SIMPOSYUM ON “SITING OF NEW NUCLEAR POWER PLANTS AND IRRADIATED FUEL FACILITIES”
LAS-ANS / CNEA / AATN – Buenos Aires-Argentina

“THE SEISMOTECTONIC ENVIRONMENT OF FUKUSHIMA ACCIDENT-LESSONS LEARNED”

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24 June 2013

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FUKUSHIMA DAIICHI NPP (F1)

INTRODUCTION

FUKUSHIMA . . . The first nuclear accident caused by a combination of extreme external events . . .

- **The seismotectonic environment, the earthquake, the tsunami**
- **The plant damage and response**
- The nuclear accident
- The management of the accident
- The radiological consequences
- The management of the emergency
- The actions by the world nuclear community

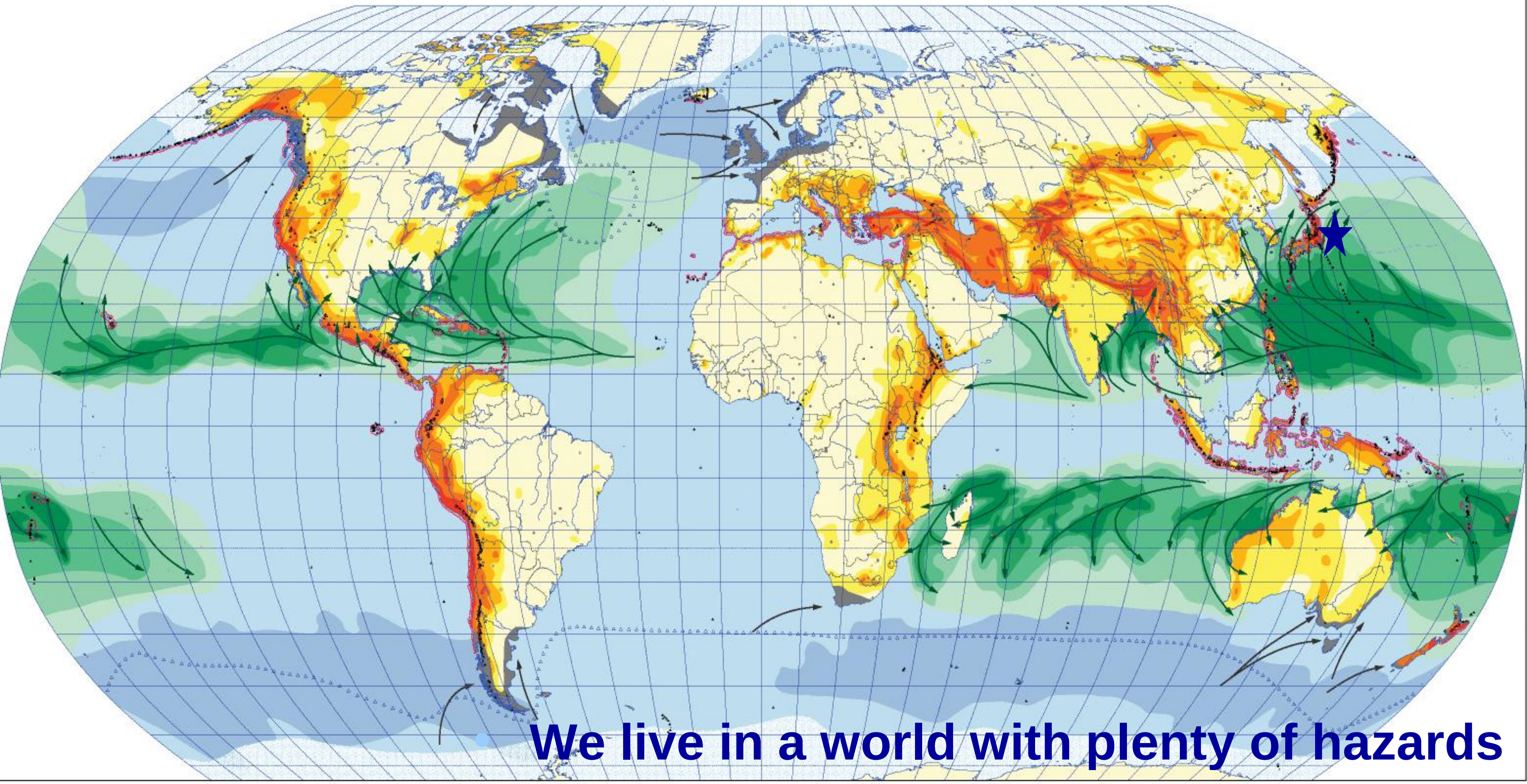
- **A COMPLEX SCENARIO of COMBINATION of EXTREME EXTERNAL EVENTS AFFECTING SEVERAL NPPs and LEADING to a NUCLEAR ACCIDENT:**
  - **An earthquake of Magnitude 9 that did not produce apparent significant damage to the nuclear installations,**
  - **A tsunami, ~45 minutes later that flooded the Tokai 2, Fukushima Daiichi and Fukushima Daini sites,**
  - **Hydrogen explosions, a few hours-days later,**
  - **Aftershocks (. . . . thousands), continuously, and**
  - **A region devastated with major damage to infrastructure and about 25000 casualties.**

Chronology of Major Events at Fukushima Daiichi Unit 1

Before the earthquake		In rated output operation
March 11, 2011	14:46	Great East Japan Earthquake
		Off-site power lost
		Reactor scram
	14:47	All control rods fully inserted
		Emergency DG startup (circuit breaker actuated)
	14:52	Isolation condenser startup
	15:41	Station black out due to the tsunami (subsequent AM response)
		Main Control Room power supply cut off
		Instrumental power supply cut off
March 12	5:46	Freshwater injection using fire pumps started
	10:17	PCV venting started
	14:30	Decrease in D/W pressure. Successful containment vessel venting
	15:36	Hydrogen explosion
	19:04	Sea water injection started

World Map of Natural Hazards

Münchener Rück
Munich Re



We live in a world with plenty of hazards

Earthquakes

- ☐ Zone 0: MM V and below
- 🟨 Zone 1: MM VI
- 🟧 Zone 2: MM VII
- 🟧 Zone 3: MM VIII
- 🟥 Zone 4: MM IX and above

Probable maximum intensity
(MM: modified Mercalli scale)
with an exceedance probability
of 10% in 50 years (equivalent to
"return period" of 475 years)
for medium subsoil conditions

Large city with "Mexico City effect"

Volcanoes

- △ Last eruption before 1800 AD
- ▲ Last eruption after 1800 AD
- ▲ Particularly hazardous volcanoes

Tsunamis and Storm Surges

- Tsunami hazard (seismic sea-wave)
- Storm surge hazard
- Tsunami and storm surge hazard

Tropical Storms and Cyclones

- 🟩 Zone 1: SS 1 (118–153 km/h)
- 🟩 Zone 2: SS 2 (154–177 km/h)
- 🟩 Zone 3: SS 3 (178–209 km/h)
- 🟩 Zone 4: SS 4 (210–249 km/h)
- 🟩 Zone 5: SS 5 (>= 250 km/h)

Probable maximum intensity
(SS: Saffir-Simpson hurricane scale)
with an exceedance probability
of 10% in 10 years (equivalent
to a "return period" of 100 years)

- ➚ Principal tracks of tropical storms

Extratropical Storms/Winter Storms

- ⬛ High extratropical storm hazard, mainly in winter
- ➚ Principal tracks of extratropical storms

Other Natural Hazards

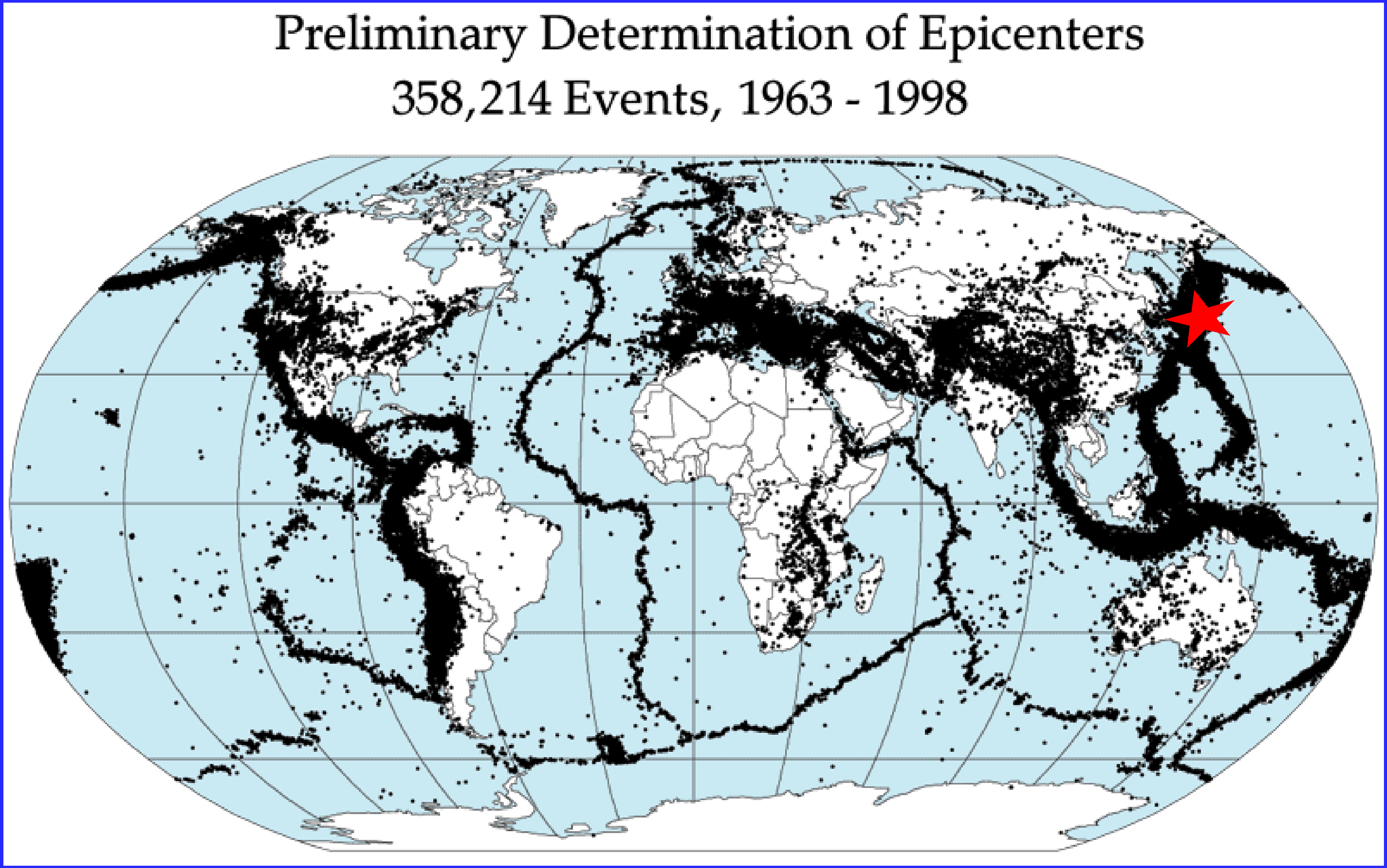
- △ △ Limit of iceberg drift
- ☐ Pack ice (winter maximum)
- 🟦 High seas with wave heights > 5 metres, exceedance probability 10% per year ("10-year wave")

Cities

□	Denver	> 1 million inhabitants
⊙	San Juan	100,000 to 1 million inhabitants
○	Maun	< 100,000 inhabitants
■ ● •	Berlin	Capital city
□	Melbourne	Munich Re office

Political Borders/Inland Waters

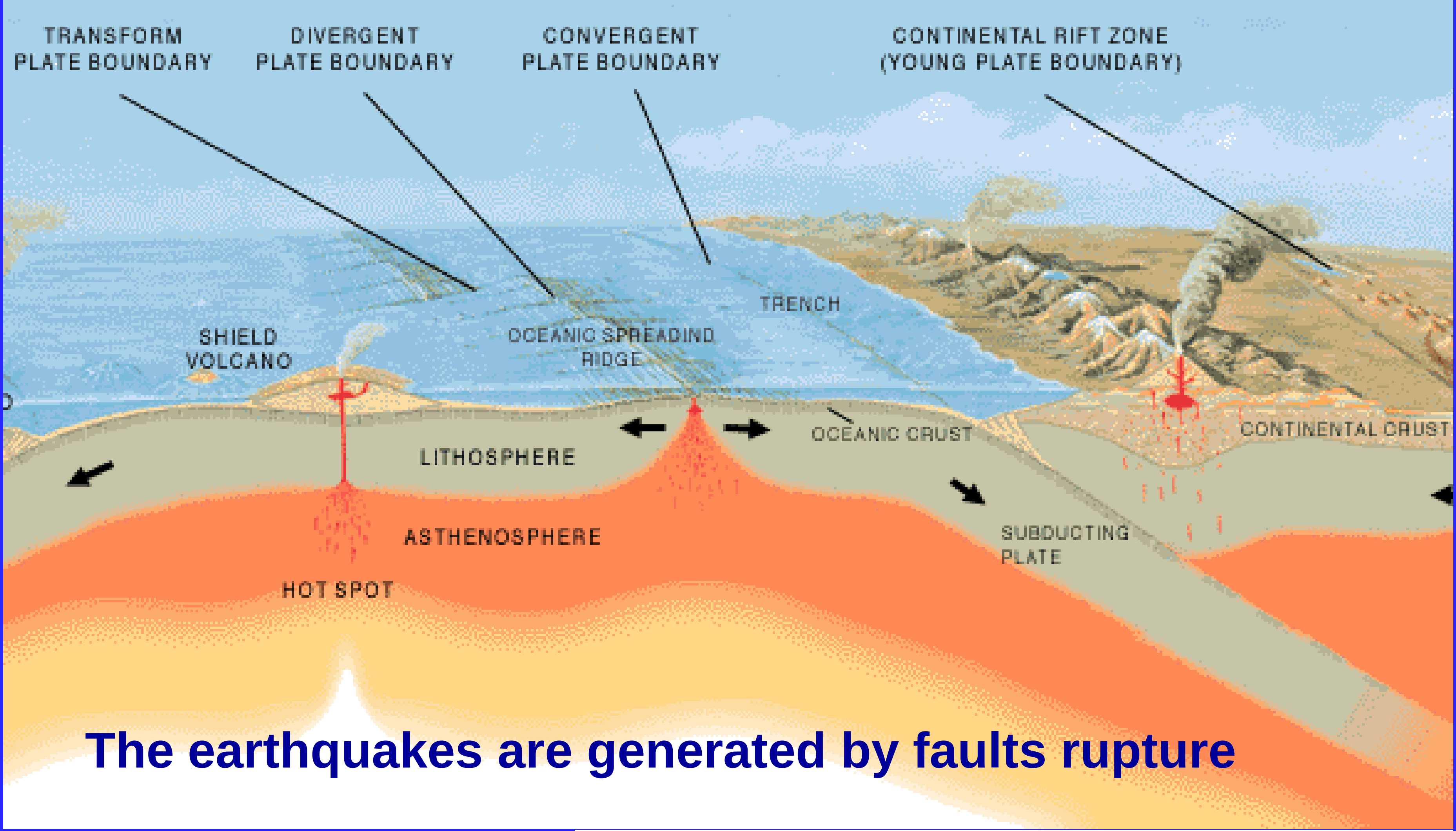
- State border
- State border, controversial (political borders not binding)
- River
- Lake
- Previous extent of lake



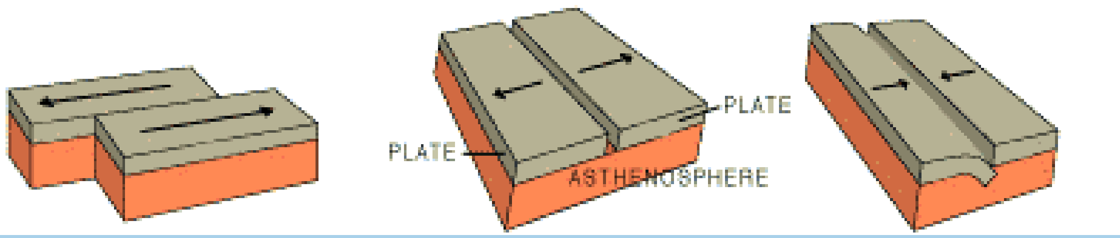
Global Seismicity

NASA DATM

Plate Tectonics



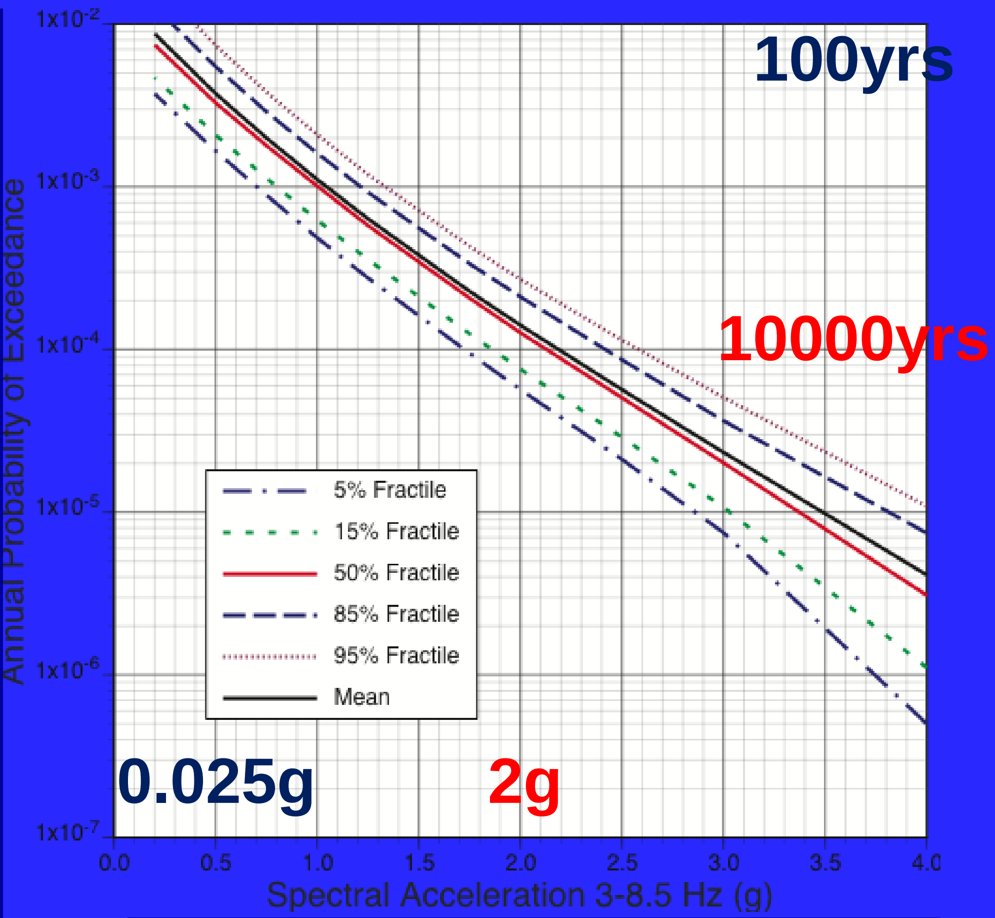
The earthquakes are generated by faults rupture



Hazard levels calculated increase with time period of observation

Rate of Occurrence

Rare Common



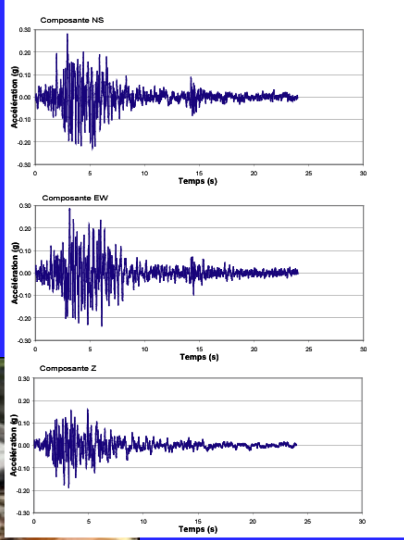
Low High

Shaking Level (pga)

