IAEA Technical Meeting on Lessons Learned and Safety Improvements Related to External Hazards Based on the IAEA Fukushima Daiichi Accident Report

Vienna, Austria, 23–25 November 2016, Board Room C, Ref. No.: J20-TM-52527

Japan's Nuclear Regulation against Natural Hazards after the Fukushima Daiichi Accident

Akira ISHIWATARI

Commissioner of Nuclear Regulation Authority, Japan (D.Sc., Geologist)

原子力規制委員会
Nuclear Regulation Authority

Thanks

- Five years have passed since the March 2011 Fukushima Daiichi nuclear accident. To prevent recurrence of such a disaster, Nuclear Regulation Authority (NRA)* was established in September 2012. NRA has worked hard for keeping nuclear safety and improving nuclear regulation. NRA expresses sincere thanks to IAEA and its member countries for their kind help in reconstructing Japan after the Fukushima Daiichi accident.

*Five commissioners and thousand staffs

Thanks

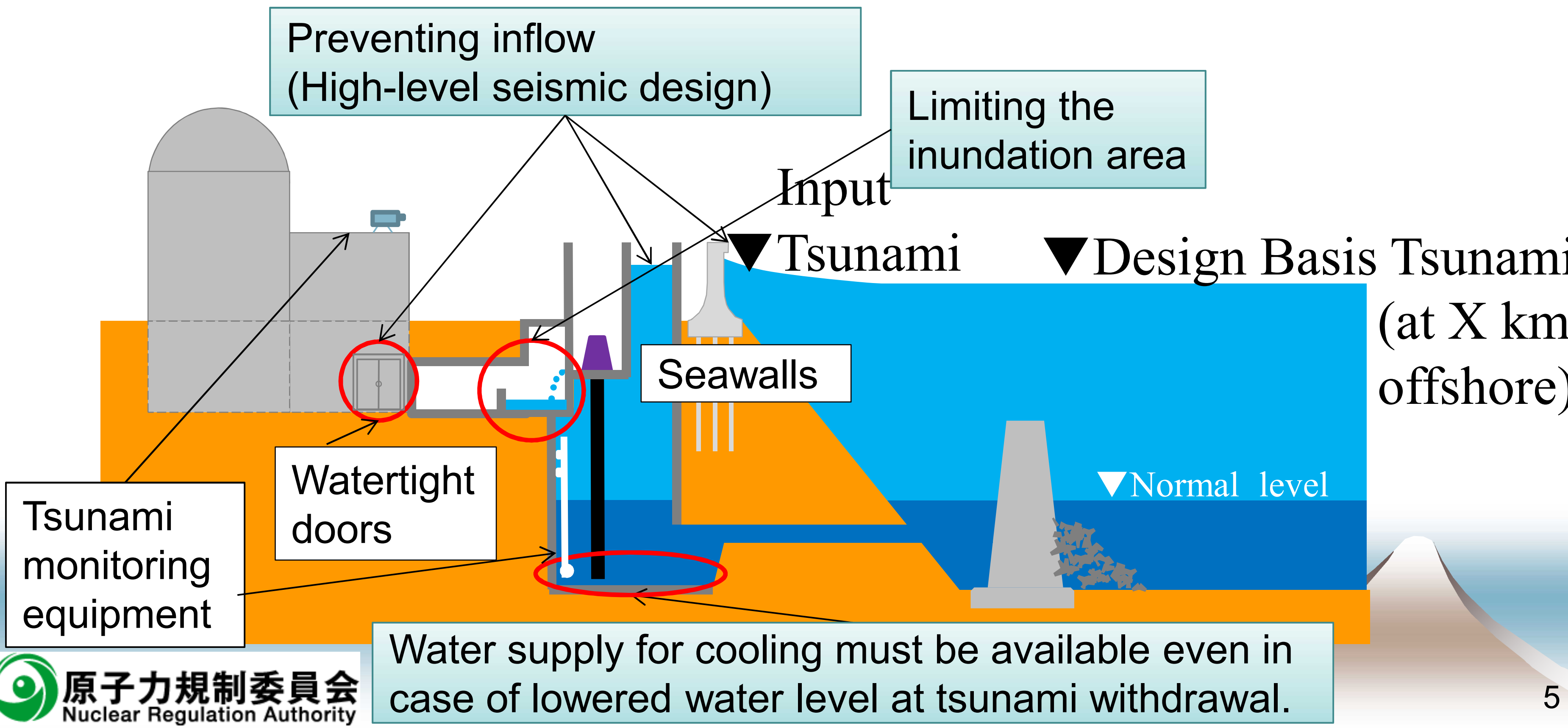
- I thank IAEA for giving me a chance of this presentation. I am glad to contribute to international nuclear safety by presenting our knowledge learned from experience of the Fukushima accident.
- Fukushima dictates that “perfect safety” or “ultimate preparedness” does not exist in nuclear safety. We keep going for further improvement of nuclear safety in Japan with international understanding.

NRA's New Regulation Standards against Natural Hazards after the Fukushima accident (Contents of this Presentation)

