2013 INTERNATIONAL ISOE ALARA SYMPOSIUM

Lessons Learned from the Fukushima Daiichi NPP's Accidents for Achievement of the First Class Safety in the world

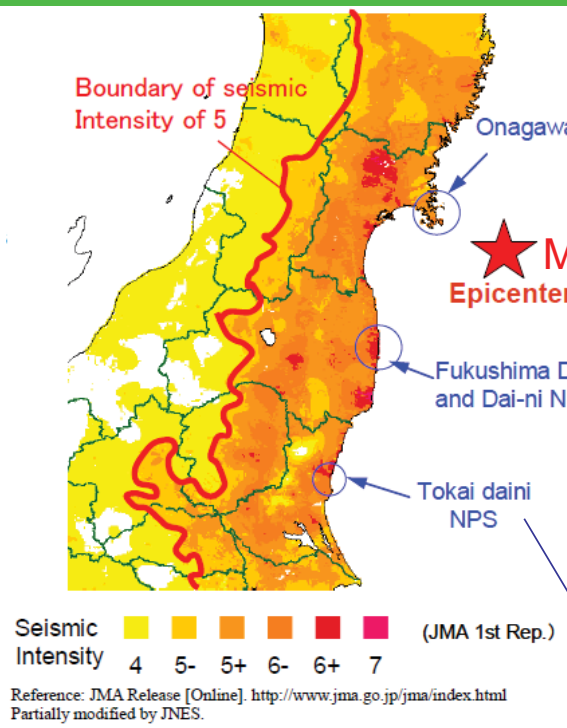
January 7, 2013 (Ft. Lauderdale, FL)

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Nuclear and Environmental Systems
Hokkaido University

OBJECITVES

- On March 11, 2011, Tokyo Electric Power Company's Fukushima Daiichi Nuclear Power Station (NPS) was hit by tsunami caused by the Tohoku-Pacific Ocean Earthquake, resulting in nuclear accidents in its Units 1 to 4.
- Many lessons can be learned from the Accidents.
- In order to enhance the safety for nuclear power stations in the world, we earnestly broaden the lessons derived from the accident, and make proposals to improve safety.

Tohoku-Pacific Ocean Earthquake



Reference: JMA Release [Online]. http://www.jma.go.jp/jma/index.html
Partially modified by JNES.

Onagawa NPS
1: 534MW, 1984-
2: 835MW, 1995-
3: 835MW, 2002-

Fukushima Daiichi NPS
1: 460MW, 1971-
2: 784MW, 1974-
3: 784MW, 1976-
4: 784MW, 1978-
5: 784MW, 1978-
6:1100MW, 1979-

Fukushima Daini NPS
1: 1100MW, 1982-
2: 1100MW, 1984-
3: 1100MW, 1985-
4: 1100MW, 1987-

Tokai Diini NPS
1100MW, 1978-

Damaged External Power

- External AC Power was lost in Fukushima Daiichi



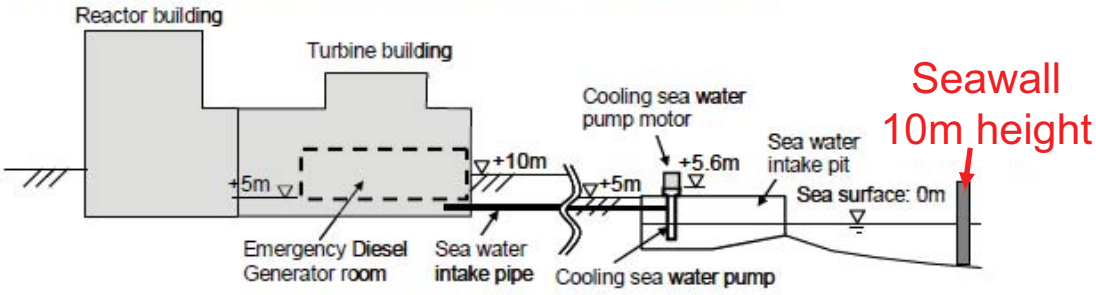
Damaged ABB(Air Blast Breaker)
Fukushima Daiichi Unit 1-4



GIS：Gas Insulated Switchgear
Onagawa Unit 1-3 were OK

Tsunami getting over seawall at the Fukushima Dai-ichi NPS

Cross section of Fukushima Dai-ichi (Unit-1)

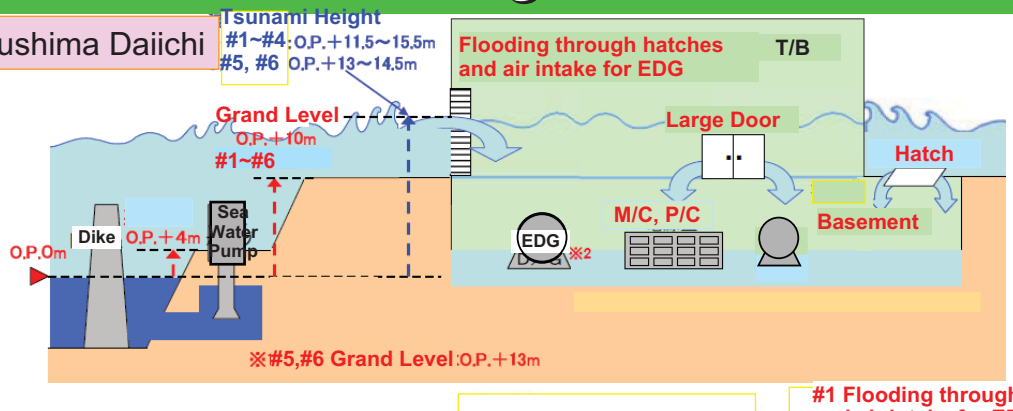




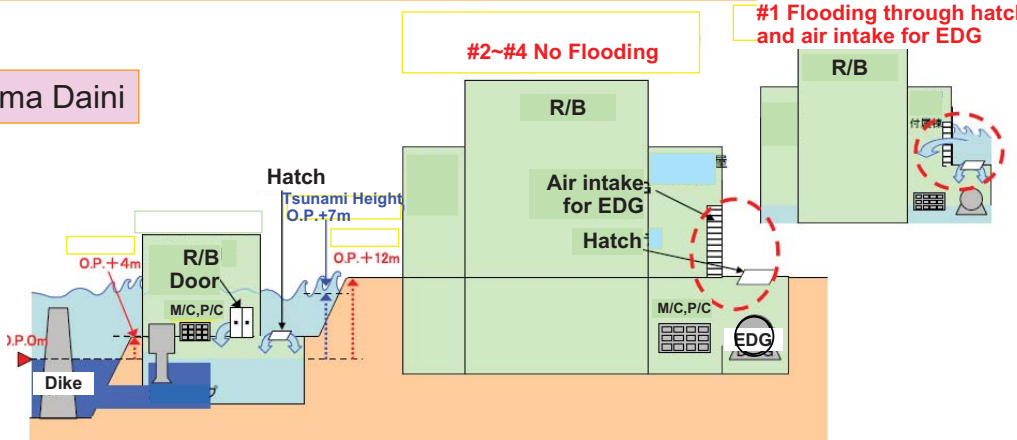
Reference: The Tokyo Electric Power Co., Inc. Release
[Online].http://www.tepco.co.jp/tepconews/pressroom/110311/index-j.html

Tsunami Flooding Area in each NPP

Fukushima Daiichi



Fukushima Daini



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	Outage (No Fuels in RPV)	Outage HeatsSink was recovered on 3/12	HPCS:OK (R/B B1)

