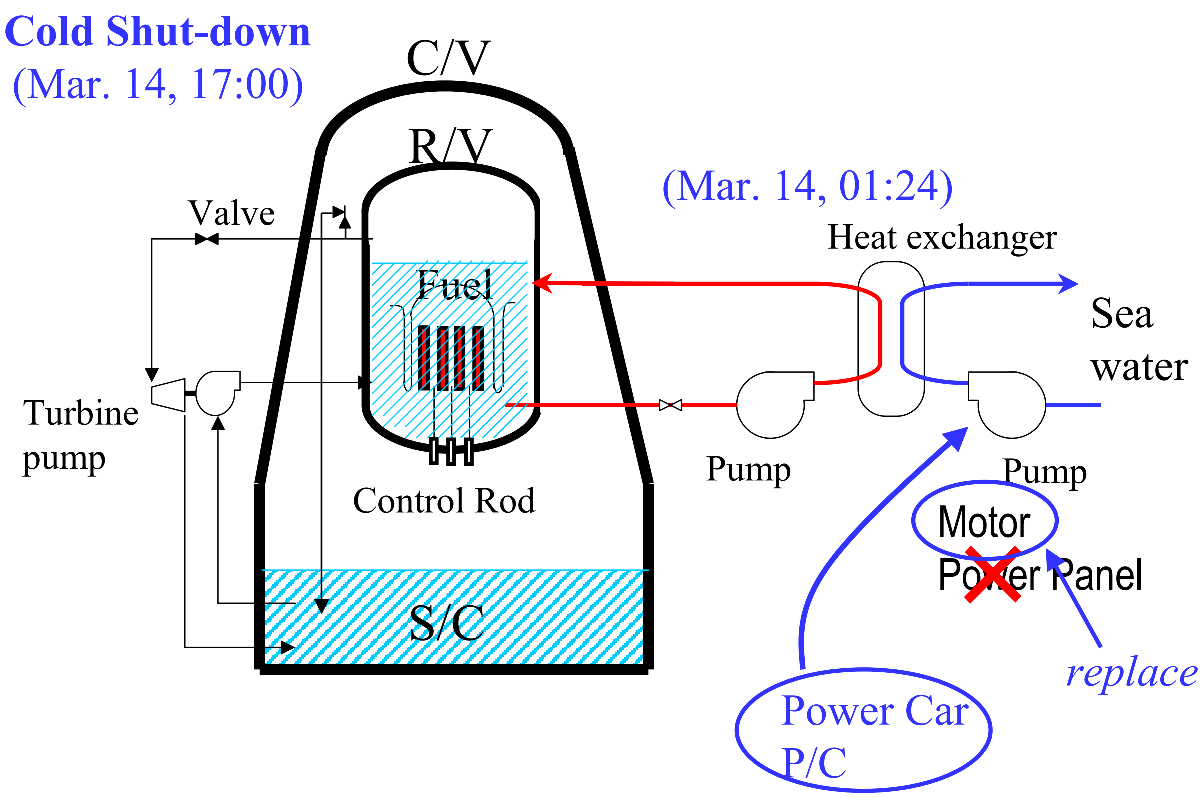
Loss of Ultimate Heat Sink

Fukushima-Daini #1



Loss of Ultimate Heat Sink

Fukushima-Daini #1



Summary for Loss of Ultimate Heat Sink

1. LUHS has relatively large time margin if AC power is available. Therefore complete SBO should be prevented in any conditions.
2. To reduce the recovery term, backup components should be prepared, e.g., motor, pump and so on.
3. Air-cooling System might be considered for improving the reliability of heat sink, especially, S/C and Spent Fuel Pool.
4. Seawater pump might be installed in waterproof building.