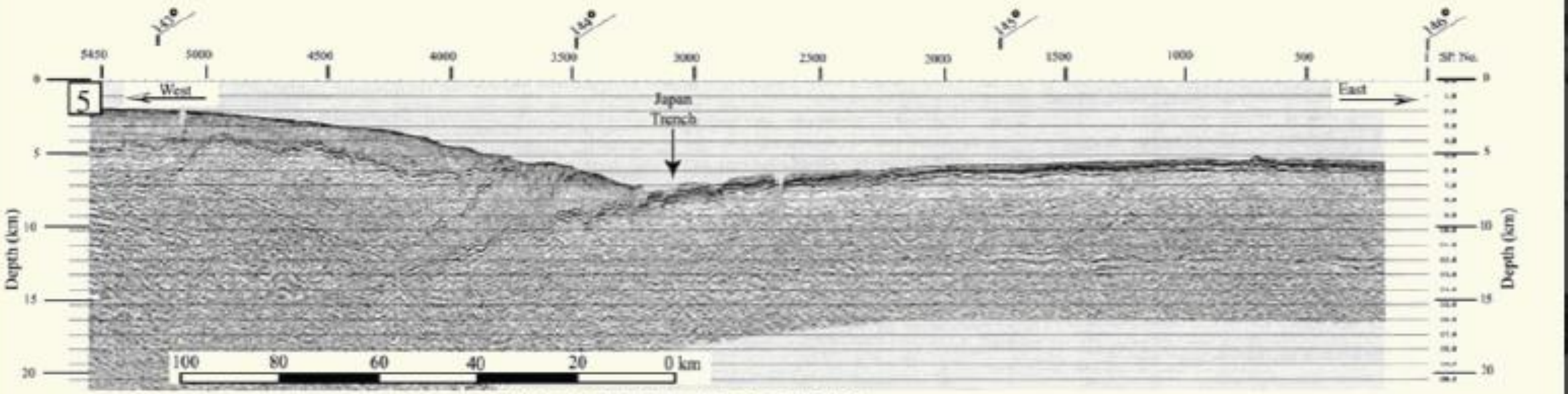
EARTHQUAKES AND “THE EARTHQUAKE”

THE SEISMIC HAZARDS:

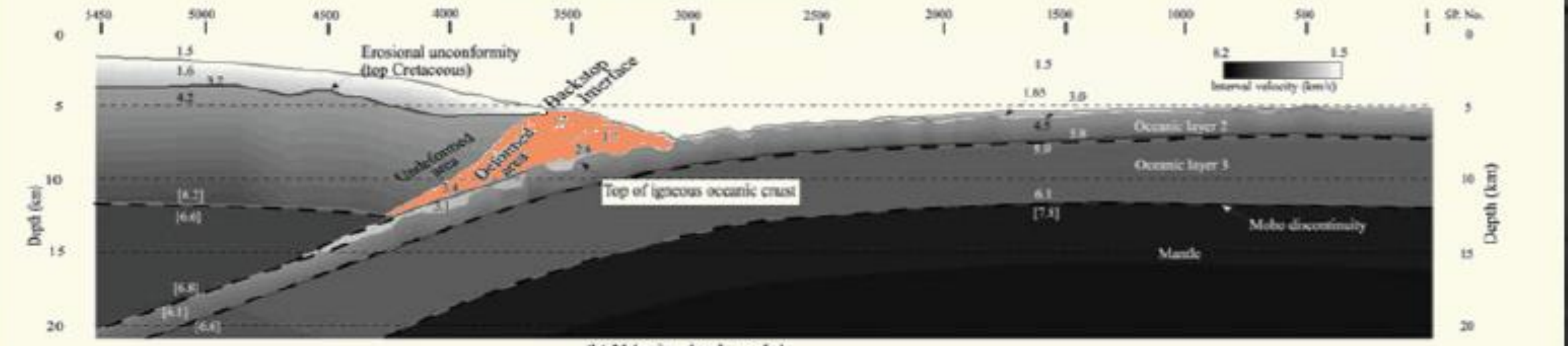
- ***Vibration of the ground***
- ***Tectonic uplift/subsidence***
- ***Landslides***
- ***Soil failures***
- ***Floods***
- ***Fires***



TSURU ET AL.: INTERPLATE COUPLING AT THE JAPAN TRENCH MARGIN **ESE** **11** - 5



(a) Prestack depth migrated section of Line 5



(b) Velocity-depth model

cross section of Japan Trench (Tsuru et al., 2002)
40 m slip on 4° dipping thrust uplifts seafloor by 2.8 m.
40 m coseismic extrusion of the wedge uplifts by 3.5 m.

Overview of 2011 Great East Japan Earthquake

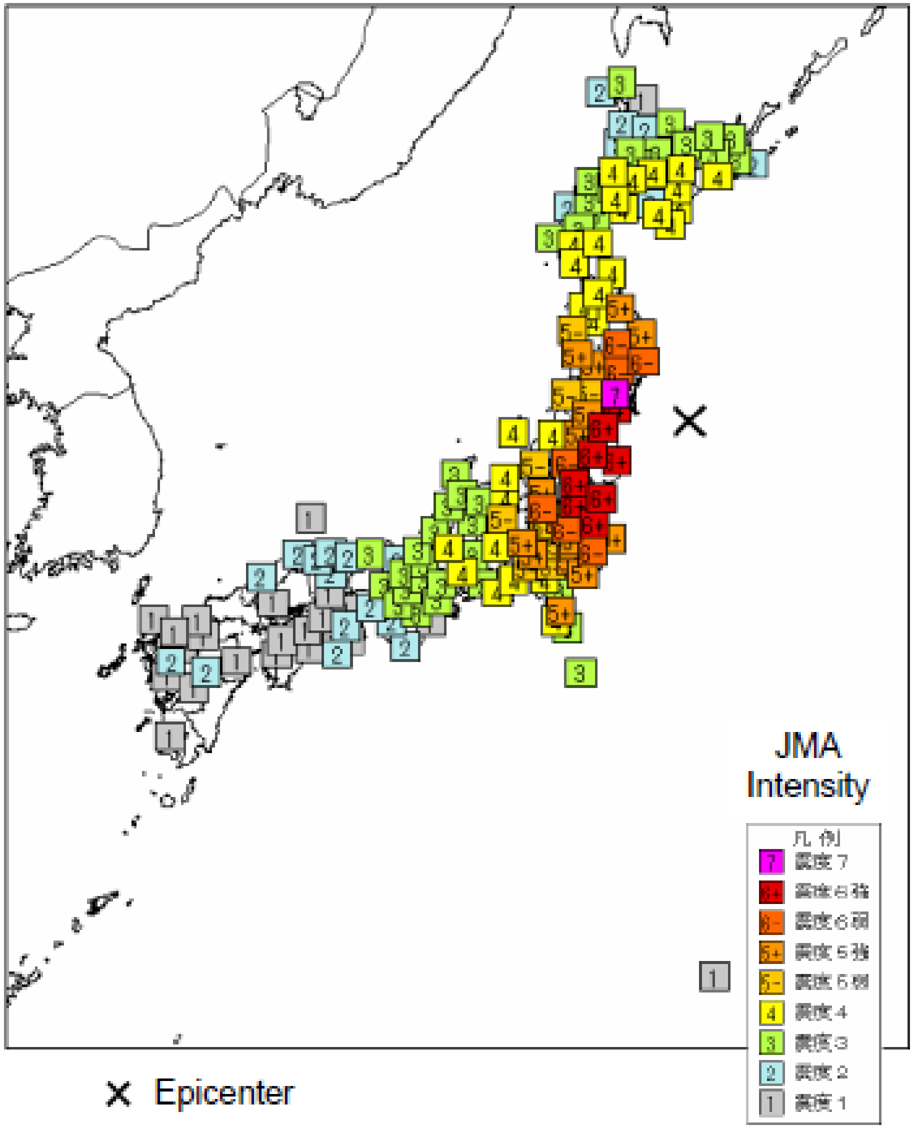
- **Commencement time:**
  14:46 on March 11, 2011

- **Epicenter:**
  Off the coast of Sanriku

- **Earthquake specification:**
  Mw 9.0
  38° 6.2”N, 142° 51.6”E
  Depth: 24km

- **Distance of epicenter from plant site:**

Fukushima Daiichi	178km
Fukushima Daini	183km

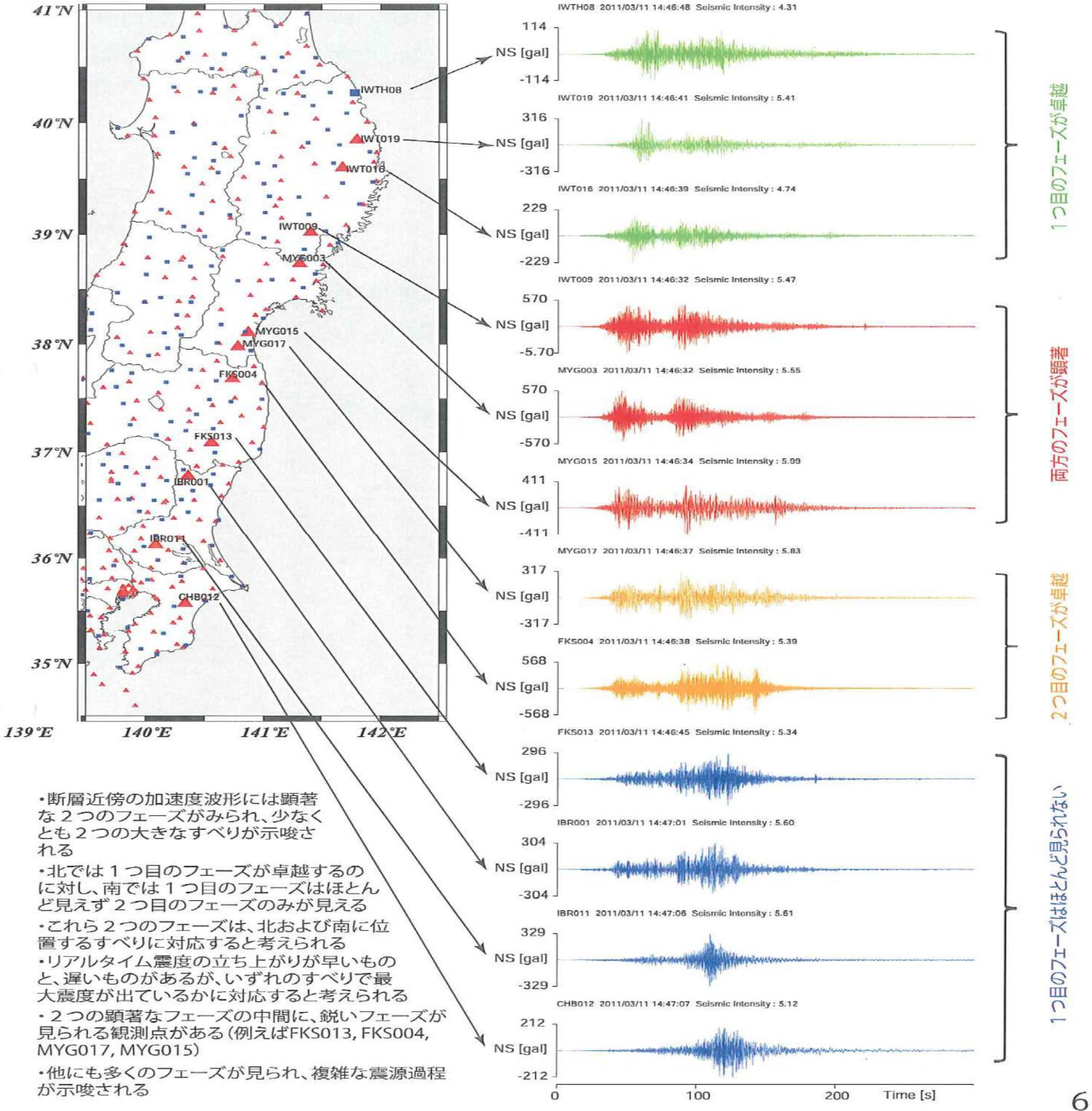


JMA Intensity map of main shock
[From Japan Meteorological Agency]


HIGASHI DORI NPP
ONAGAWA NPP
Epicenter
Tokyo
FUKUSHIMA DAI-ICHI NPP
Osaka
TOKAI DAI-NI NPP
FUKUSHIMA DAI-NI NPP
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

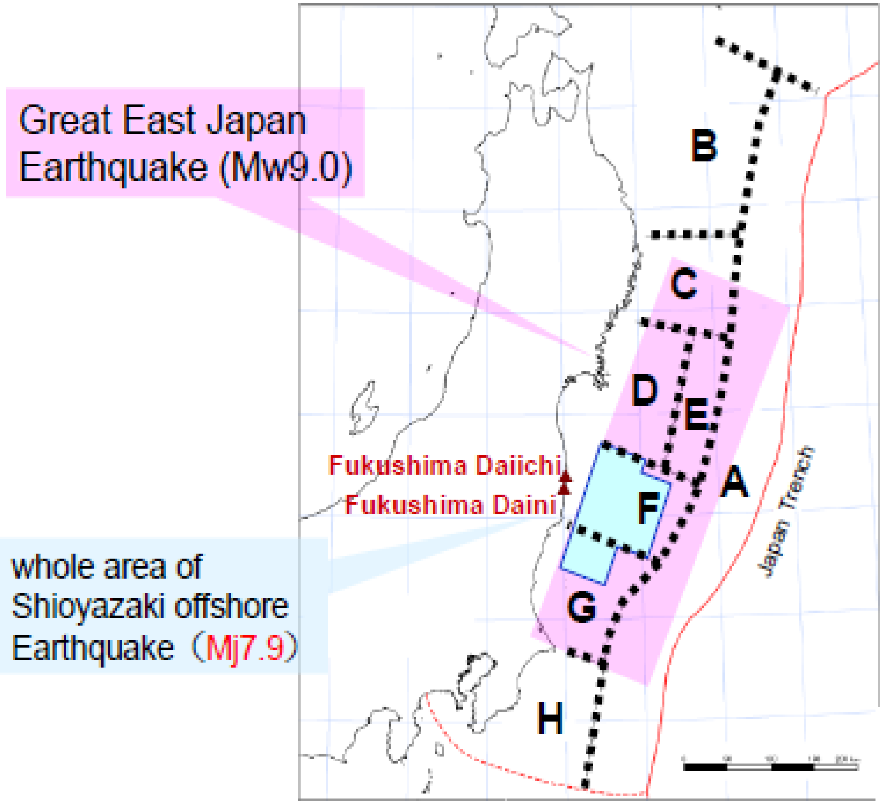
近地強震動波形に見られるフェーズの特徴

防災科学技術研究所資料



- 断層近傍の加速度波形には顕著な２つのフェーズがみられ、少なくとも２つの大きなすべりが示唆される
- 北では１つ目のフェーズが卓越するのに対し、南では１つ目のフェーズはほとんど見えず２つ目のフェーズのみが見える
- これら２つのフェーズは、北および南に位置するすべりに対応すると考えられる
- リアルタイム震度の立ち上がりが早いものと、遅いものがあるが、いずれのすべりで最大震度が出ているかに対応すると考えられる
- ２つの顕著なフェーズの中間に、鋭いフェーズが見られる観測点がある（例えばFKS013, FKS004, MYG017, MYG015）
- 他にも多くのフェーズが見られ、複雑な震源過程が示唆される

Source Fault of 2011 Great East Japan Earthquake



Great East Japan Earthquake (Mw9.0)

whole area of Shioyazaki offshore Earthquake（Mj7.9）

	Sea area	Estimated Mj	
A	Sanriku offshore to Boso offshore along the Japan Trench	8.2	
B	Northern Sanriku offshore	8.0	
C	Middle Sanriku offshore	N/A	
D	Miyagi pref. offshore	7.5	whole area 8.0
E	Close to the trench in southern Sanriku offshore	7.7	
F	Fukushima pref. offshore	7.4	
G	Ibaraki pref. offshore	6.7 - 7.2	
H	Boso offshore	8.1	

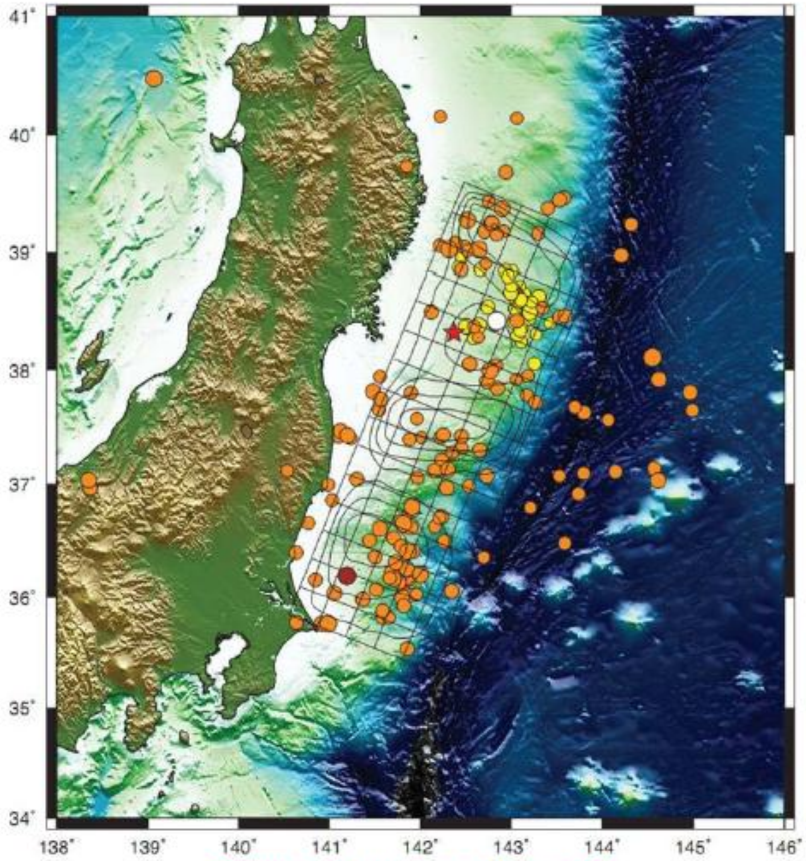
Comparison with areas assessed by the Earthquake Research Committee of the Headquarters for Earthquake Research Promotion
【Revised by the Earthquake Research Committee (2009)】

- Assessment of earthquakes for each area were conducted, but such a large interlock of multiple source areas as the earthquake was not conducted.

- Even the Headquaters for Earthquake Research Promotion (HERP), a govermental organization, had not evaluated such a interlock as the earthquake.

- Design basis ground motion Ss for Fukushima Daiichi and Fukushima Daini are determined under consideration of Mj7.9 earthquake, which was defined by interlocking large three source fault within the area "F" and is beyond the estimation for the area "F" by HERP (Mj7.4).

Source Fault of 2011 Great East Japan Earthquake



Source of this earthquake
【By Earthquake Research Institute, The University of Tokyo】

Largest earthquakes in the world
【From USGS】

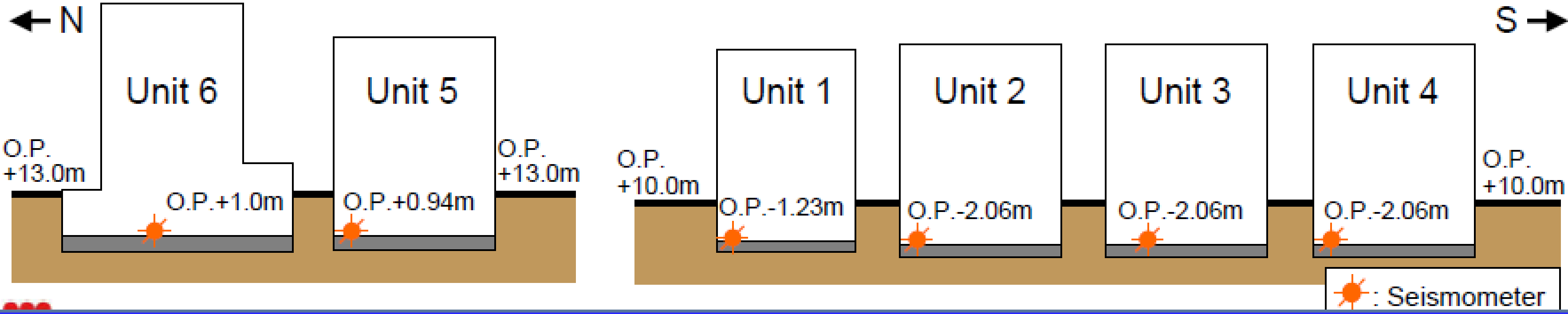
Earthquake	Mw
1960 Chile	9.5
1964 Alaska	9.2
2004 Sumatra	9.1
2011 Great East Japan	9.0
1952 Kamchatka	9.0

The March 11th earthquake occurred as multiple sources where earthquakes had occurred in the past interlocked, and the magnitude was the largest in recorded history for earthquakes occurring in the area surrounding Japan and the 4th largest in the world.

