# Fukushima-Daiichi NPP Accident

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# IAEA Safety Fundamentals (SF-1)

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

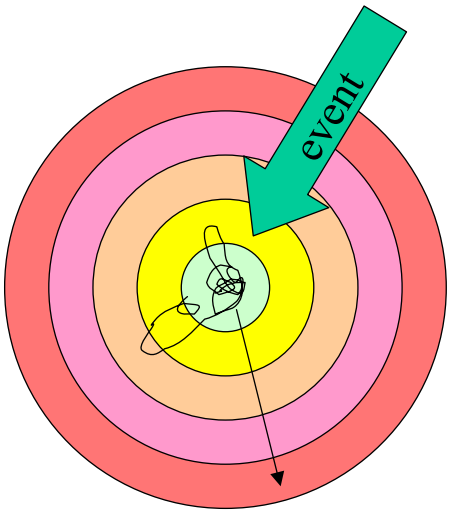
Principle 1: Responsibility for safety
Principle 2: Role of government
Principle 3: Leadership and management for safety
Principle 4: Justification of facilities and activities
Principle 5: Optimization of protection
Principle 6: Limitation of risks to individuals
Principle 7: Protection of present and 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
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

Design, Operation, Maintenance,…

Anticipated Transient Accident

Design Basis Accident

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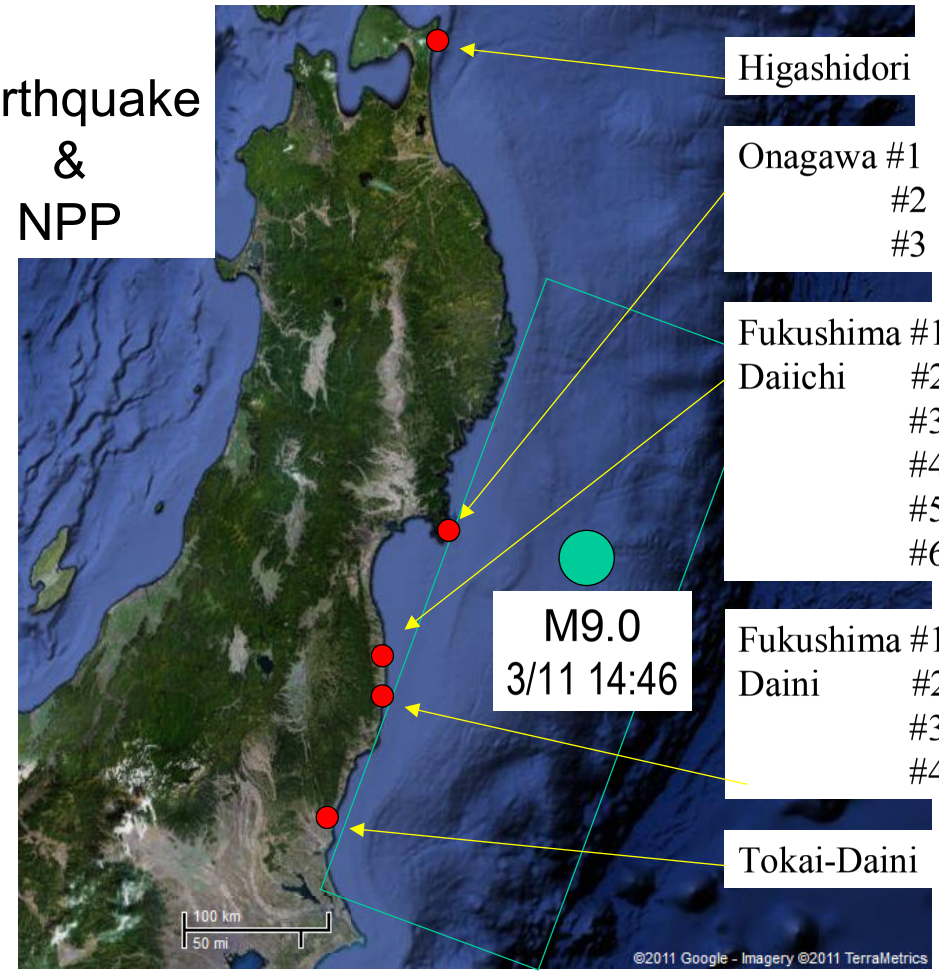
Sever Accident

Emergency response

# Earthquake & NPP




Higashidori 1,100MW, 2005

Onagawa #1 524MW, 1984
#2 825MW, 1995
#3 825MW, 2002

Fukushima Daiichi #1 460MW, 1971
#2 784MW, 1974
#3 784MW, 1976
#4 784MW, 1978
#5 784MW, 1978
#6 1,100MW, 1979

Fukushima Daini #1 1,100MW, 1982
#2 1,100MW, 1984
#3 1,100MW, 1985
#4 1,100MW, 1987

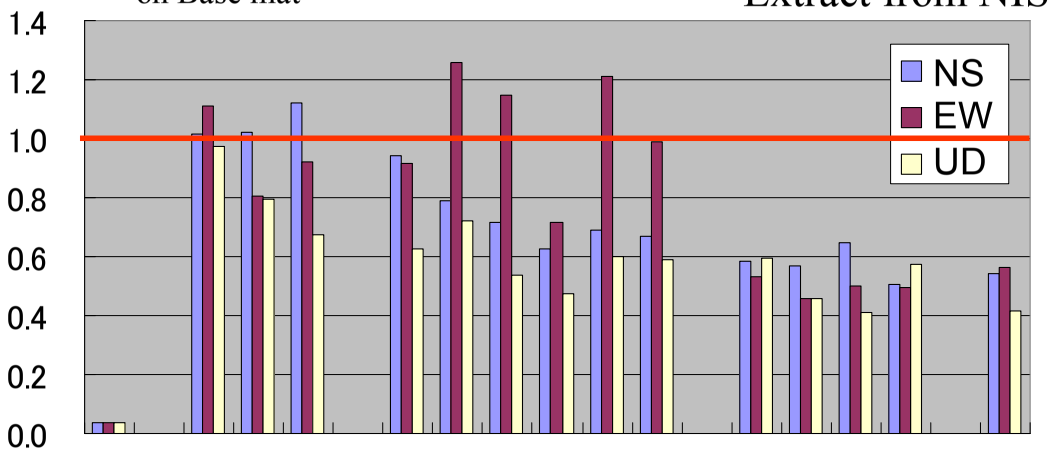
Tokai-Daini 1,100MW, 1978

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

# Seismic Design on Fukushima Daiichi

- Seismic Response Analysis
  - Almost elastic response for Buildings
  - Simulation shows no damages on safety related Systems
  - Walk down for unit #5 found no damages on important components
- Plant Parameter Evaluation before Tsunami
  - Parameter shows no leakages on primary boundaries.
  - Simulation correctly explain the responses of cooling systems without any damages.