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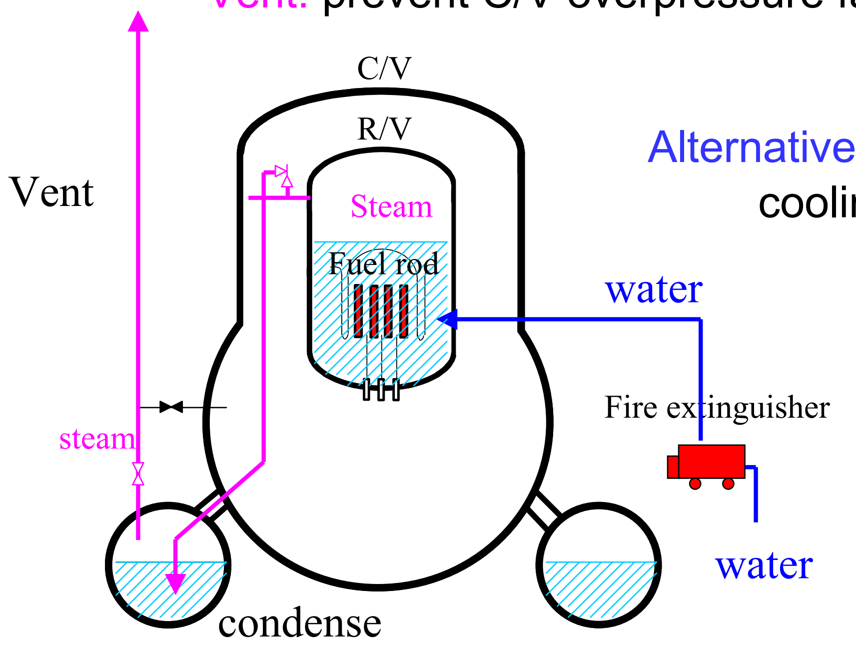
Accident Management

(To mitigate SA, all resources should be applied.)

Vent: prevent C/V overpressure failure

Alternative water injection: cooling fuel decay heat



Vent trial for Unit #1

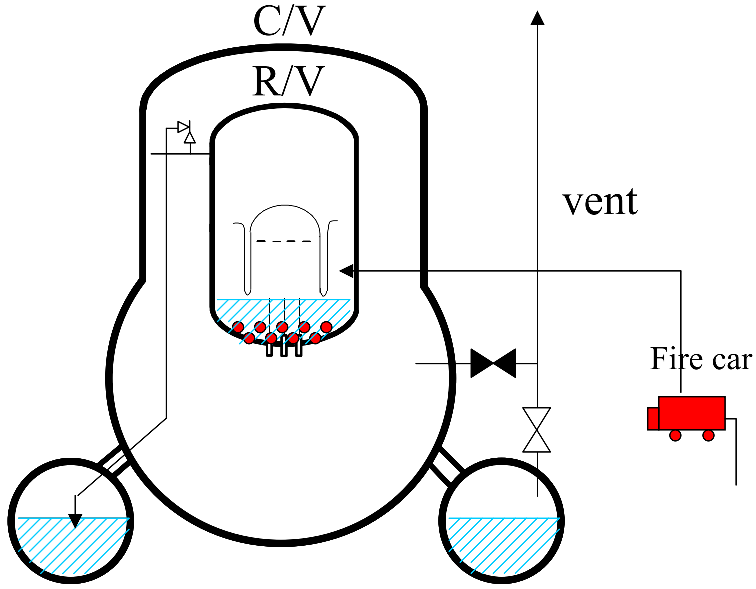
Mar. 11, 15:37 Tsunami

Mar. 12, 00:06
Prepare for Vent

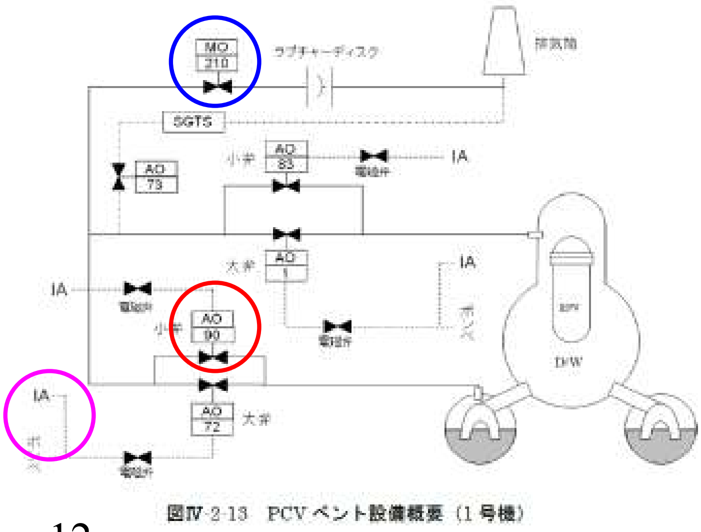
Mar. 12, 05:46 ~ 14:53
Water Injection by fire extinguisher car
(Total 80ton)