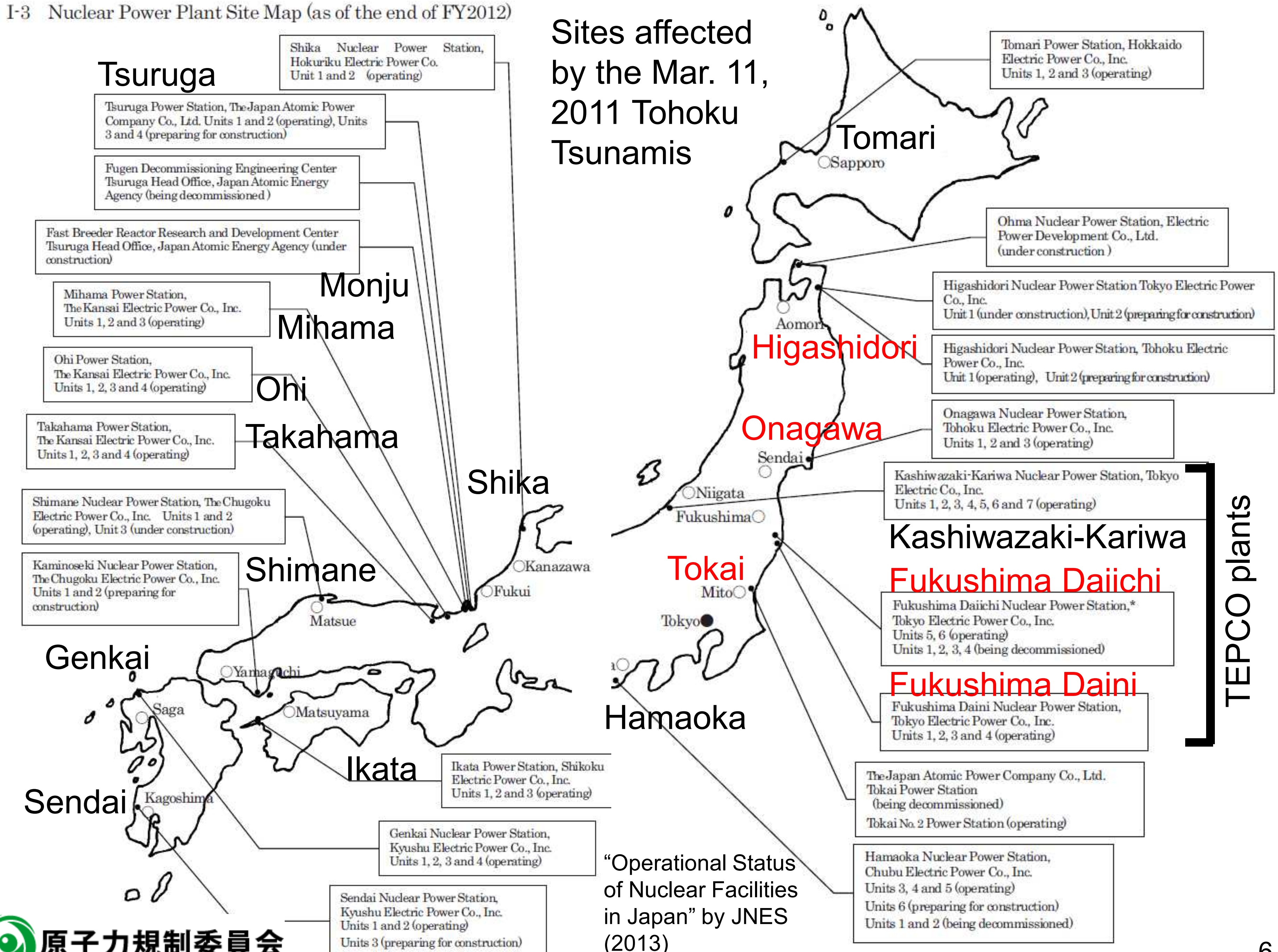
- More stringent standards on tsunami
- Clarification of requirements for fault displacement
- More precise methods to define design basis ground motion (DBGM) by earthquake
- Assessment & monitoring of volcanic activity
- An example: Sendai Nuclear Power Plants (NPPs), Kyushu Electric Power Co.

More stringent Standards on Tsunami

- Define "Design Basis Tsunami" that exceeds the largest in the historical records
- Requirements for multiple protective measures



Sites affected by the Mar. 11, 2011 Tohoku Tsunamis



"Operational Status of Nuclear Facilities in Japan" by JNES (2013)

原子力規制委員会
Nuclear Regulation Authority

Mar. 11 Tsunamis at NPPs

NPP	Tsunami Height (Mar. 11, 2011)	Input Tsunami (before Mar. 11)	Input Tsunami (after Mar. 11)
Higashidori	4 m [13 m]	6.5 m	11.7 m*
Onagawa	13 m [15 m]*	9.1 m	23.1 m*
Fukushima Daiichi	15 m [10 m]	5.4 – 5.7 m	26.3 m** (14.13 m)
Fukushima Daini	15 m [12 m]	5.1 – 5.2 m	27.5 m***
Tokai	5 m [8 m]	5.7 m	17.1 m*

Site caused severe accident
Site affected by tsunami

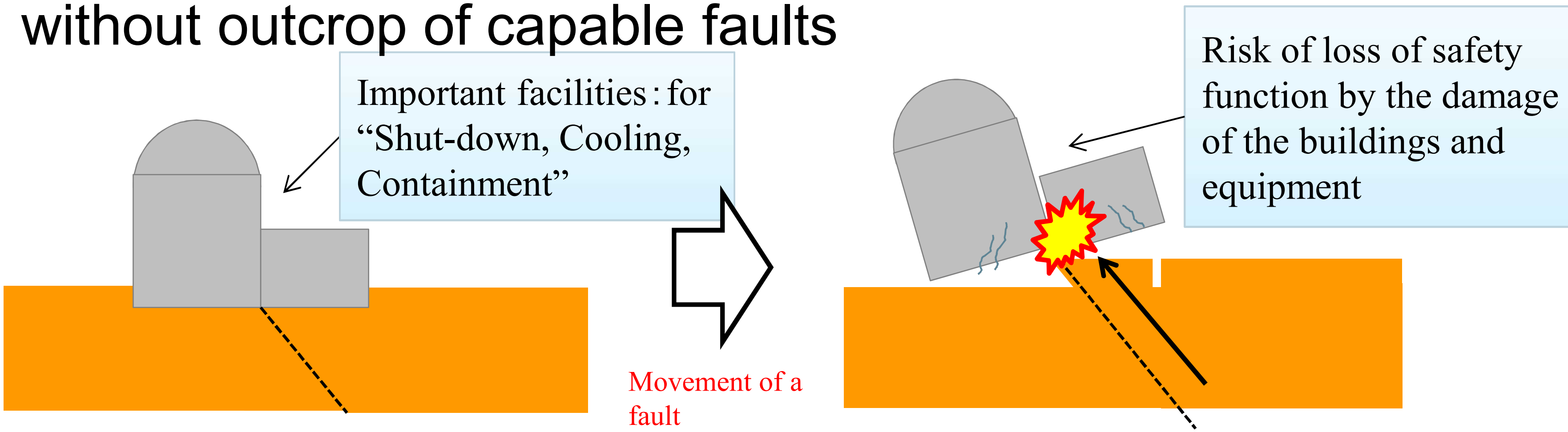
[ ] Site elevation
*Site subsided 1 m by the earthquake (Elevation was 14 m at tsunami input)

*Currently under evaluation or not yet evaluated
**For consideration
***Proposed by TEPCO

Data from various sources (Credit: A. Ishiwatari)

Clarification of requirements for fault displacement

- "Capable faults" need to be determined as those whose activities since the late Pleistocene (approx.120,000 to 130,000 years ago or later) cannot be denied
- Important facilities have to be constructed on the ground without outcrop of capable faults



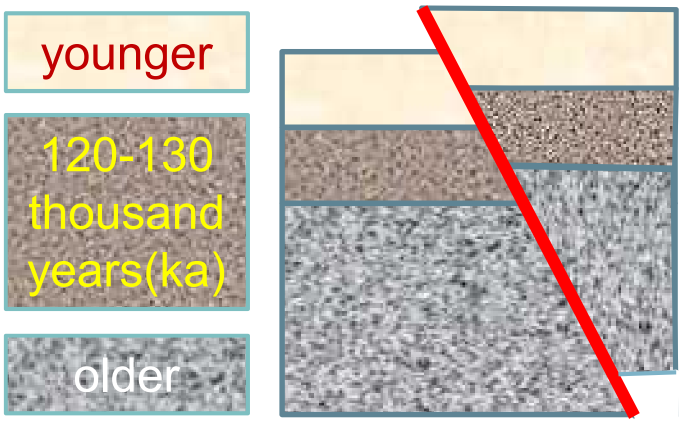
○Movement of the fault under important facilities like Reactor Building may result in the concentration of deadweight onto the spot and cause damage of the building.
○Even in case damage of the building is avoided, safety function can be lost due to the deformation of the facilities or damages of the internal equipment.