*NISA meeting (Dec. 9, 2011)*

Plant has no significant damage by Earthquake

## Status of NPPs after Earthquake

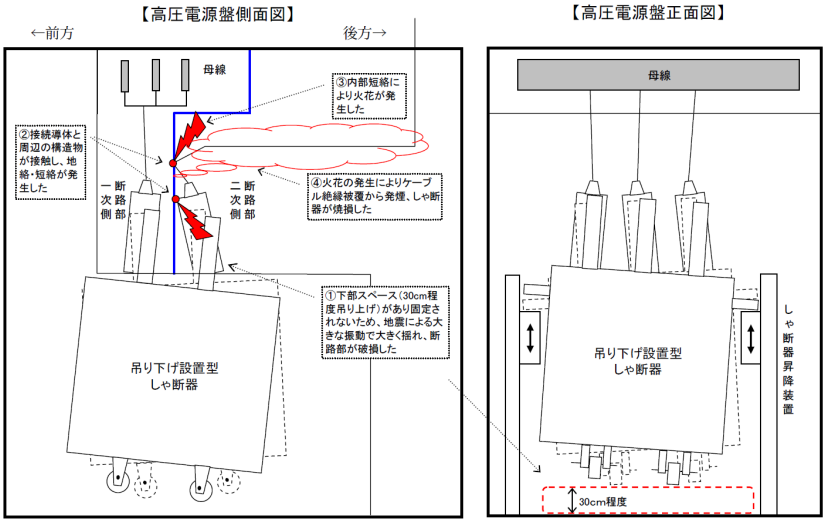
| | | Operation | DiD1 | DiD2 |
|---|---|---|---|---|
| Onagawa | #1 | Full-power | Shut-down | non-emerg. M/C Fire |
| | #2 | Start-up | Shut-down | |
| | #3 | Full-power | Shut-down | |
| Fukushima Daiichi | #1 | Full-power | Shut-down | Offsite Power lost |
| | #2 | Full-power | Shut-down | Offsite 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)