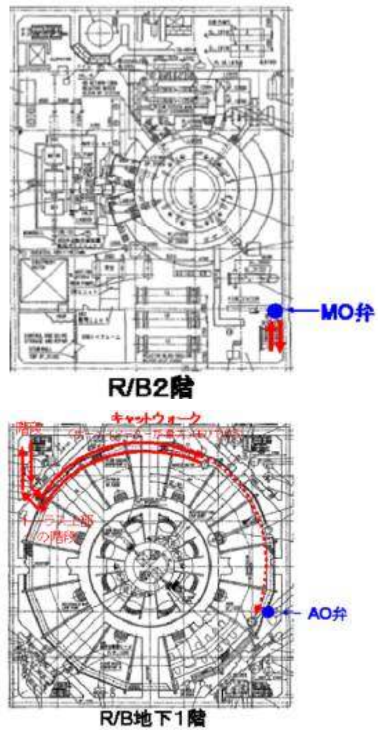
Mar. 12, 15:35
Hydrogen Explosion

Mar. 12, 19:04
Sea water injection



http://www.tepco.co.jp/cc/press/betu11_j/images/110618l.pdf





Mar. 12

0:06 Prepare for Vent (by Station mgr.)

9:15 MO-V_{210} 25% Open

9:30 AO-V_{90} Cannot approach

10:17 At operation room, V_{90} Open

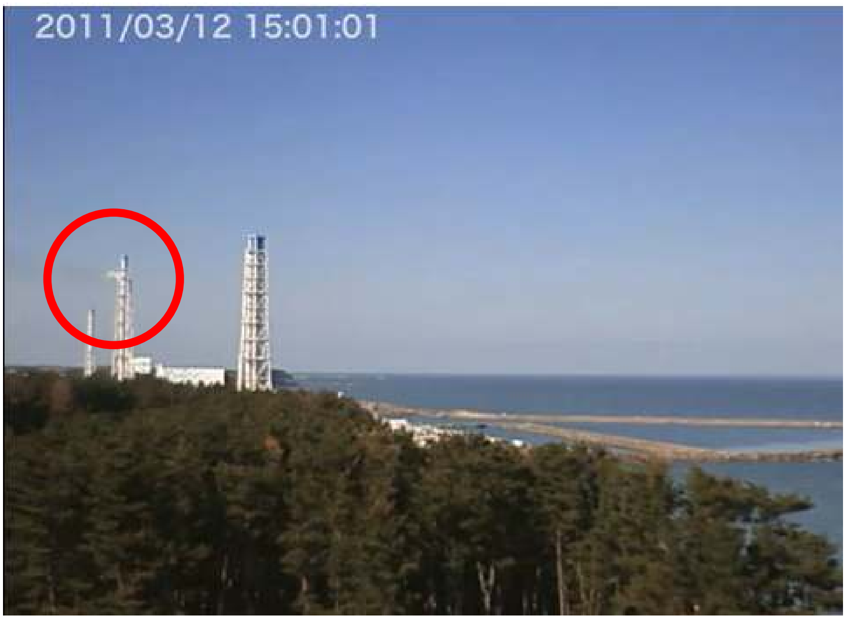
14:00 Compressor operation(AO-V_{72})

