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# The Accident at Fukushima

Consequences of the Seaquake and Tsunami
for the Nuclear Power Plant Fukushima Daiichi

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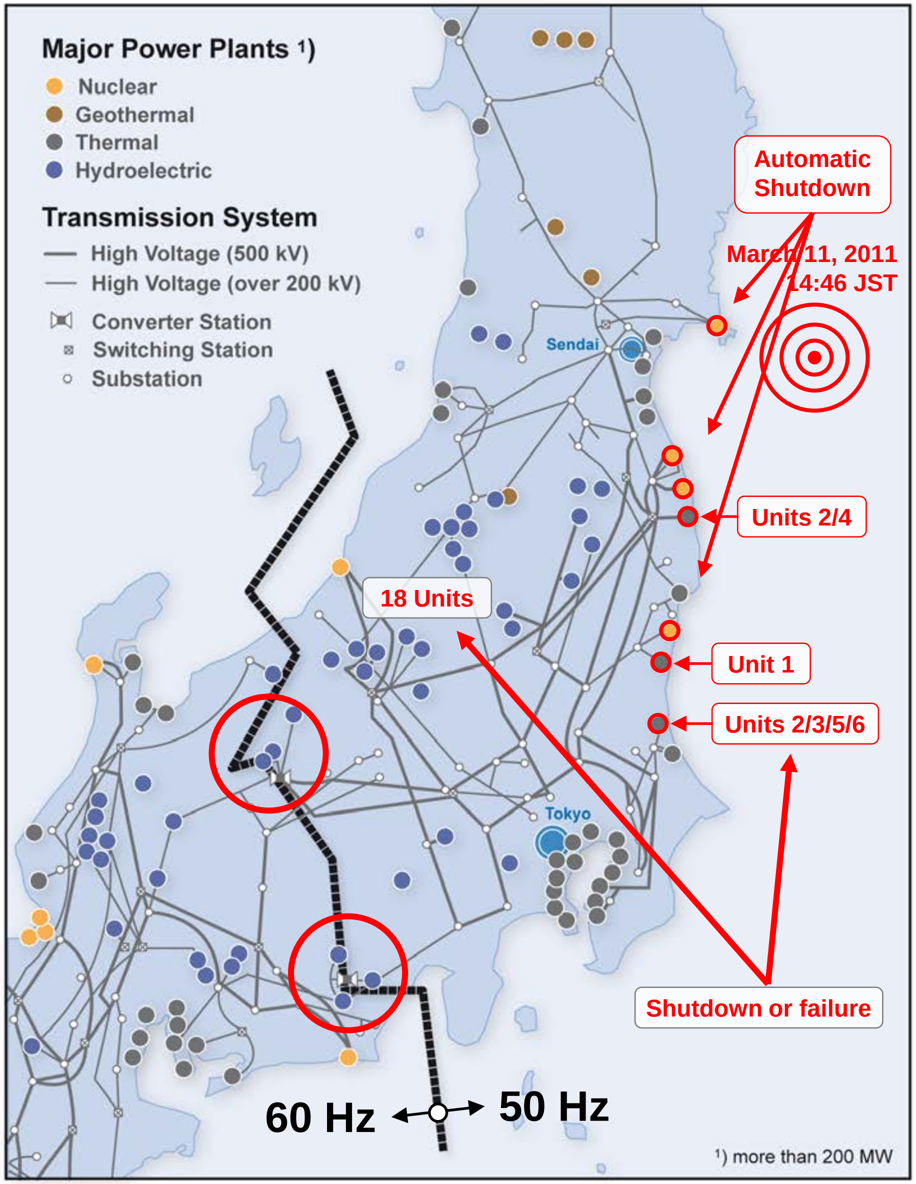
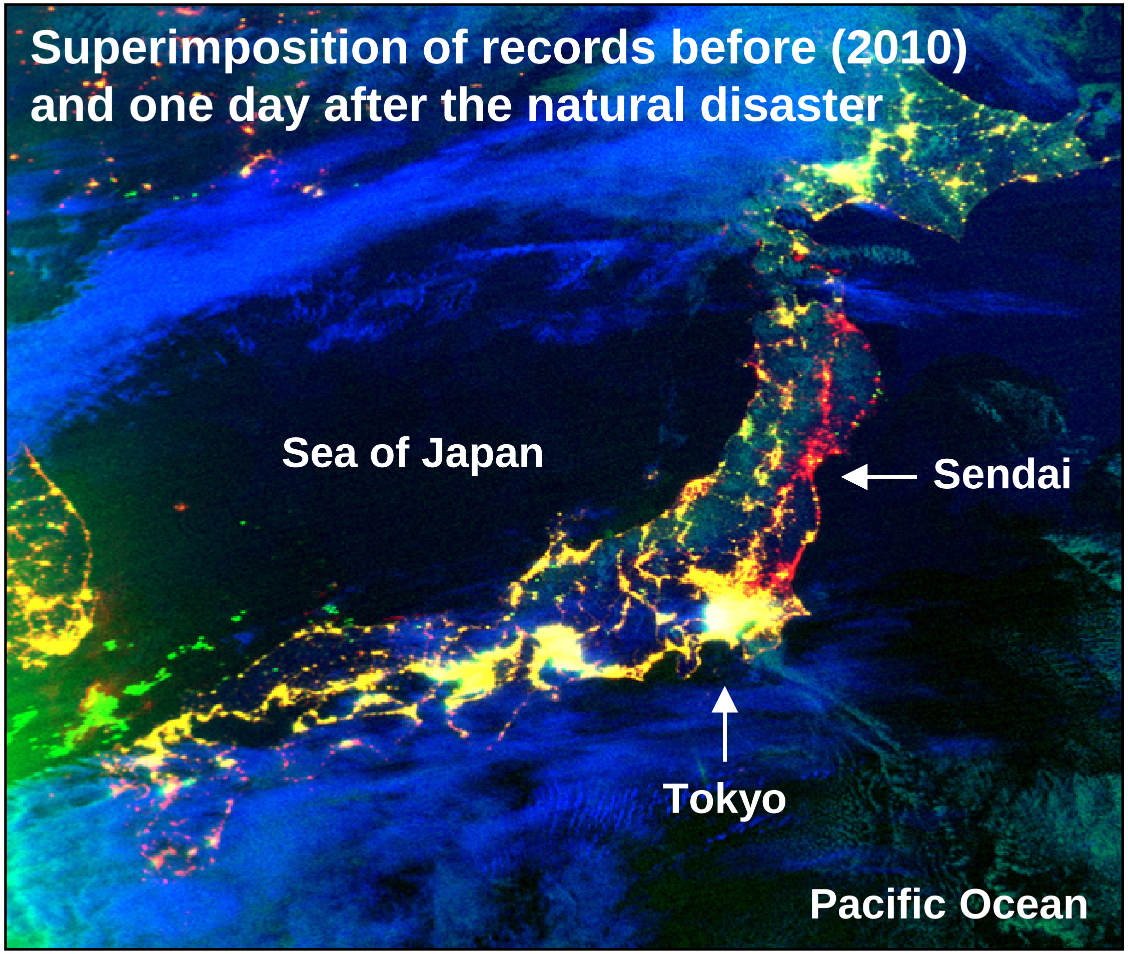
# Northern Honshu ► Power Supply System




