

Japan's Earthquake, Tsunami, & Fukushima And the Effect on the Future of Nuclear Power

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地震の前



地震後(爆発前)



海に面した多くの構造物が破壊されている

J.S. Choi was formerly project professor at the University of Tokyo, Japan on 3/11/11.
Opinion expressed here is strictly that of his, it may or may not agree with his former affiliations.

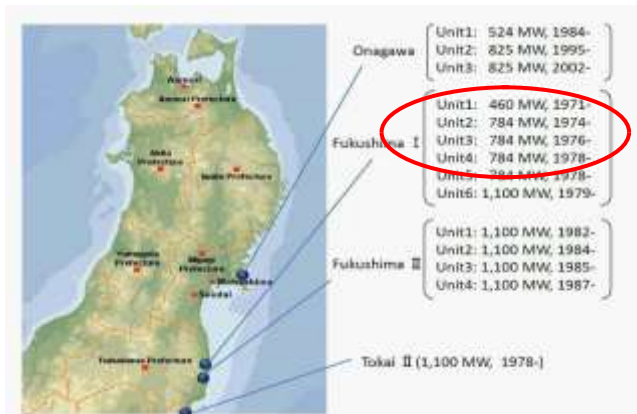
The Nuclear Disaster

- 2 Big natural events:
 - 9.0 Earthquake
 - A powerful Tsunami

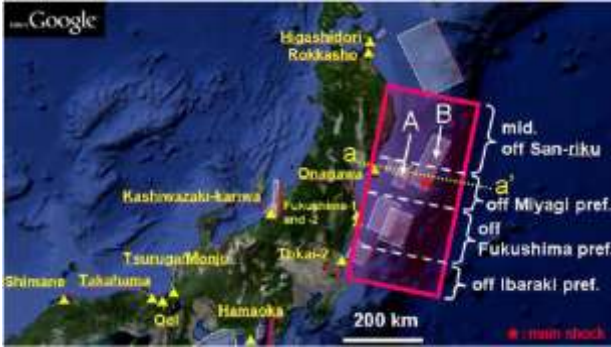


A multiple nuclear-plant emergency at Fukushima Daichi Unit 1-4, caused by common mode failures,

- Loss of
 - off-site power
 - emergency DGs
 - ultimate heat sink



A 9.0-Earthquake: 14:46, 3/11/11



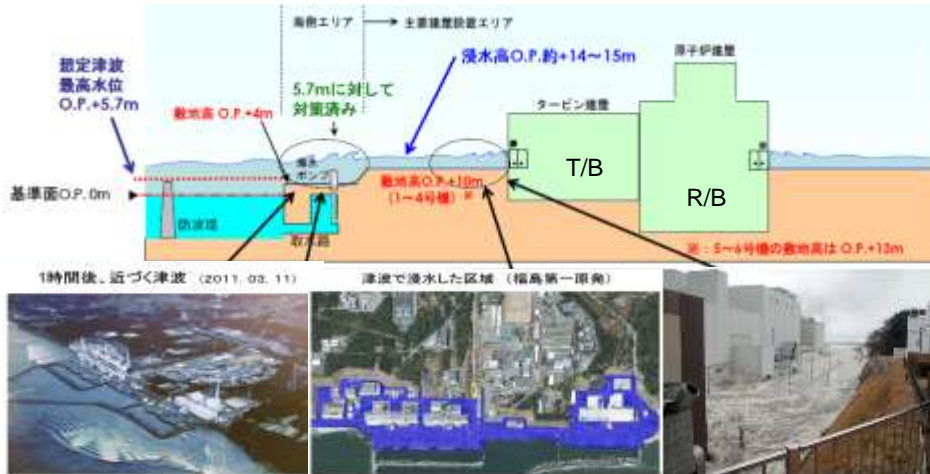
- The East Japan Earthquake, the most powerful earthquake ever recorded in Japan,
- Earthquake damage in Fukushima: **Not fully inspected but may be not significant to safety systems**
- Reactor Scram by the earthquake
Set points by acceleration at R/B basement: **Horizontal=135 gal, Vertical=100 gal**



Damage to transmission lines/tower
Caused the **loss of offsite power**

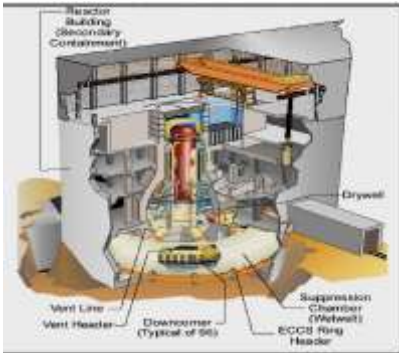
Unit	Observed (Gal)			Design (Gal)		
	N-S	E-W	Vertical	N-S	E-W	Vertical
1Fuk1	460	447	258	487	489	412
1Fuk2	348	550	302	441	438	420
1Fuk3	322	507	231	449	441	429
1Fuk4	281	319	200	447	445	422
1Fuk5	311	548	256	452	452	427
1Fuk6	298	444	244	445	448	415

A 14+ m – Tsunami: ~15:46, 3/11/11



- Design Basis Tsunami: **5.7 m**, Observed height: **>14 m**
- Loss of Emergency diesel generators (EDG), this plus the loss of DC (**battery**), resulting in station black out
- Loss of seawater pumps (or ultimate heat sink, **UHS**), resulting in loss of RHR, CHR, and long-term cooling