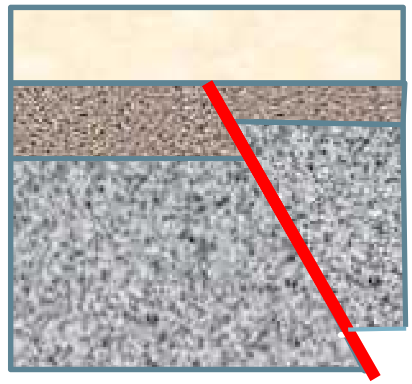
How to find a capable fault?

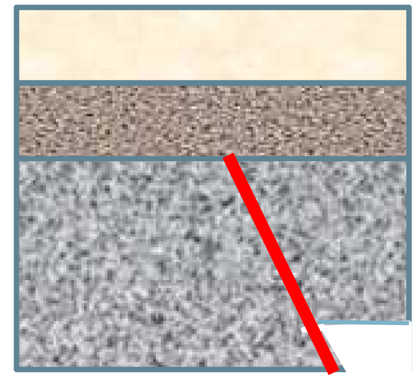
"Capable fault" is the official term for "active fault" that is defined in IAEA Safety Standards Series No. SSG-9 "Seismic hazards in site evaluation for nuclear installations". The "120-130 ka" is the base age of Upper Pleistocene.

1. Covering Bed Method

Geological age of bed



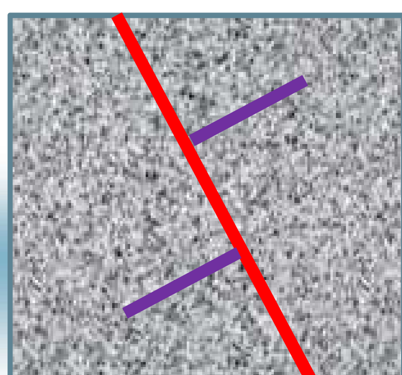




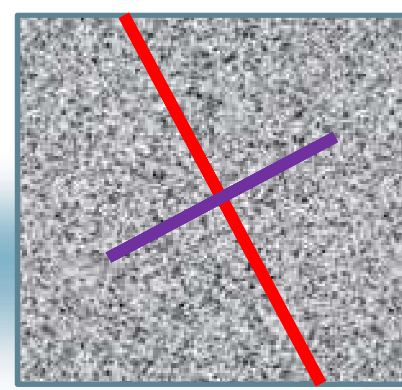
Judge: Capable Fault | Capable Fault | Not Capable Fault

2. Crossing Vein Method

— 120-130 ka dike or vein



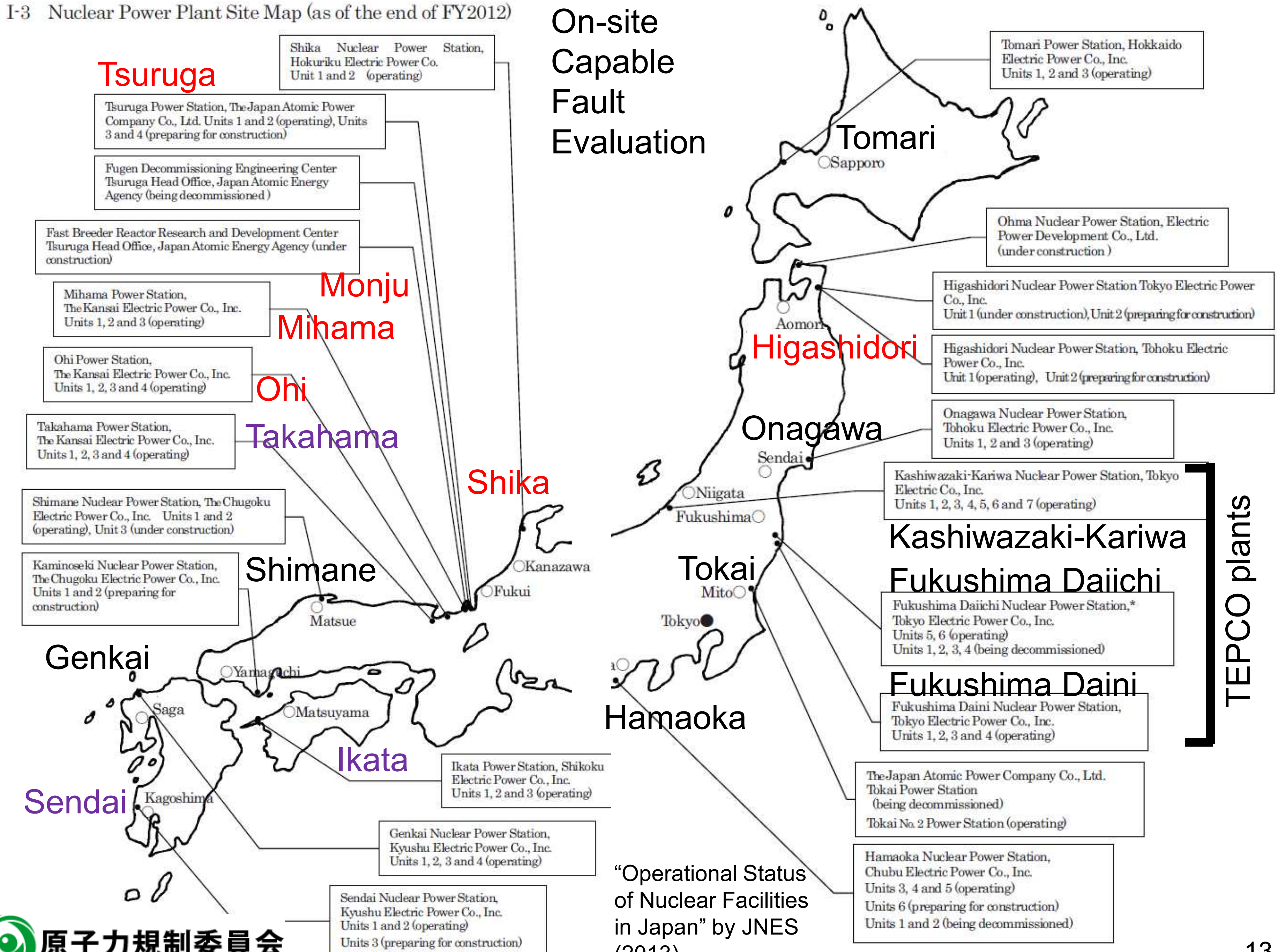
Capable Fault



Not Capable Fault

原子力規制委員会
Nuclear Regulation Authority

On-site Capable Fault Evaluation



"Operational Status of Nuclear Facilities in Japan" by JNES (2013)