Records of Observations at Base-mat Slab of Reactor Building at Fukushima Daiichi NPS

	Maximum acceleration value from observation records (Gal)			Maximum response acceleration value (Gal)					Static horizontal acceleration (Gal)
				New design-basis seismic ground motion Ss			Original design-basis seismic ground motion		
	NS	EW	UD	NS	EW	UD	NS	EW	
Unit 1	460	447	258	487	489	412	245		470
Unit 2	348	550	302	441	438	420	250		
Unit 3	322	507	231	449	441	429	291	275	
Unit 4	281	319	200	447	445	422	291	283	
Unit 5	311	548	256	452	452	427	294	255	
Unit 6	298	444	244	445	448	415	495	500	

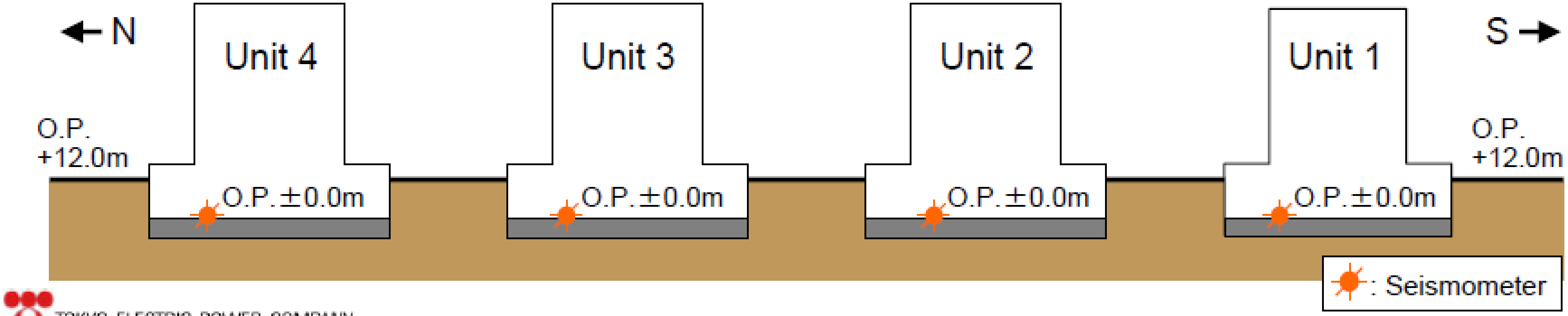
* □ indicates the observed value was beyond the response of Ss, the others were under the response of Ss.



Records of Observations at Base-mat Slab of Reactor Building at Fukushima Daini NPS

	Maximum acceleration value from observation records (Gal)			Maximum response acceleration value (Gal)					Static horizontal acceleration (Gal)
				New design-basis seismic ground motion Ss			Original design-basis seismic ground motion		
	NS	EW	UD	NS	EW	UD	NS	EW	
Unit 1	254	230	305	434	434	512	372	372	470
Unit 2	243	196	232	428	429	504	317	309	
Unit 3	277	216	208	428	430	504	196	192	
Unit 4	210	205	288	415	415	504	199	196	

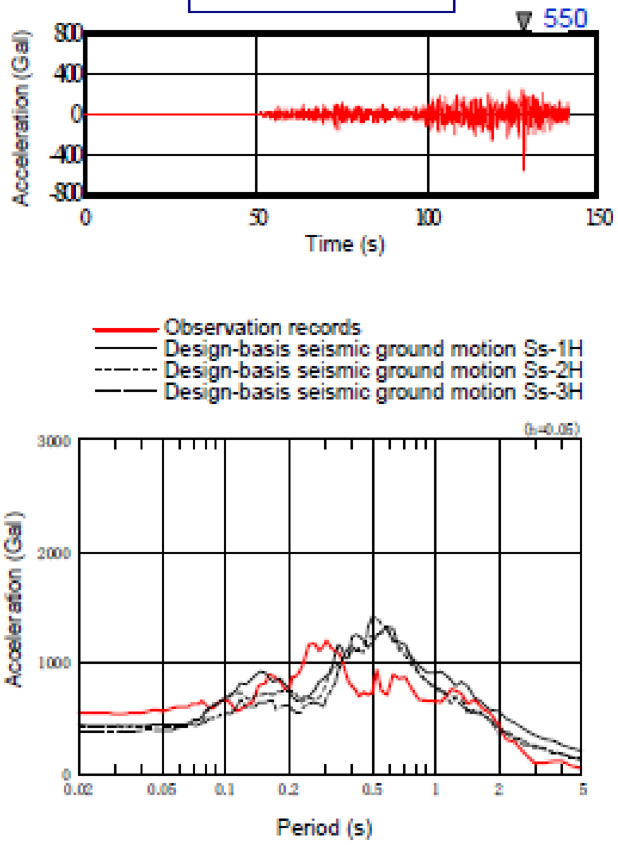
* All observed maximum acceleration values were under the response of Ss.



Comparison of Great East Japan Earthquake and NCO Earthquake

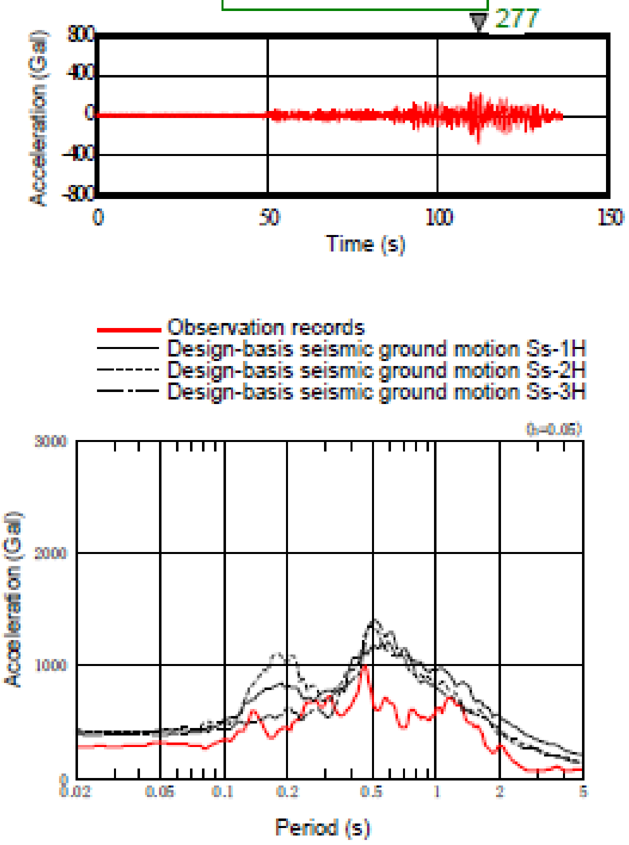
2011 Great East Japan Earthquake

Fukushima Daiichi



Unit 2 EW direction

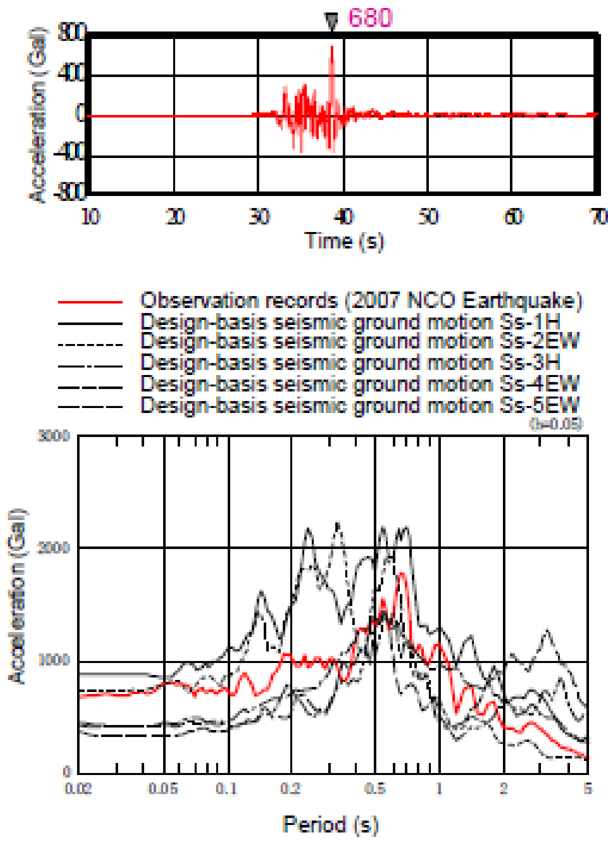
Fukushima Daini



Unit 3 NS direction

2007 NCO Earthquake

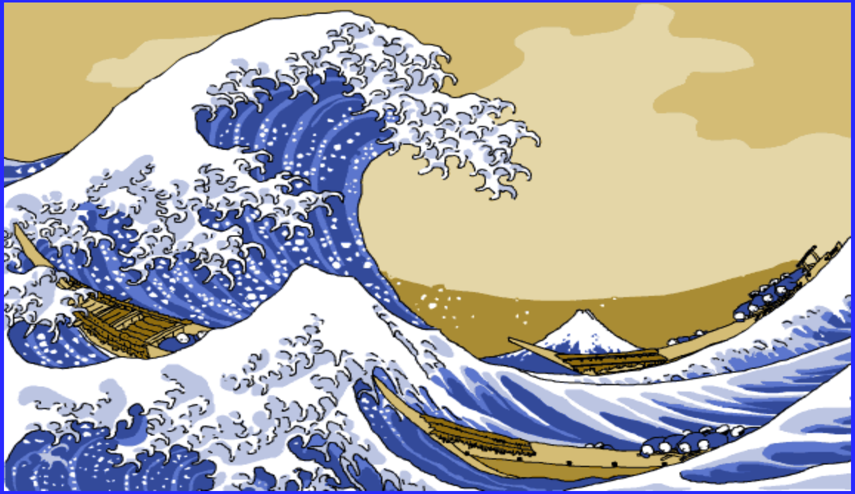
Kashiwazaki-Kariwa



Unit 1 EW direction

TSUNAMIS AND “THE TSUNAMI”

1. What is a tsunami?

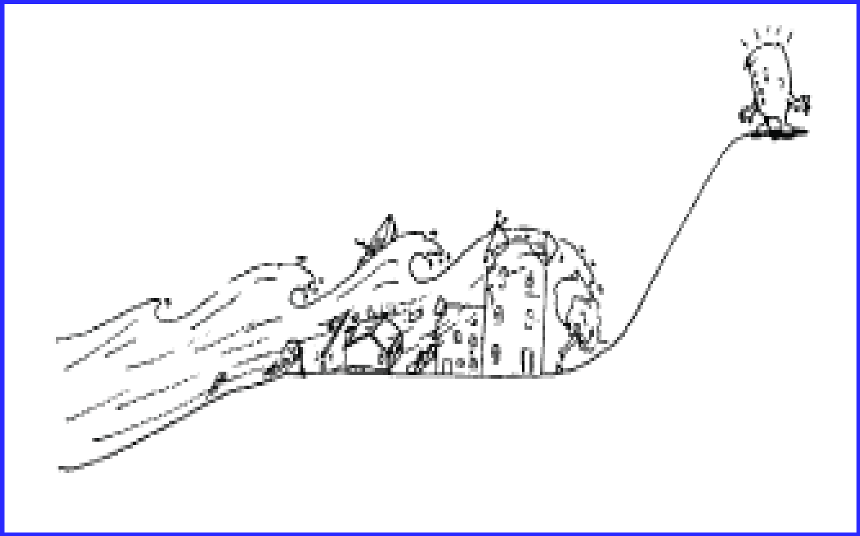


Tsunami Definition

Tsunami is a Japanese term, meaning **wave** (“**nami**”) in a **harbour** (“**tsu**”).

Terrae motus → Terremoto ↔ Earthquake

Mare motus → Maremoto ↔ Tsunami



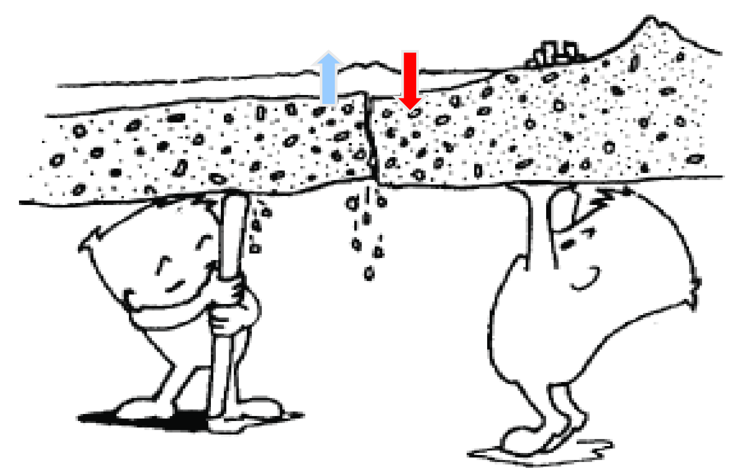
Tsunami Definition

- *A **tsunami** is a wave …*

  . . . is a series of traveling waves of extremely long length and period, . . .

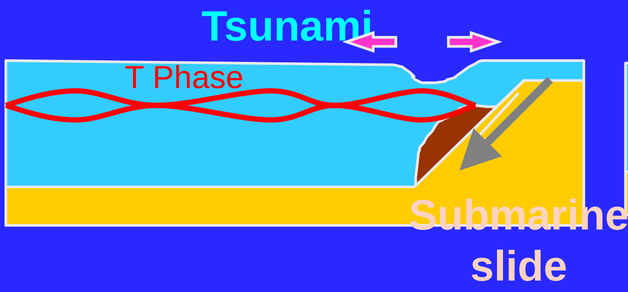
  . . . generated by rapid (impulsive) disturbances usually associated with earthquakes occurring below the sea floor,

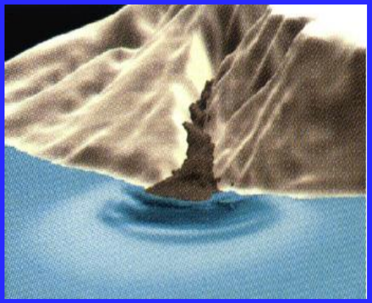
  . . . near the coast of a sea or ocean, . . . or near a large body of water.



Tsunamis can also be generated by:

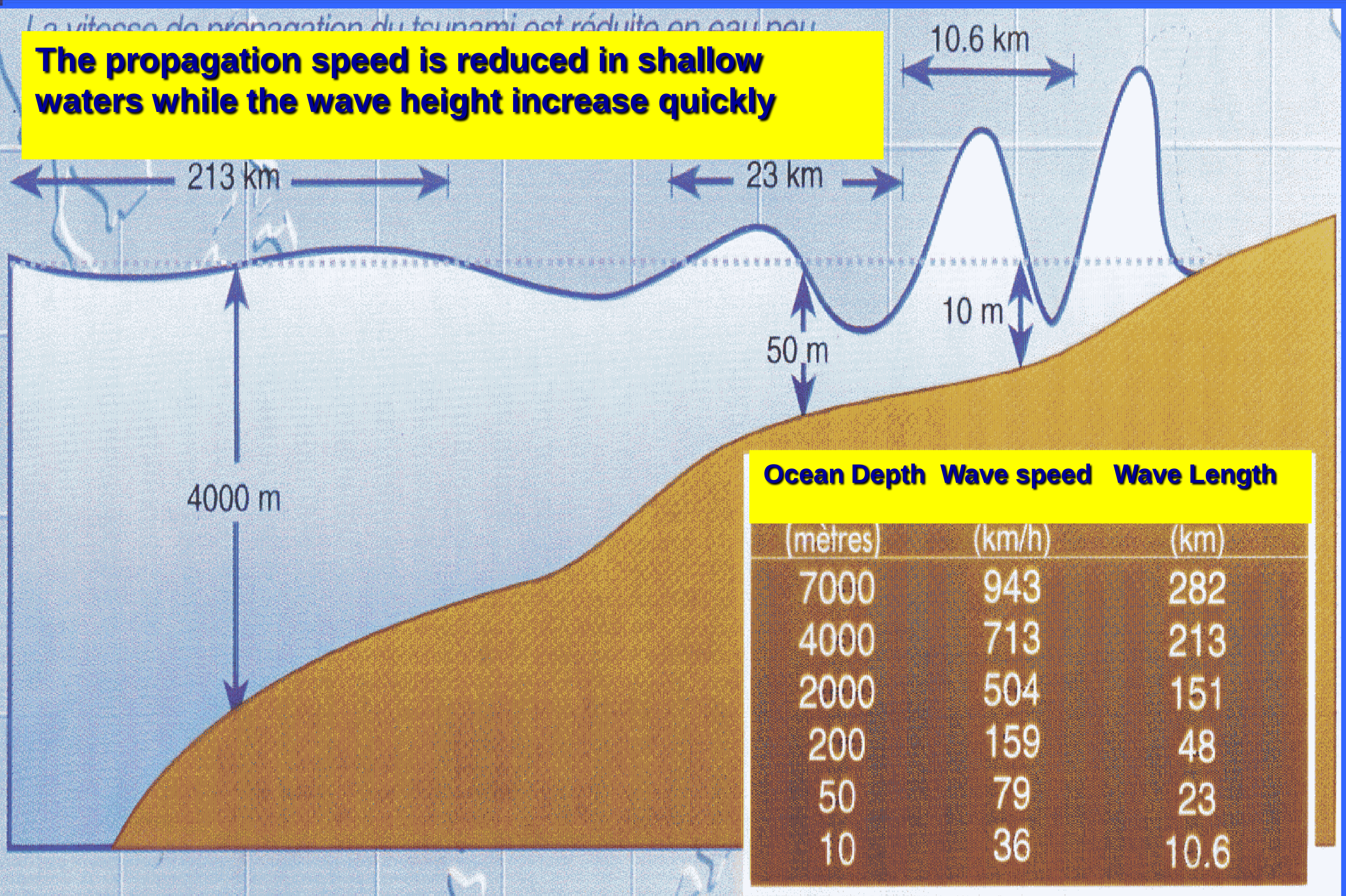
- *Volcanic explosions or collapses,*
- *Submarine landslides,*
- *Coastal rock falls and landslides (triggered or not by earthquakes or volcanic eruptions),*
- *Large meteorite impacting the ocean.*





Tsunamis have no connection with tides; the popular name of “tidal wave”
Is entirely misleading.

Tsunami Process



The propagation speed is reduced in shallow waters while the wave height increase quickly

Ocean Depth (mètres)	Wave speed (km/h)	Wave Length (km)
7000	943	282
4000	713	213
2000	504	151
200	159	48
50	79	23
10	36	10.6

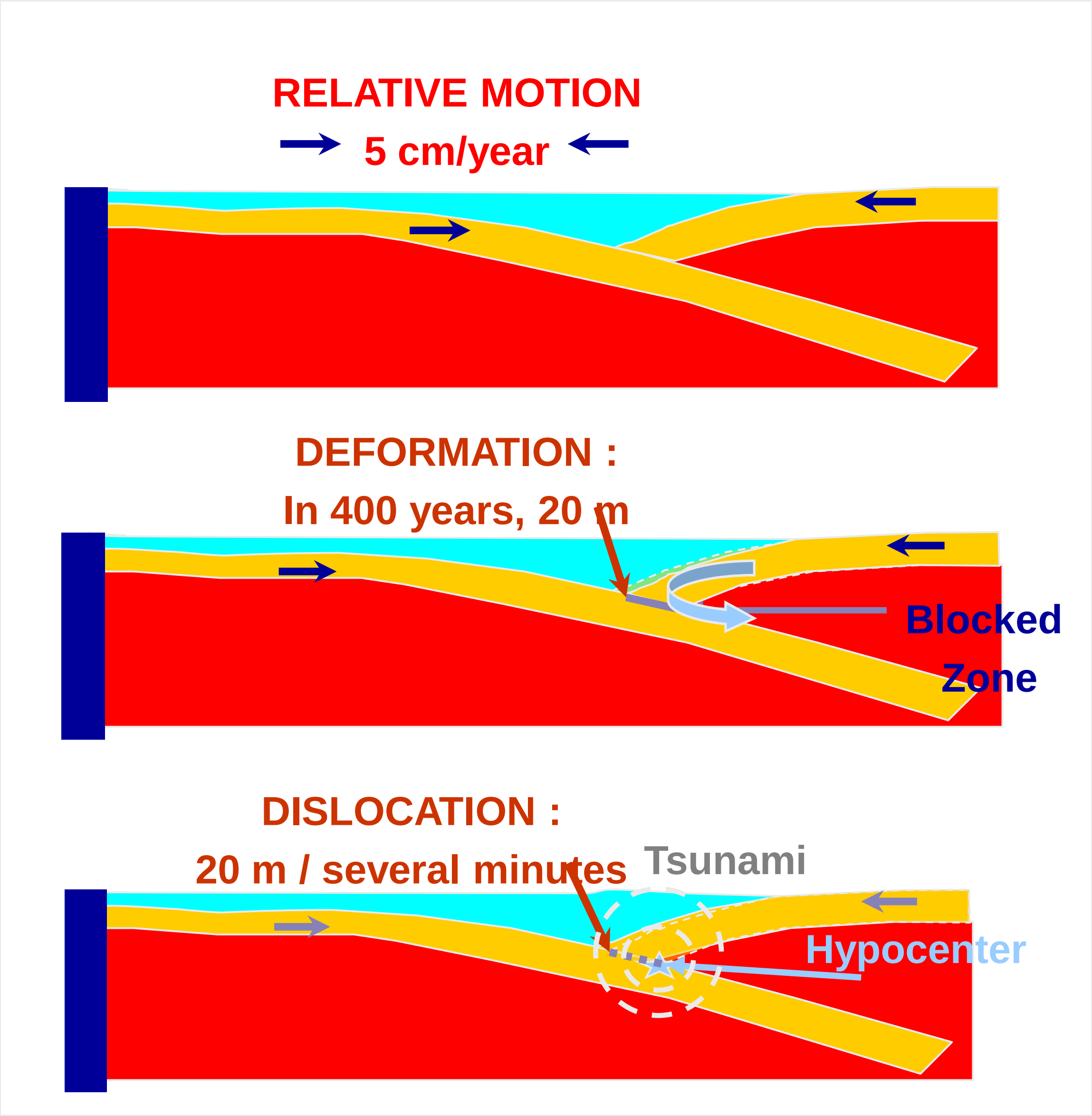
How is a tsunami generated?