14:30 Vent Success（D/W 0.75→0.58MPa）

15:35 Hydrogen Explosion

http://www.tepco.co.jp/cc/press/betu11_j/images/110618l.pdf

Fukuichi Live Camera System

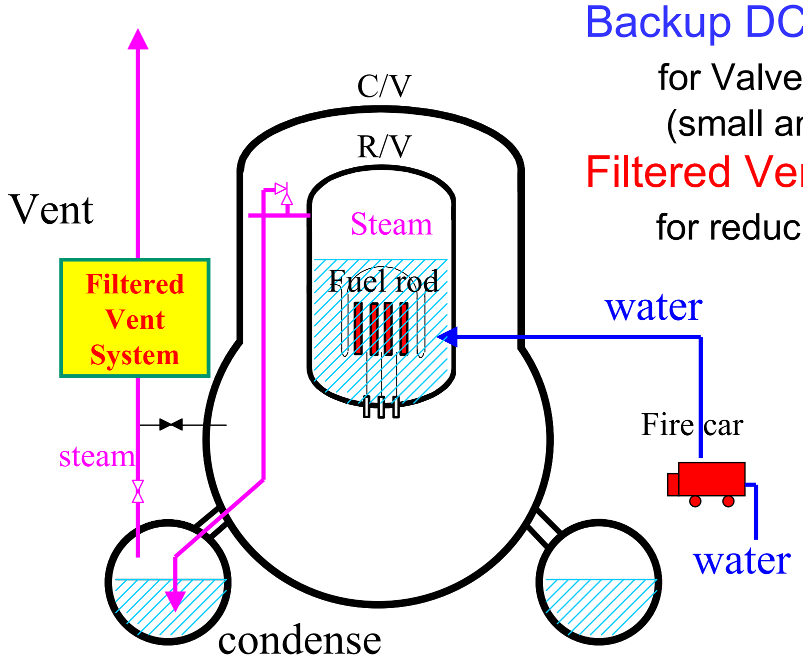


Steam were seen for the Vent from 14:30

at 15:35, Hydrogen Explosion at Unit #1

http://www.youtube.com/watch?v=y5FtdES8of0

Summary of Accident Management (Vent)



Backup DC battery

for Valve operation and Instrument (small amount of electricity)

Filtered Vent System

for reducing the radioactive risk

Even when the core damaged, radioactive materials could be filtered.

Defense-in-Depth and regulation

	Present	Future
1. Prevent deviations from normal operation	Regulation Law	New Regulation
2. Prevent from escalating to accident	Deterministic Approach	Deterministic + Probabilistic Approach
3. Prevent core damage or significant off site release		
4. Mitigate the consequence of sever accident	Self-evaluation by utilities	Accident Management
5. Mitigate radiological consequence	Emergency Law	New Law

Regulation system hardly takes new knowledge

- Japanese NRC written in DPJ manifesto had not been discussed almost 2 years after DPJ took government
- Nuclear Facility Installation Guideline is never revised almost 50 years.
- Seismic Design Guideline had been revised on 2006, more than 10 years after the Kobe Earthquake on 1995.
- In the safety analysis, very old code are still used, because new code needs huge efforts for both utilities and regulators.
- Risk-informed Regulation is still under discussion for more than 10 years.
- Safety target was still midterm report around 10 years.
- Regulation for Sever Accident is also under discussion for more than 10 years.

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- Safety [illegible]as still midterm report around 10 years.
- R[illegible]n for Sever Accident is also under discussion for [illegible] than 10 years.

Japanese (government) cannot decide anything!!!

KAIZEN is most important to sustain the safety.

IAEA Safety Fundamentals (SF-1)

Principle 1: Responsibility for safety
The prime responsibility for safety must rest with the person or organization responsible for facilities and activities that give rise to radiation risks.

Principle 2: Role of government
An effective legal and governmental framework for safety, including an independent regulatory body, must be established and sustained.

Principle 3: Leadership and management for safety
Effective leadership and management for safety must be established and sustained in organizations concerned with, and facilities and activities that give rise to, radiation risks.

http://www-pub.iaea.org/MTCD/publications/PDF/Pub1273_web.pdf

Lessons Learned from the Accident

- People and the environment should be protected by risk of radiation
- Nuclear Safety should be based on the Defense-in-Depth Concept
  - Accident Management should be re-checked with serious viewpoints
  - Complete station blackout should be prevented in any conditions
  - Alternate AC and DC system should be prepared
  - To recover Loss of ultimate heat sink, backup components should be prepared
  - Air-cooled System should be considered for cooling diversity
  - Filtered Vent might be useful to protect environment
- Kaizen from the experience should be most important to keep the nuclear safety