- ► **System Border**

  50 Hz ► Northern Part,
  60 Hz ► Southern Part.

- ► Only three frequency converter stations with limited total capacity of ≈ 1 GW.
- ► Seaquake-induced shutdown of large number of conventional power plants (hydroelectric and fossil-fired).
- ► Automatic shutdown of all nuclear power plants (11 units at 4 sites) in the northeastern part of Honshu.
- ► Installed Capacity (Tepco): ≈ 60 GW
- ► Available Capacity: ≈ 50 GW
- ► Capacity Loss (Disaster): ≈ 19 GW
- ► Remaining Capacity: ≈ 31 GW
- ► Total Load (Tepco): ≈ 41 GW
- ► **Power Supply Gap: ≈ 10 GW**




**Blue**
► Clouds.

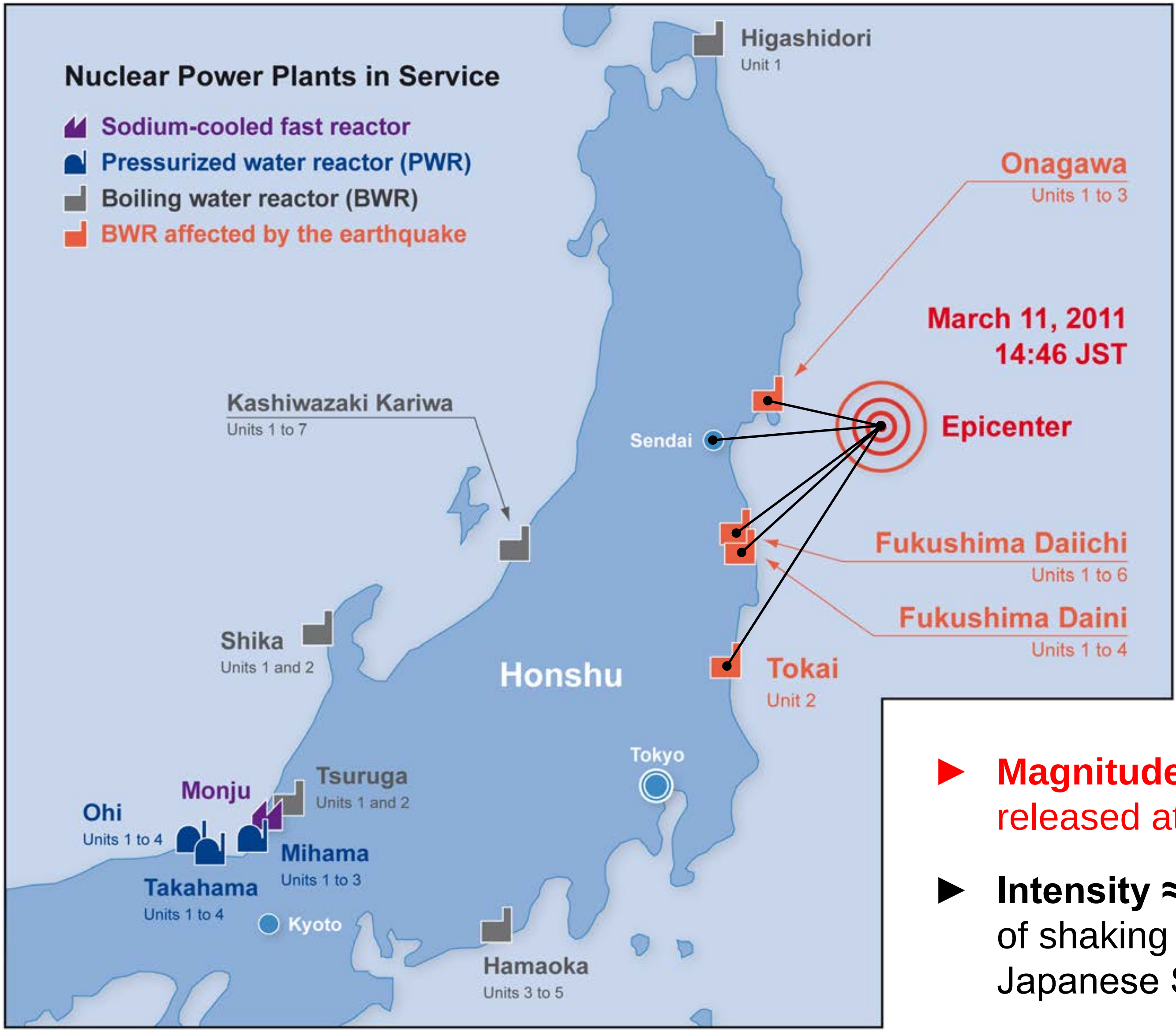
**Yellow**
► Functioning lights before and after the natural disaster.

**Red**
► Power outages one day after the natural disaster compared to 2010 observation data.

**Green**
► Either clouds above areas of functioning lights after the natural disaster or lights not observed in 2010.

- ► **Visible and infrared light spectrum.**
- ► **Widespread loss of electricity along northeastern coast of Honshu.**
- ► **Nearly 4 million homes and total area of 550 km$^2$ inundated by tsunami.**

Source: Nasa Earth Observatory, 2011




## Epicenter Location

38,3 °N and 142,4 °O

### Distances

- ► Onagawa ≈ 90 km
- ► F-Daiichi ≈ 160 km
- ► F-Daini ≈ 170 km
- ► Tokai ≈ 260 km
- ► Sendai ≈ 150 km

- ► **Magnitude 9.0** (measures energy released at the epicenter).
- ► **Intensity ≈ 11** (measures strength of shaking at a certain location, Japanese Scale: ≈ 7).



Quelle:GRS, 2011 F: Fukushima JST: Japan Standard Time (Ortszeit)

# The Tohoku Seaquake ► Measured Accelerations

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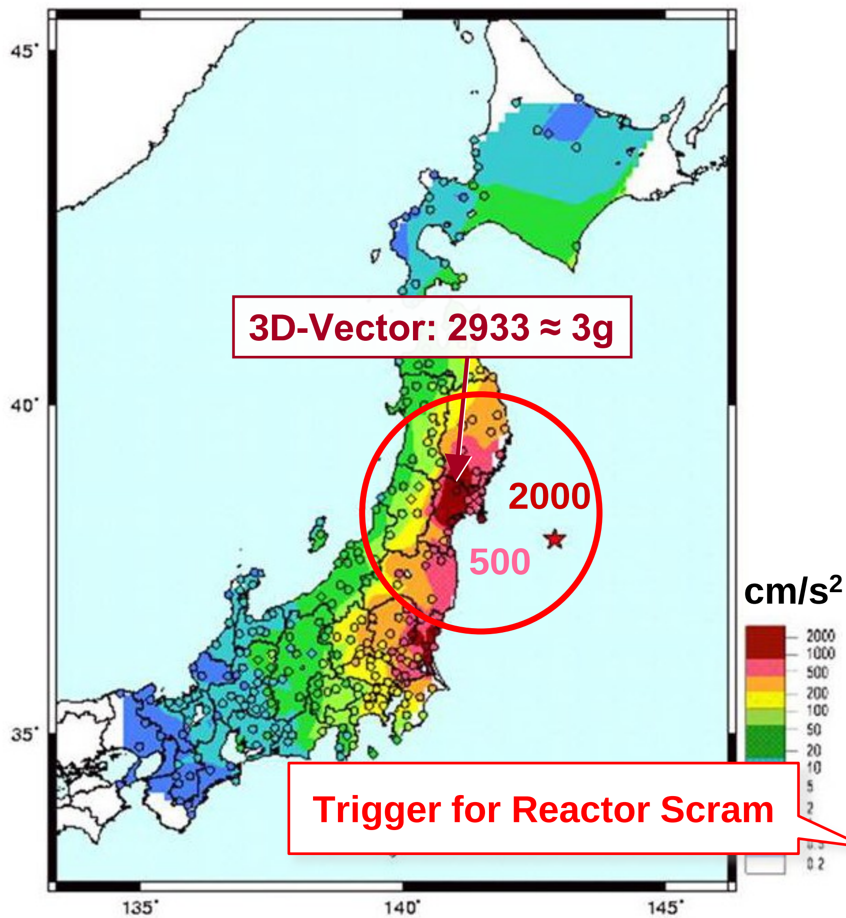
## Peak Accelerations