原子力規制委員会
Nuclear Regulation Authority

On-site capable fault evaluation

NPP	by Specialists or NRA	Evaluation Result
Higashidori	Specialists	Capable Fault*
Shika	Specialists	Capable Fault*
Tsuruga	Specialists	Capable Fault*
Monju	Specialists	Not Capable Fault
Mihama	Specialists and NRA	Not Capable Fault
Ohi	Specialists	Not Capable Fault
Takahama	NRA	Not Capable Fault
Ikata	NRA	Not Capable Fault
Sendai	NRA	Not Capable Fault

Site operation permitted
(Ikata and Sendai are currently on operation)

Credit: NRA

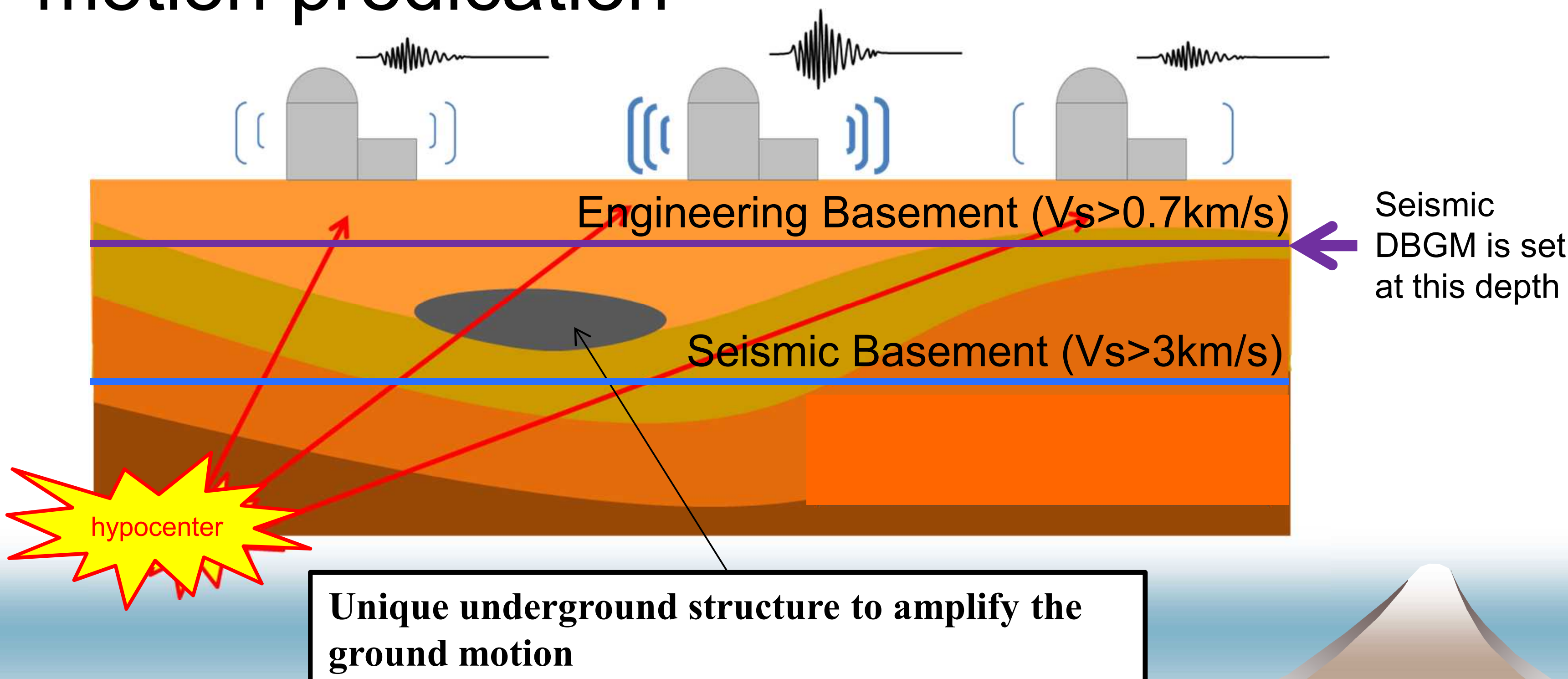
*Evaluation of fault(s) directly beneath the reactor is not fixed (on evaluation by NRA)

Note: Specialists' evaluation is (will be) taken as important information in the final NRA's judgment.