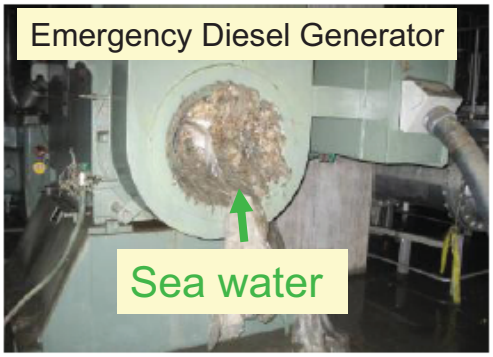
Cause of SBO in Fukushima Daiichi

Damages of heat exchanger room and heat exchanger (Unit 1)





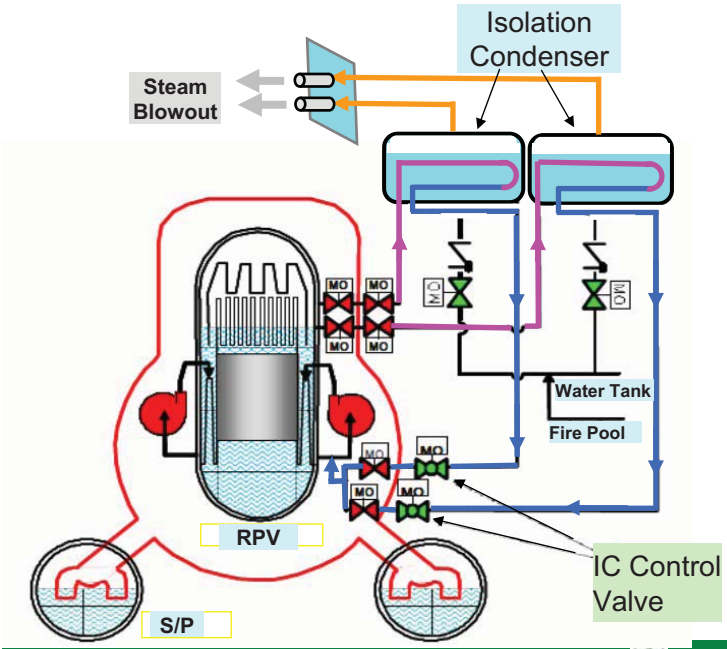




Damages of reactor building and emergency diesel generator (Unit 1)

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 cooling.
- It was a fail-dangerous system.
- If the IC continue to operate, the accident would be terminated.

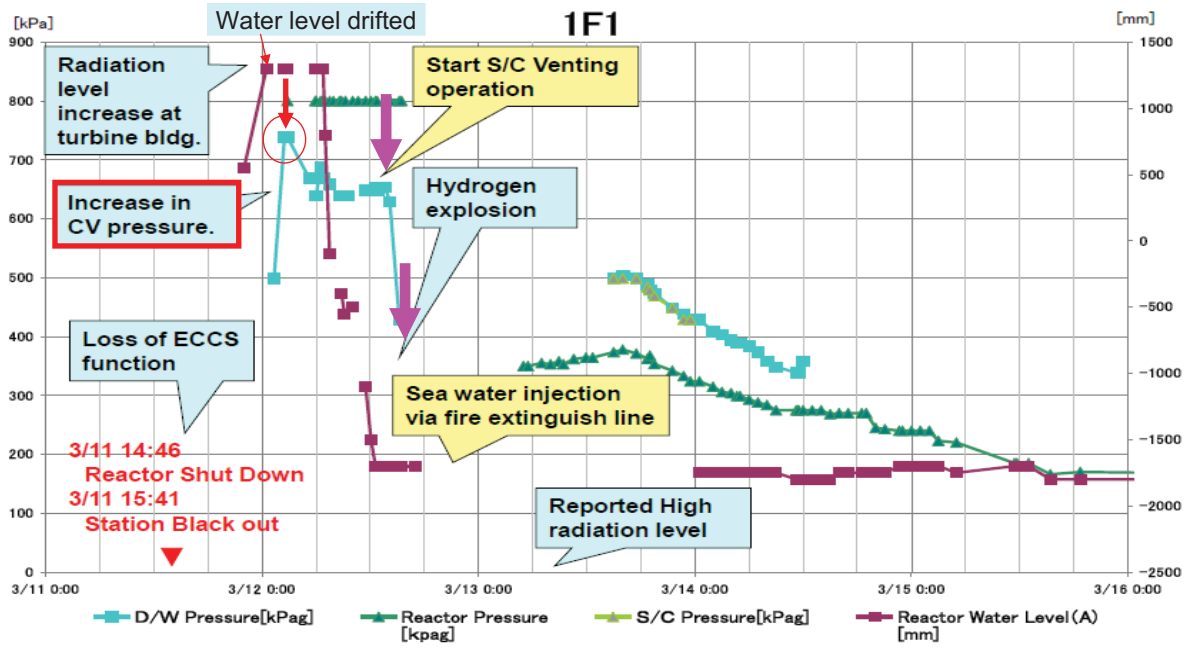




- RCIC steam turbine also stopped by loss of battery power in Unit 3.
- S/P temperature and pressure were so high that AM water injection took a lot of times.

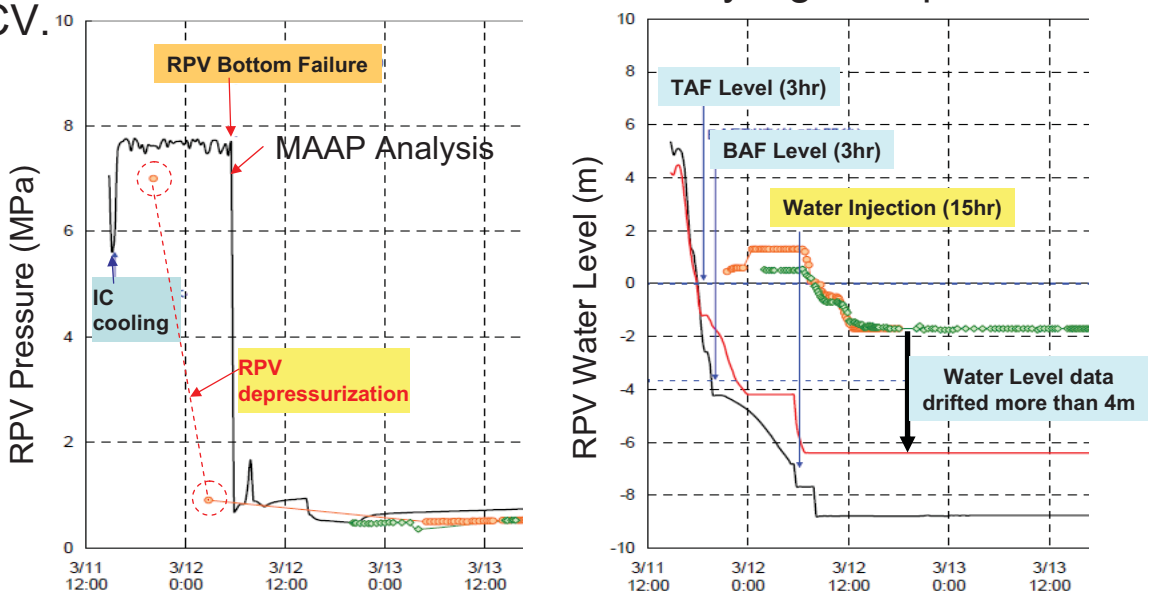
CV Pressure Trend in unit #1

- After loss of ECCS and IC core cooling, CV pressure increased.
- Water level drifted by vaporizing water in reference leg.
- Radiation level increased at T/B.
- Hydrogen explosion occurred after S/C wet venting.