Subduction Zone:

1) ~400 Years ago

2) Just before earthquake

3) When the earthquake occurred, tsunami is generated

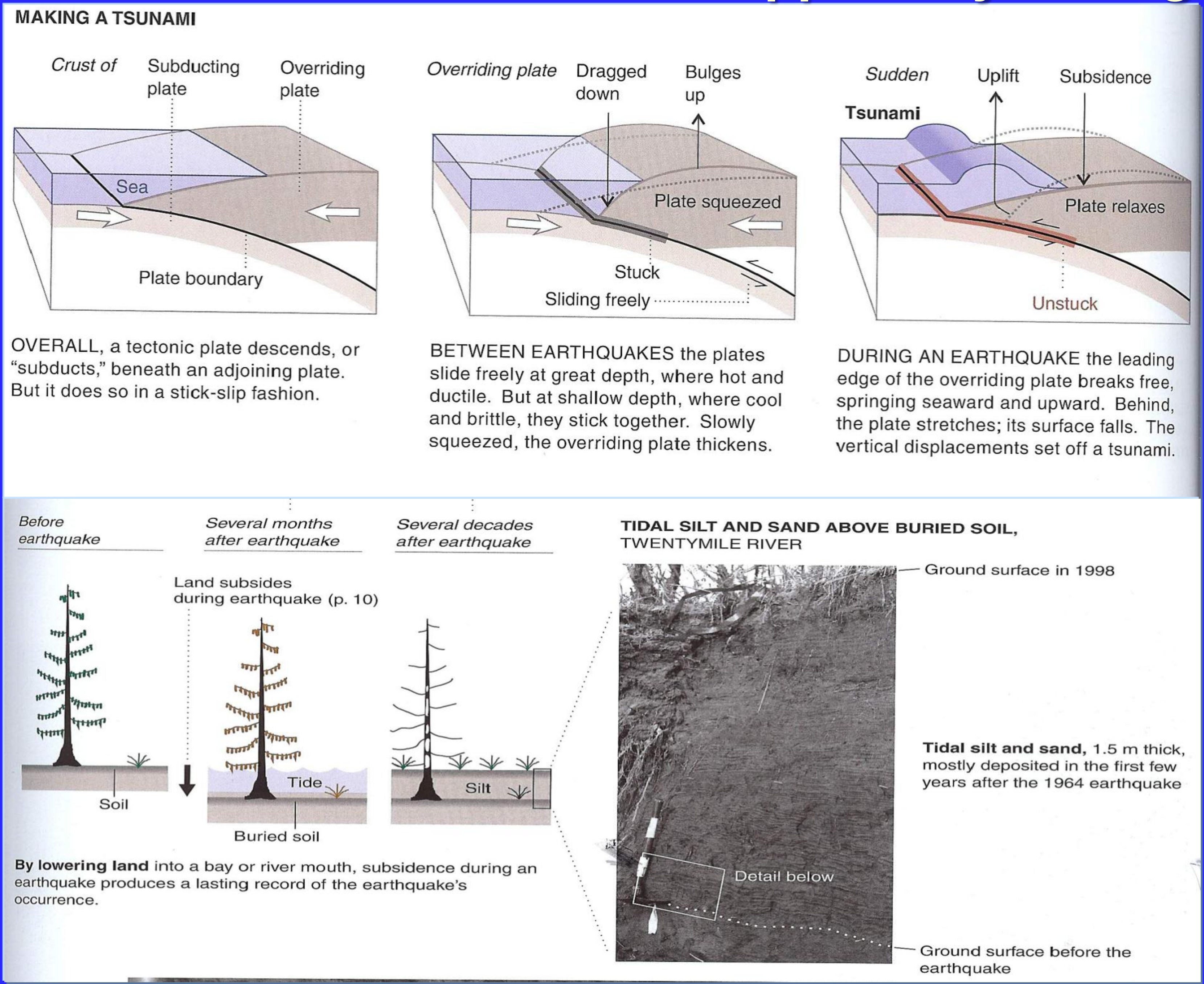


The 3 stages of a tsunami

Three basic stages of tsunami behaviour:

1. **Generation,** in the subduction fault
2. **Propagation,** in the open sea, and
3. **Inundation,** when reaches the coast.

How we know that a tsunami happened years ago?



MAKING A TSUNAMI

OVERALL, a tectonic plate descends, or "subducts," beneath an adjoining plate. But it does so in a stick-slip fashion.

BETWEEN EARTHQUAKES the plates slide freely at great depth, where hot and ductile. But at shallow depth, where cool and brittle, they stick together. Slowly squeezed, the overriding plate thickens.

DURING AN EARTHQUAKE the leading edge of the overriding plate breaks free, springing seaward and upward. Behind, the plate stretches; its surface falls. The vertical displacements set off a tsunami.

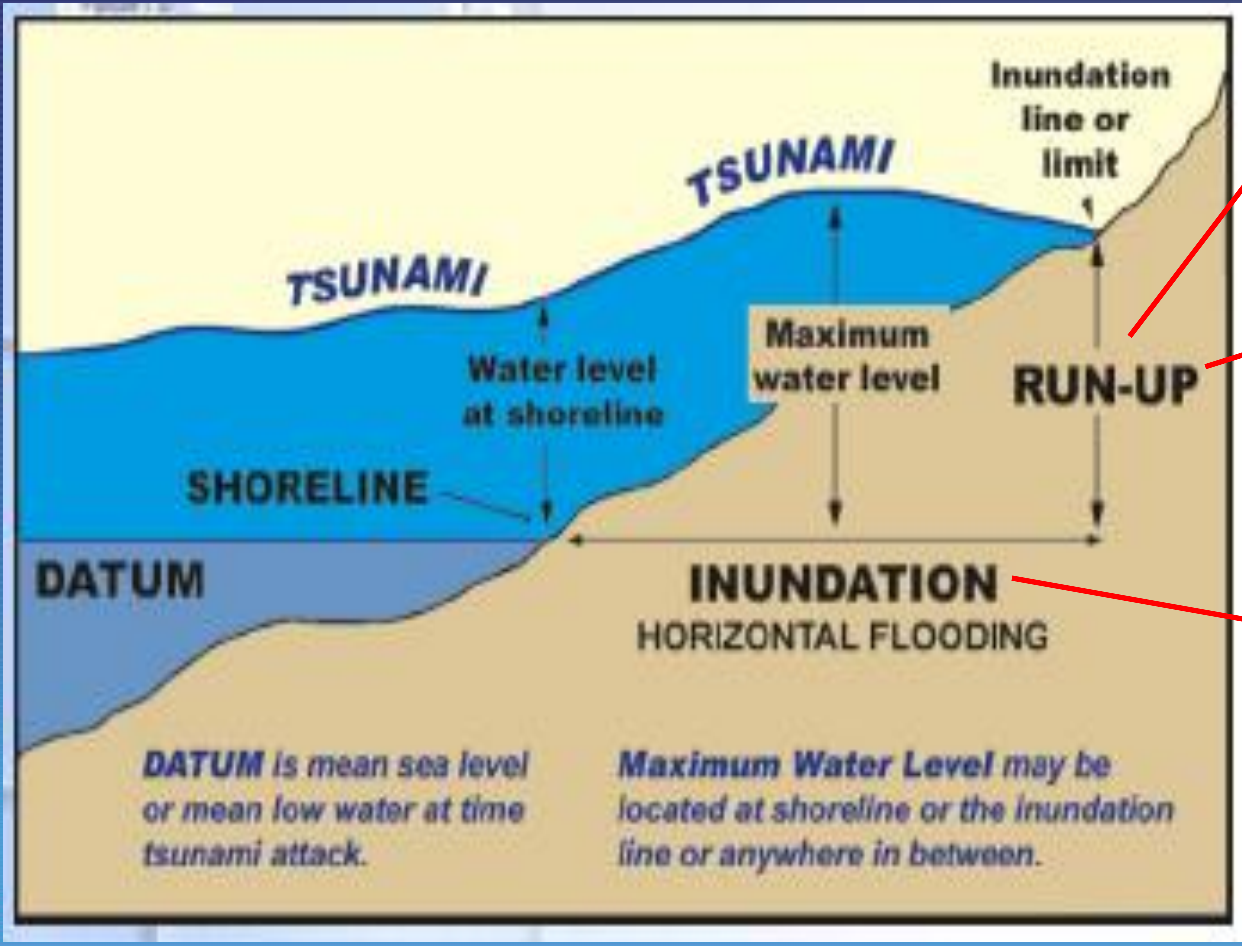
By lowering land into a bay or river mouth, subsidence during an earthquake produces a lasting record of the earthquake's occurrence.

TIDAL SILT AND SAND ABOVE BURIED SOIL,
TWENTYMILE RIVER

Tidal silt and sand, 1.5 m thick, mostly deposited in the first few years after the 1964 earthquake

Tsunami Definitions

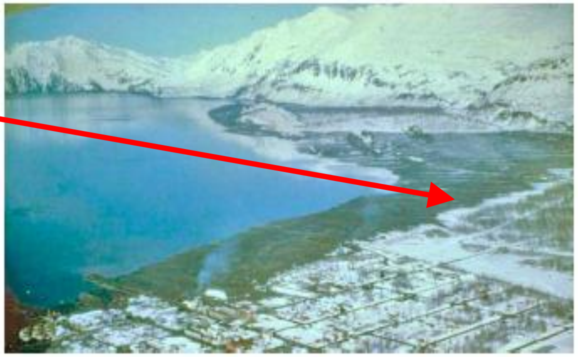
- **Run-up > Maximum water level (2 to 3)**
- **Inundation**
- **Maximum Water Level**
- **Water Level at shoreline**



***DATUM** is mean sea level or mean low water at time tsunami attack.*

***Maximum Water Level** may be located at shoreline or the inundation line or anywhere in between.*

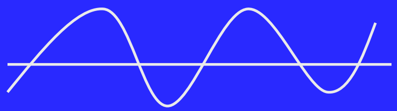
Tsunami stripped forested hills of vegetation leaving clear marker of tsunami runup, Banda Aceh, 26 December 2004 Sumutra tsunami. Photo courtesy of Yuichi Nishimura, Hokkaido University.



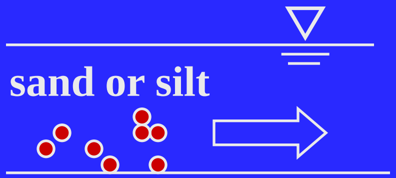
Dark area shows inundation area from the 1964 Alaska tsunami. Photo courtesy of NGDC.

Tsunamis Direct Effects

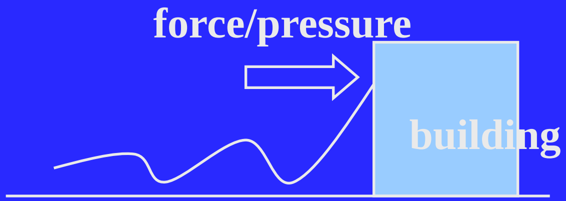
- Variation (+ / -) of Water Level,



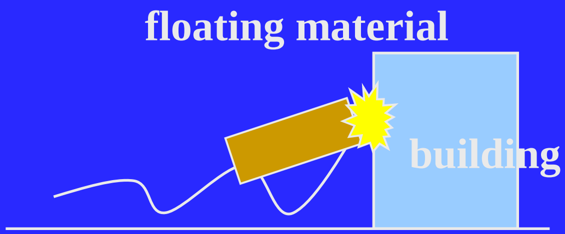
- Sand Movement,



- Water dynamic effects: Wave Pressure / Force,



- Floating Material (debris of all types),



General Effects of External Flooding

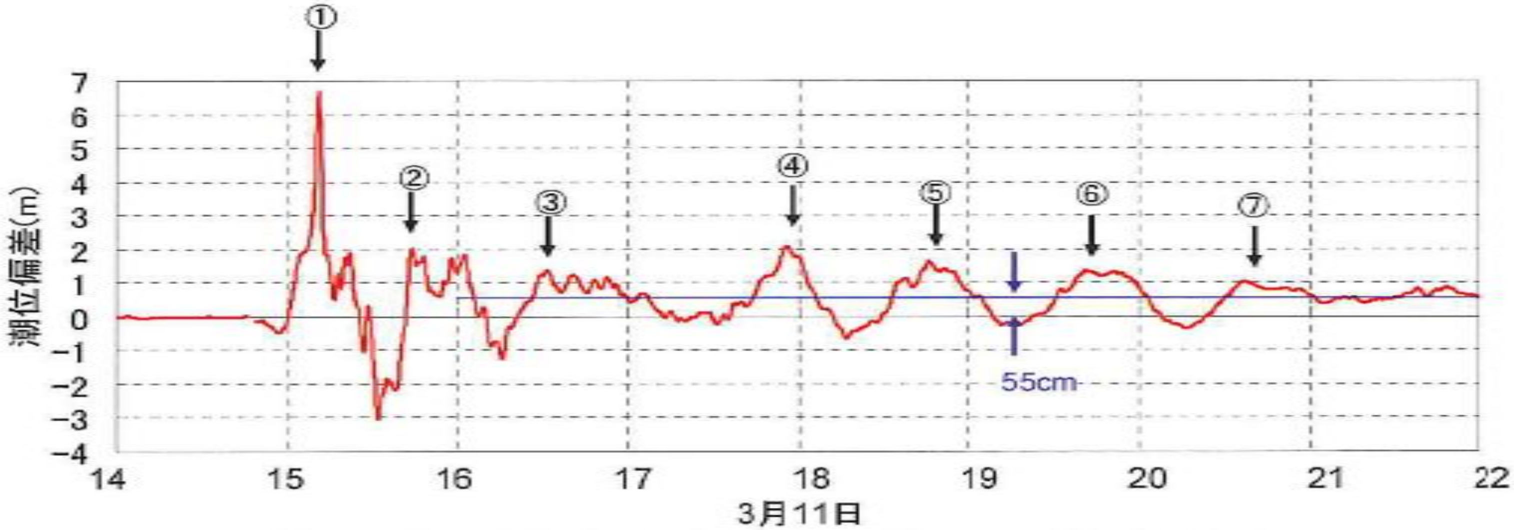
- Common cause failure for safety related systems:
  - Cooling Water Systems
  - Emergency power supply system.
  - Electric switchyard.
  - Loss of external connection to the electric power grid.

- Infiltration of water to internal areas of the plant:
  - Increase of water pressure on walls and foundations.
  - Deficiencies in drainage system, causing flooding at the plant facilities with consequent large scale damage.

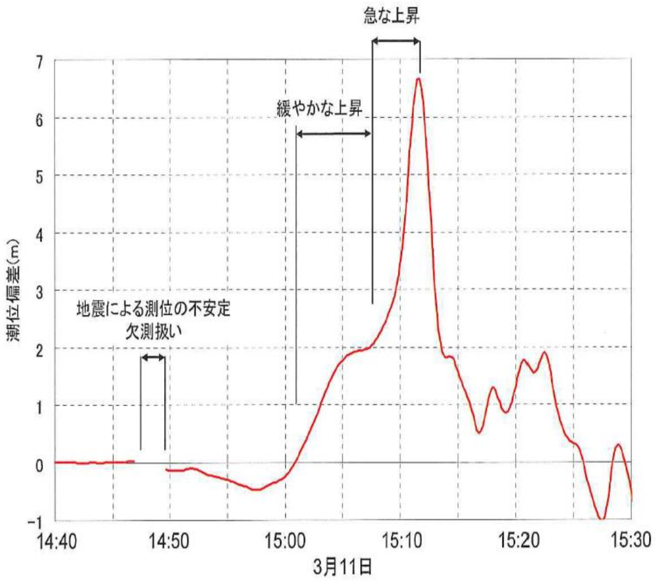
- Dynamic effects of the water and erosion at the site boundary.
- Effects on communication and transport networks around the plant site.