| Fukushima | Acceleration ¹) in cm/s² | | |
|---|---|---|---|
| | Horizontal | | Vertical |
| | N-S | E-W | |
| Daiichi-1 | 460 | 447 | 258 |
| Daiichi-2 | 348 | 550 | 302 |
| | | 507 | 231 |
| | | 319 | 200 |
| Daiichi-5 | 311 | 548 | 256 |
| Daiichi-6 | 298 | 444 | 244 |
| Design Basis | 441 to 487 | 438 to 489 | 412 to 429 |
| Daini-1 | 254 | 230 | 305 |
| Daini-2 | 243 | 196 | 232 |
| Daini-3 | 277 | 216 | 208 |
| Daini-4 | 210 | 205 | 288 |
| Design Basis | 415 | 415 | 504 |
| Threshold | 135 to 150 | | 100 |

Beyond Design Basis

► **Measured accelerations up to 26 % higher than earthquake design basis for Fukushima Daiichi (≈ 10 % for Onagawa).**



E-W: East-West N-S: North-South Sources: Nied, Wano Tokio, Tepco ¹) maximum response

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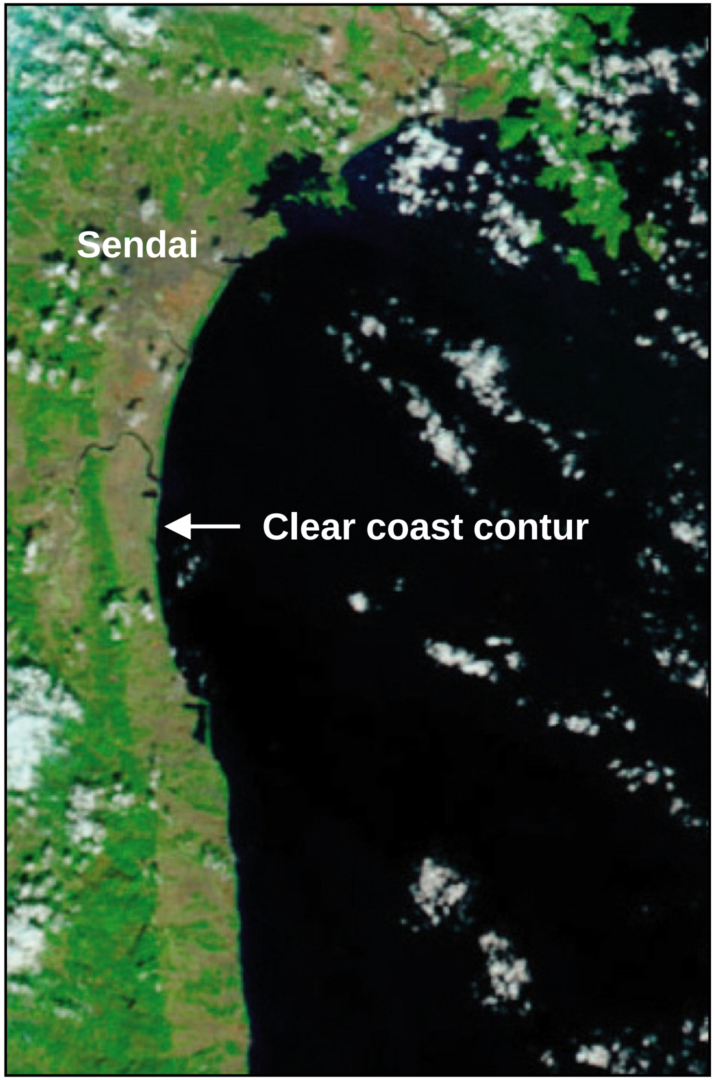
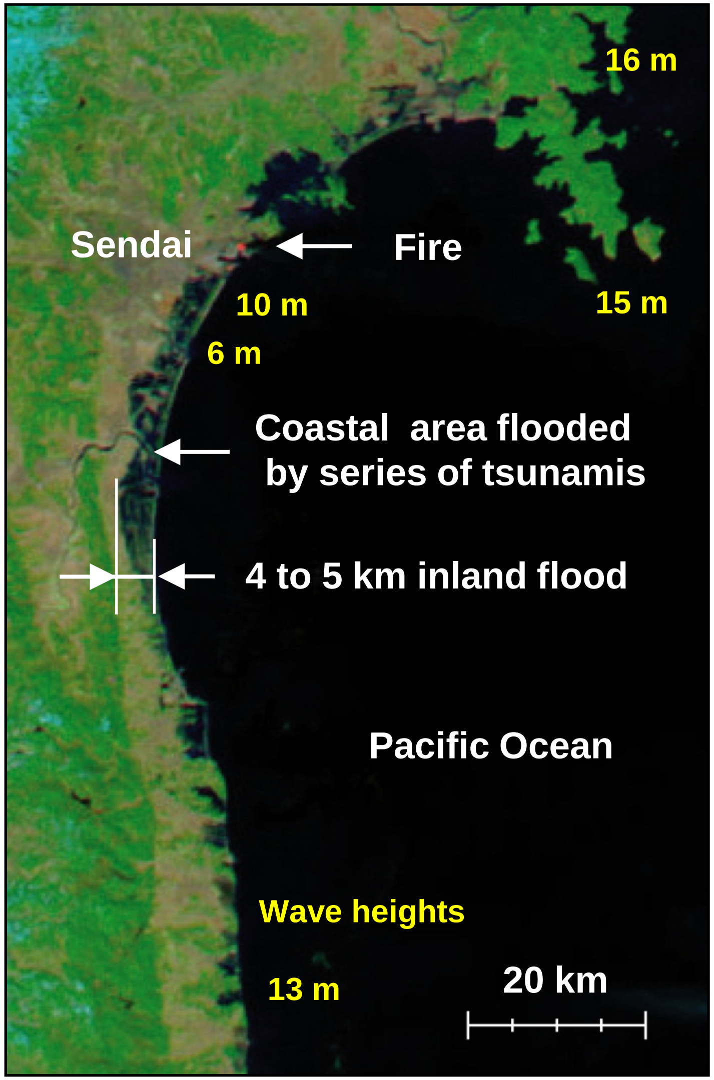
26 February 2011