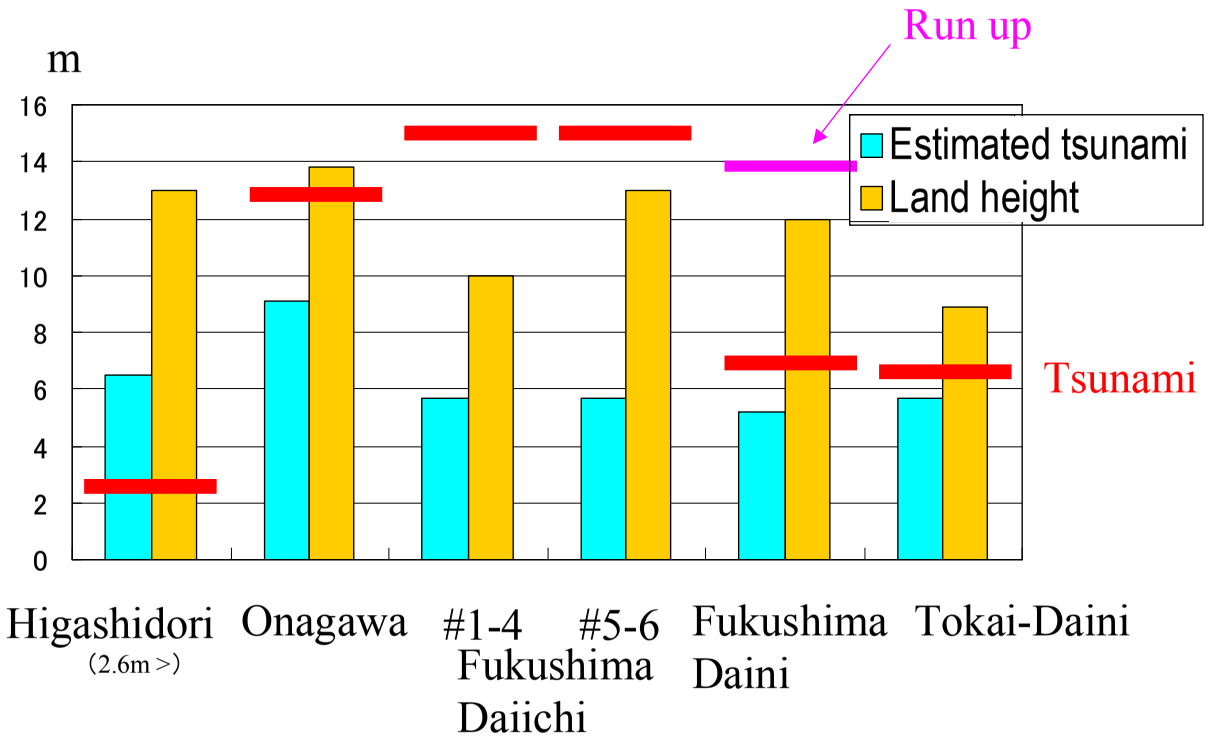
A few damages for Class-B & C SSC

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




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

# Tsunami height



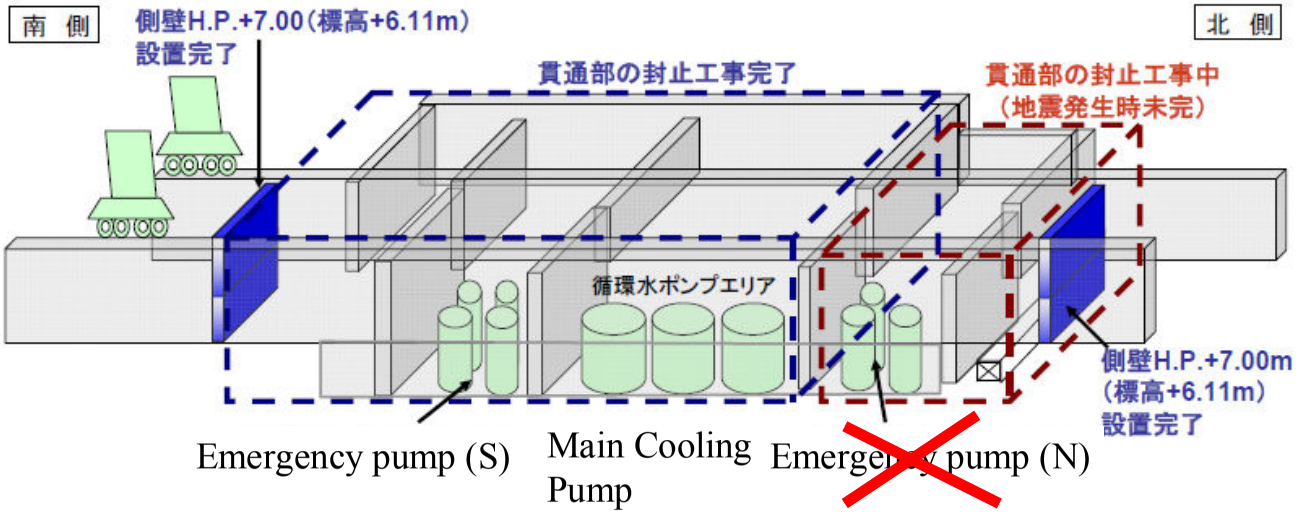

Design against Tsunami was failed, causing Accidents

# 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 × | | |

# Tokai-Daini

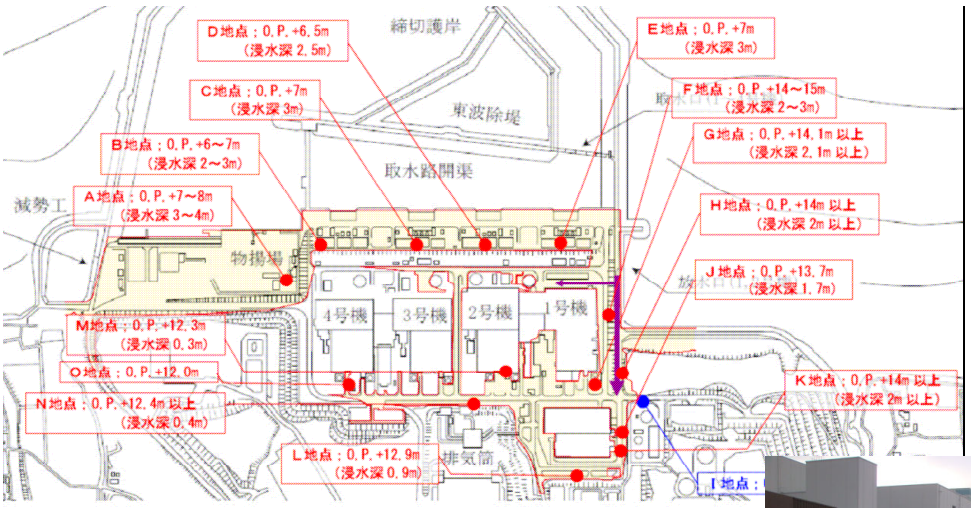
www.meti.go.jp/press/2011/04/20110407003/20110407003.pdf




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

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

# Fukushima-Daini




Est. +5.2m

Height +12m

Tsunami
+6.5～7m
South #1 +14m

Power, Cooling ○ ×

Sea water pump → damaged (except #3)
D/G → unit #1,#2 damaged

http://www.meti.go.jp/press/2011/04/20110413006/20110413006.pdf

# Status of Fukushima Daini after Tsunami

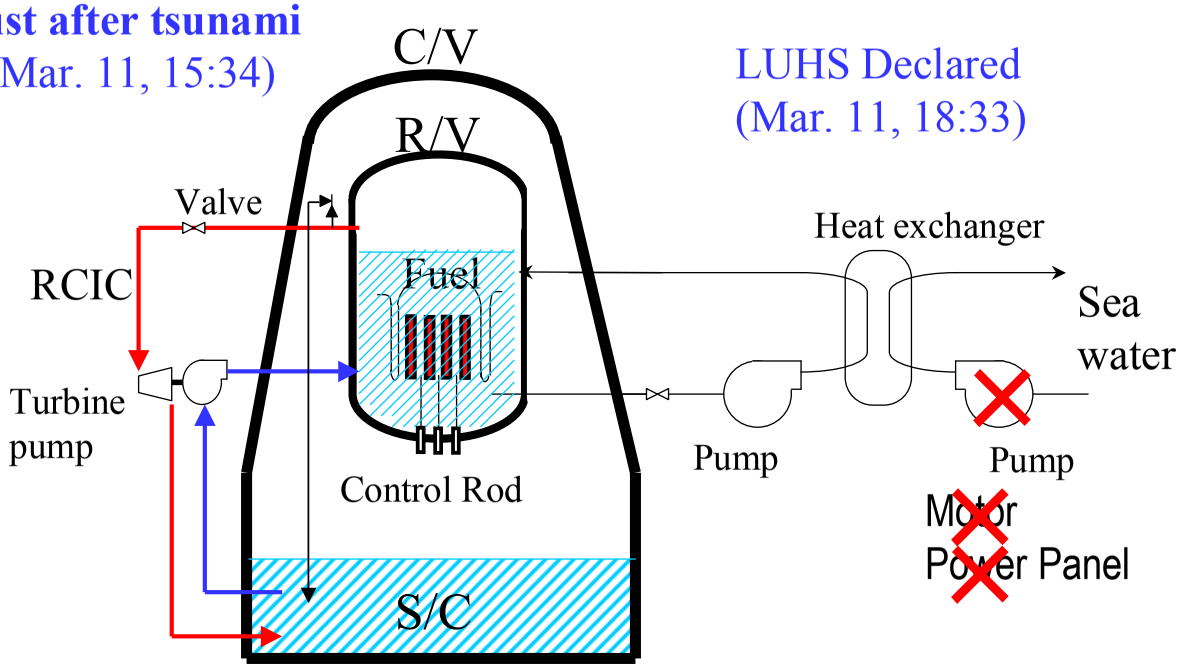
| | #1 | #2 | #3 | #4 |
|---|---|---|---|---|
| Offsite Power | ○ | ○ | ○ | ○ |
| Emergency D/G<br>A/C: Air-cooled<br>*: cooling pump flooding | ×<br>×<br>× | ×*<br>×*<br>×* | ×*<br>○<br>○ | ×*<br>×*<br>○ |
| M/C (Emergency) | 1/3 | ○ | ○ | ○ |
| M/C (non-Emrg.) | ○ | ○ | ○ | ○ |
| P/C (Emergency) | 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 | × |