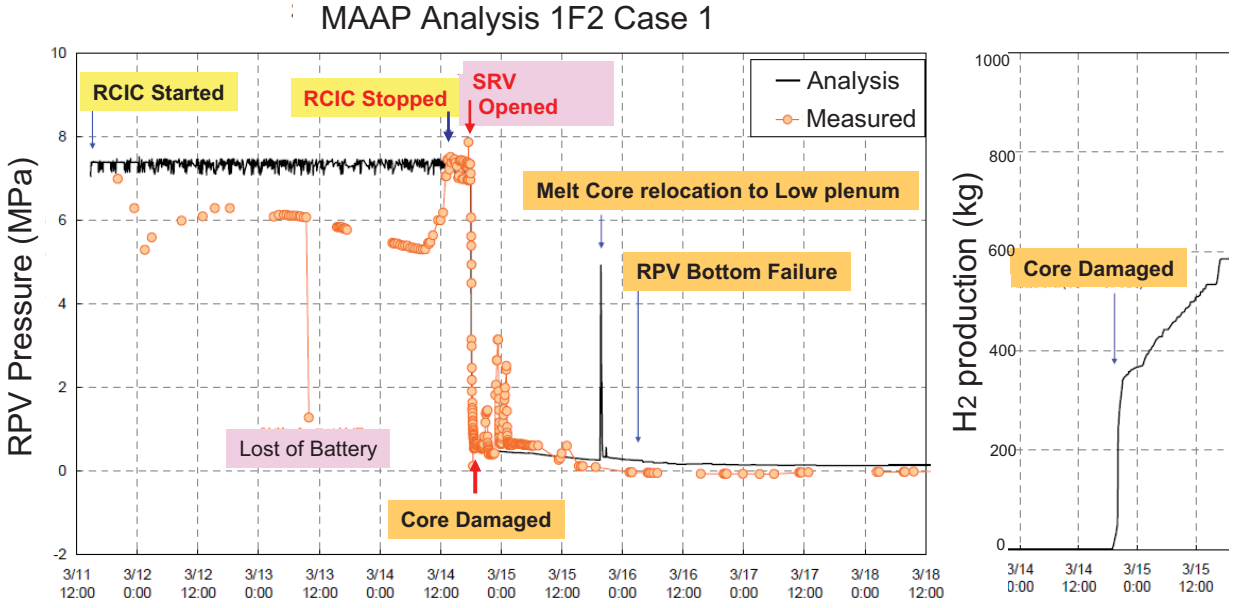
Pressure and Water Level in #1 RPV

- Analysis results show the RPV depressurization started before RPV bottom failure. It might be caused through melted TIP tubes in the core or Main steam SRV flange.
- Water level measurement was drifted by high-temperature in CV.



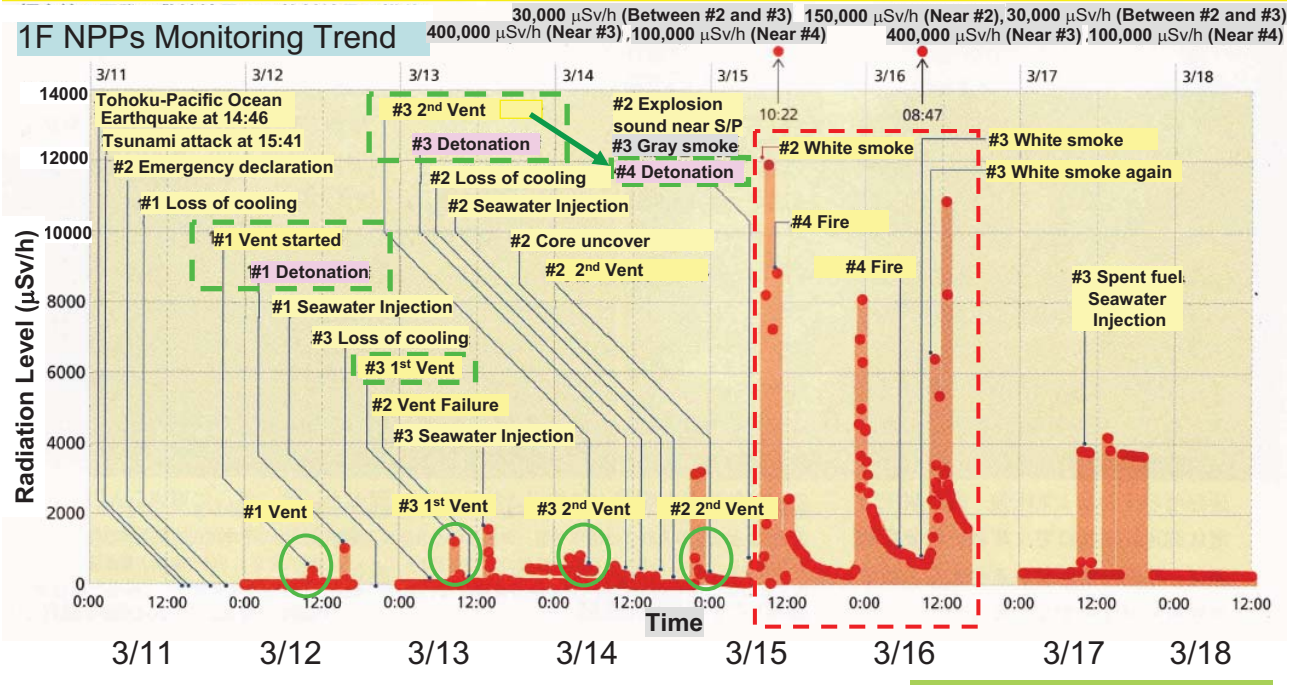
Failure of prompt water injection in #2

- Failure of prompt water injection after RCIC stopped in unit #2 caused the core damage and H_2 generation started.
- High-pressure discharge pump driven by diesel engine should be used.



Radiation level increased after CV rapture

- H_2 detonation were occurred after vent operation (#1, #3, #4)
- Radiation level increased soon after #2 CV rapture