13 March 2011



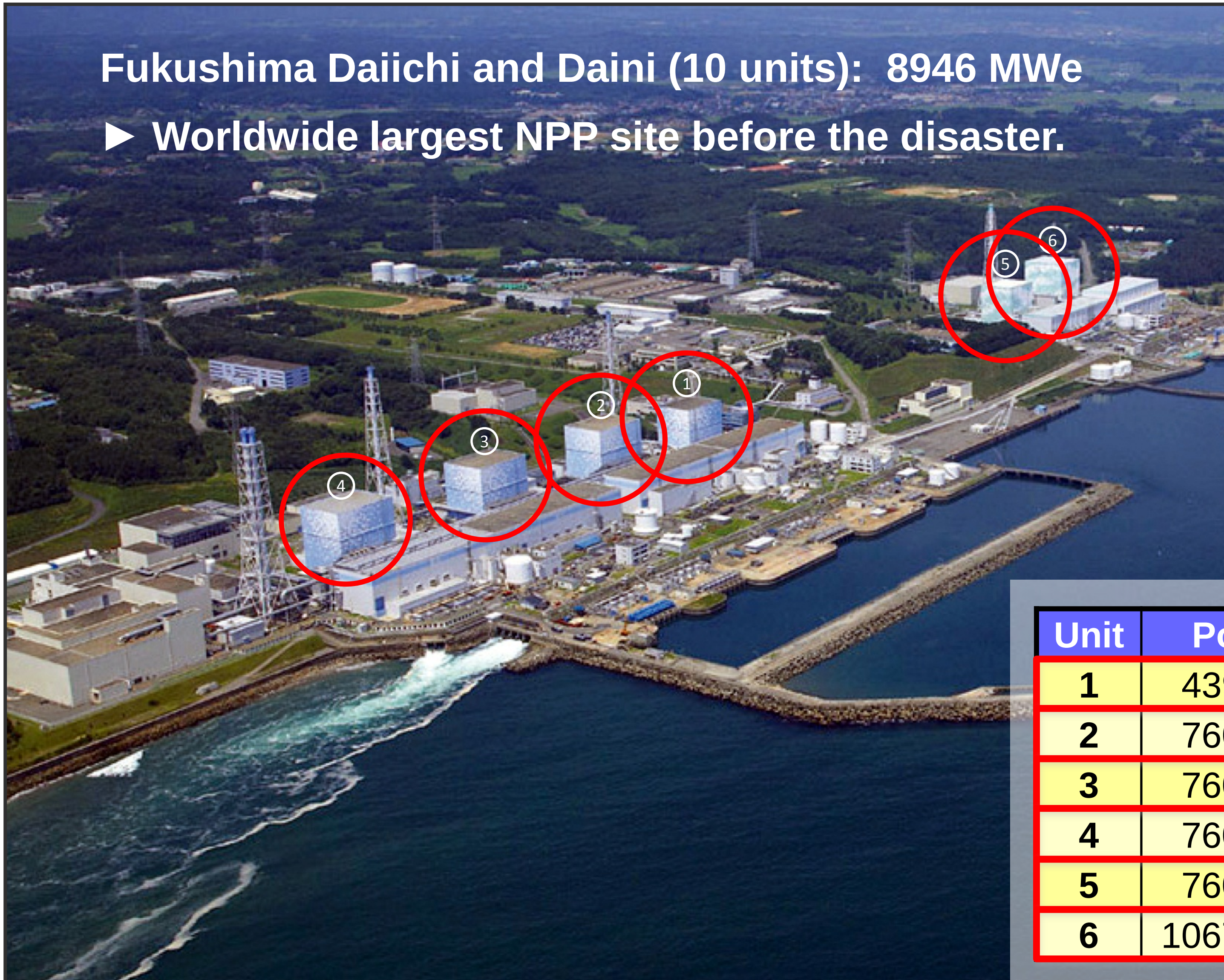

Fukushima Daiichi



Source: Nasa Earth Observatory, 2011

**Fukushima Daiichi and Daini (10 units): 8946 MWe**

**► Worldwide largest NPP site before the disaster.**



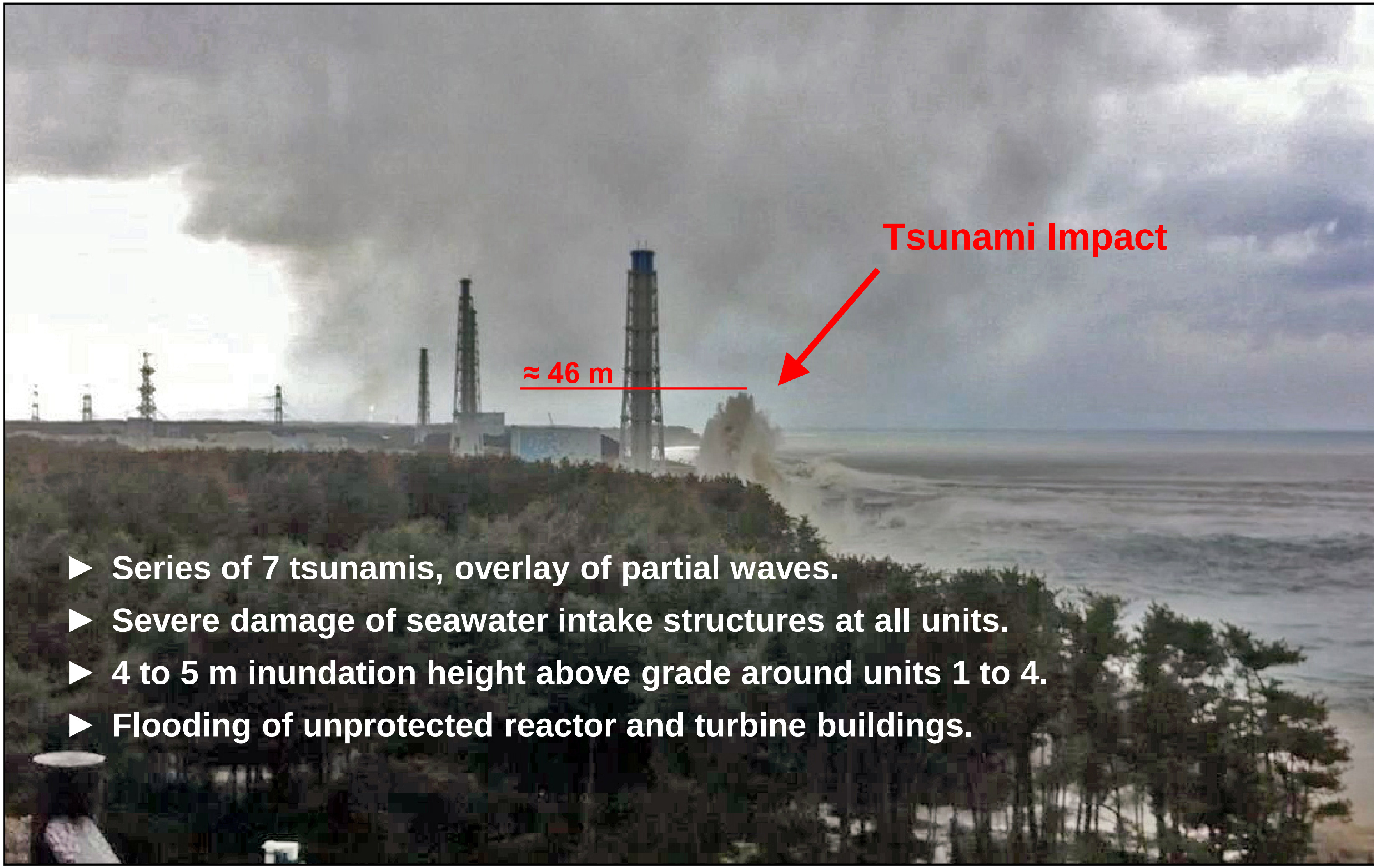

| Unit | Power | Status [1]) |
|---|---|---|
| 1 | 439 MWe | Operating |
| 2 | 760 MWe | Operating |
| 3 | 760 MWe | Operating |
| 4 | 760 MWe | Outage |
| 5 | 760 MWe | Outage |
| 6 | 1067 MWe | Outage |