原子力規制委員会 Nuclear Regulation Authority

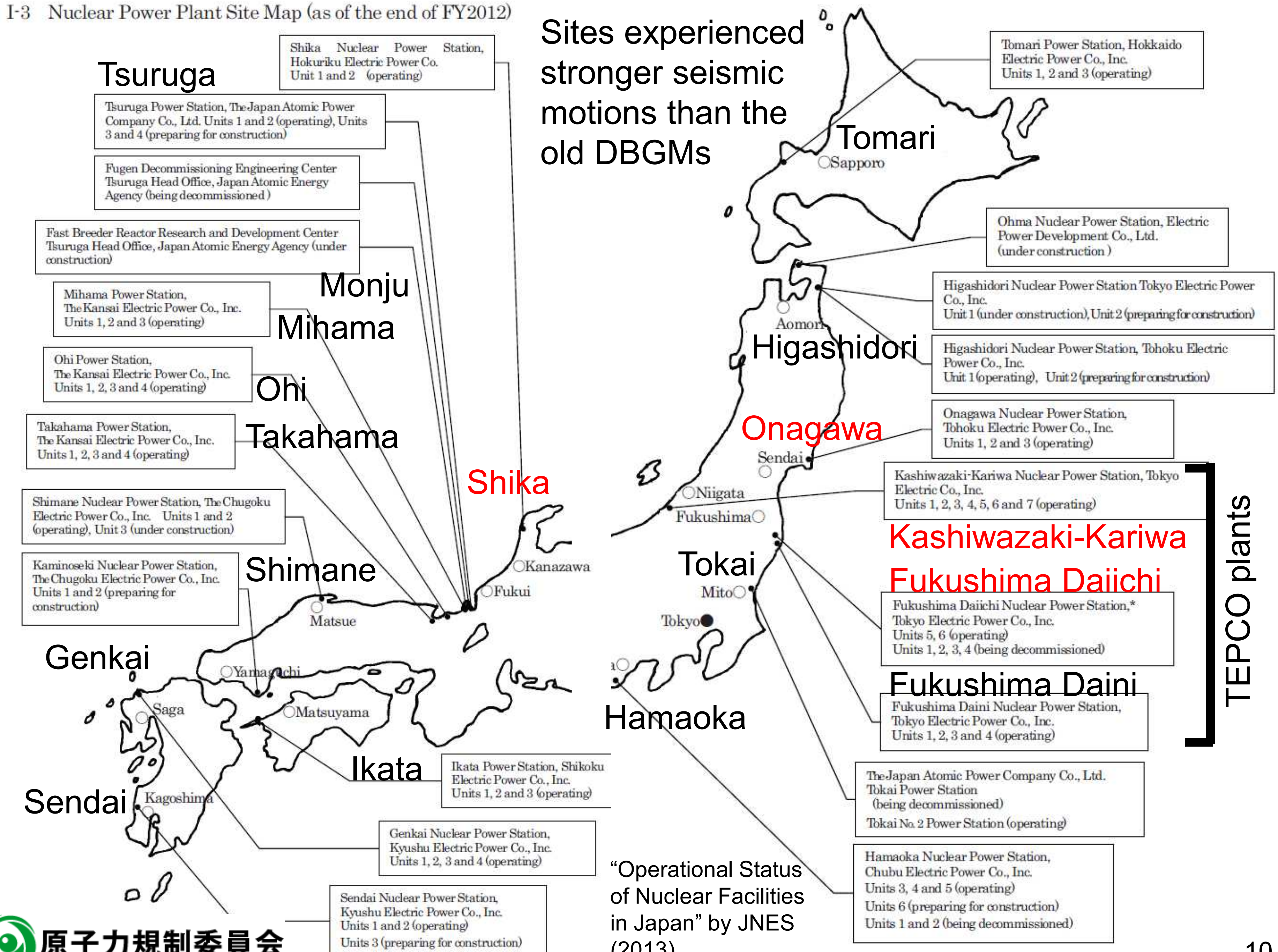
More precise methods to define Design Basis Ground Motion (DBGM)

- Survey 3D geological structure of the site
- Take into consideration of seismic ground motion predication



https://www.nsr.go.jp/data/000070101.pdf P.14 (2013)

Sites experienced stronger seismic motions than the old DBGMs



"Operational Status of Nuclear Facilities in Japan" by JNES (2013)

原子力規制委員会
Nuclear Regulation Authority

Sites experiencing earthquakes with strong motions larger than the old DBGMs[3)]

原子力規制委員会
Nuclear Regulation Authority

(gal = cm/s^2) Credit: NRA

NPP site	Earthquake Name	Date	Magnitude M_w	PGA basemat	Distance to site	Operation Status
Onagawa	Miyagi-Oki earthquake	August 16, 2005	7.1	316 gal [1)]	84km	SCRAM at Units #1, 2, 3
Shika	Noto Peninsula earthquake	March 25, 2007	6.7	226 gal [1)]	18km	Under periodical inspection
Kashiwazaki -Kariwa	Chuetsu-Oki earthquake	July 16, 2007	6.6	680 gal [2)]	16km	SCRAM at Units #3, 4, 7. Others; under periodical inspection
Onagawa	Tohoku earthquake	March 11, 2011	9.0	607 gal [2)]	125km	SCRAM at Units #1 & 3. Unit 2; under periodical inspection
Fukushima Daichi	Tohoku earthquake	March 11, 2011	9.0	550 gal [2)]	180km	SCRAM at Units #1, 2, 3. Others: under periodical inspection
Onagawa	Miyagi-Oki earthquake	April 7, 2011	7.1	398 gal [1)]	78km	Under periodical inspection

1) Response spectra exceeded the design basis ground motion (DBGM, Ss or S_2) at some periods
2) Peak ground acceleration (PGA) and response spectra (at some periods) exceeded the DBGM (Ss or S_2)
3) Design basis ground motions (DBGMs) before and after the March 11, 2011 Tohoku Earthquake (at 50 Hz):

Site	Onagawa	Shika	Kashiwazaki-Kariwa	Fukushima-Daiichi
Before	580 gal	600 gal	450 gal*	600 gal (*Before back check)
After	1000 (on evaluation)	1000 (on evaluation)	1209-2300 (on eval.)	900 (for consideration)

4) SCRAM threshold ground acceleration at Kashiwazaki-Kariwa: horizontal =120-185 gal, vertical = 100 gal

Reassessment of Sendai Nuclear Power Plants (NPPs): an example

- Owned by Kyushu EPC
- 2 PWRs, 890,000kW each
- About 30 years operation
- Front onto East China Sea (not to plate boundary)

Time sequence of reassessment

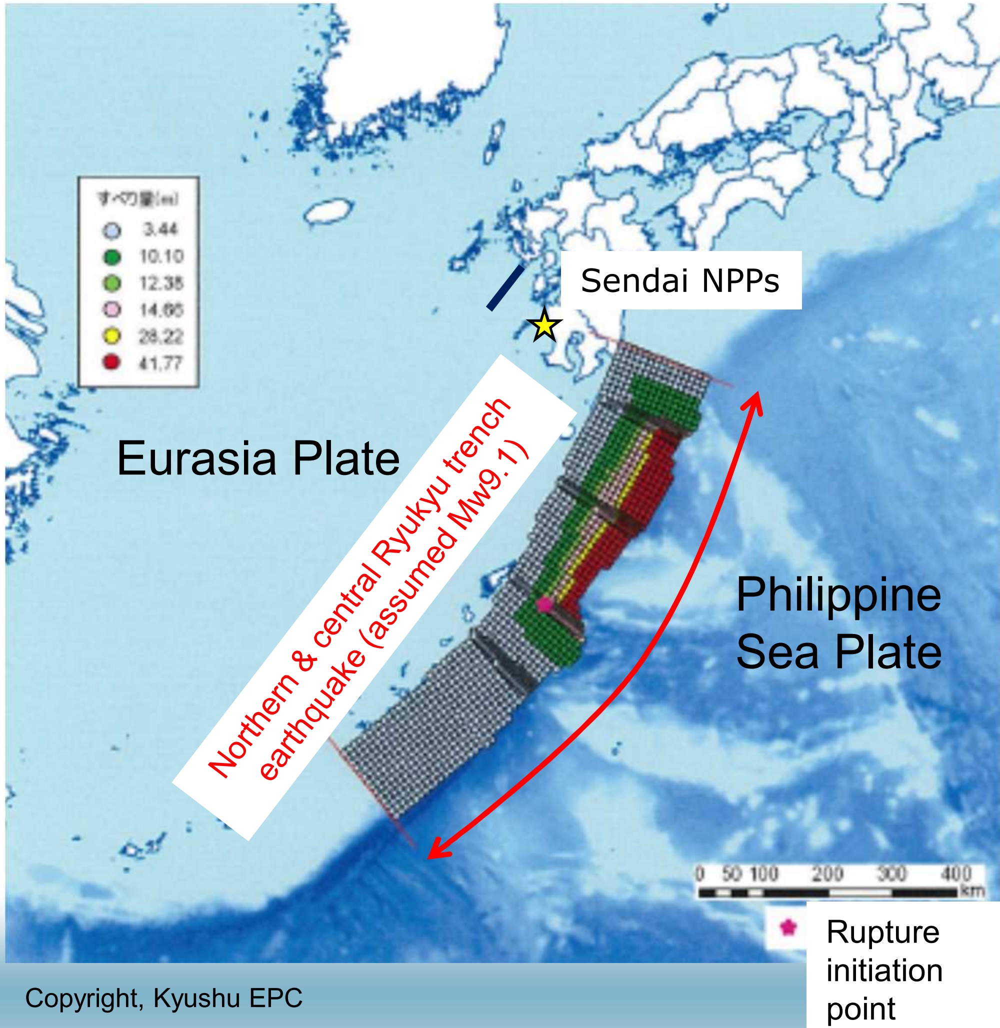
Jul. 8, 2013
Back-fit safety assessment completed