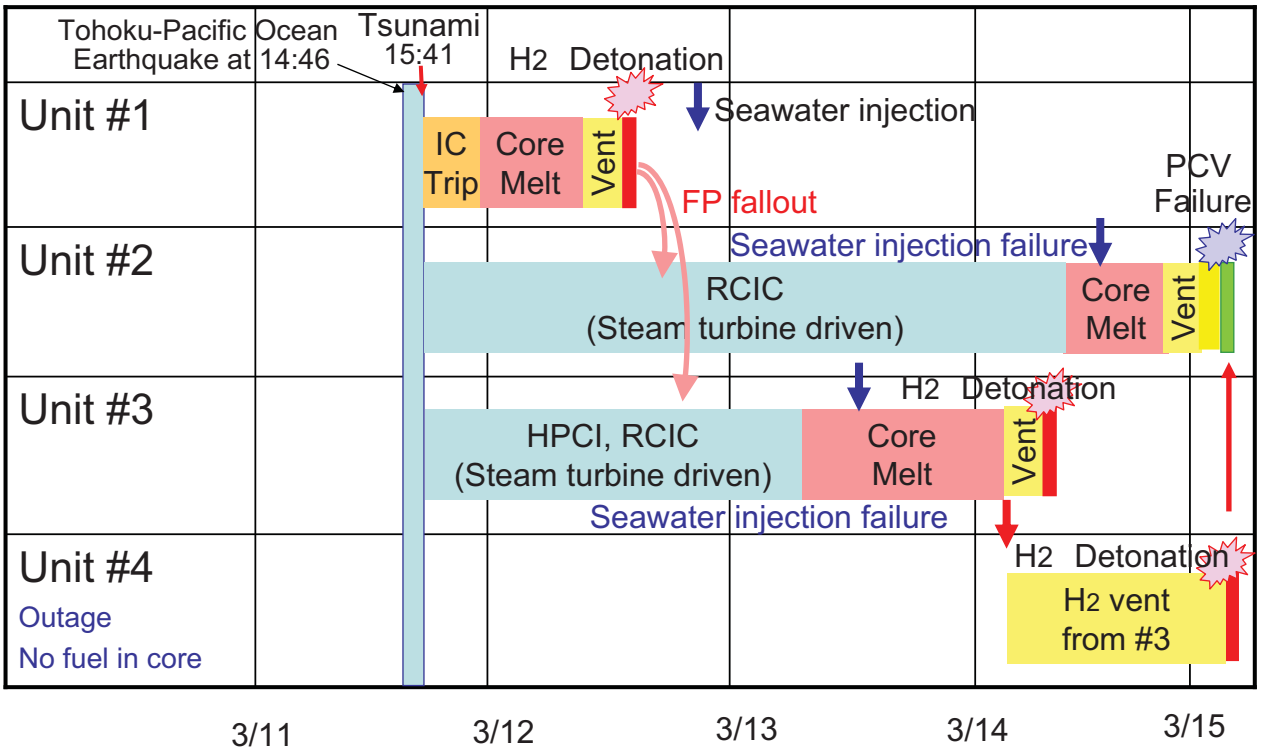


Nikkei Science, July 2011

Hydrogen Detonation and CV Rapture

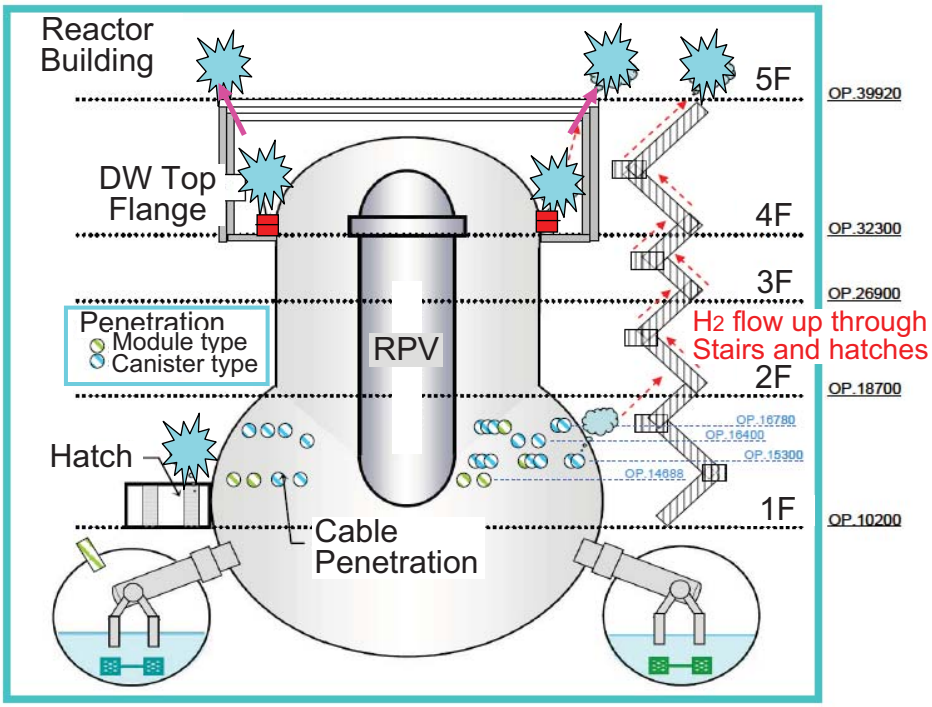


Fukushima Daiichi Severe Accidents



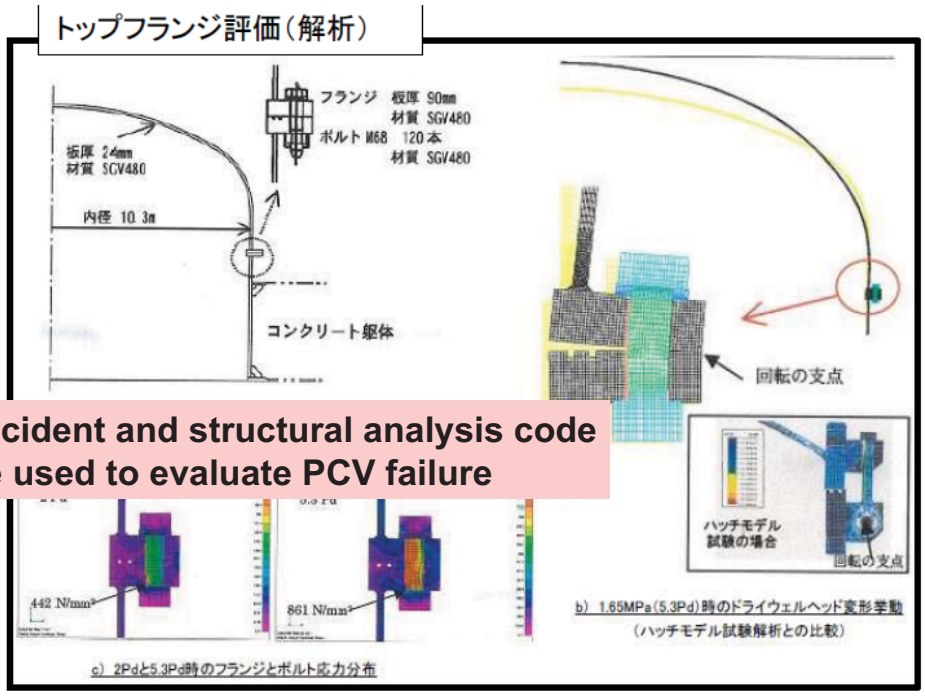
H2 Leak Path from CV

- CV top flange and hatches might be leak pass



PCV Failure Study by overheat

- PCV top flange is lost its function by overheat

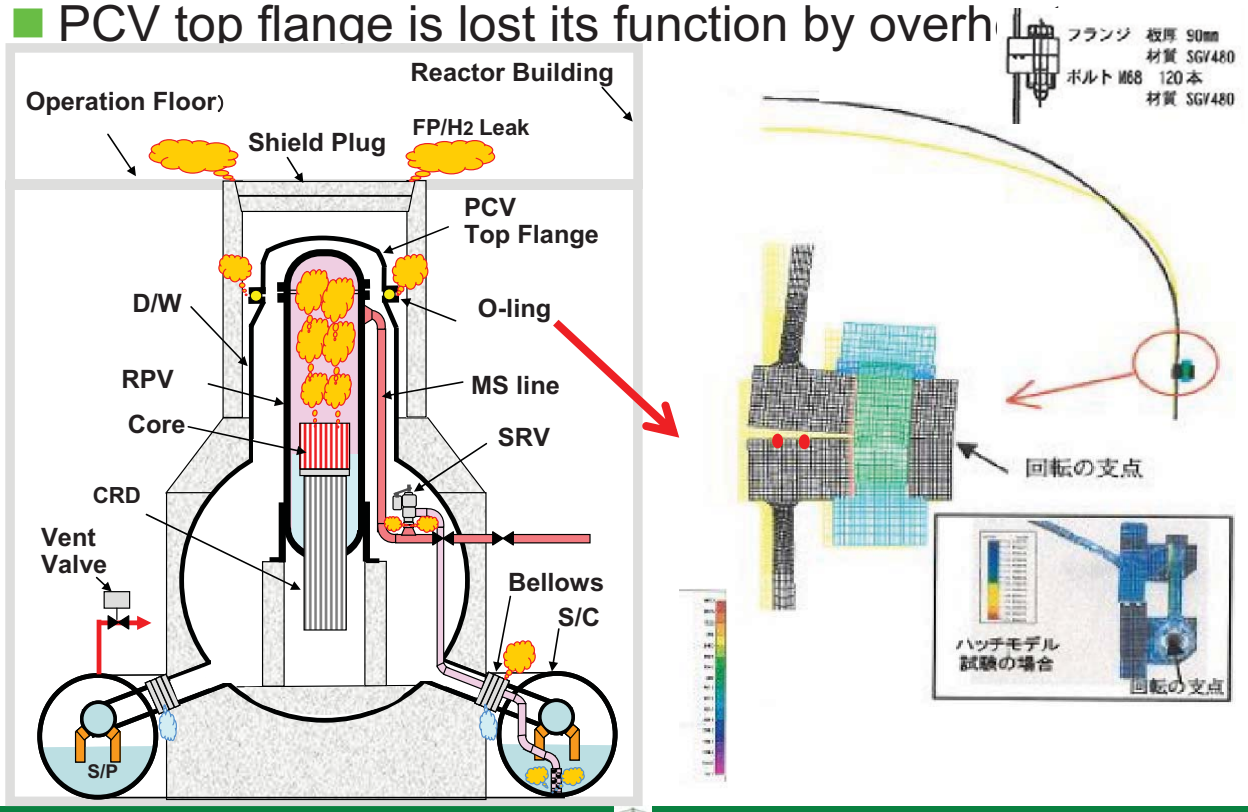


Severe accident and structural analysis code should be used to evaluate PCV failure

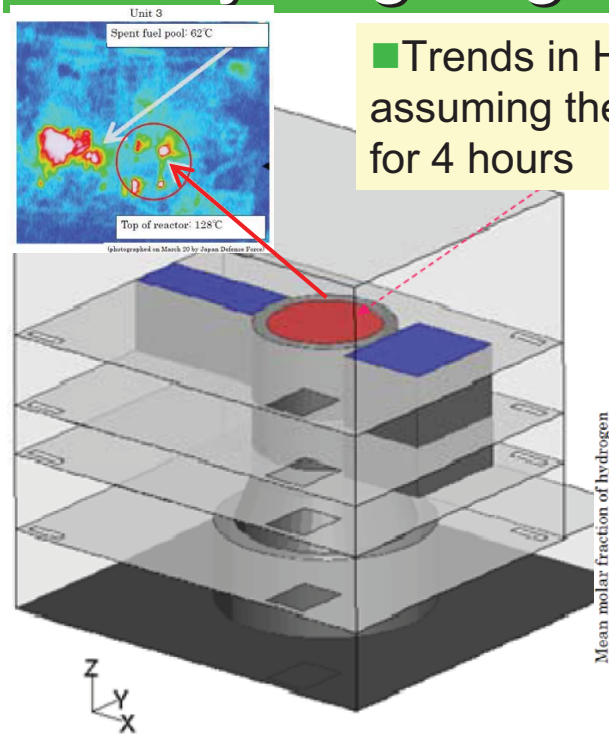