[1]) before Seaquake



NPP: Nuclear Power Plant Quelle: Tepco, 2011

# Fukushima Daiichi ► Tsunami Arrival




- Series of 7 tsunamis, overlay of partial waves.
- Severe damage of seawater intake structures at all units.
- 4 to 5 m inundation height above grade around units 1 to 4.
- Flooding of unprotected reactor and turbine buildings.

Source: Tepco, 2011

## Buildings and plant equipment close to unit 4


Local time

15:42

15:43

15:44

15:46

15:57

**4 to 5 m inundation height above grade at units 1 to 4.**

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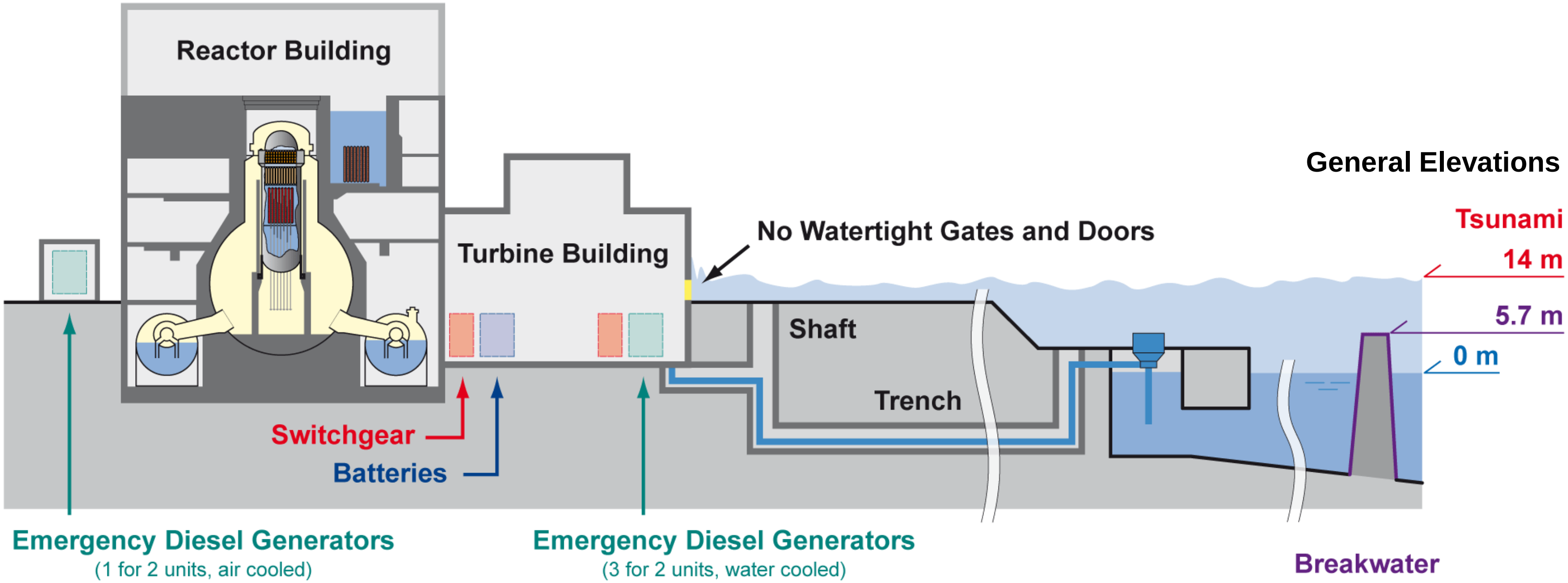


- ► **Tsunami Design Parameters**
  - ► Original design basis ► **3.1 m** maximum height.
  - ► 2002 Design basis review ► **5.7 m** maximum height.
- ► **Additional Safety Margin** ► **4.3 m** due to plant grade level of **10 m.**



All levels are related to the base level of Onahama Bay Source: Janti, 2011

# Fukushima-Daiichi ► Flooded Equipment Room at Unit 3

Source: Tepco, 2011

# Fukushima-Daiichi: Temporary Batteries for Instrumentation

Source: Tepco, 2011

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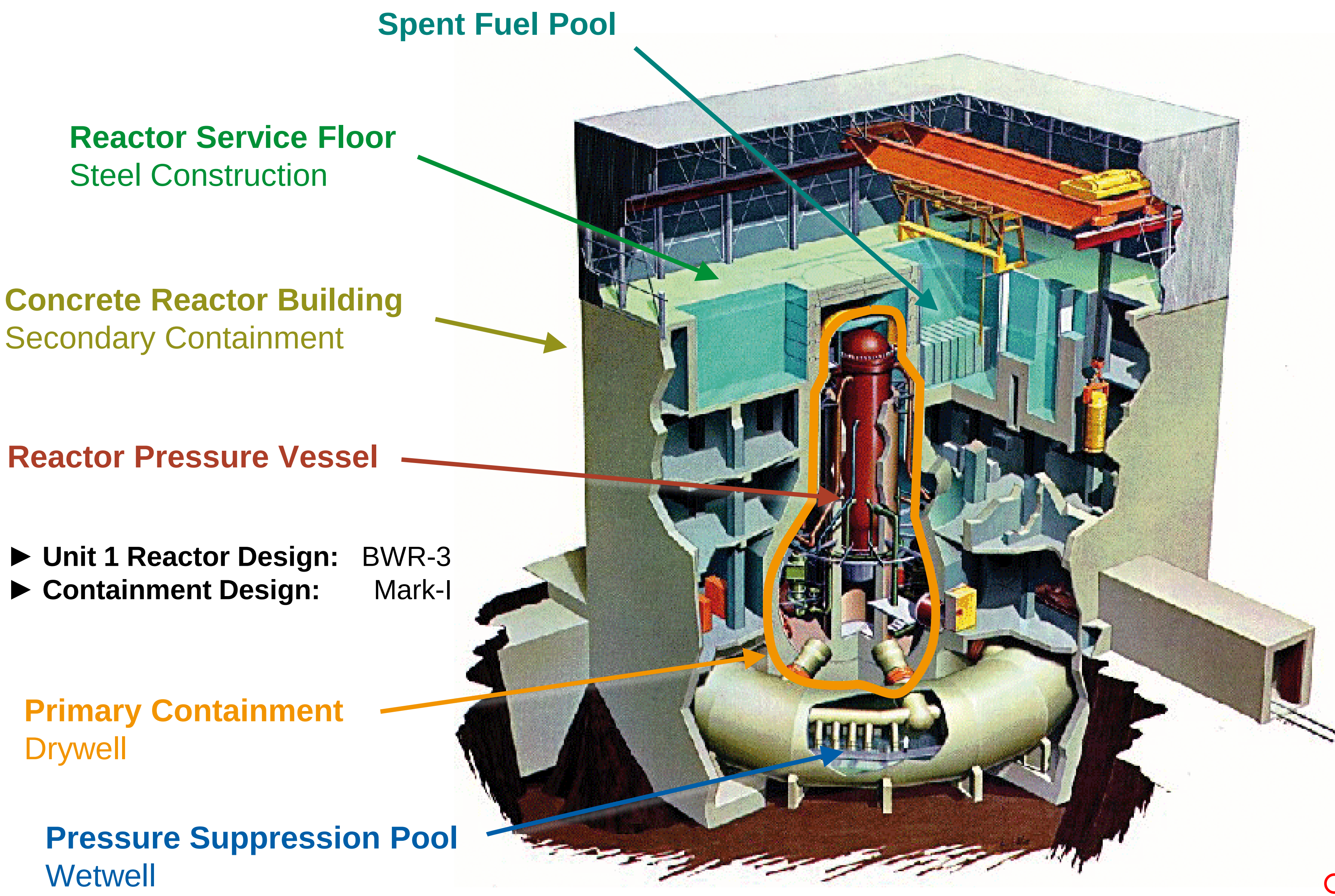