# Loss of Ultimate Heat Sink

Fukushima-Daini #1

**Just after tsunami**
(Mar. 11, 15:34)

LUHS Declared
(Mar. 11, 18:33)



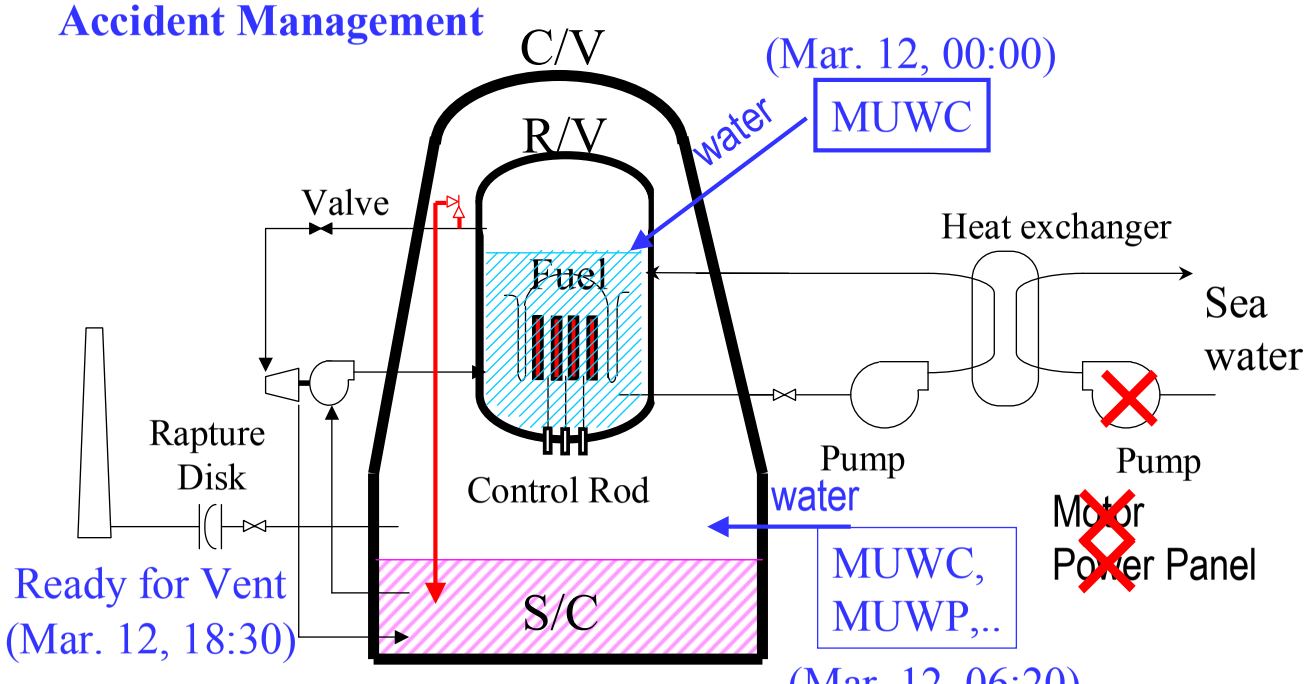

Cooled by RCIC
(Mar. 11, 15:36)

S/C temp. → increase

# Loss of Ultimate Heat Sink

Fukushima-Daini #1

**Accident Management**



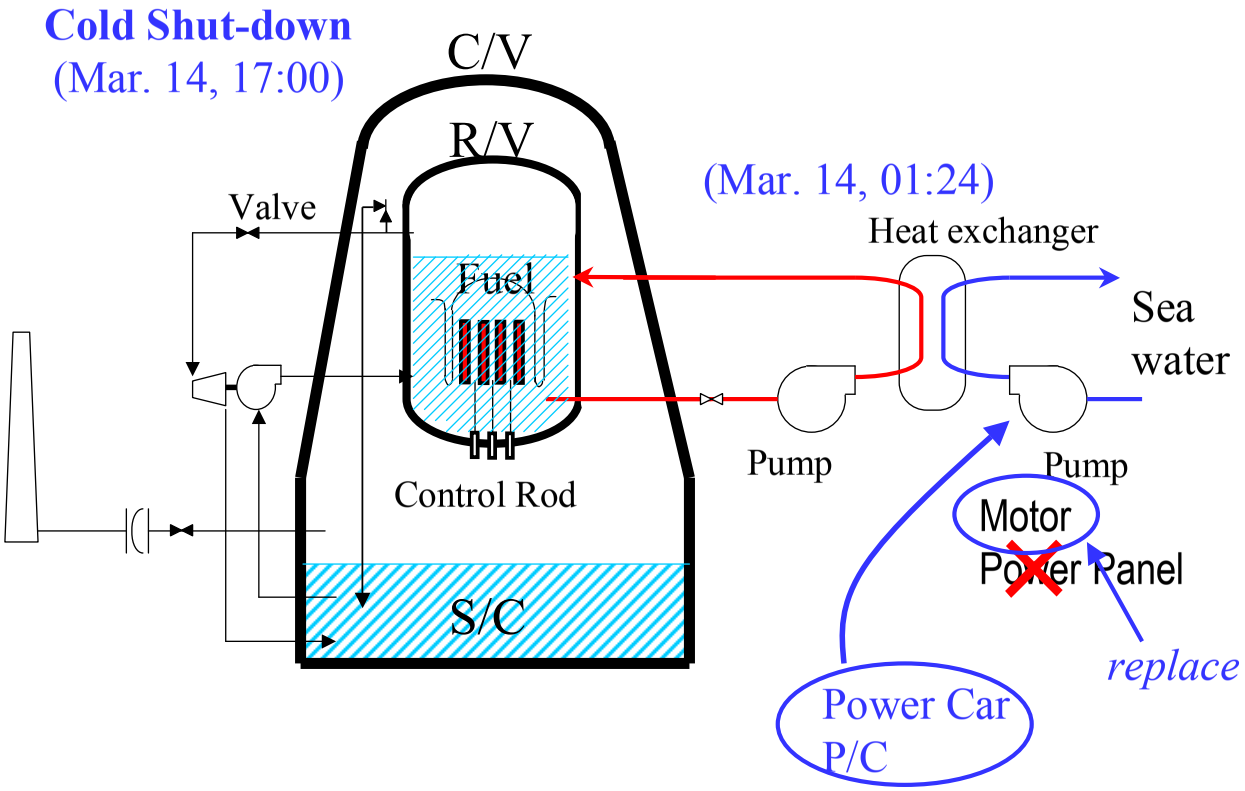

Ready for Vent
(Mar. 12, 18:30)