TSUNAMIS

2. The 11 March 2011 Tsunami . . . the “reality”



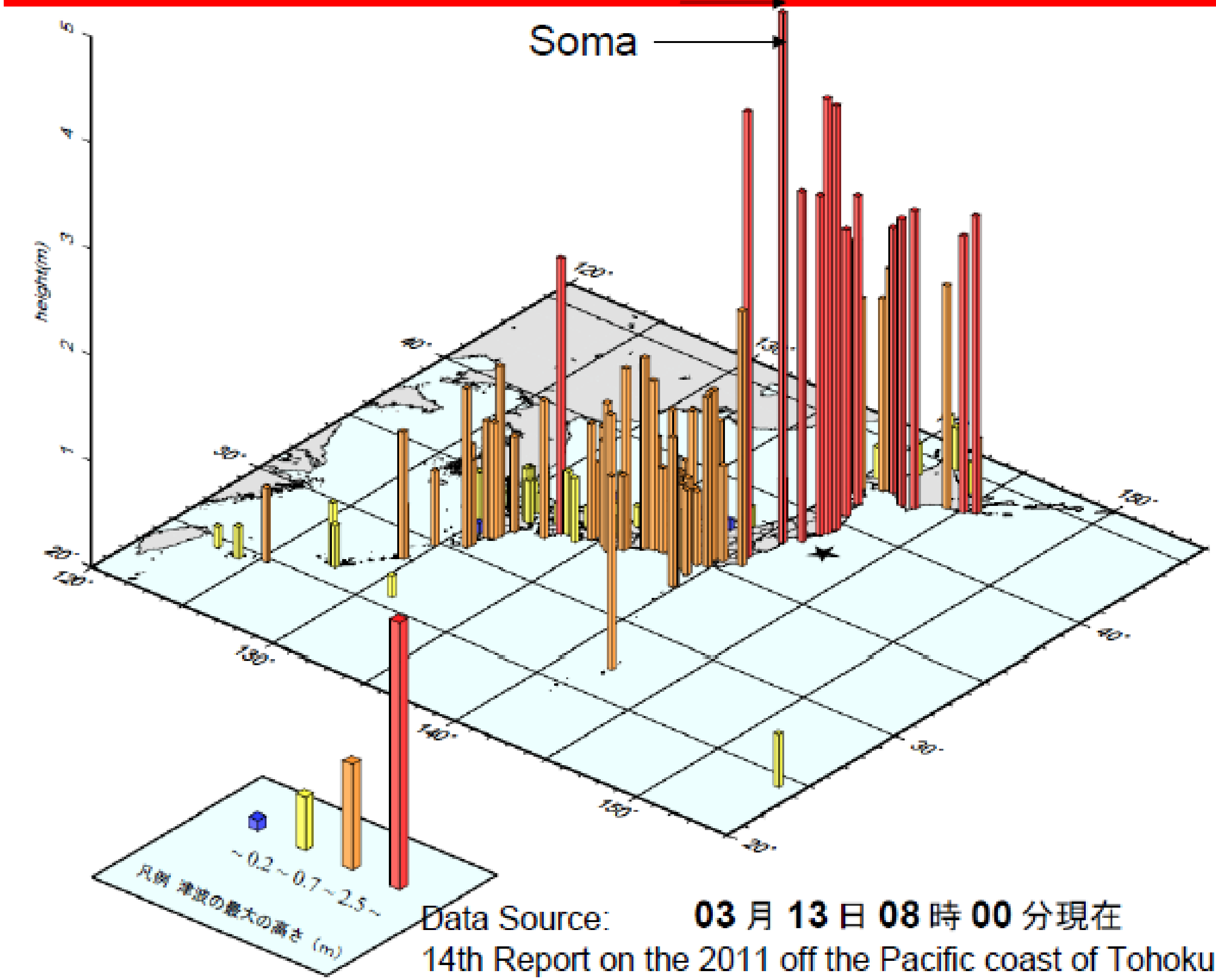
図－２　岩手南部沖ＧＰＳ波浪計で捉えた津波の初期の波形



The 11-03-2011 Tsunami waves

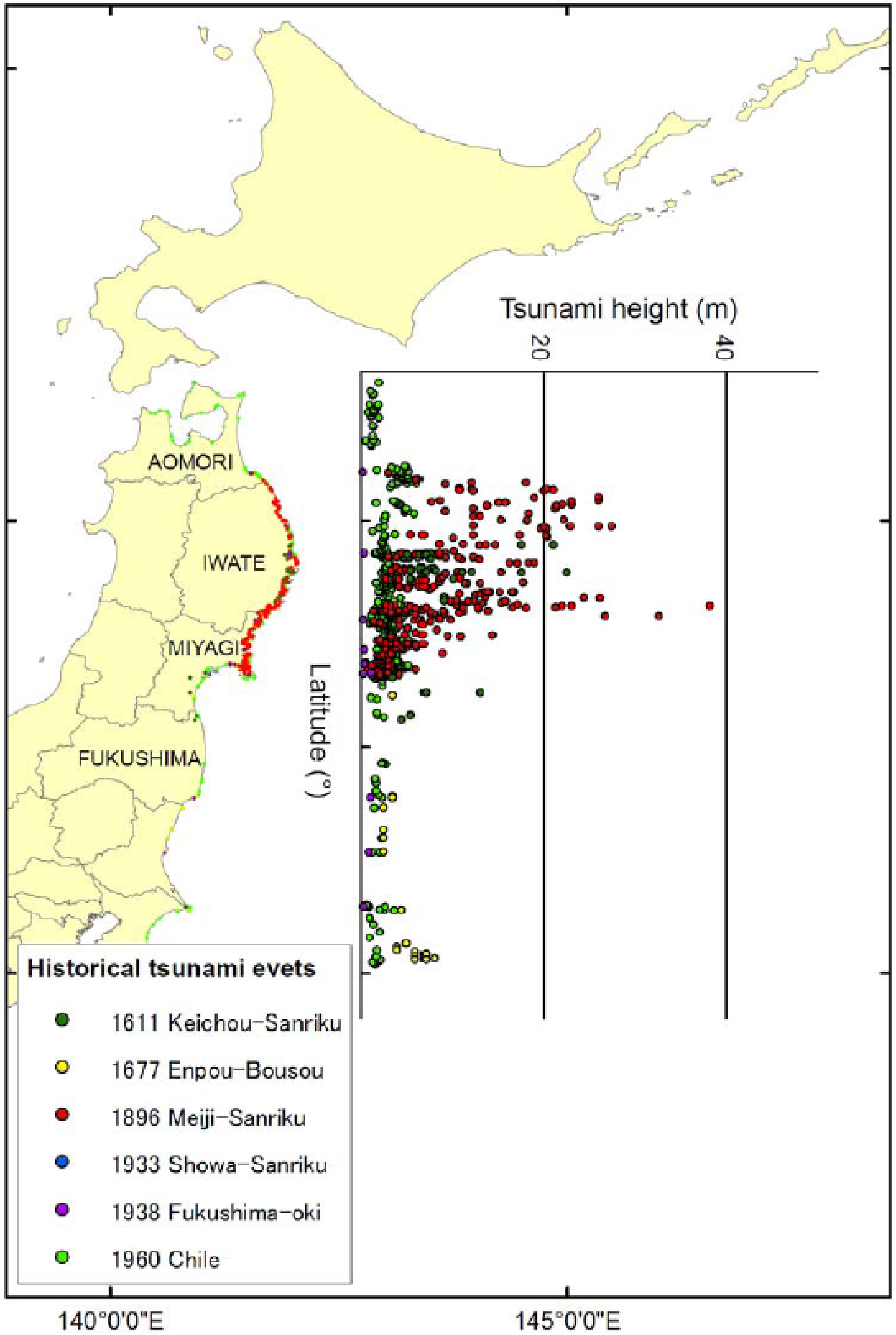
Height of Tsunami

High tsunami wave arrived on the coasts of Miyagi and Fukushima



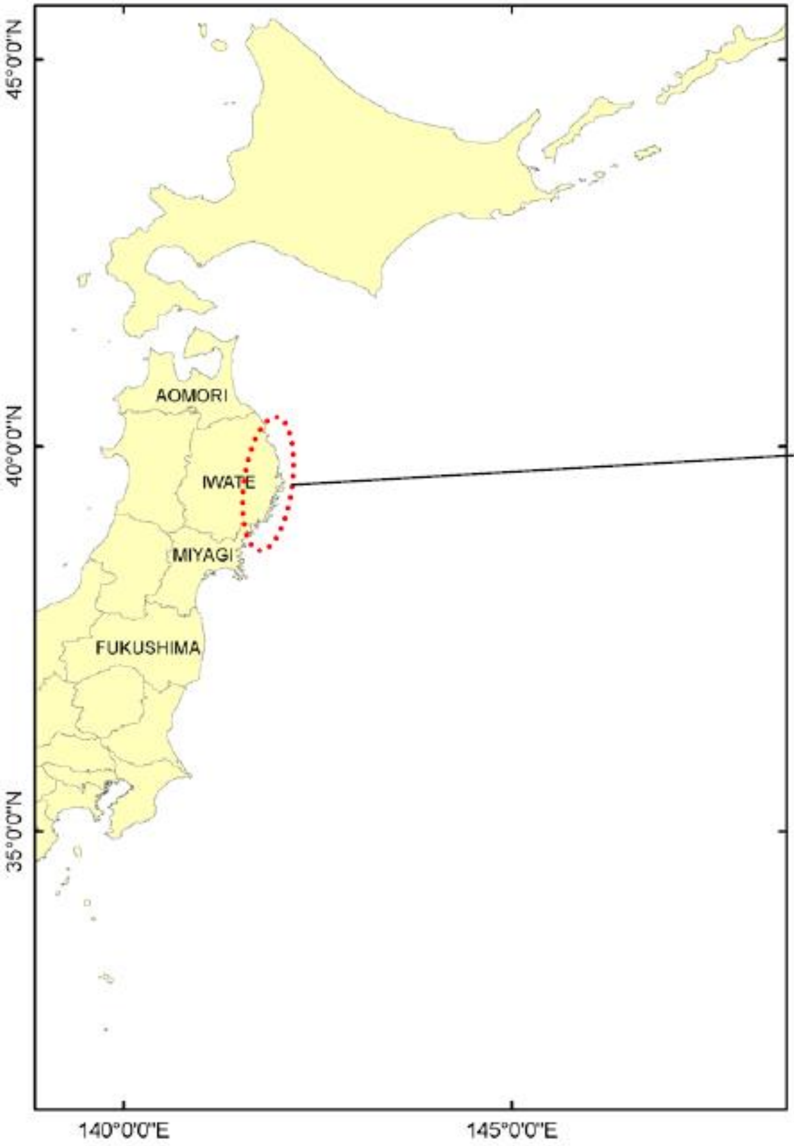
Data Source: **03 月 13 日 08 時 00 分現在**
14th Report on the 2011 off the Pacific coast of Tohoku Earthquake by Japan Meteorological Agency (Mar. 13 2011)

Historical tsunami heights along the coast of Tohoku area

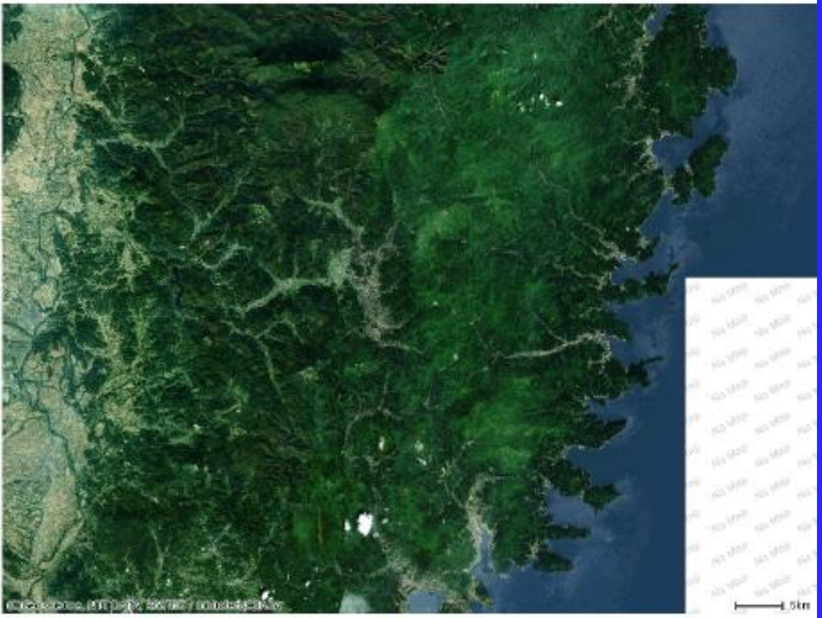


Historical tsunamis show that the heights of the tsunamis along Iwate and Miyagi coast are larger than that of Fukushima coast.

Topography of Iwate and Miyagi coast



The tsunami wave is amplified at bays in the ria-coast



©Yahoo JAPAN

The factor affecting the height of tsunami along Iwate and Miyagi coast

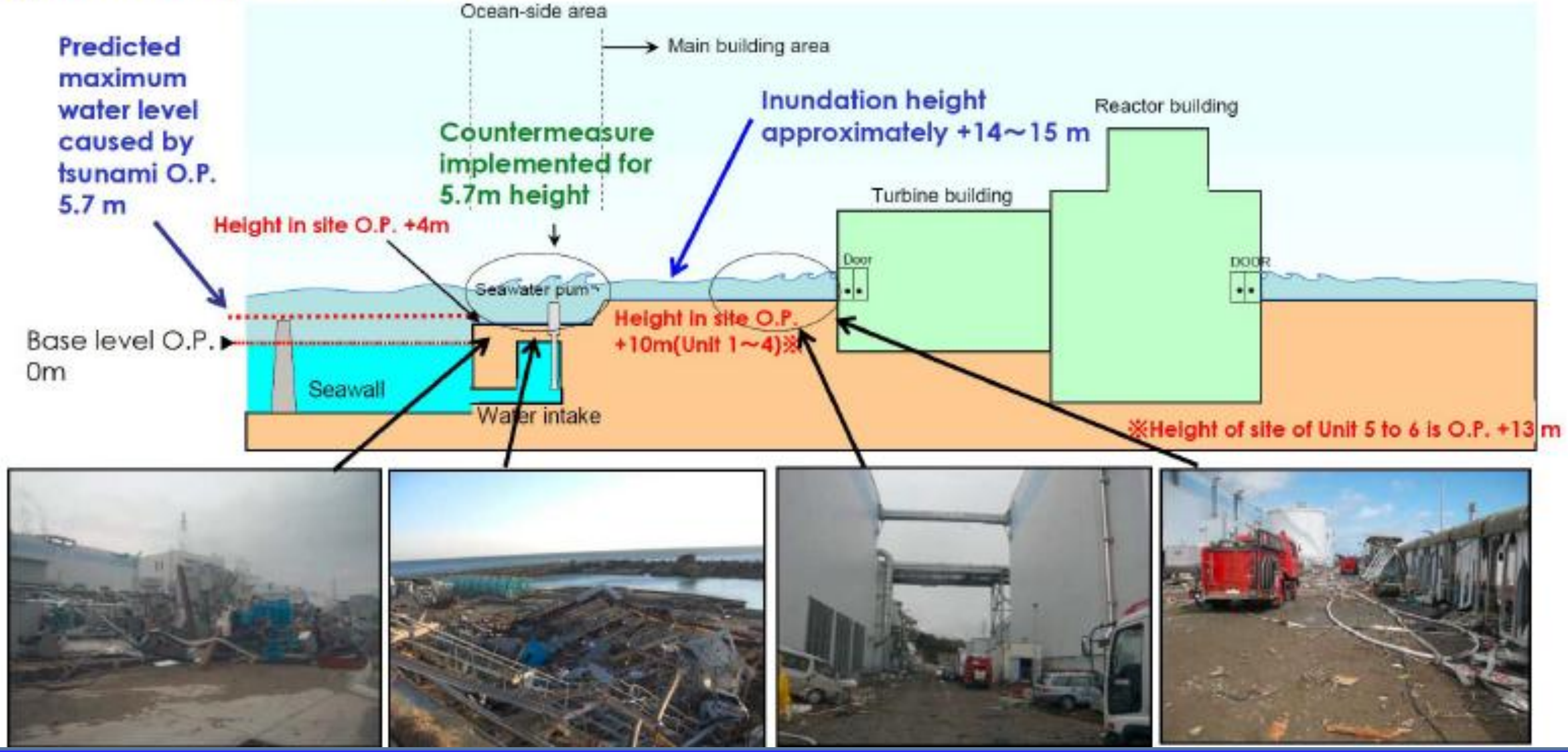
TSUNAMIS

3. The effects of 11 March 2011 Tsunami on the F1/F2 NPPs.

Trace of the Tsunami on March 11th, 2011.

1 F

(1)Inundation height
Approximately O.P. +14 to 15 m (inundation depth: approximately 4 to 5 m) in most of the ocean-side of main building area.
(2)Inundation area
Most of the ocean-side area (height of site: O.P. +4 m) and the main building area.
(3)Run-up height
Approximately O.P. +14.5 m.



Tsunami Attack to Fukushima Daiichi NPS


重油タンク
ール水サージタンク


サージタンク

Date : 2011/3/11 15:42

Date : 2011/3/11 15:43

Date : 2011/3/11 15:43

Date : 2011/3/11 15:44

Date : 2011/3/11 15:46

Date : 2011/3/11 15:49

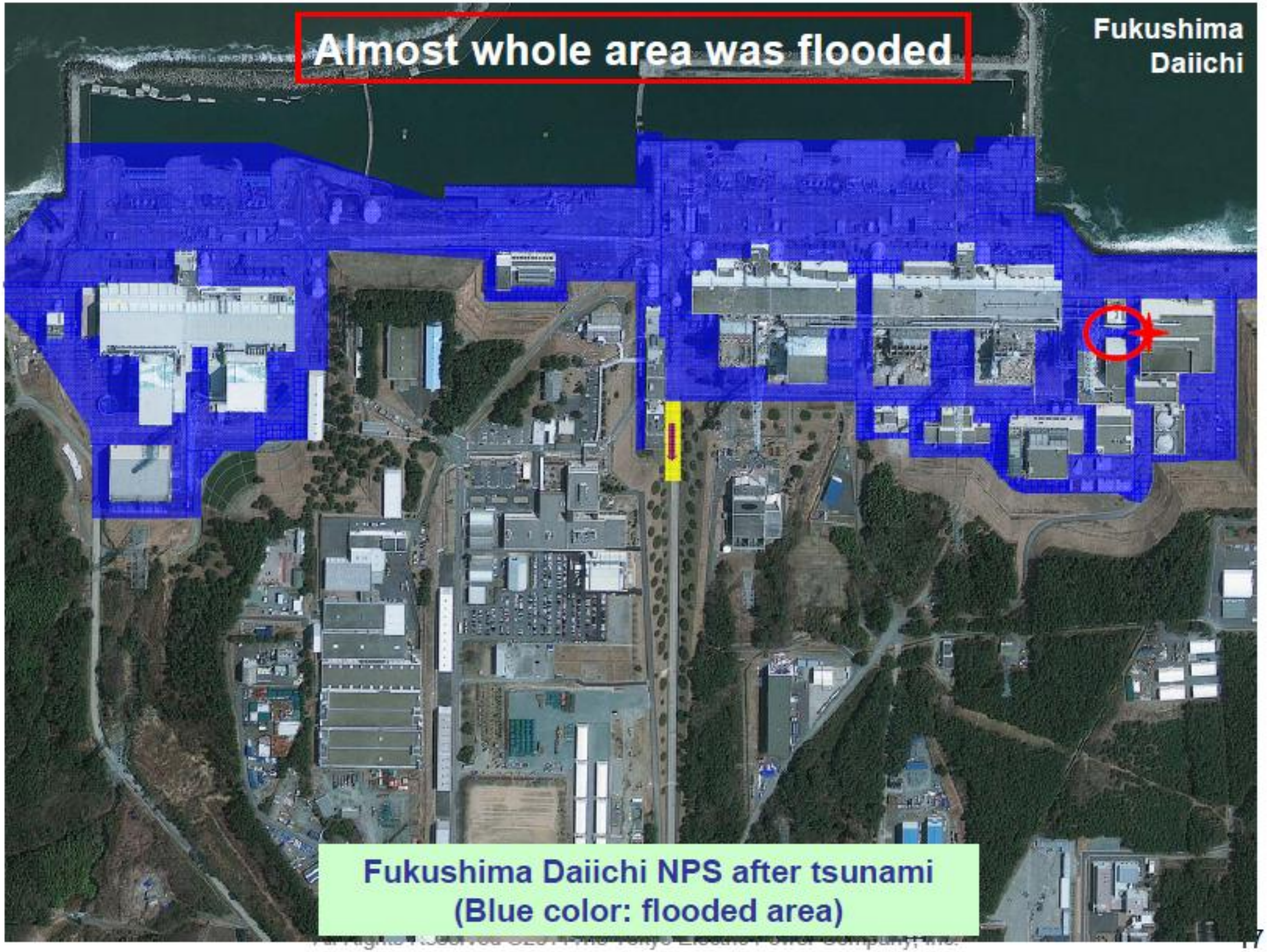
Pictures before / after Tsunami

**Fukushima
Daiichi**

Trees were stripped away

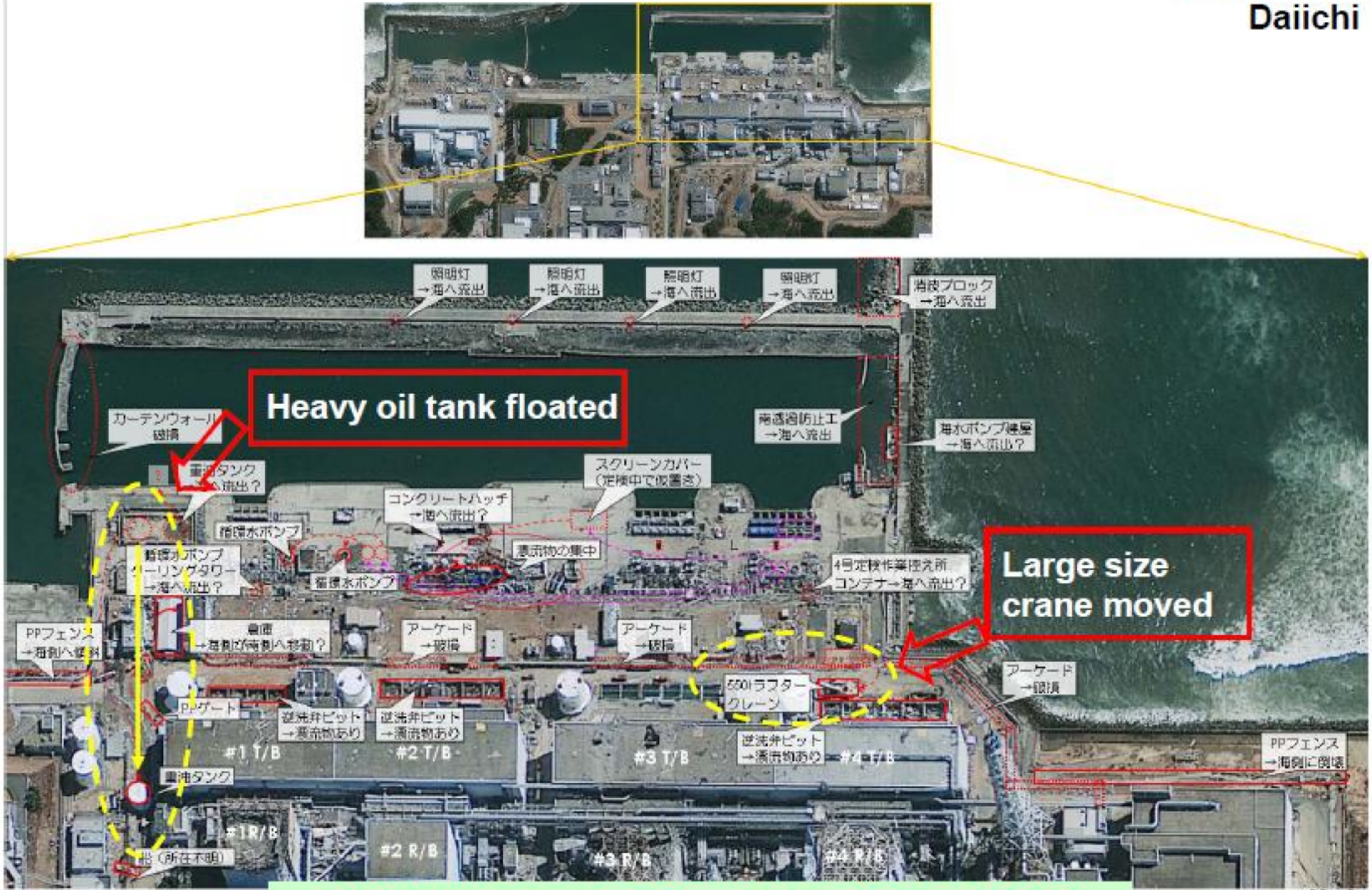
Fukushima Daiichi NPS after tsunami

Almost whole area was flooded



Fukushima Daiichi NPS after tsunami
(Blue color: flooded area)