- **Unit 1 Reactor Design:** BWR-3
- **Containment Design:** Mark-I



Source:NRC, General Electric, www.nucleartourist.com, 2011

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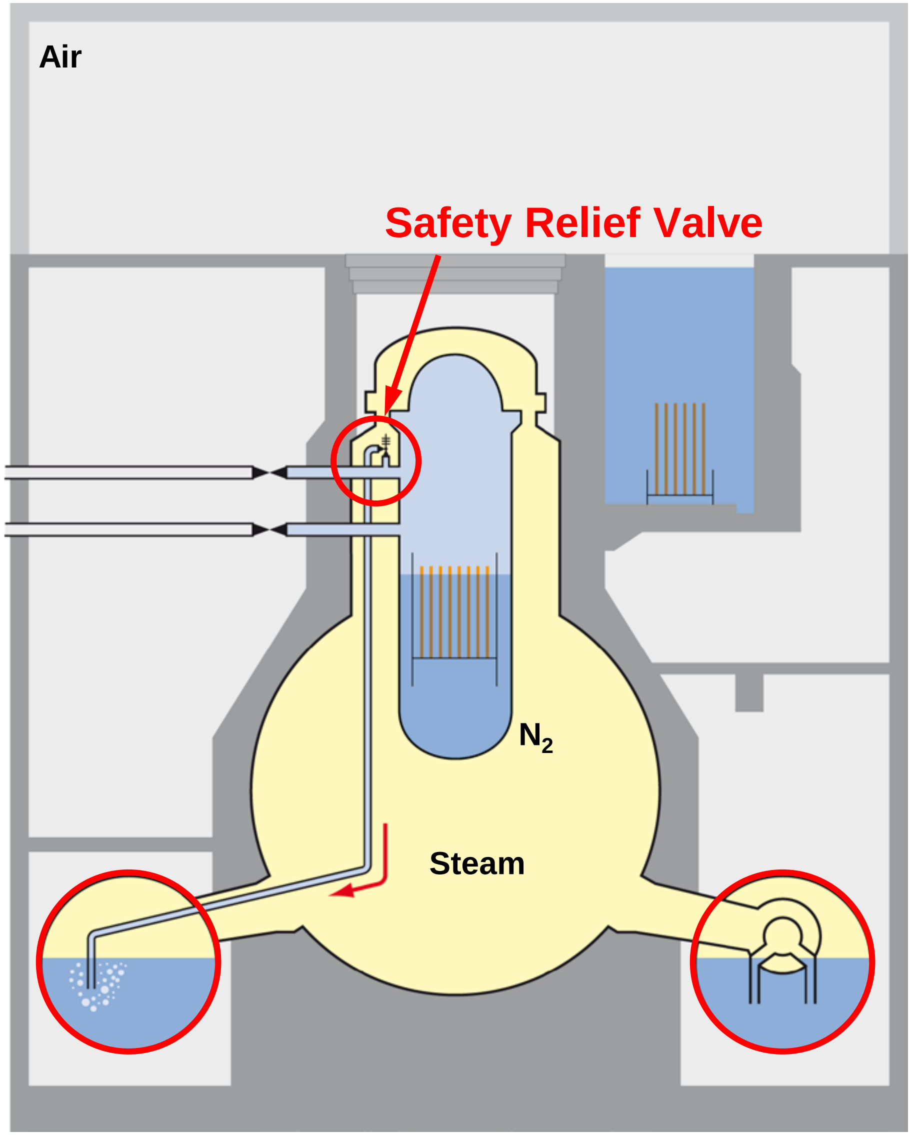
- **Total loss** of external electrical power supply due to seaquake.
- **Successful start** and operation of emergency diesel generators.
- **Total loss** of emergency diesel generators/batteries (tsunami).
- **Dry out** of the reactor core by evaporation (decay heat).
- **Dropping water level**, exposure of hot metallic surfaces to steam, pressure and temperatures rise.
- **Steam release** via the safety relief valves into the wet well.
- **Temperature and pressure** increase in the wet well.