出典：（財）原子力発電技術機構：重要構造物安全評価（原子炉格納容器信頼性実証事業）に関する総括報告書：平成15年3月4、4.構造挙動試験　4.1項SCV試験

PCV Failure Study by overheat

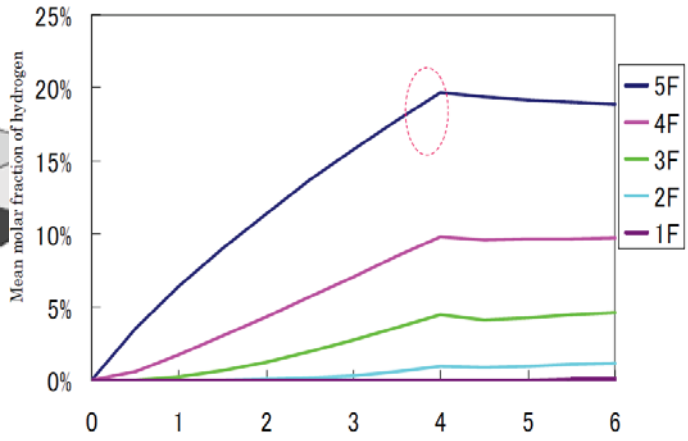
- PCV top flange is lost its function by overh



Hydrogen gas accumulation

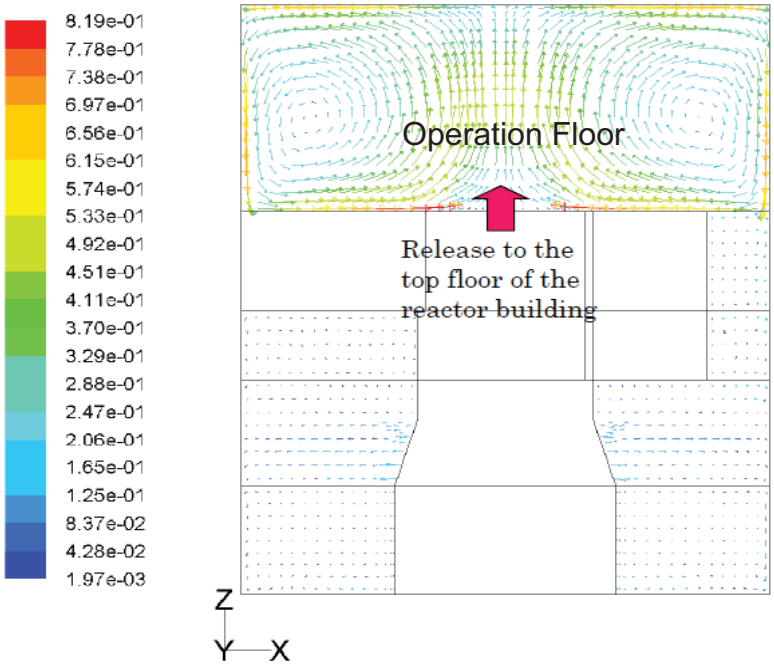


■Trends in Hydrogen in the reactor building, assuming the release of hydrogen of 100kg/h for 4 hours



Hydrogen gas accumulation

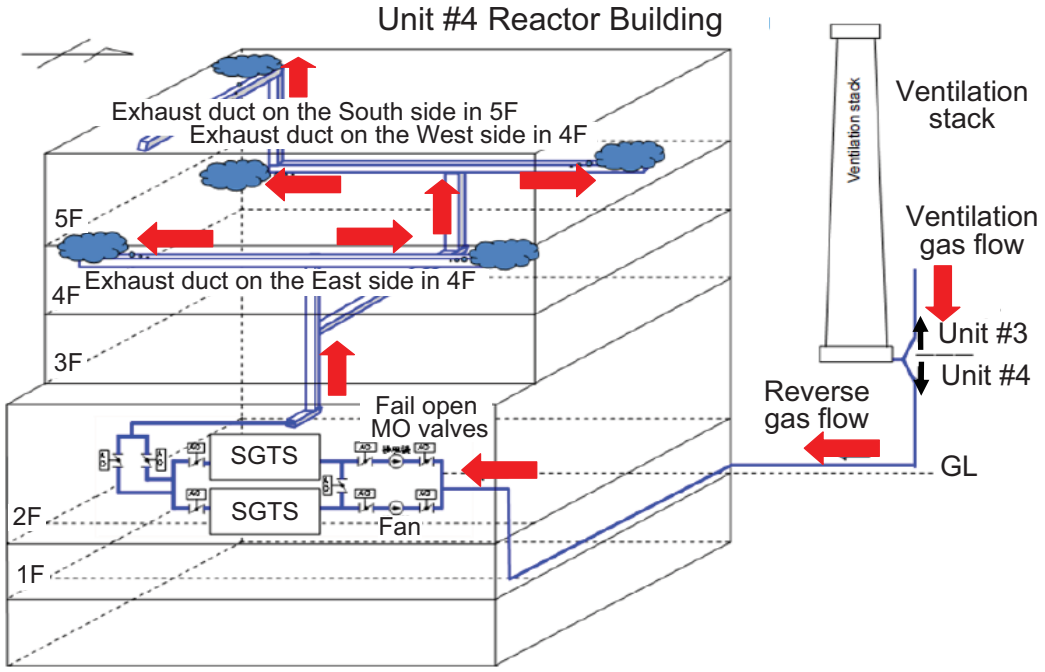
■Analytical result of hydrogen gas accumulation, assuming the release of hydrogen of 400kg from the surface of operating floor.