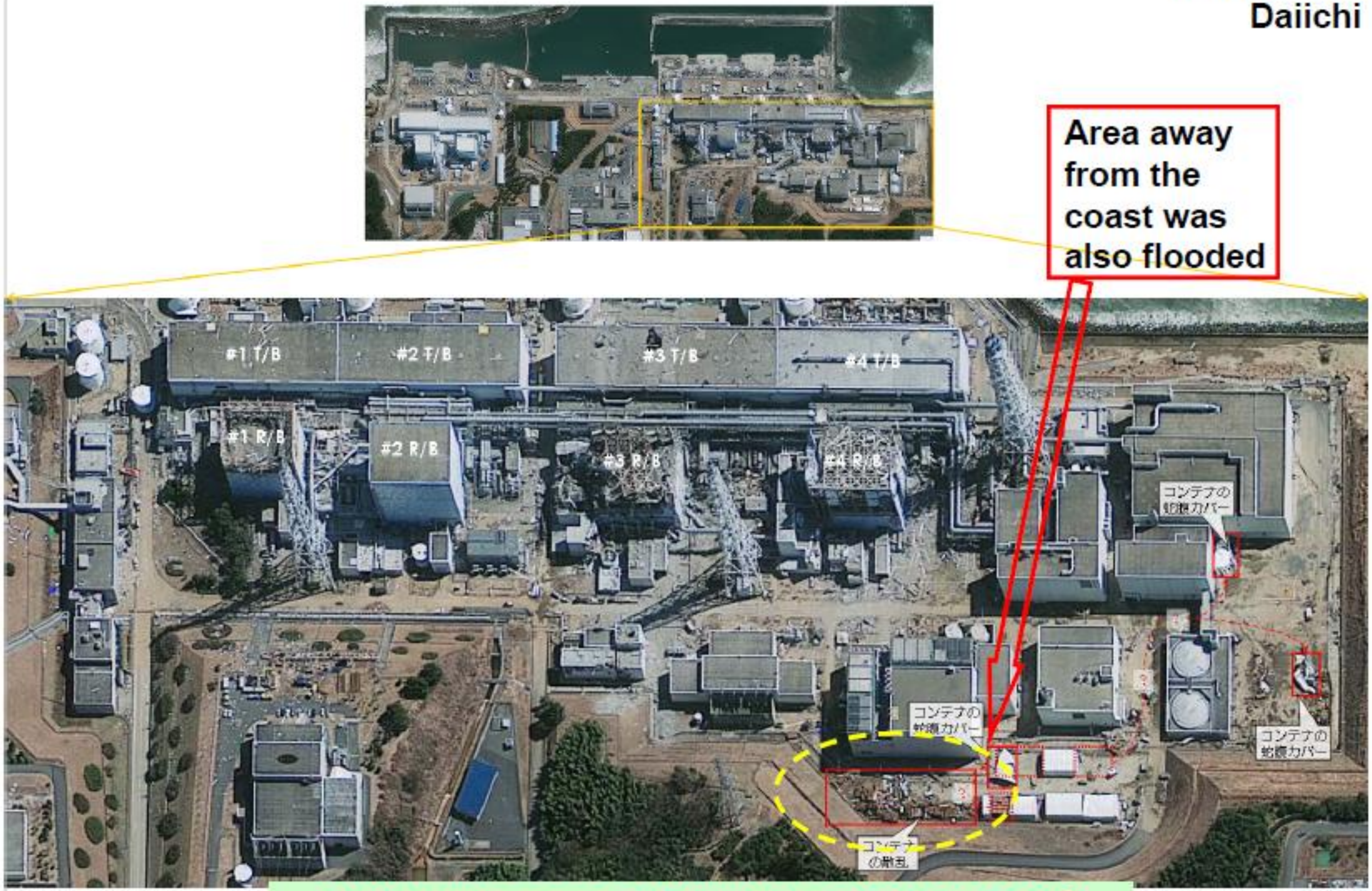
Fukushima Daiichi



©GeoEye

Adrift equipments at Fukushima Daiichi NPS ①

Fukushima Daiichi



Area away from the coast was also flooded

Adrift equipments at Fukushima Daiichi NPS ②


IAEA
IAEA
立入禁止

External factors that made field work difficult (inside the building)

- As there was no power, work inside the building was conducted in complete darkness.
- As there was no power, temporary instrument power had to be installed separately for each instrument.

Work in complete darkness

Photo of the Service Building entrance taken from inside the building. Objects were scattered on the floor.

Temporary instrument power

As there was no power, temporary batteries were connected and used as a power supply for instruments.

Monitoring by the assistant shift supervisor

Confirmed readings in complete darkness using a light

Monitoring by the assistant shift supervisor

Condition of the assistant shift supervisor's desk. Monitoring in complete darkness wearing a full-face mask

External factors that made field work difficult (yard)

- During the initial response, there were several aftershocks, and work was conducted in extremely poor conditions, with uncovered manholes and cracks and depressions in the ground (in particular, nighttime work was conducted in the dark).
- There were also many obstacles blocking access routes.

Depressions in roads, etc.

Areas that were dangerous even to walk. Particularly dangerous at night.

Obstacles on access routes

Fire hoses, etc., were laid around access routes. After the explosion, rubble and damaged fire tucks became additional obstacles.

Access to lay temporary power sources

In order to enter the building, the large object delivery entrance was destroyed using heavy equipment.

Laying of temporary power sources

Employees other than electricity-related personnel helped in laying the cables.

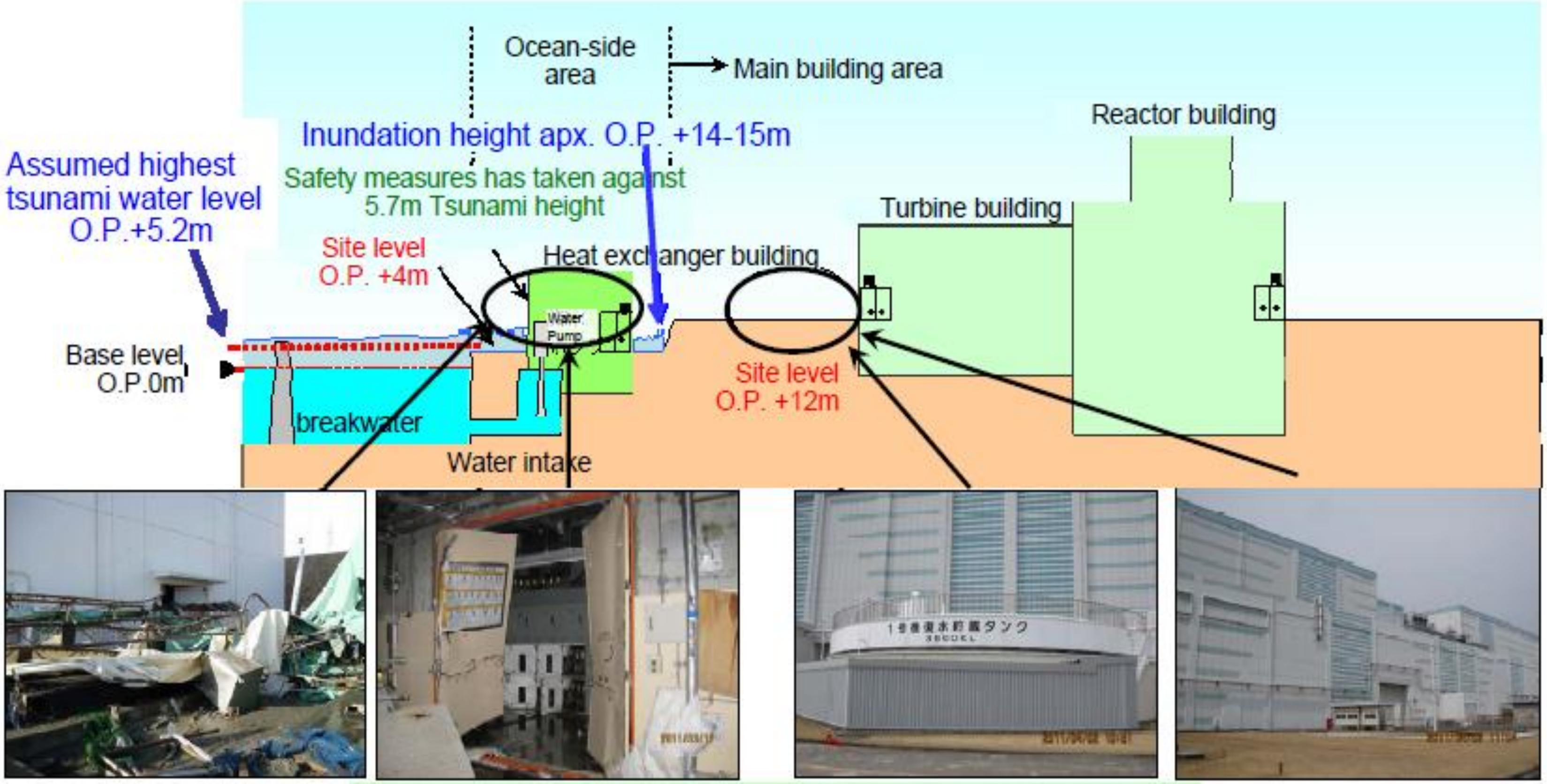

#6T/B
#5T/B
R/B
R/
#1T/
#2T/B
#3T/B
#4T/B
R/
R/
R/
R/


#6T/B
#5T/B
R/B
R/
#1T/
#2T/B
#3T/B
#4T/B
R/
R/
R/
R/
Rw/B

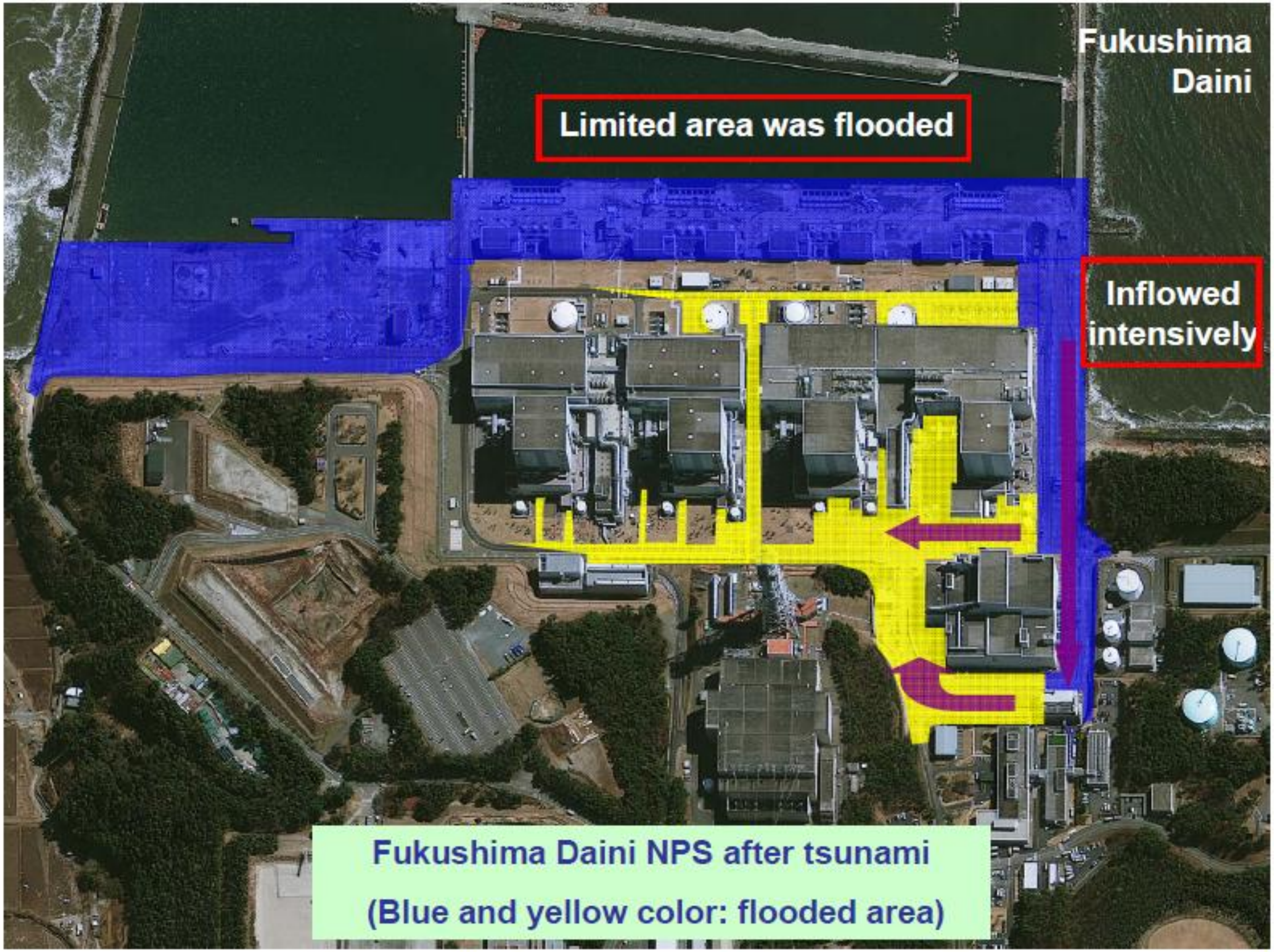
Fukushima Daini

Assumed highest tsunami water level O.P.+5.2m

Inundation height apx. O.P. 7m
(South of Unit 1 O.P. +14-15m)



Tsunami Attack at Fukushima Daini NPS

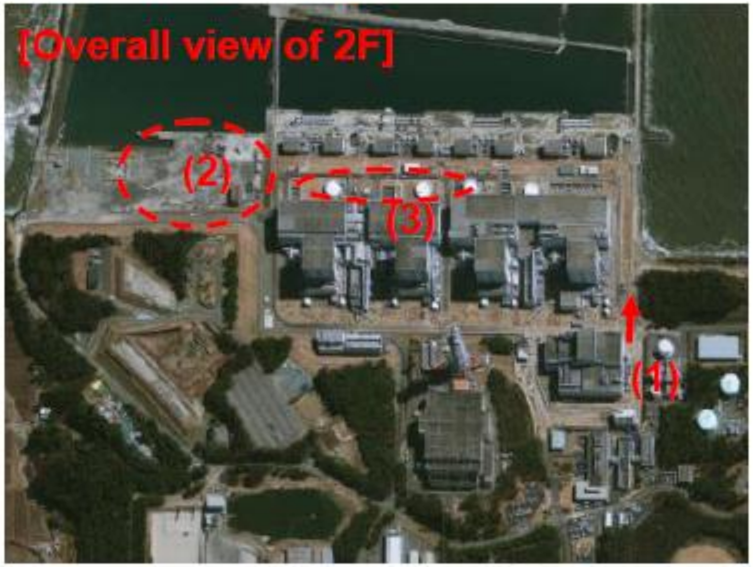


Fukushima Daini NPS after tsunami

(Blue and yellow color: flooded area)

Fukushima Daini NPS after tsunami

Fukushima Daini


[Overall view of 2F]


(1)Tsunami run-up


(2)Tsunami damage in low-lying areas (shallow draft quay)


(3) No damage to the Unit 3 and 4 Turbine Building

Tsunami damage at Fukushima Daini NPS

Fukushima Daini

Flooding of the Fukushima Daini Unit 1 Annex Area from the intake louver


(1)Outside of the Unit 1 emergency fan room


(2)Inside of the Unit 1 emergency fan room


(3)Unit 1 DG(A) control room

[Power supply at Fukushima Daiichi: Immediately after the tsunami]

Fukushima Daiichi Units 1-4

No surviving power source

Okuma Line 1L, 2L

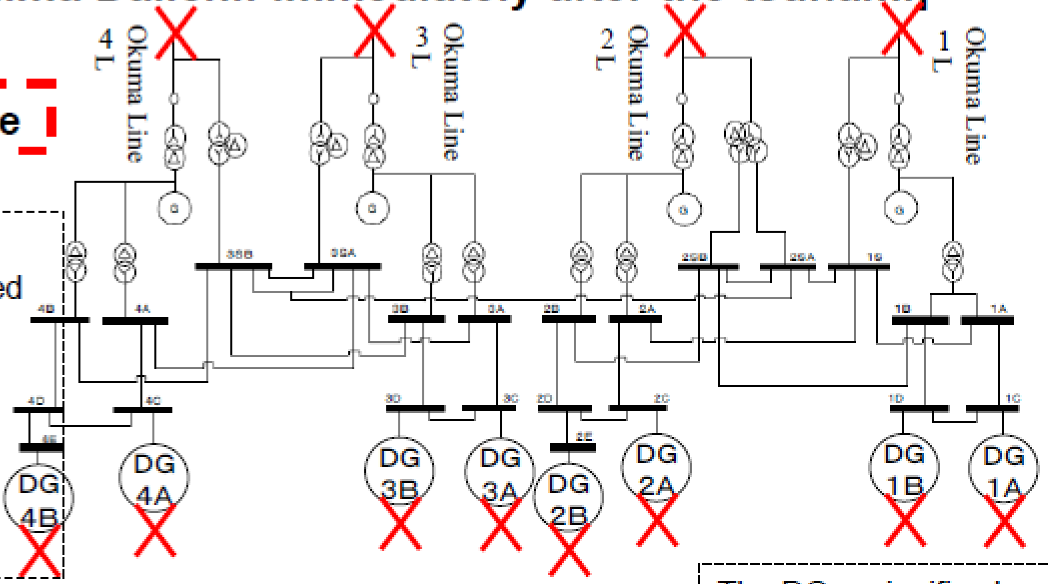
Receiving circuit breaker damaged in earthquake

Okuma Line 3L

Renovation work in progress

Okuma Line 4L

Cause of shutdown is currently being investigated



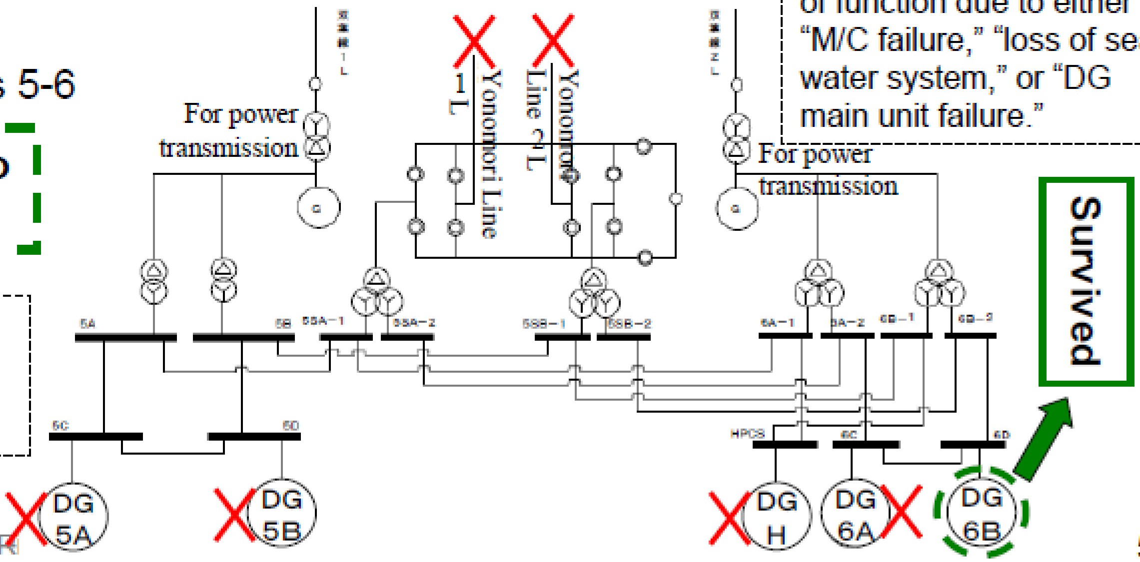
The DG × signifies loss of function due to either "M/C failure," "loss of sea water system," or "DG main unit failure."