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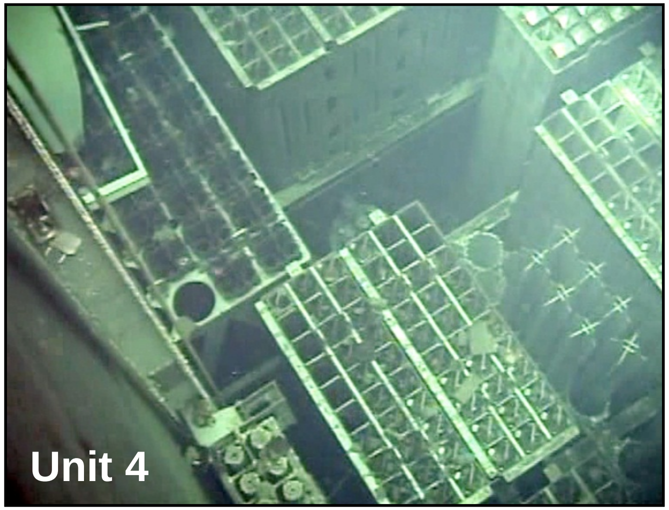
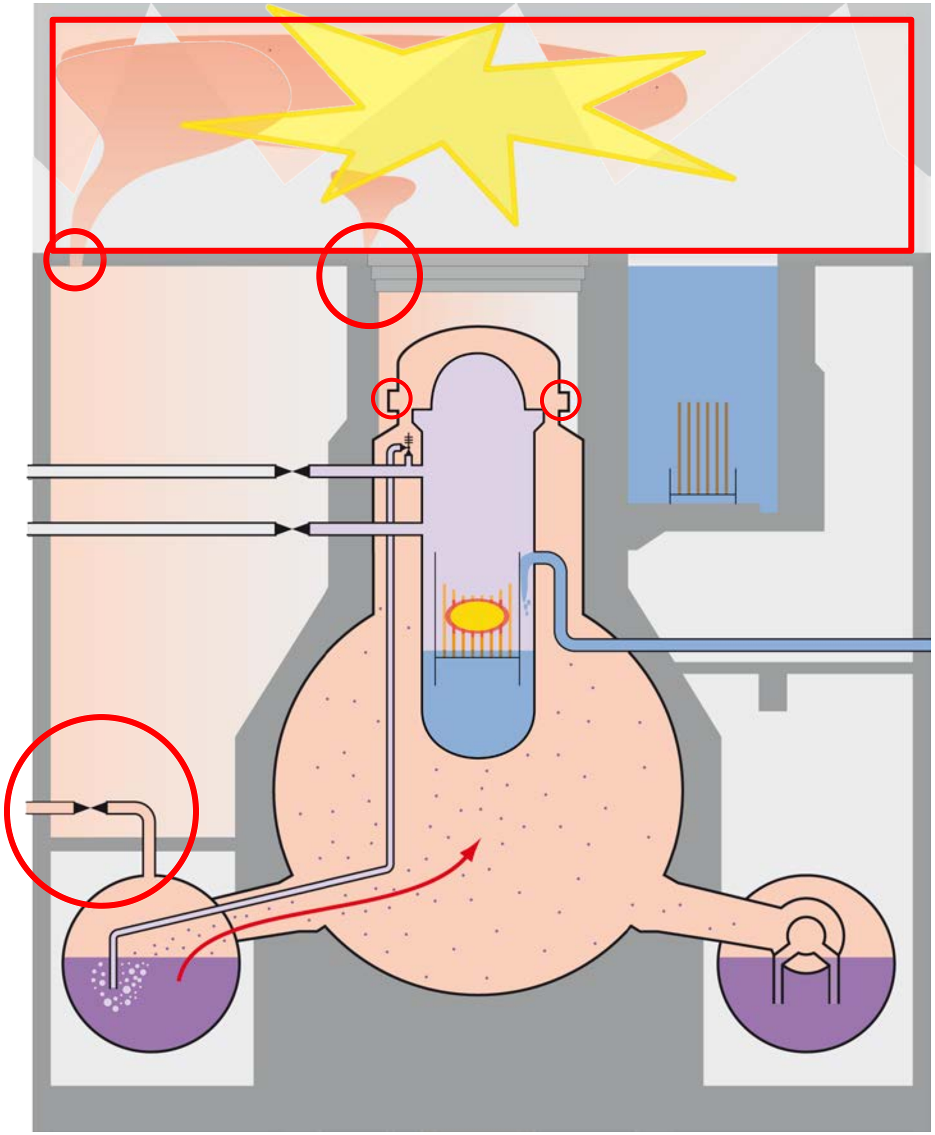
## Units 1 to 4

- No recombiners for severe accident conditions (units 1 to 4).
- Hydrogen explosion inside the reactor service floor (1, 3, 4).
- Destruction of steel framework structures in upper part (1, 3, 4).
- Intact reinforced concrete buildings.
- Substantial core damages (1 to 3).
- Dry out of spent fuel pools?



- Emergency generators at high elevations or in watertight bunkered buildings and watertight connections between emergency power supplies and plant.
- Robust design of cooling and venting systems which may also be manipulated and operated without power (e.g. regarding valves).
- Power trucks should be kept close on or very close to the nuclear power plant site.
- Independent and secured battery systems to power crucial instrumentation during emergencies.
- Passive catalytic hydrogen recombiners designed to cope with hydrogen releases under severe accident conditions.
- Passive filters on vent lines to remove radioactivity and allow for venting without harming nearby residents (no evacuation).
- **Regulatory quality and independence.**



Source: 24 Hours at Fukushima, IEEE Spectrum, November 2011

# Analysis of Historical Tsunami Data

## ▶ Is Fukushima Daiichi a matter of **residual risk** of nuclear energy?

| Date | Affected Region | Earthquake 1) | Tsunami 2) |
|---|---|---|---|
| 11.03.2011 | Japan | M = 9.0 | 39 m |
| 04.10.1994 | Kuril Islands | M = 8.3 | 11 m |
| 12.07.1993 | Sea of Japan | M = 7.7 | 31.7 m |
| 26.05.1983 | Noshiro | M = 7.7 | 14.5 m |
| 07.1 | | | n |
| 02.0 | | | n |
| 01.0 | | | n |
| 07.0 | | | n |
| 15.0 | | | n |
| 24.12.1854 | Nankaido | M = 8. | 28 m |
| 29.06.1780 | Kuril Islands | M = 7.5 | 12 m |
| 24.04.1771 | Ryukyu Islands | M = 7.4 | 85 m |
| 28.10.1707 | Japan | M = 8.4 | 11 m |
| 31.12.1703 | Tokaido-Kashima | M = 8.2 | 10.5 m |
| 02.12.1611 | Sanriku | M = 8.0 | 25 m |
| 20.09.1498 | Nankaido | M = 8.6 | 17 m |
| **Resulting Actual Design Basis** | | **M ≈ 7.4** | **> 10 m** |

**Even with earthquake magnitudes as low as 7.4 (equivalent) a large tsunami with a maximum height above ≈ 10 m can be produced!**

▶ **Analysis of Historical Data**

16 large tsunamis with wave heights of at least 10 m in past 513 years.

▶ **Experienced Frequency**

$$f = \frac{16}{513\ \text{a}} \approx 0.0312\ \text{a}^{-1} \approx \frac{\mathbf{1}}{\mathbf{30\ a}}$$

Thus, within a **thirty years period** one large tsunami must be expected somewhere in Japan!

▶ **Site-Specific Frequency**

Within a **100 to 1 000 years period** one large tsunami must be expected at every coastal location in Japan **(Fukushima: 300 to 400 years).**

## ▶ No, it is rather a matter of having underestimated a high specific risk!



1) equivalent 2) maximum amplitude Source: Dr. Nöggerath, Swiss Nuclear Society, 2011