Source: JNES Material

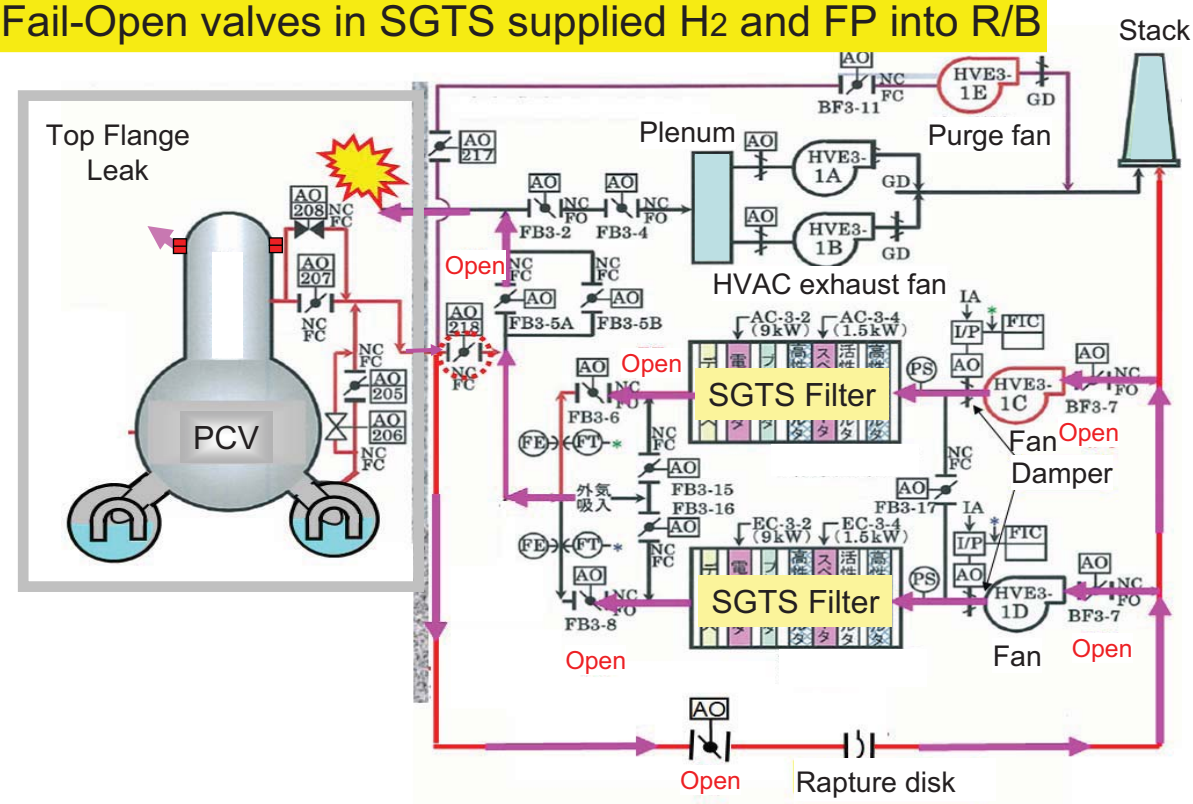
Cause of H_2 Detonation in #4 R/B

- Unit 4 was in outage. No fuels in the core
- Hydrogen from unit 3 flowed into unit 4 via SGTS



Vent line valves might be a cause of FP leak

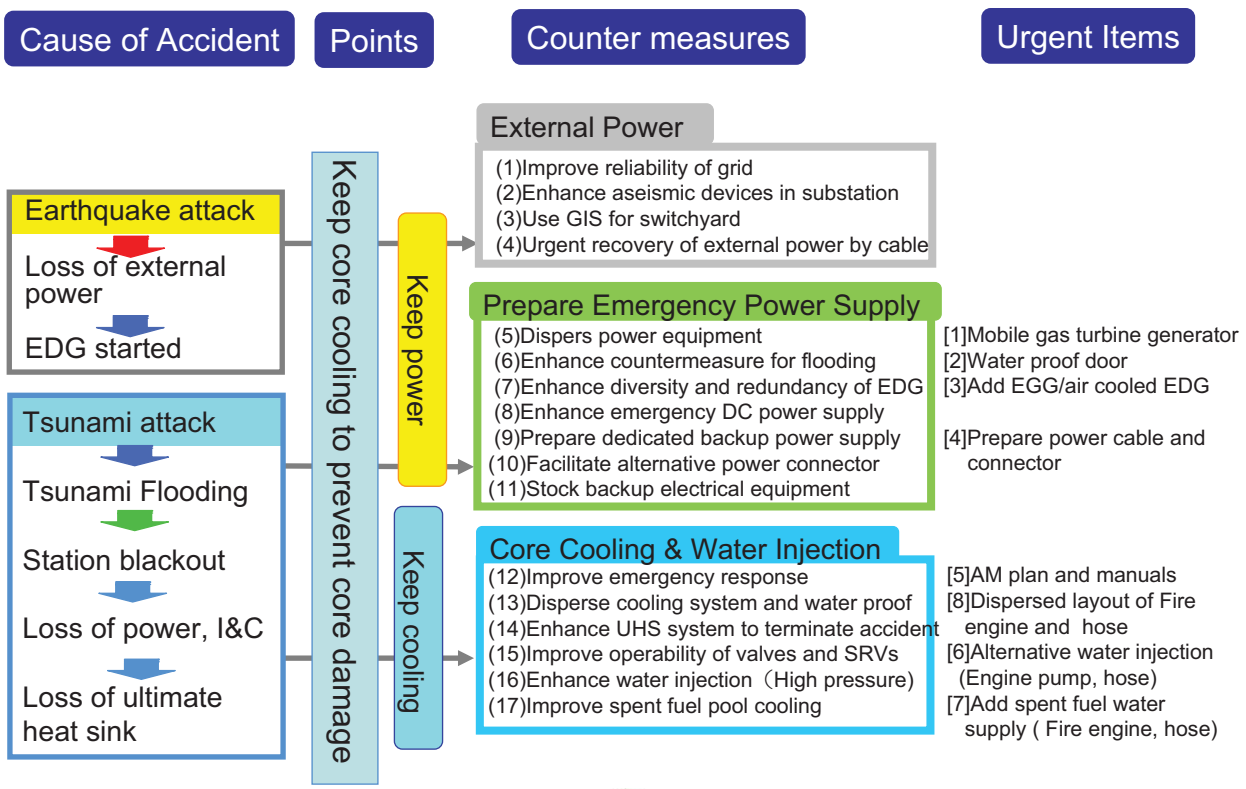
Fail-Open valves in SGTS supplied H_2 and FP into R/B



Causes of SA and Countermeasures

Loss of external Power by Earthquake	Enhance aseismic electric device (Use GIS, Flexible Insulators)
Loss of EDG, P/C DC Battery, I&C and phone	Water proof door, hatches, and Mobile power on hill
Loss of water in Core Meltdown, Hydrogen	Diversity of water injection, heat sink
Loss of containment function, heat damage	CV cooling, Filtered vent system
Slow judgment to protect against nuclear disasters	Establish new nuclear regulatory Quck action by Self-Defense Force