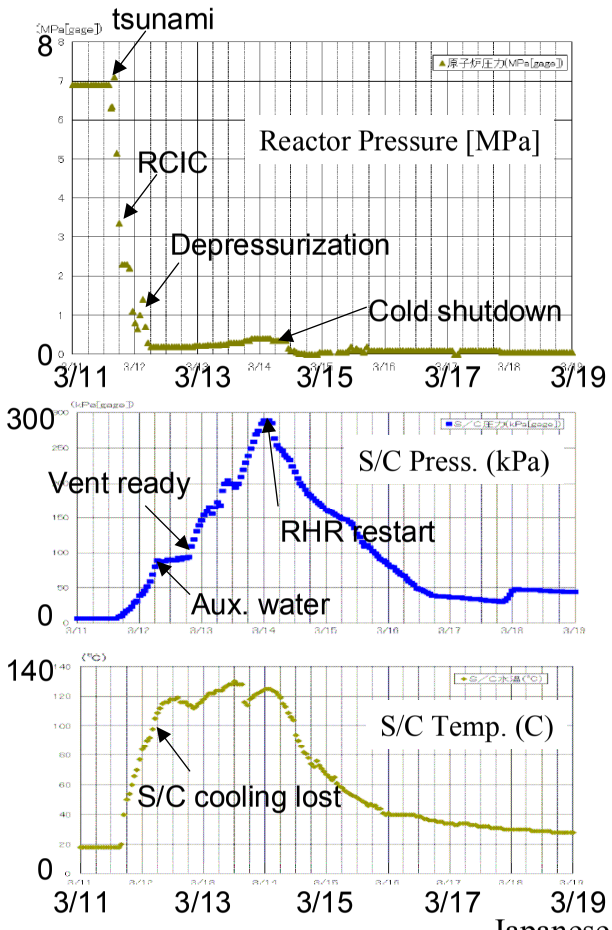
Depressurization
(Mar. 12, 03:50)

(Mar. 12, 06:20)
Auxiliary Water Injection

# Loss of Ultimate Heat Sink

Fukushima-Daini #1




Fukushima-Daini #1

Recovery from
Loss of Ultimate Heat Sink

Japanese government Report for IAEA (Sept. 2011)

# Summary for Loss of Ultimate Heat Sink

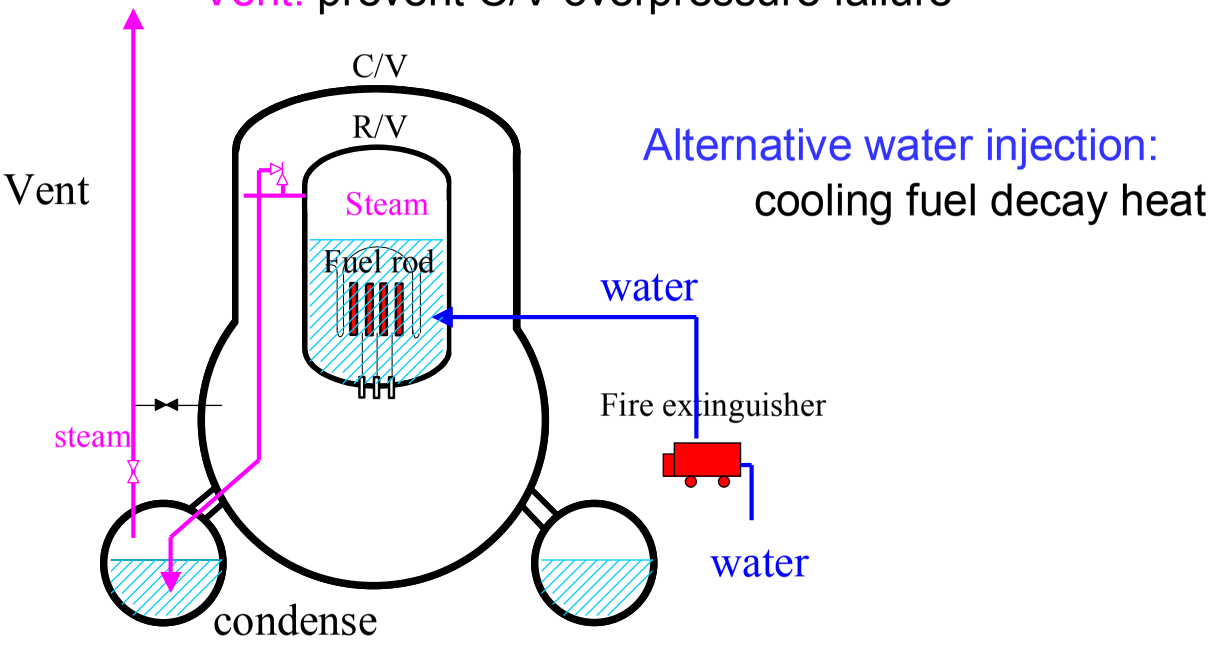
Accident Management at Fukushima-Daini NPP is a good practice to learn lots of things.