Jul. 16, 2013
Examination by NRA commissioners and secretariats started.
>60 times open-to-public meetings
~700 times closed meetings
Revision after public comments

Sep. 10, 2014
Permission for basic design decided.

Sep. 10, 2015 and Nov. 17, 2015
Commercial operation of Reactors #1 and #2 restarted, respectively. Both reactors are currently on operation.

Tsunami sources



Nagasaki spur fault (length:86km, Mw7.6)

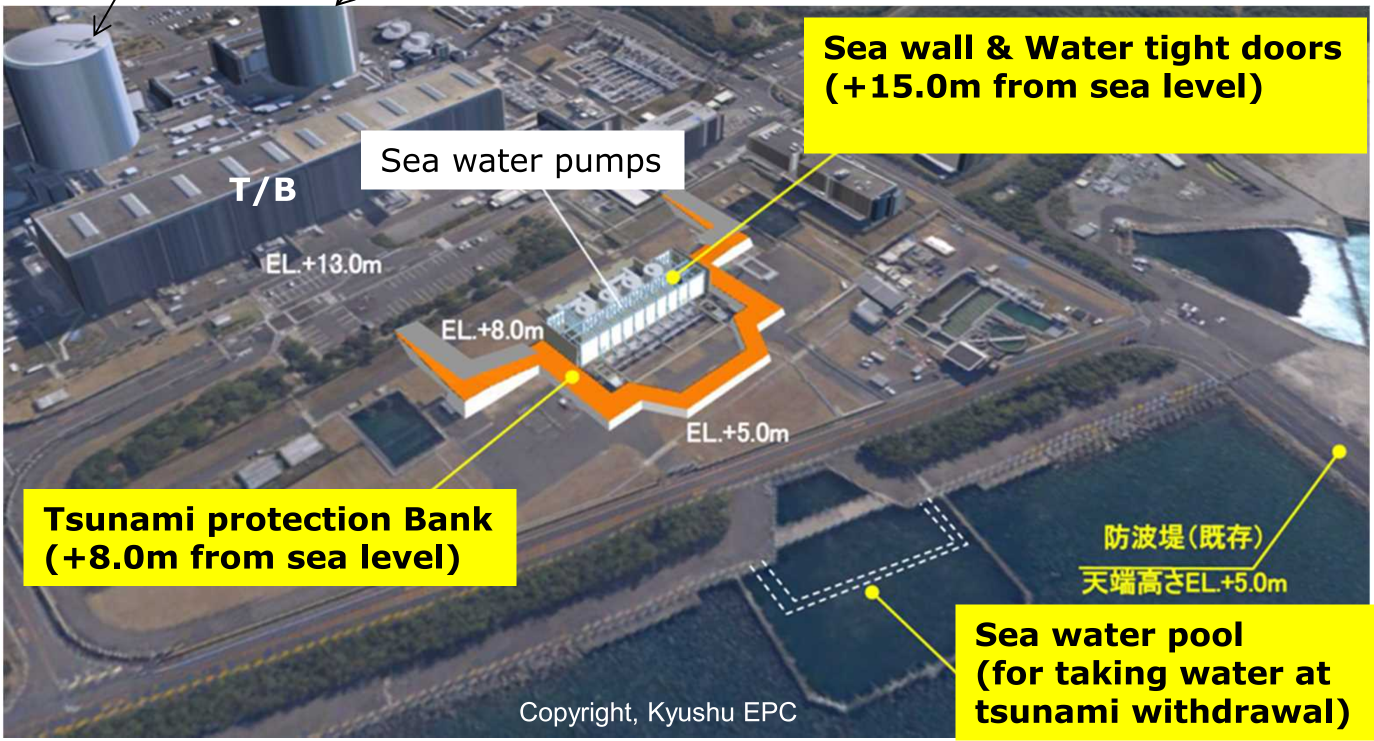
Northern and central part of Ryukyu trench (length:approx.900km, Mw9.1)

NRA required to estimate the tsunami height caused by northern and central part of Ryukyu trench*

* Any tsunami caused by this wide area have never been recorded, but the possibility to break several segment simultaneously, as in case of the Great East Japan Earthquake, should be considered.

Tsunami protection

Unit 2 C/V Unit 1 C/V



Design Basis Tsunami (DBT) of Sendai NPPs is calculated at the point 8 km offshore and 50 m water depth.

Input Tsunami Height is the maximum at the site waterfront.

Site Elevation is the ground height where reactors are placed.

NPPs	DBT	Input Tsunami	Site Elevation
Sendai	2.0m	7.0m	13m
Ikata	1.9m	8.7m	10m
Takahama	1.7m	6.7m	3.5m
Mihama	3.3m	4.2m	3.5m

原子力規制委員会
Nuclear Regulation Authority

Capable faults on site?