Items to be Regulatory Activities (1)



Items to be Regulatory Activities (2)

Cause of Accident | Points | Counter measures | Urgent Items

Loss of core injection
Depressurize failure
Loss of water in core
Core damage (H_2)
Core melt down
Vent delay/failure
PCV failure by overheating
H_2 detonation
FP release / contamination

Prevent FP release from PCV

Prevent FP leak

Prevent FP release from PCV, H_2 explosion
(18)Enhance diversity of PCV cooling
(19)Prevent PCV overheating by cooling
(20)Proceed low pressure core injection
(21)Improve maneuverability of vent system
(22)Mitigate FP effect by FCVS
(23)Ensure independency of vent system
(24)Prevent H2 explosion (PER, Igniter, vent)

[9]Prepare manual to proceed LPCI injection
[10]Prepare N2 supply for air-operated valves

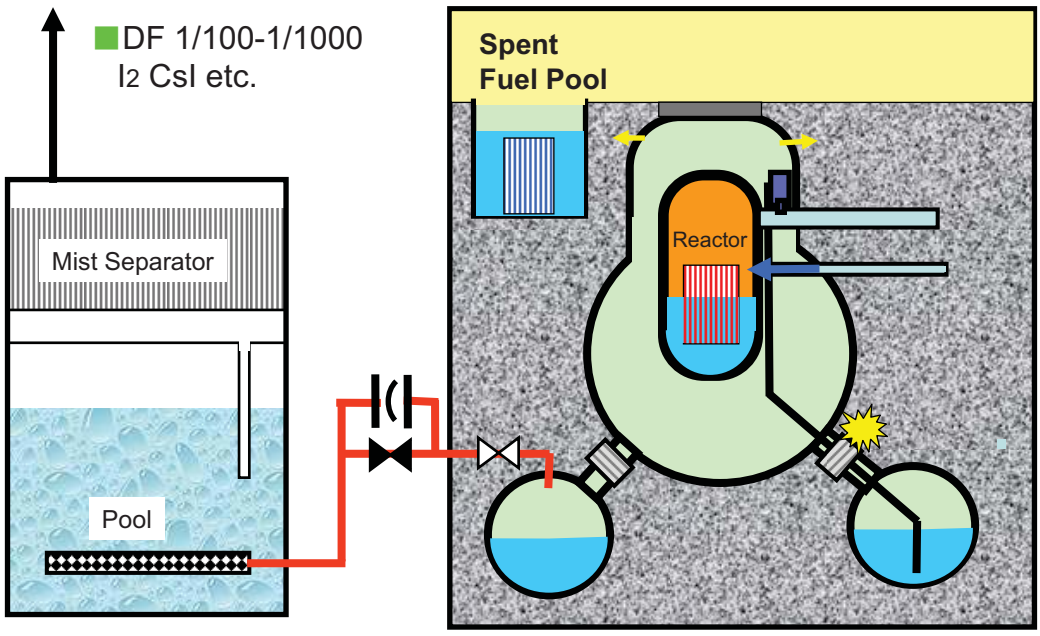
Accident Manegement

Management/Monitoring
(25)Prepare emergency command center
(26)Secure communication tools for accident
(27)Improve measurement equipment for AM
(28)Enhance monitoring for plant conditions
(29)Enhance emergency monitoring functions
(30)Create structure and conduct training for emergency response

[11]DC power supply for communication system
[12]DC power supply for plant monitoring
[13]Check and training for accident management devises

Filtered Containment Venting System

- **Lessons of Chernobyl NPP Accidents promoted the installation of Filtered Vent System to protect radioactive materials exhaust.**
  (French, German, Switzerland, Finland, Sweden)

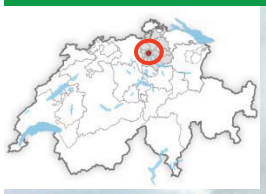


Visit Chooz NPP, EDF France





Visit Leibstadt NPP, KKL, Switzerland





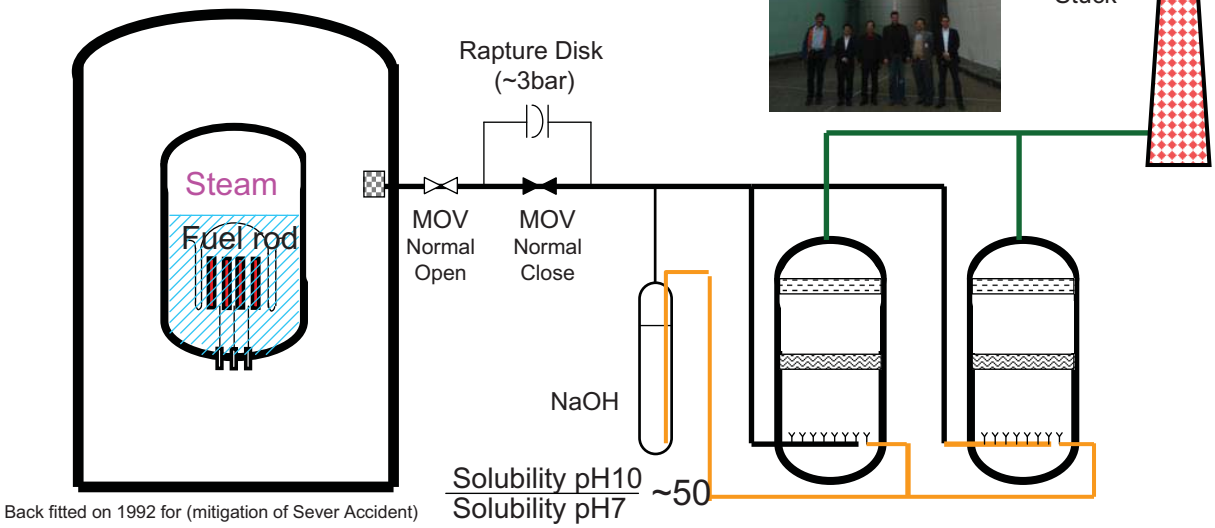
FCVS:Filtered Containment Venting System

■Vent valve will be open by manual shaft when SBO






DF
> 1000 Aerosol
> 100 I_2



Back fitted on 1992 for (mitigation of Sever Accident)

Good Practice for Tsunami Protection

Visit Diablo Canyon NPP, USA



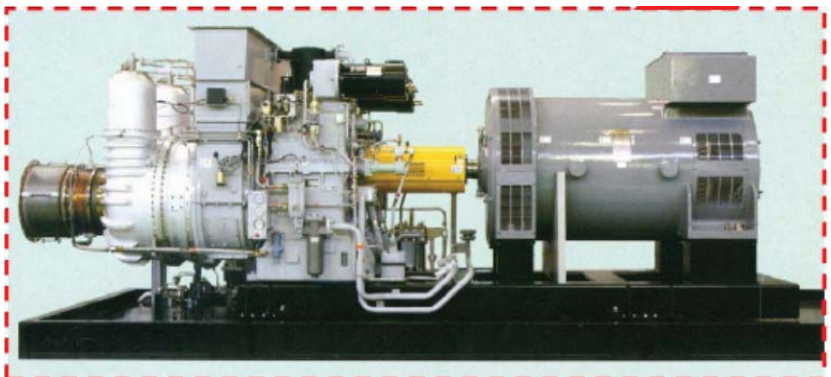
Special Power Generator on Height

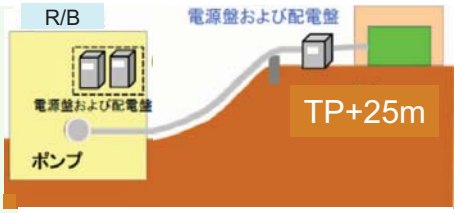
- 4000kVA mobile gas-turbine generator at 31m parking（Hepco）