Fukushima Daiichi Units 5-6

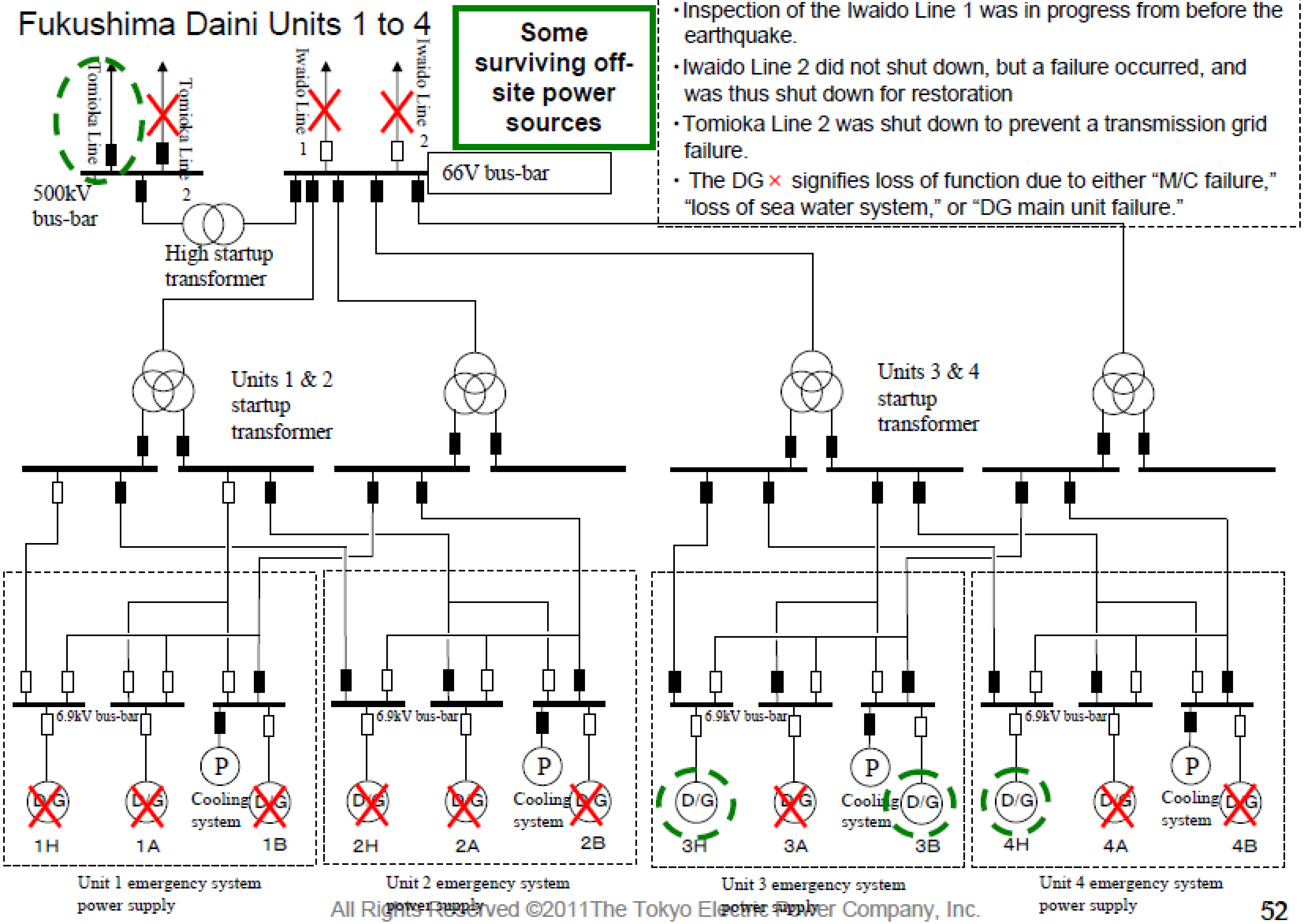
Only power source to survive was DG6B

Yonomori Line 1L, 2L

Partial collapse of the iron tower



[Power supply at Fukushima Daini: Immediately after the tsunami]



Fukushima Daini Units 1 to 4

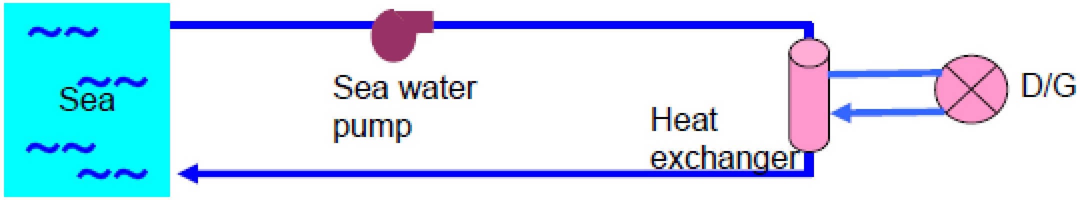
Some surviving off-site power sources

- Inspection of the Iwaido Line 1 was in progress from before the earthquake.
- Iwaido Line 2 did not shut down, but a failure occurred, and was thus shut down for restoration
- Tomioka Line 2 was shut down to prevent a transmission grid failure.
- The DG × signifies loss of function due to either "M/C failure," "loss of sea water system," or "DG main unit failure."

[Fukushima Daiichi: DG System Outline]

Sea water-cooled DG (10)

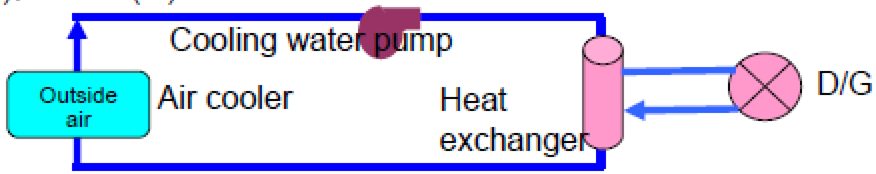
Unit 1 (A)(B), Unit 2 (A), Unit 3 (A)(B), Unit 4 (A), Unit 5 (A)(B), Unit 6 (A)(H)



All function was lost after the tsunami

Air-cooled DG (3)

Unit 2 (B), Unit 4 (B), Unit 6(B)

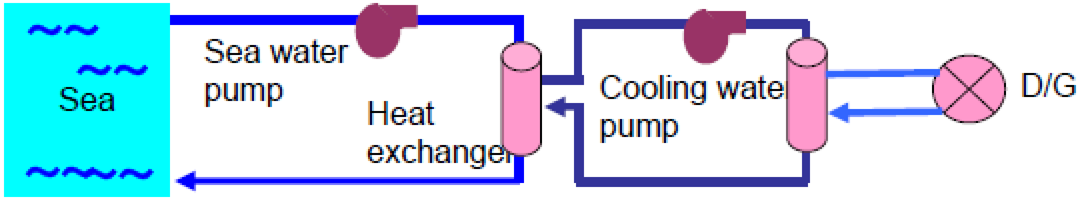


Power was secured in Unit 6 (B) only

[Fukushima Daini: DG System Outline]

Sea water-cooled DG (12)

Unit 1 to Unit 4(A)(B)(H)



Power was secured in Unit 3 (B)(H) and Unit 4 (B) only

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4. Tsunami Hazard Assessment before 11 March 2011

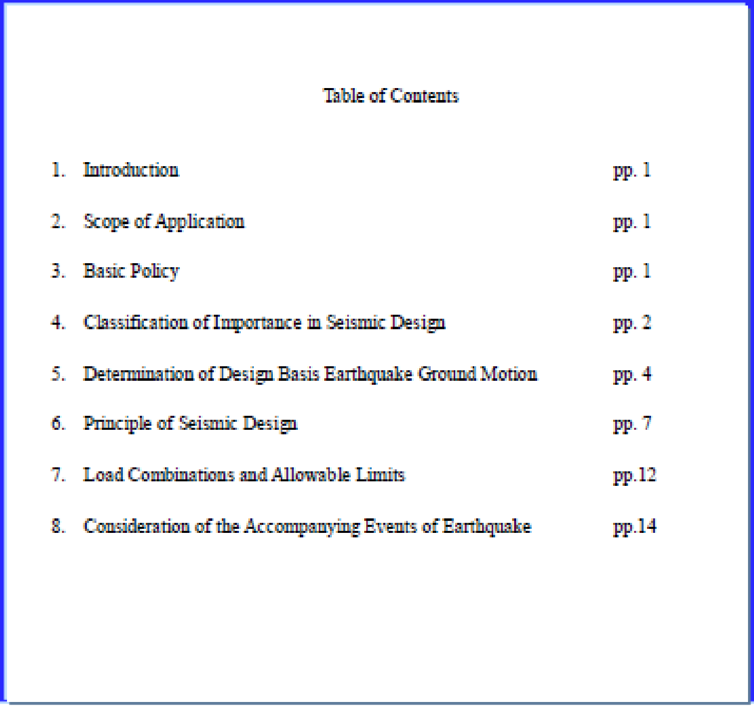
NSC

Regulatory Guide for Reviewing Seismic Design of Nuclear Power Reactor Facilities

September 19, 2006.

Nuclear Safety Commission

(URL:http://www.nsc.go.jp/english/taishin.pdf)



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4. Classification of Importance in Seismic Design pp. 2
5. Determination of Design Basis Earthquake Ground Motion pp. 4
6. Principle of Seismic Design pp. 7
7. Load Combinations and Allowable Limits pp.12
8. Consideration of the Accompanying Events of Earthquake pp.14

8. Consideration of the accompanying events of earthquake

Facilities shall be designed regarding the accompanying events of earthquake with sufficient consideration to the following terms.

(1) Safety functions of Facilities shall not be significantly affected by the collapses of the inclined planes around Facilities which could be postulated in the seismic events.

(2) Safety functions of Facilities shall not be significantly affected by the tsunami which could be postulated appropriately to attack but very scarcely in the operational period of Facilities.

Tsunami assessment in construction permit

site	unit	Permission year	rise	drawdown	Notes
Fukushima Daiichi NPS	1	1966	O.P.＋3.122m Historic high water level	O.P.－1.918m Historic low water level	Height of the tide at Onahama port on May 24,1960 Chilean tsunami
	2	1968			
	3	1970			
	4	1972			
	5	1971			
	6	1972			
Fukushima Daini NPS	1	1974			
	2	1978	O.P.＋3.690m	O.P.－1.918m Historic low water level	O.P.+1.490m+2.2m=O.P.+3.690m 2.2m:height of the tsunami component at Onahma port on May 24,1960 Chilean tsunami O.P.+1.490m:Mean of high tides
	3	1980	O.P.＋3.705m	O.P.－1.918m Historic low water level	O.P.+1.505m+2.2m=O.P.+3.705m 2.2m:height of the tsunami component at Onahma port on May 24,1960 Chilean tsunami O.P.+1.505m:Mean of high tides
	4	1980			

In those days, there was no tsunami assessment methodology based on numerical simulation for nuclear power plants.

JSCE Method

"Tsunami Assessment Method for Nuclear Power Plants in Japan (2002) "

原子力発電所の津波評価技術

平成14年2月

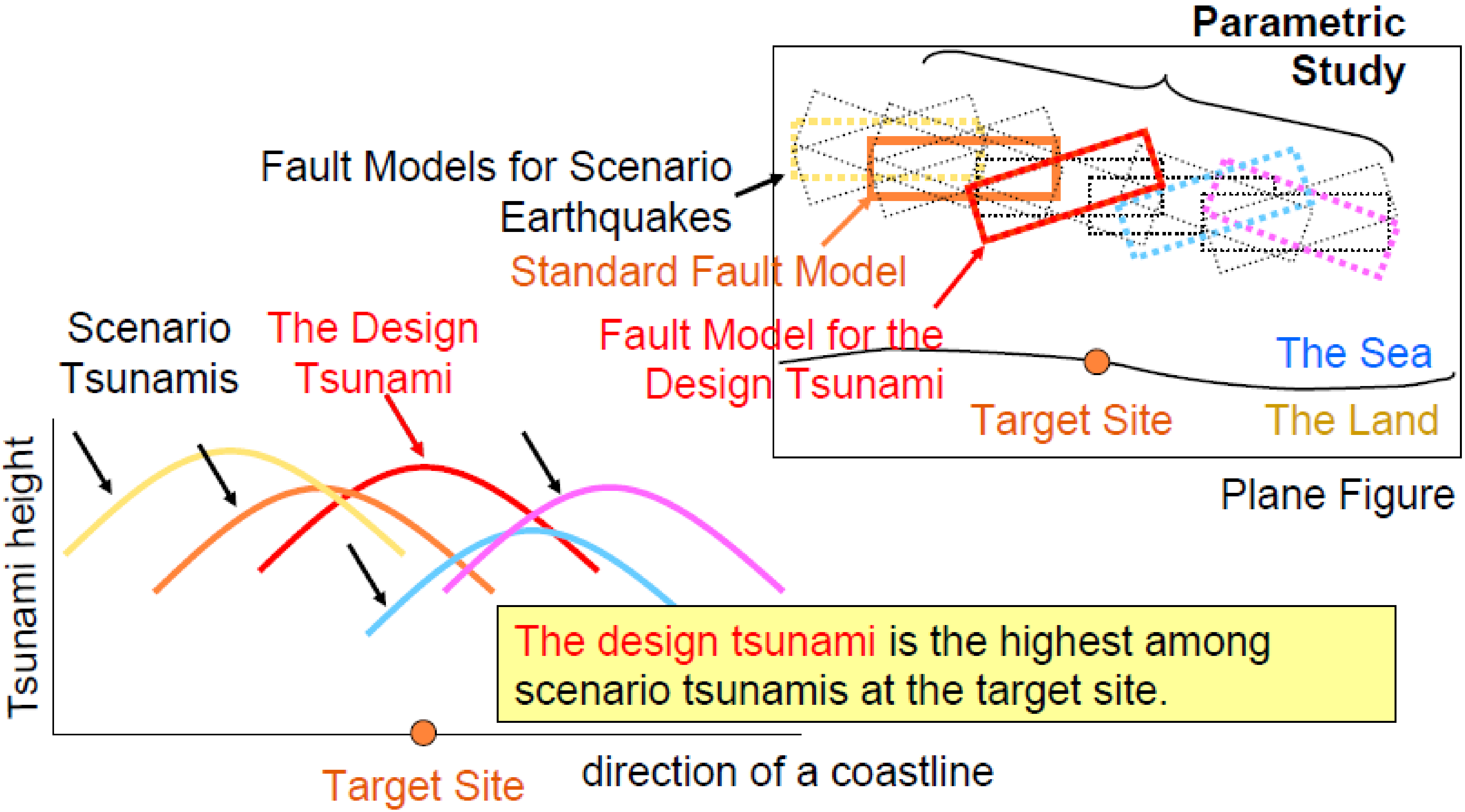
社団法人　土木学会
原子力土木委員会 津波評価部会

published by

Tsunami Evaluation Subcommittee,
Nuclear Civil Engineering Committee,
JSCE (Japan Society of Civil Engineers)

English version
http://www.jsce.or.jp/committee/ceofnp/Tsunami/eng/tsunami_eng.html

Parametric Study of Tsunami Source



Parametric Study

Fault Models for Scenario Earthquakes

Standard Fault Model

Fault Model for the Design Tsunami

The Sea

Target Site

The Land

Plane Figure

Scenario Tsunamis

The Design Tsunami

Tsunami height

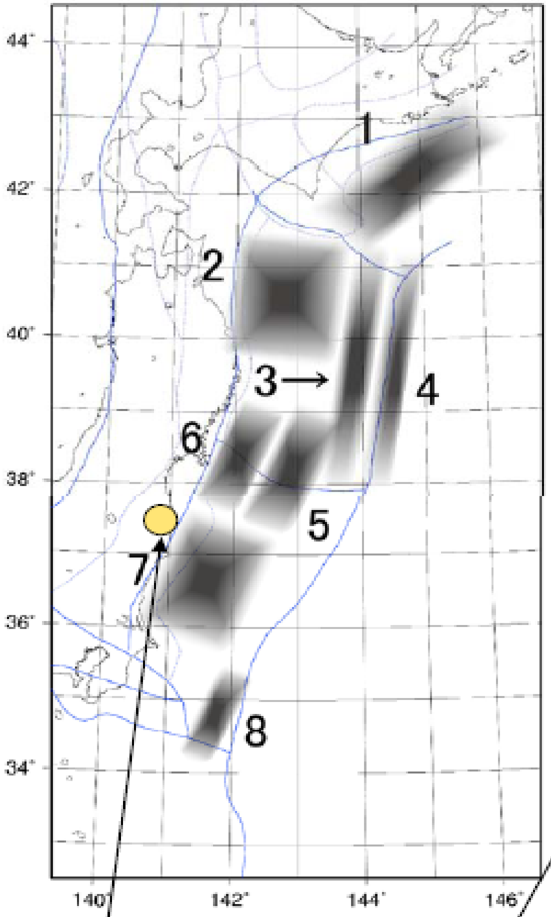
Target Site

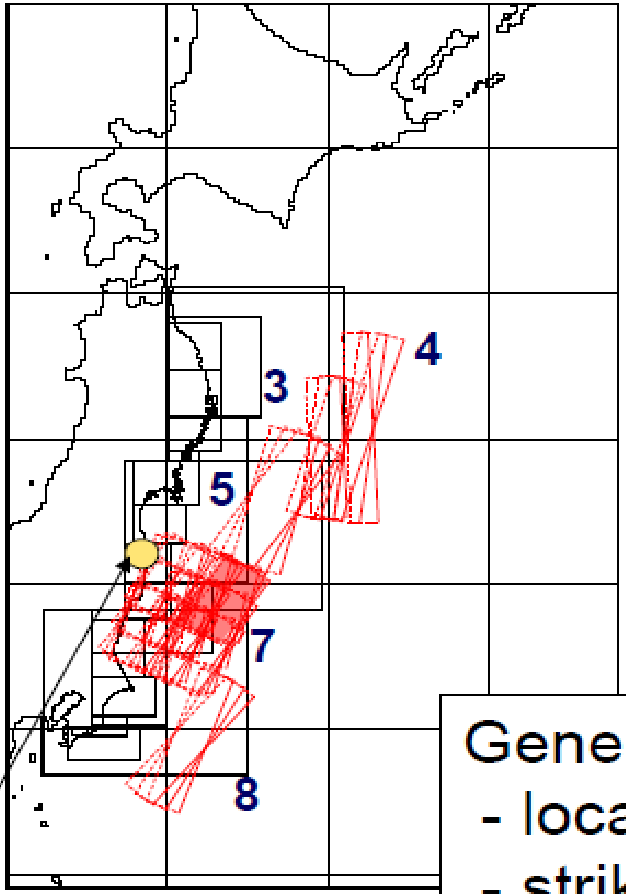
direction of a coastline

The design tsunami is the highest among scenario tsunamis at the target site.