Geological Map of the Sendai Nuclear Power Plant site

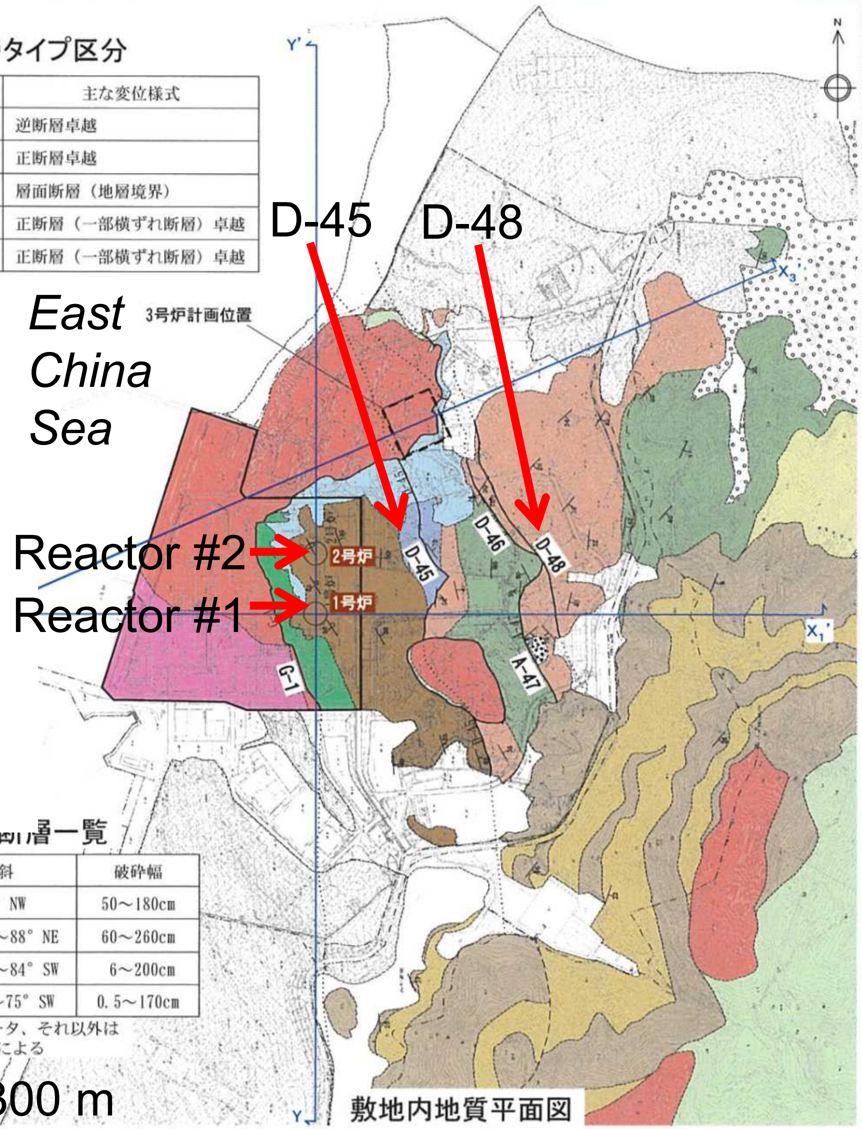
Two reactors are built on the Cretaceous conglomerate bed.

The longest and youngest faults (e.g. D-45 and D-48) are selected for detailed assessment.

Mar. 19, 2014, Assessment Meeting #95, Doc. 2-1, p. 81, Sendai NPPs, Fault (Kyushu EPC)

断層タイプ区分

断層タイプ	走向・傾斜	主な変位様式
A	NS系低角度	逆断層卓越
B	EW系低角度	正断層卓越
C	–	層面断層（地層境界）
D	NS系高角度	正断層（一部横ずれ断層）卓越
E	EW系高角度	正断層（一部横ずれ断層）卓越



敷地東部の断層一覧

断層番号	走向・傾斜	破砕幅
A-47	N10° E/35° NW	50～180cm
D-45	N13～16° W/84～88° NE	60～260cm
D-46	N25～45° W/54～84° SW	6～200cm
D-48	N1～8° W/68～75° SW	0.5～170cm

＊ A-47断層はトレンチデータ、それ以外は3号炉調査試掘坑データによる

地質時代			地層名	地質
新生代	第四紀	完新世〜更新世	盛土	礫, 砂, シルト等
			第四系 海浜堆積物	礫, 砂等
			第四系 沖積層	礫, 砂, 泥等
			第四系 砂丘堆積物	砂等
			第四系 段丘堆積物	礫, 砂, シルト等
	新第三紀	鮮新世	火砕流堆積物	溶結凝灰岩
			北薩火山岩類Ⅱ（輝石安山岩質）	安山岩溶岩, 火山角礫岩, 凝灰角礫岩, 火山礫凝灰岩, 凝灰岩
			みやま層	凝灰質シルト岩, 凝灰質砂岩, 凝灰質礫岩, 軽石凝灰岩
		中新世	北薩火山岩類Ⅰ（角閃石安山岩質）	軽石質凝灰角礫岩 / 火山角礫岩, 凝灰角礫岩, 火山礫凝灰岩
中生代	白亜紀	後期	混在岩	泥質岩基質及び岩塊（砂岩, 礫岩, 石灰岩等）
		前期	滄浪層	砂岩, 礫岩, 頁岩
			久見崎層 上部層	頁岩, 砂岩, 礫岩
			久見崎層 下部層	礫岩, 砂岩, 頁岩
			川内層 上部層	粘板岩, 砂岩, 礫岩
			川内層 下部層	礫岩, 砂岩, 粘板岩
	ジュラ紀		変はんれい岩類	蛇紋岩メランジュ（変はんれい岩, 角閃岩, 蛇紋岩等）

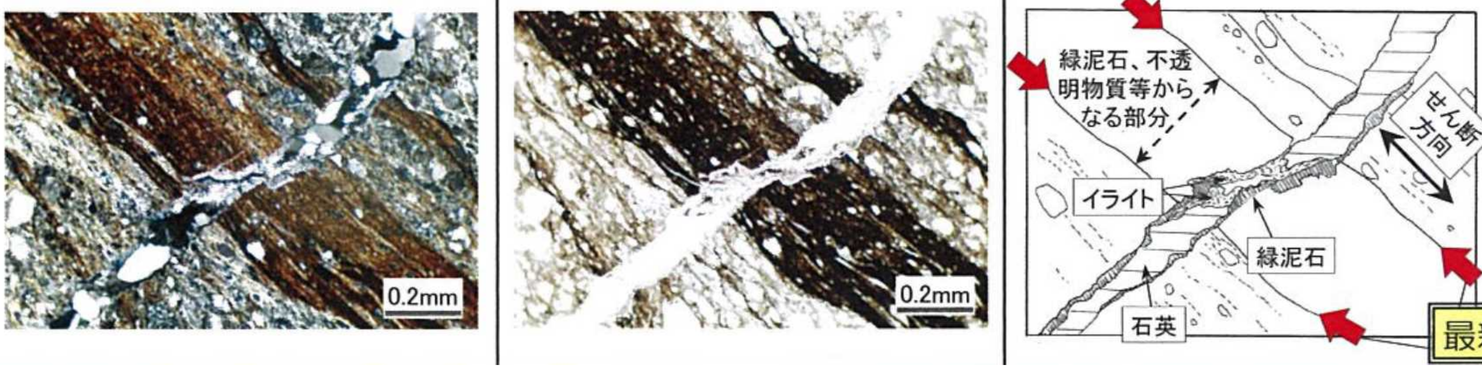
＊ 1, 2号炉周辺の枠内は、主に基礎掘削工事で確認した地質分布を表現（第四系及び盛土を除いて図示し、標高は箇所ごとに異なる）。