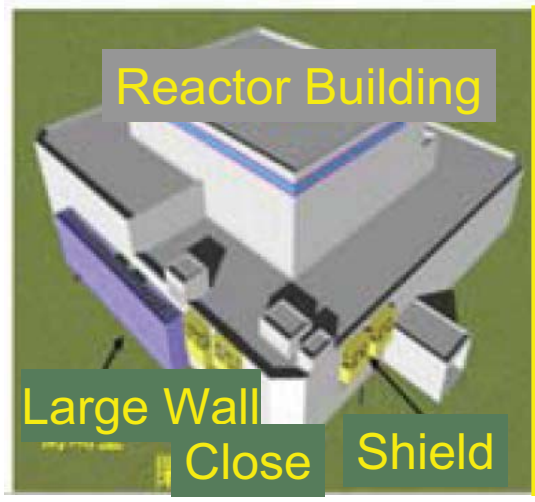
- Gas-turbine generator will be installed at 25m（Chubu Electric)





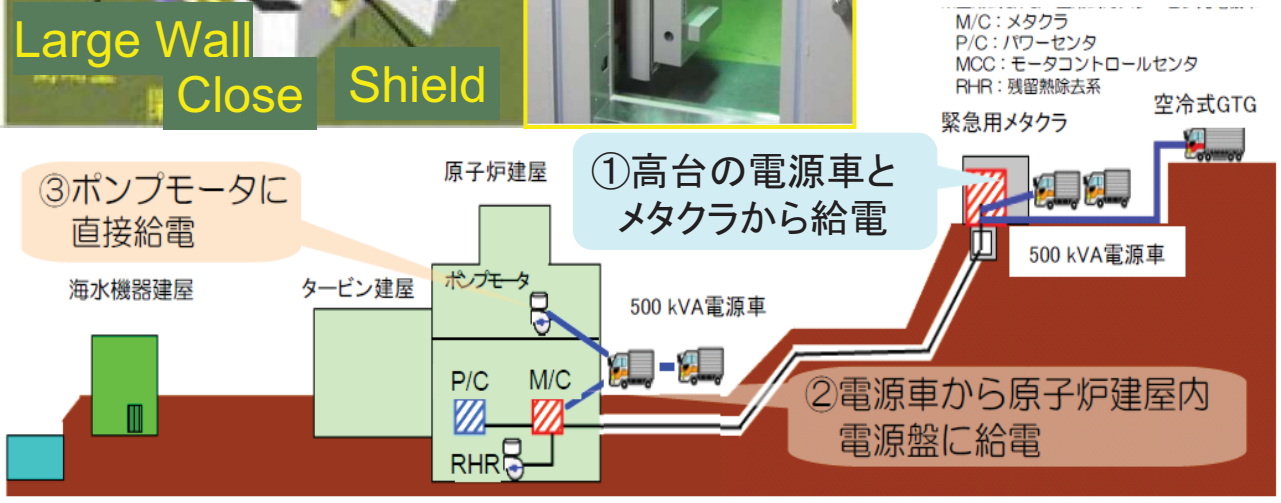
Gas-Turbine Generetor
4000kVA, 3.2MW
3.3kV-6.6KV
Start within 40sec

Countermeasure for tsunami











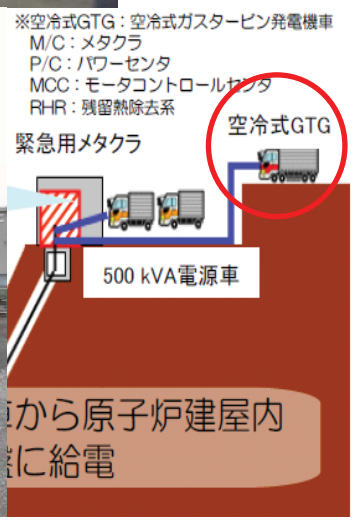
Reactor building was enforced to be a castle for ECCS survival.

Unit 1 elevation 5m, Unit 7 12m in Kashiwazaki-Kariwa NPS

Mobile Gas Turbine Generator on hill







Countermeasure 4
Mobile heat sink and fire engines







Heat Sink will be activated for AM cooling

Mobile heat sink cooling



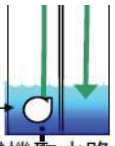










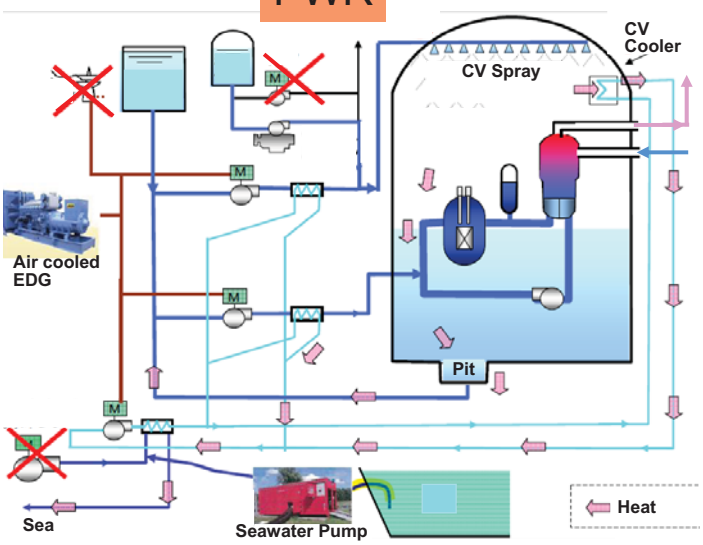


Countermeasures for PCV cooling

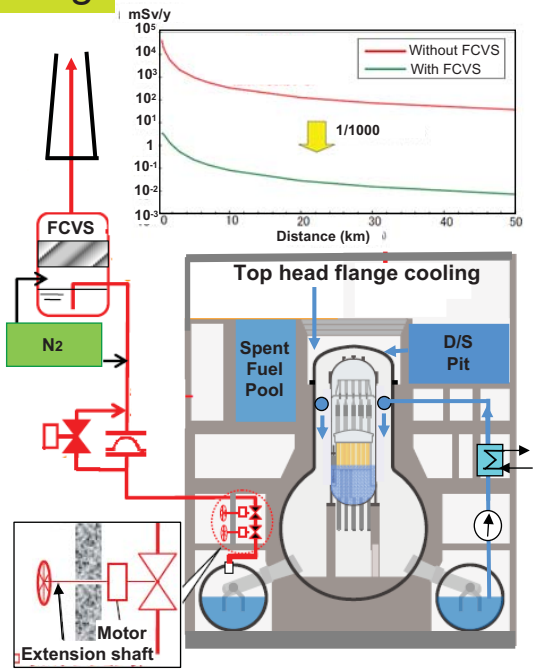
PWR CV spray and Decay heat removal

BWR Filtered vent and Top flange cooling

PWR



BWR



Conclusion

- Fukushima Daiichi NPP accident would be terminated, if sufficient examination lead to install countermeasures for tsunami, such as water proof door, mobile power, etc.
- In Europe, it had already installed the Heat Removal System and Filtered Venting System from the lessons of TMI and Chernobyl Accidents.
- Vent line should be independent from SGTS/HVAC line.
- From the Lessons of Fukushima-Daiichi Accidents, we should achieve the 1st class Nuclear safety in the world NPPs.
- Countermeasures for tsunami and severe accidents are planned and conducted in each NPP in Japan.
- Water proof door, hatches were installed, and mobile gas turbine generators and mobile heat sink are deployed on a hill.
- Filtered venting system and large embankment will be installed within 3 years for almost BWRs and PWRs in Japan.