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

# 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

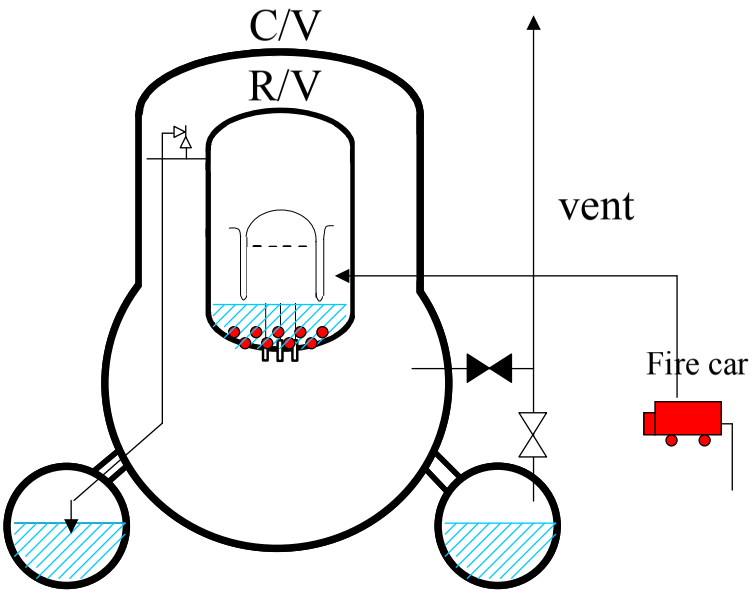
Mar. 11, 15:37 Tsunami

Mar. 12, 00:06
Prepare for Vent

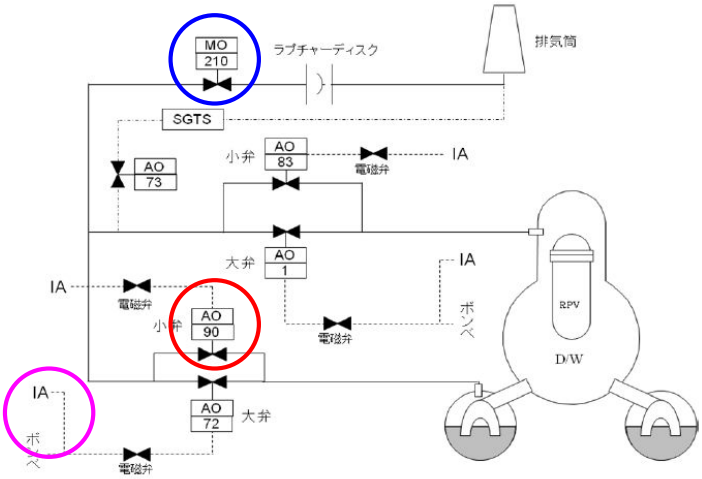
Mar. 12, 05:46 ~ 14:53
Water Injection by
fire extinguisher car
(Total 80ton)

Mar. 12, 15:35
Hydrogen Explosion

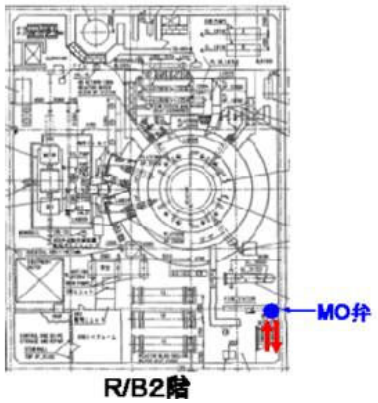
Mar. 12, 19:04
Sea water injection

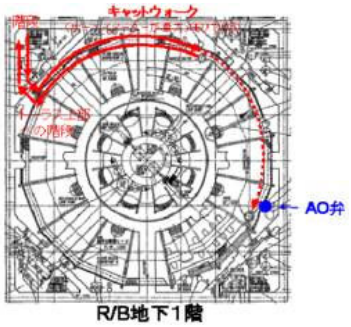



http://www.tepco.co.jp/cc/press/betu11_j/images/110618l.pdf




図Ⅳ-2-13 PCV ベント設備概要（1 号機）



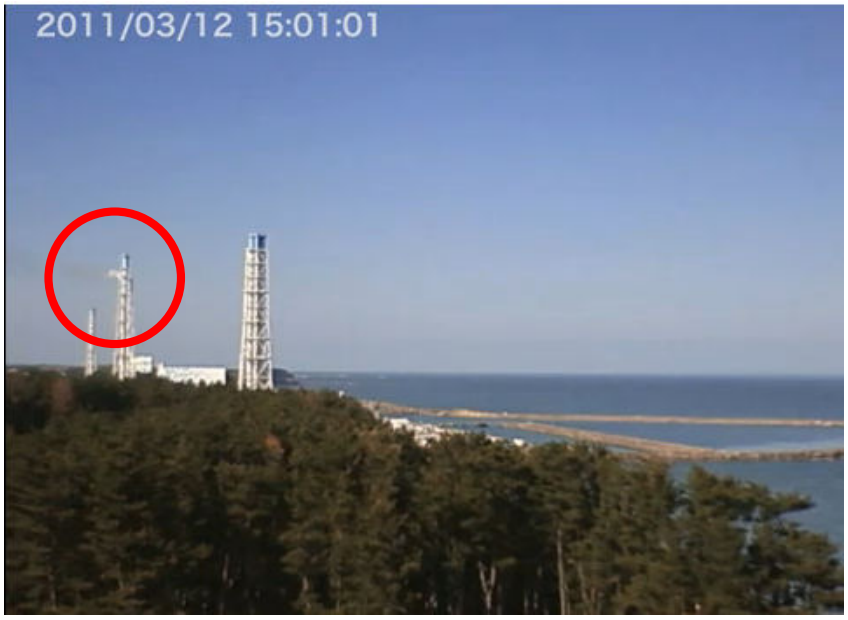




Mar. 12

0:06 Prepare for Vent (by Station mgr.)
9:15 MO-V210 25% Open
9:30 AO-V90 Cannot approach
10:17 At operation room, V90 Open
14:00 Compressor operation(AO-V72)
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