JSCE document indicates explicitly the seismogenic source areas to be adopted for the THA

General parametric study in the near field





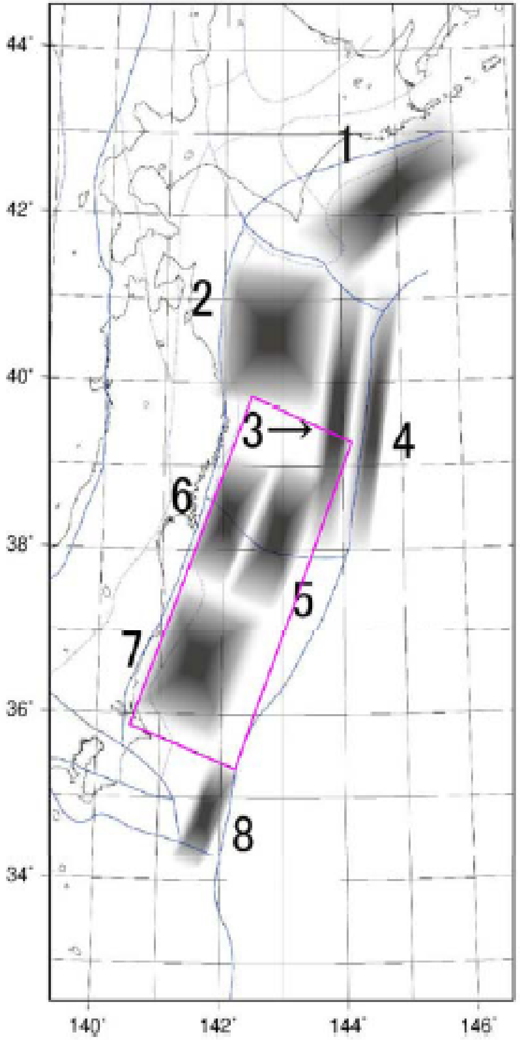
3	Mw 8.3
4	Mw 8.6
5	Mw 8.2
7	Mw 8.0
8	Mw 8.2

General parametric study
- location
- strike

Fukushima Daiichi NPS

- **Fukushima Daini NPS**

The 2011 off the Pacific coast of Tohoku Earthquake



▭ 2011/3/11 source area

（http://outreach.eri.u-tokyo.ac.jp/eqvolc/201103_tohoku/#Inversion　2011/3/18）

In JSCE 2002, earthquakes are assumed in 8 area individually. Earthquake on March 11th occurred cross over several areas.

No	Mw	Earthquake
1	8.2	1952 Nemuro-oki
2	8.4	1968 Tokachi-oki
3	8.3	1896 Meiji-Sanriku
4	8.6	1611 Keicho-Sanriku
5	8.2	1793 Miyagi-oki
6	7.7	1978 Miyagi-oki
7	7.9	1938 Fukushima-oki
8	8.1	1677 Enpo-Bousou

Consideration of tide and safety evaluation

The Design Tsunami

Tidal Conditions

Design High Water Level

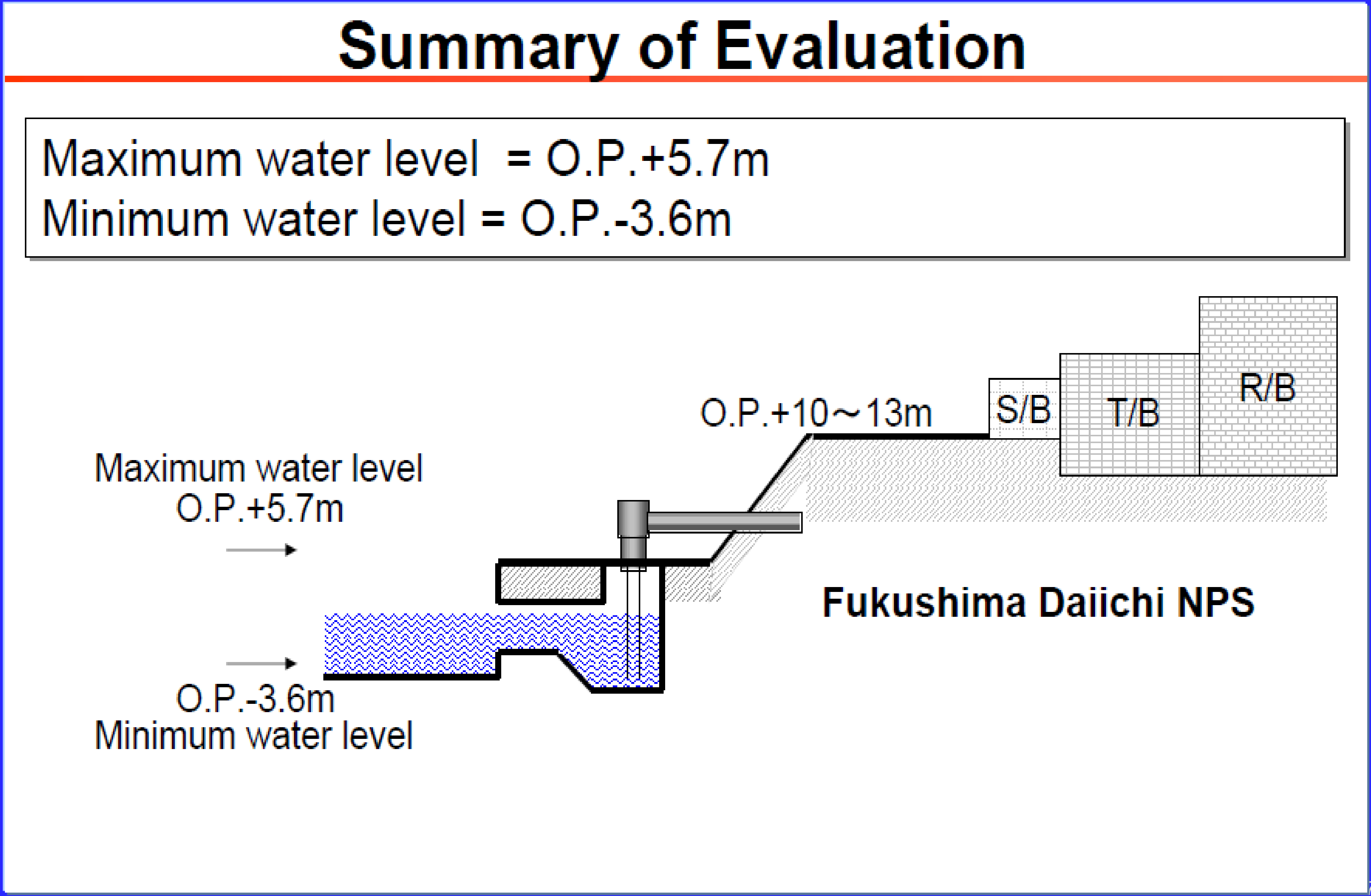
= Maximum water rise + Mean of high tides

Design Low Water Level

= Maximum water fall + Mean of low tides

Evaluation of the safety of NPP

RESULTS USING JSCE METHODOLOGY



Summary of Evaluation

Maximum water level = O.P.+5.7m

Minimum water level = O.P.-3.6m

CONCLUSIONS - EARTHQUAKE

- **Although it appears that the Great East Japan earthquake exceeded the licensing based design basis ground motion of the F1 plant at the level of the foundation base mat in all units, the operating plants were automatically shutdown and all units behaved in a safe manner, during and immediately after the earthquake.**

- **It was also confirmed that in some cases the observed values even exceeded the recently determined maximum response acceleration values showing apparently an underestimation of the new DBGM Ss.**

CONCLUSIONS - EARTHQUAKE

- The three fundamental safety functions of (a) reactivity control, (b) removal of heat from the core and (c) confinement of radioactive materials were available until the tsunami reached the sites.

- It is very difficult to separate earthquake damage from others in that situation; i.e. tsunami with extended flood, three explosions and possible thermal related failures due to sea water cooling (e.g. to the spent fuel pools from helicopters). As there was not enough time for a seismic walkdown in 45 minutes (before the tsunami came), it is not possible to rule out at least some damage due to the earthquake. However, the walkdown performed by US EPRI at F2 confirmed good performance and plant response to the earthquake.

CONCLUSIONS - EARTHQUAKE

- **Based on the reports from Japanese experts and plant personnel, safety related structures, systems and components of the plant seemed to have behaved well for such a strong extreme earthquake, possibly due to conservatisms introduced at different stages of the design process. Similar to Kashiwazaki-Kariwa NPP experience and performance to NCO earthquake in 2007.**

- **The combined effects of these conservatisms were apparently sufficient to compensate for uncertainties in the data available and the methods applied at the time of the design of the plant and also the re-evaluated ground motions.**

CONCLUSIONS - EARTHQUAKE

- **The underestimation of the hazard in the original hazard study as well as in more recent re-evaluations mainly result from the use of recent historical seismological data in the estimation of the maximum magnitudes especially associated with the neighbouring subduction zone east of the sites.**
- **No consideration of higher magitudes already occurred in same seismotectonic environment, i.e. Pacific subduction rim.**

LESSONS LEARNED - EARTHQUAKE

- It should be recognized worldwide the need to consider potential maximum seismic events greater than those observed or recorded in historical time.

- Although the need to consider pre-historical and historical data is well established in the international safety requirements for assessing the natural hazards at nuclear installations, this has not been followed especially in older nuclear power plants and in recent ones in which certain upper bounds to the maximum values are defined without proper consideration of experiences from time longer than recent historical records. Use of paleoseismology studies should be promoted.

LESSONS LEARNED - EARTHQUAKE

- **The current IAEA safety standards establish a clear time scale (going back to historical and pre-historical eras) as well as tectonic capacity considerations in the estimation of maximum magnitudes associated with seismogenic structures.**

- **There is a need for Member States regulations to reflect these considerations both for the new build as well as for re-evaluation of existing NPPs.**

LESSONS LEARNED - EARTHQUAKE

- **Japan has undergone a seismic hazard re-evaluation (back check) recently on the basis of recent investigations and data. However, it was confirmed that these assessments were exceeded by the March 2011 event. This experience shows the importance of a permanent oversight of the potential hazards and of performing all required actions for taking necessary measures for maintaining and increasing the safety level.**
- **The Fukushima experience has also shown that there is a need to have in place a consistent and comprehensive pre-earthquake planning and post-earthquake response actions programme for all NPPs worldwide. IAEA has developed the new Safety Report 66 in this subject.**

GENERAL OBSERVATIONS

- Operators and regulators need to make a greater effort to understand external hazards – external hazards should be treated as mainstream nuclear safety and not as an ‘afterthought’ – there is much room for progress in this area.

- For emergency preparedness, radiological emergency and a rare external hazard may occur together.

GENERAL OBSERVATIONS

- **Suppliers should understand that "*standard designs*" for '0.25g' or '0.3g' are inadequate for many parts of the world – economic pressure in 'new build' countries to decrease hazard estimates (may have happened at F-1 in the 1960s).**

- **In the past 25 years:**
    - **Seismic hazard values increased by a factor of about 2**
    - **Maximum observed accelerations increased by about 4 (from 1g to 4g)**
    - **Standard seismic design values more or less stayed the same**

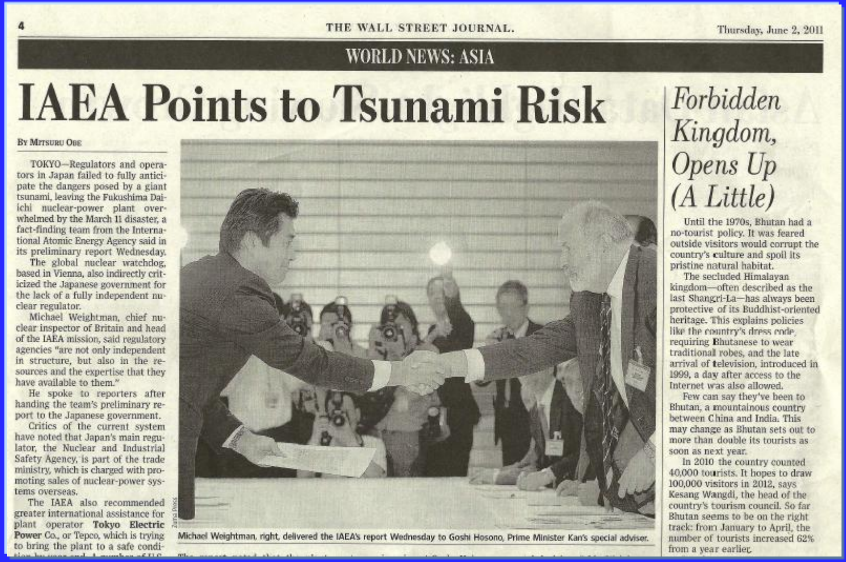
GENERAL OBSERVATIONS

- **All levels of Defense in Depth were challenged at the same time – concepts of redundancy, diversity and physical separation need to include external hazards.**

- **Safety analysis is performed for single unit whereas multi units and multi sites may be affected by a single external hazard.**

CONCLUSIONS - TSUNAMI

- **There were <u>insufficient</u> defence-in-depth provisions for tsunami hazards. Although tsunami hazards were considered both in the site evaluation and the design of the Fukushima Daiichi NPP and the expected tsunami height was later increased (without changing the licensing documents) after 2002, the <u>tsunami hazard and associated risk was underestimated</u> due to the underestimation of the maximum M magnitude associated with the subduction zone.**



4 THE WALL STREET JOURNAL. Thursday, June 2, 2011

WORLD NEWS: ASIA

IAEA Points to Tsunami Risk

BY MITSURU OBE

TOKYO—Regulators and operators in Japan failed to fully anticipate the dangers posed by a giant tsunami, leaving the Fukushima Daiichi nuclear-power plant overwhelmed by the March 11 disaster, a fact-finding team from the International Atomic Energy Agency said in its preliminary report Wednesday.

The global nuclear watchdog, based in Vienna, also indirectly criticized the Japanese government for the lack of a fully independent nuclear regulator.

Michael Weightman, chief nuclear inspector of Britain and head of the IAEA mission, said regulatory agencies "are not only independent in structure, but also in the resources and the expertise that they have available to them."

He spoke to reporters after handing the team's preliminary report to the Japanese government.

Critics of the current system have noted that Japan's main regulator, the Nuclear and Industrial Safety Agency, is part of the trade ministry, which is charged with promoting sales of nuclear-power systems overseas.

The IAEA also recommended greater international assistance for plant operator **Tokyo Electric Power Co.**, or Tepco, which is trying to bring the plant to a safe condi-

Zuma Press

Michael Weightman, right, delivered the IAEA's report Wednesday to Goshi Hosono, Prime Minister Kan's special adviser.

Forbidden Kingdom, Opens Up (A Little)

Until the 1970s, Bhutan had a no-tourist policy. It was feared outside visitors would corrupt the country's culture and spoil its pristine natural habitat.

The secluded Himalayan kingdom—often described as the last Shangri-La—has always been protective of its Buddhist-oriented heritage. This explains policies like the country's dress code, requiring Bhutanese to wear traditional robes, and the late arrival of television, introduced in 1999, a day after access to the Internet was also allowed.

Few can say they've been to Bhutan, a mountainous country between China and India. This may change as Bhutan sets out to more than double its tourists as soon as next year.

In 2010 the country counted 40,000 tourists. It hopes to draw 100,000 visitors in 2012, says Kesang Wangdi, the head of the country's tourism council. So far Bhutan seems to be on the right track: from January to April, the number of tourists increased 62% from a year earlier.

CONCLUSIONS - TSUNAMI

- **Furthermore, considering that it was not possible to provide for a ‘dry site’ condition for these operating NPPs, the additional protective measures taken as result of the evaluation conducted after 2002 were not sufficient to cope with the unexpectedly higher tsunami run up values and all associated hazardous phenomena (hydrodynamic forces and impact of large debris).**

Even the tectonic subsidence was not taken into account regarding the grade level to which the tsunami waves reached.

CONCLUSIONS - TSUNAMI

- **Moreover, the re-evaluation of the hazard after 2002 and the adequacy of the protective actions taken were not reviewed and/or approved by the Regulatory Authority.**

- **Because failures of SSCs when subjected to floods are generally not incremental, the plants were not able to withstand the consequences of tsunami heights greater than those expected (cliff edge effect).**

CONCLUSIONS - TSUNAMI

- **The tsunami warning and notification system, if implemented and available, was not able to provide appropriate and timely response for plant reaction to the event. Japan, for example, has developed the TIPEEZ System which was not used as F1 plant and the operators were not aware of the coming of tsunami waves.**

CONCLUSIONS - TSUNAMI

- **It is recognized worldwide that Japan has a high level of expertise and also experience regarding tsunami hazard and provides leadership in this topic worldwide. This is reflected in the major influence that Japanese academic, scientific and technical institutions have on the international research and development of this topic.**

It seems that organizational and governance issues have prevented this expertise to be applied to practical cases at the three NPPs affected.

LESSONS LEARNED - TSUNAMI

- There is need to incorporate large safety factors to estimate tsunami run up for NPP sites for the following reasons:

(i) large aleatory and epistemic uncertainties in parameters involved in tsunami hazard particularly the characterization of the tsunamigenic sources,

(ii) significant variations in inundation levels at different parts of the site considering the specific and detailed plant layout and plant sector elevations,

(iii) difficulties in incorporating effective tsunami protection measures for operating plants after an increase in tsunami height estimation,

(iv) high vulnerability of NPP SSCs to increased flood levels, i.e. to flood related cliff edge effects.

LESSONS LEARNED - TSUNAMI

- **There is also need to use a systemic approach for dealing with the design and layout of the plant SSCs for an effective protection against tsunami hazards.**
- **Leak tightness and water resistance should be assured through a comprehensive evaluation of all potential water ways.**
- **However, this measure can only be used as a redundancy (i.e. in conjunction with a dry site or an effective site protection measure).**

LESSONS LEARNED - TSUNAMI

- **For well defined tsunamigenic (fault controlled) sources, a large earthquake will always precede the tsunami. If the source is near the site, the vibratory ground motion will provide a warning.**

For all tsunamis that may occur at the site, notification from the national tsunami warning system should be transmitted to the control room for immediate operator actions.

A clear procedure should be followed by plant management in preparing for a possible tsunami until the warning is lifted.

LESSONS LEARNED - TSUNAMI

- **An updating of regulatory requirements and guidelines should be performed reflecting the experience and data obtained during the Great East Japan Tsunami, using also the criteria and methods established in the IAEA related safety standards for comprehensively coping with tsunamis and in general all correlated external events.**
- **The national regulatory documents need to include data base requirements and assessment methodologies compatible with those required by IAEA Safety Standards.**
- **The methods for hazard estimation and the protection of the plant need to be compatible with the advances in research and development in this field.**

LESSONS LEARNED - TSUNAMI

- **The potential for scenarios involving flooding hazards and multiple units (and possible multiple sites) needs to be fully and comprehensively investigated for new and existing nuclear power plants worldwide and if they cannot be screened out provisions for:**
  - **plant layout,**
  - **site protection measures,**
  - **design, accident management and emergency preparedness and response**

  should be taken in order to adequately protect the installation against these disasters.

LESSONS LEARNED – EXTERNAL EVENTS

- **After a major disaster which may cause severe disruption to the plant the changed plant state and physical conditions of the SSCs need to be taken into consideration. The changed plant state (degraded systems and degraded physical conditions of the SSCs) may have lost design robustness and may have degraded defense in depth.**

LESSONS LEARNED – EXTERNAL EVENTS

- **The safety profile of the plant needs to be well understood (e.g. the required SSCs) for different plant states (e.g. shutdown) in order to provide for a consistent protection and a plan for upgrades.**

- **A major natural disaster may temporarily alter the environment at regional scale. In order to provide for an uninterrupted recovery process, there is a need for understanding the plant vulnerabilities and the new environment and providing protection for the plant and the recovery action accordingly in a timely manner.**

LESSONS LEARNED – EXTERNAL EVENTS

There is a need to ensure that in considering external natural hazards the siting and design of nuclear plants should include sufficient protection against infrequent and complex combinations of external events and these should be considered in the plant safety analysis – specifically those that can cause site flooding and which may have longer term impacts;

LESSONS LEARNED – EXTERNAL EVENTS

There is a need to ensure that in considering external natural hazards:

- **plant layout should be based on maintaining a ‘dry site concept’, where practicable, as a defense-in-depth measure against site flooding as well as physical separation and diversity of critical safety systems;**

- **common cause failure should be particularly considered for multiple unit sites and multiple sites, and for independent unit recovery options, utilizing all on-site resources should be provided;**

FINAL REMARKS

- *“one in one million it does not mean that is impossible”;*
- *hazard assessment should be based on pre-historical and historical database;*
- *less complacent with human errors in the decision making process and the governance deficiencies;*
- *peer reviews by independent peers: effective way to learn and to generate changes and improvements*
- *was this accident preventable?*

Thank you for your attention

Questions? **agodoy@aon.at**