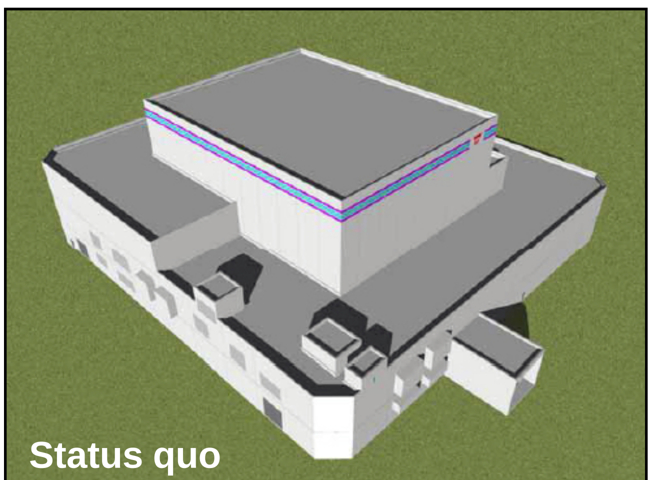
# Short-Term Remedy

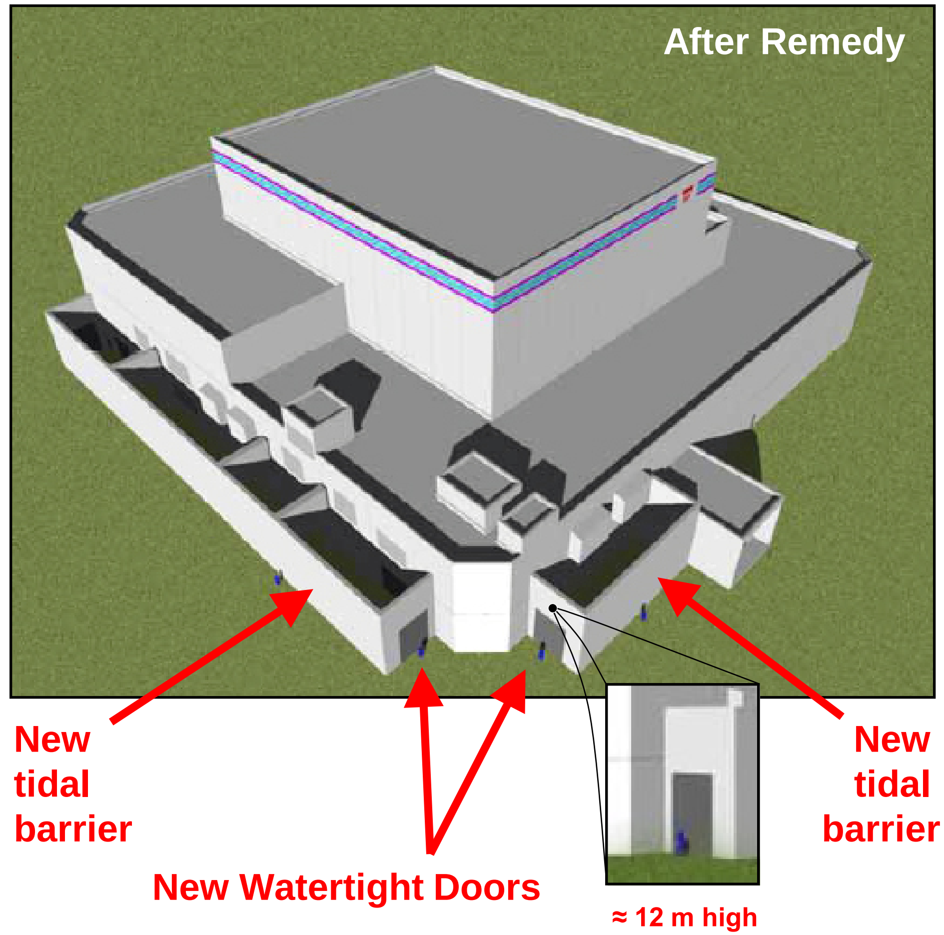
## NISA Regulatory Requirements

- ► Improvement of accident management (diesels, cables, hose connections ...)
- ► New tidal barriers with watertight doors.

**Example**

**NPP Kashiwazaki Kariwa**



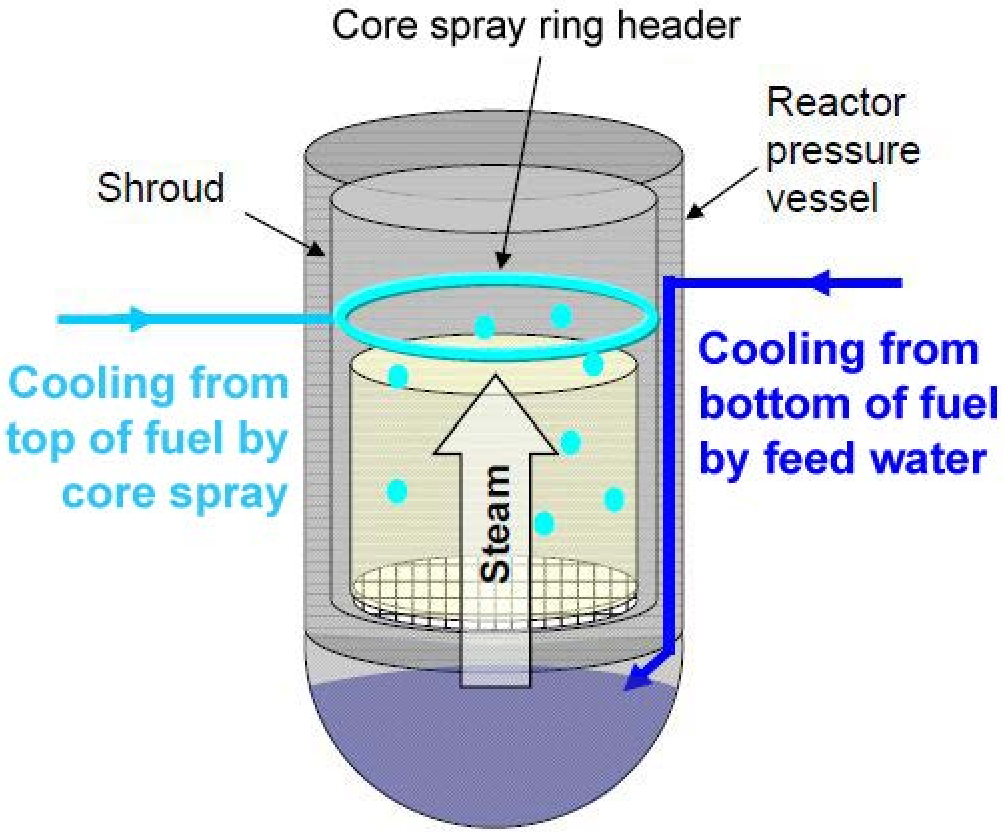



Nisa: Nuclear and Industrial Safety Agency, NPP: Nuclear Power Plant Source: Tepco, 2011

**July 11, 2011:** New Shelter Building for Unit 1

**September 11, 2011**

**September 11, 2011:** Additional Cooling System for Unit 3



| Range Classification | Number of Engaged Workers March 2011 to April 2012 | | |
|---|---|---|---|
| Cumulative Dose [1]) | Tepco | Contractors | Total |
| 250 mSv or more | 6 | 0 | **6** |
| 200 to 250 mSv | 1 | 2 | **3** |
| 150 to 200 mSv | 22 | 2 | **24** |
| 100 to 150 mSv | 117 | 17 | **134** |
| 50 to 100 mSv | 449 | 376 | **825** |
| 20 to 50 mSv | 614 | 2 428 | **3 042** |
| 10 to 20 mSv | 493 | 2 893 | **3 386** |
| 10 mSv or less | 1 715 | 12 499 | **14 214** |
| **Total** | **3 417** | **18 217** | **21 634** |
| **Maximum Dose** | **678.80 mSv** | **238.42 mSv** | **678.80 mSv** |
| **Average Dose** | **24.77 mSv** | **9.53 mSv** | **11.94 mSv** |

[1]) combined extrernal and internal exposure doses Source: Tepco, 2012

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► **Concluding Summary:**

- **9 workers 200 to 670 mSv,**
- 158 workers 100 to 200 mSv,
- other workers less than 100 mSv.

► **Statistical Population Data:**

- Natural risk of death from cancer of total population: 25 %
- Risk of death from cancer of **fuming** population: 35 %

► **10 % higher natural risk of death from cancer for smokers!**

► **Increased statistical risk of death from late cancer by radiation according to linear Dose-Risc-Relationship (ICRP):**

- **200 mSv: + 2 %**
- **670 mSv: + 6.7 %**

# Thank you for your attention!


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