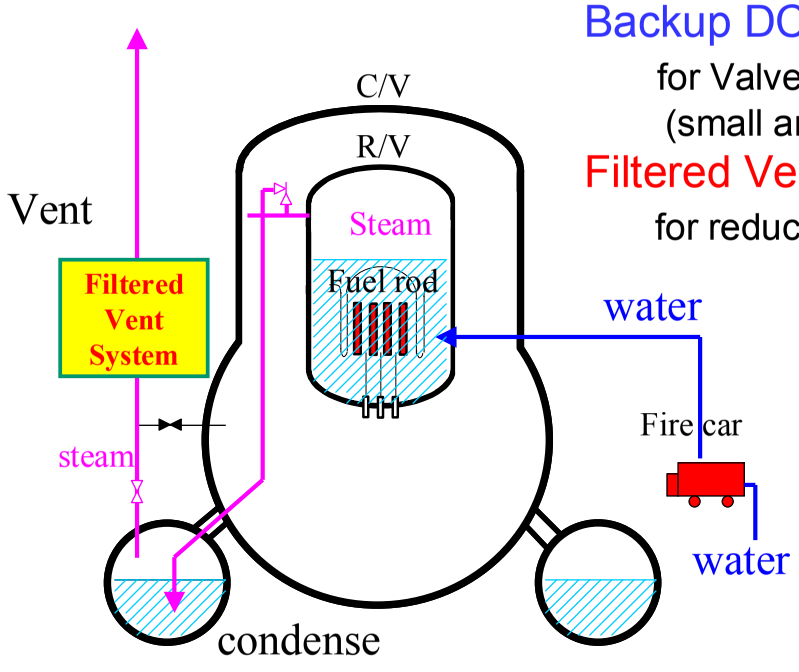



Steam were seen for the Vent from 14:30

at 15:35, Hydrogen Explosion at Unit #1

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

# Summary of Accident Management (Vent)

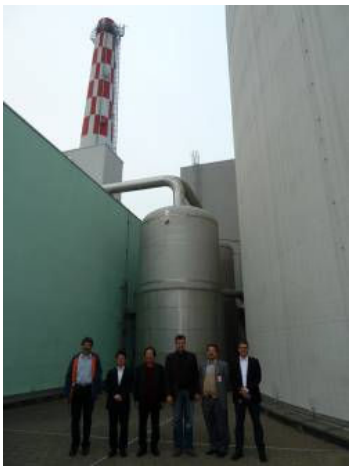



Backup DC battery

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.

One of the most important lessons is

Preventing C/V rupture
Preventing Radioactive material exhaust

| Fukushima Daiichi NPP | |
|---|---|
| #1 C/V 7bar + Vent + $H_2$ Explosion | ~1day |
| #2 C/V 7bar + No Vent + C/V rapture | ~3.5day |
| #3 C/V 6bar + Vent + $H_2$ Explosion | ~3day |

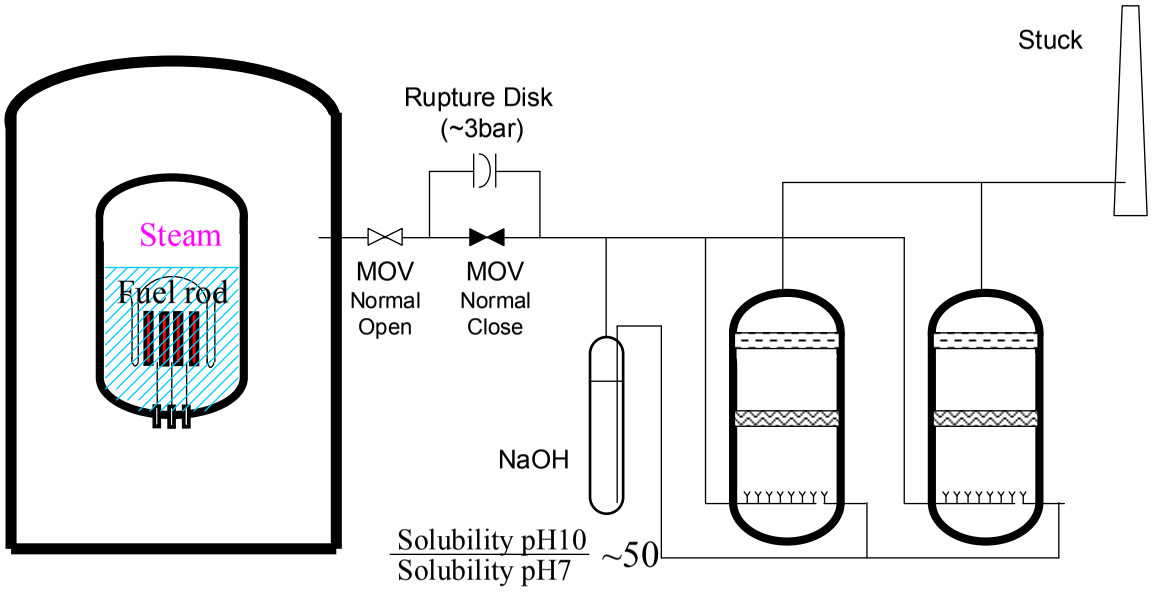
Prevent over-pressure C/V rupture + Exhaust of RI and $H_2$
→ Filtered Containment Venting System (FCVS)

Prevent over-temperature C/V rupture + $H_2$ leakage
→ Special Emergency Heat Removal System (SEHR)

*JSME visit Leibstadt NPP, Swiss, on Nov.11,2011*

# FCVS *(Filtered Containment Venting System)*

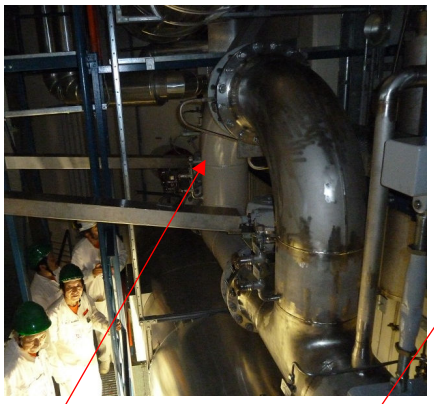
Backfitted on 1992 for DiD4 (mitigation of Sever Accident)




Prevent C/V overpressure failure
Capture radioactive materials
Feed and Bleed under Long SBO & LUHS