The Reactor: A BWR Mark I



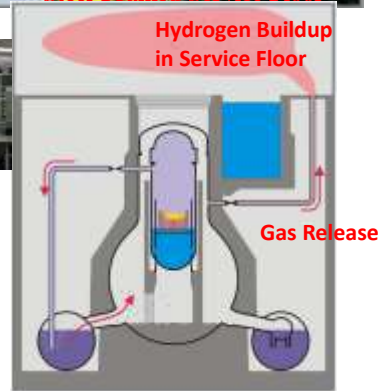
BWR Mark I Reactor Building



Steel-Framed Service Floor



Station Blackout

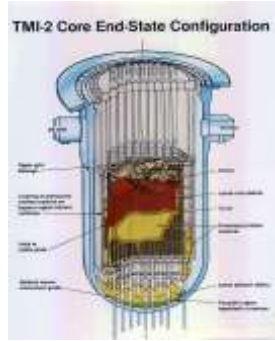


The Event Sequence (simplified)

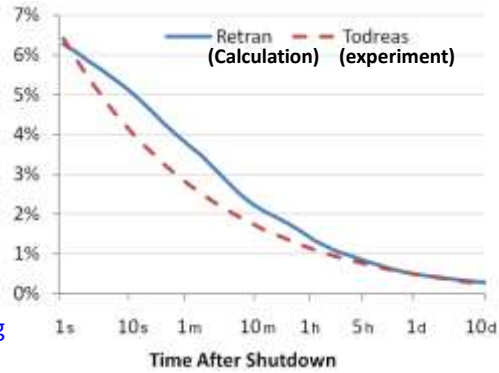
Fukushima, as compared to TMI

	TMI	Fukushima		
Day 1 (for Fukushima 00 = 14.46, 3/11/11)	00 Tb trip, Loss of FW 03 s SRV stuck open 100 m Loss of EECS 113-174 m Core uncover 174 m Fuel collapse 224 m Fuel slump to RPV bottom	00 Earthquake, EDGs start, IC(1Fuk1), RCIC(1Fuk2 & 1Fuk3), all 3 units has HPCI 1 h Tsunami, Loss of EDGs (AC power), UHS		
		1Fuk1	1Fuk2	1Fuk3
Day 2		2 h Loss of IC 4 h HPCI?		
		~12 h Loss of DC, station black out 15 h Core uncover 23 h H ₂ explosion 27 h Inject seawater	~12 h Loss of DC, station black out	~12 h Loss of DC, station black out
Day 3				35 h Loss of RCIC&HPCI 40-43 h Core uncover 44 h Inject seawater
Day 4			68 h Loss of RCIC 69 h Inject seawater 75-77 h Core uncover?	68 h H ₂ explosion
Day 5			88 h Explosion sound near S/C	

Core Meltdown



Decay Heat (% of Reactor Power)



Core Uncover

Loss of Coolant

Fuel Cladding Ballooning and Bursting

Greater than 830 °C (1520 °F)

Fuel Cladding (Zircaloy) Rapid Oxidation

Greater than 1230 °C (2240 °F)

Debris Bed Formation

Zircaloy Melting Point: 1430 °C (2600 °F)

(Corium) Slumping to Lower Plenum

Liquid Metal-Ceramic Eutectic: 1927 - 2927 °C (3500 - 5300°F)

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The Explosions

15:35, 3/12 → 1号機

11:15, 3/14 → 2号機

06:15, 3/15 → 3号機

08:55, 3/15 → 4号機



Lessons (to be) learned

- **Who is in charge?**

In the US extensive damage mitigation guidelines procedures specify that if the control room staff and field operators are compromised, then the shift security commander becomes the incident coordinator until an operator can be found.

- **Better communication?**

Integrated efforts among nuclear emergency responders, nuclear steam supply system (NSSS) vendors, the regulatory community, owners groups, government agencies, and other organizations:

- Institute of Nuclear Power Operations (INPO),
- World Association of Nuclear Operators (WANO), and
- International Atomic Energy Agency (IAEA).

Lessons (to be) learned

- **Station blackout?**

- Extend durations during emergency events through load shedding – by powering only those equipment and systems that are essential to cooling operations,
- Alternate methods to recharge the batteries,
- Needed improvement in portable generators for AC and DC power and equipment to connect gas cylinders to air operated valves to cope with an extended station blackout.

- **Extended cooling?**

Condensate storage tank, water supply pumps and piping used in station blackout response, fire protection and extensive damage mitigation guideline actions should be seismic or tornado qualified (protected).

Lessons (to be) learned

- **Hydrogen explosion prevention?**
 - Hydrogen venting via strong pipes,
 - Use of hydrogen-oxygen recombiners,
 - Use of fail-open (on power loss) louvers in buildings.
- **Safety/Security interface: Elevated spent fuel pool?**
 - Spent fuel inventory should be reduced to a minimum,
 - Emergency procedures provided (i.e., the B.5.b plan by US utilities after the 9/11/2001 terrorist attack).
- **Others?**

The Nuclear Future in Japan

Uncertain

- **Changes/Reform:**
 - Regulatory bodies
 - TEPCO
- **Would Japan become more**
 - Anti-nuclear (power)
 - “Green”
 - Reliance on Russia for energy (just like Germany)?
- **What would happen to the BWR technology?**
 - A US-Japan (GE-H/T) technology alliance
 - Change of global nuclear technology landscape?