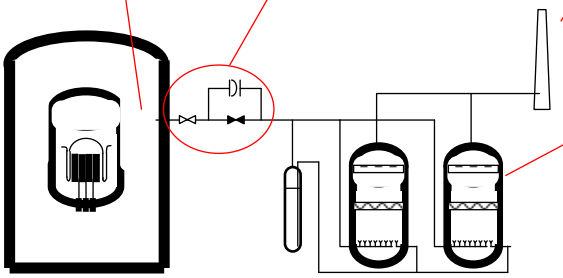
DF > 1000 aerosol
> 100 $I_2$

# FCVS *(Filtered Containment Venting System)*



entrance

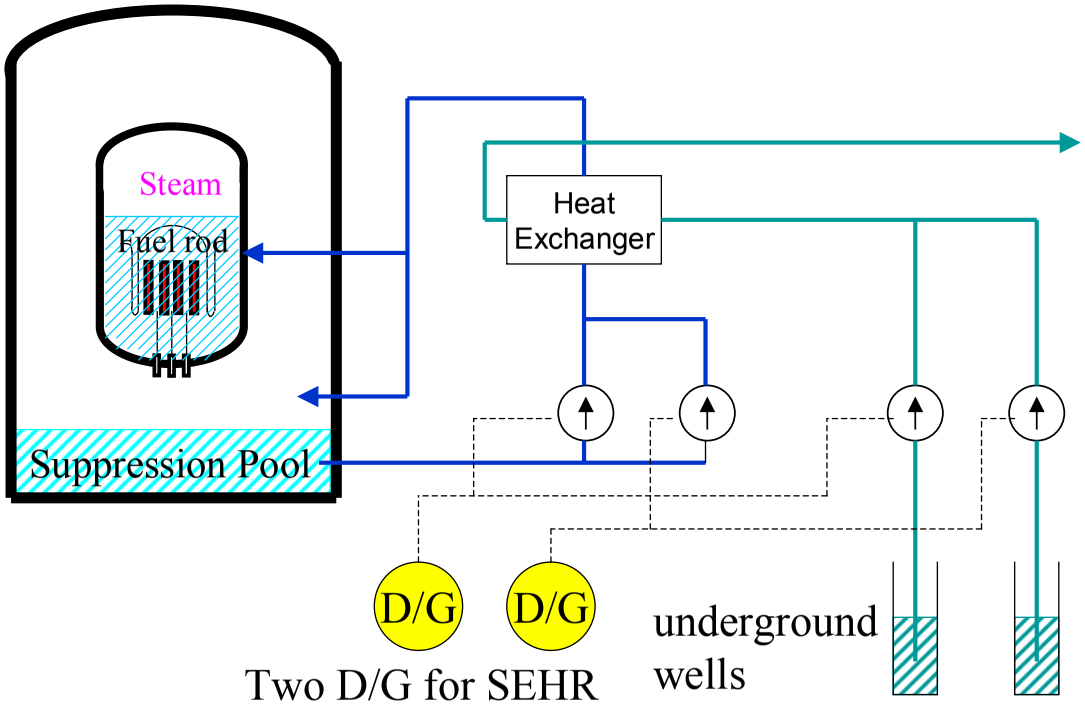
rupture disk



*JSME visit Leibstadt NPP, Swiss, on Nov.11,2011*

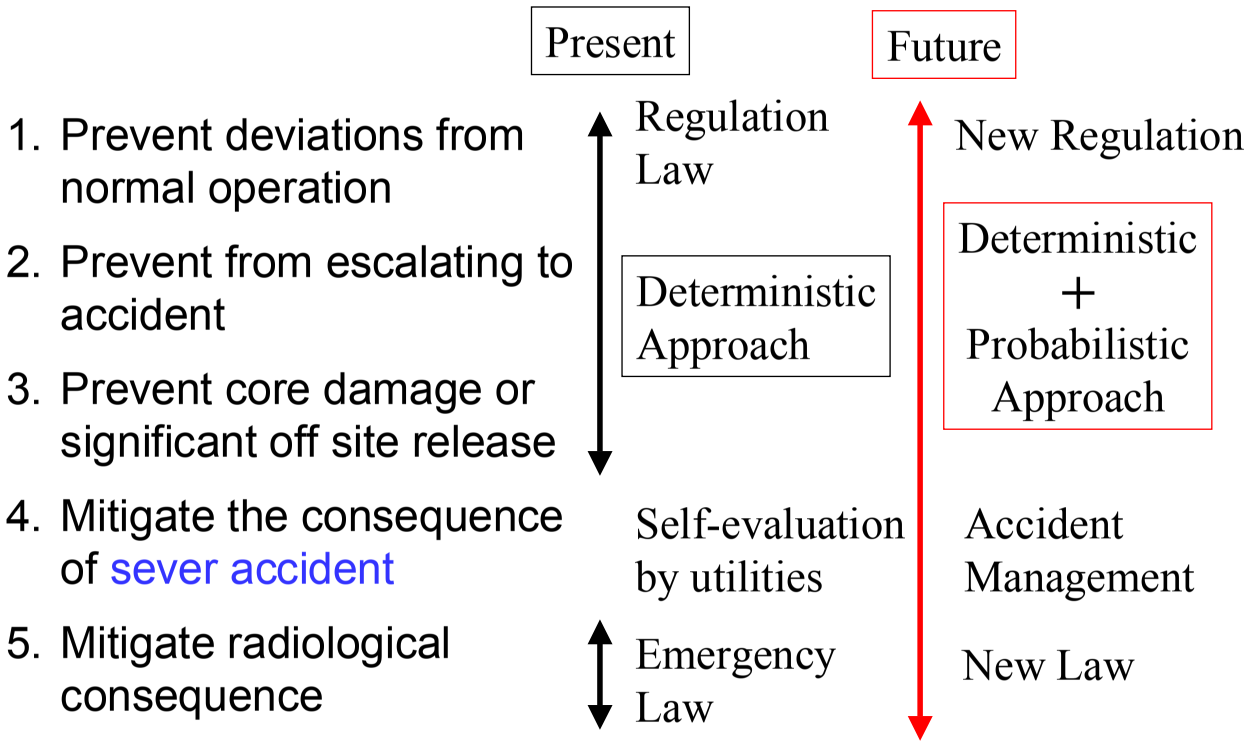
# SEHR *(Special Emergency Heat Removal System)*

Backfitted on late '70s for DiD3 (additional C/V cooling)
and DiD4 (mitigation of Sever Accident)




Two D/G for SEHR

# Defense-in-Depth and regulation




# Regulation system hardly takes new knowledge

- Japanese NRC written in DPJ manifesto had not been discussed more than 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.

KAIZEN is most important to sustain the safety.

# Lessons Learned from the Accident

- People and the environment should be protected from 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