記号凡例

- 敷地境界線
- 地質境界線
- 断層（破線は推定を表す）（点線は伏在を表す）
- 断面図位置
- 地層の走向傾斜（正常層）
- 地層の走向傾斜（逆転層）
- 断層の走向傾斜

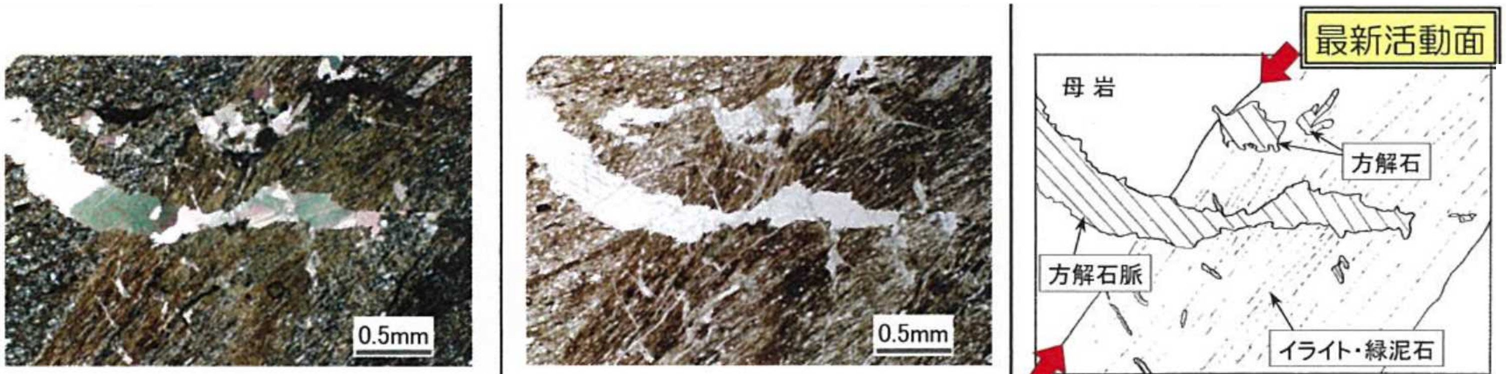
Mineral veins cutting fault zones

D-45 fault zone is cut by a quartz vein including chlorite and illite (p.109)



The newest rupture planes of fault zones are indicated by red arrows.

D-48 fault zone is cut by calcite veins (p. 117)



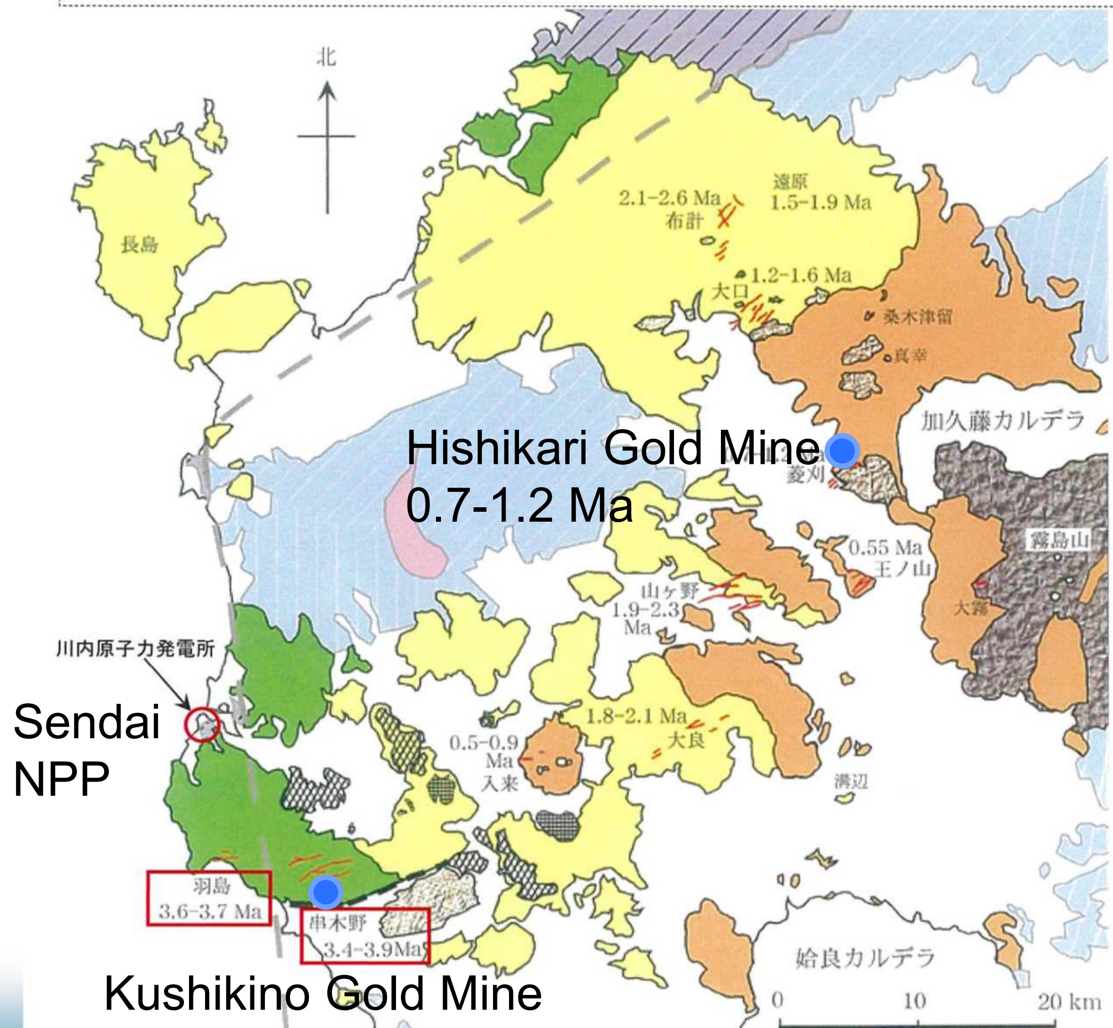
Chlorite and illite are also present in the fault zones.

Mar. 19, 2014, Assessment Meeting #95
Doc. 2-1, Sendai NPPs (Kyushu EPC)

Age of hydrothermal veins: 3 Ma in the Sendai-Kushikino area

○ 敷地内の熱水変質活動の年代については、井澤 (2004)*に基づき、3～4Maと判断している。

On-site faults of Sendai NPPs formed before (or geologically at the same time with) the 3 Ma hydro-thermal activity. Thus **they are not capable faults**.

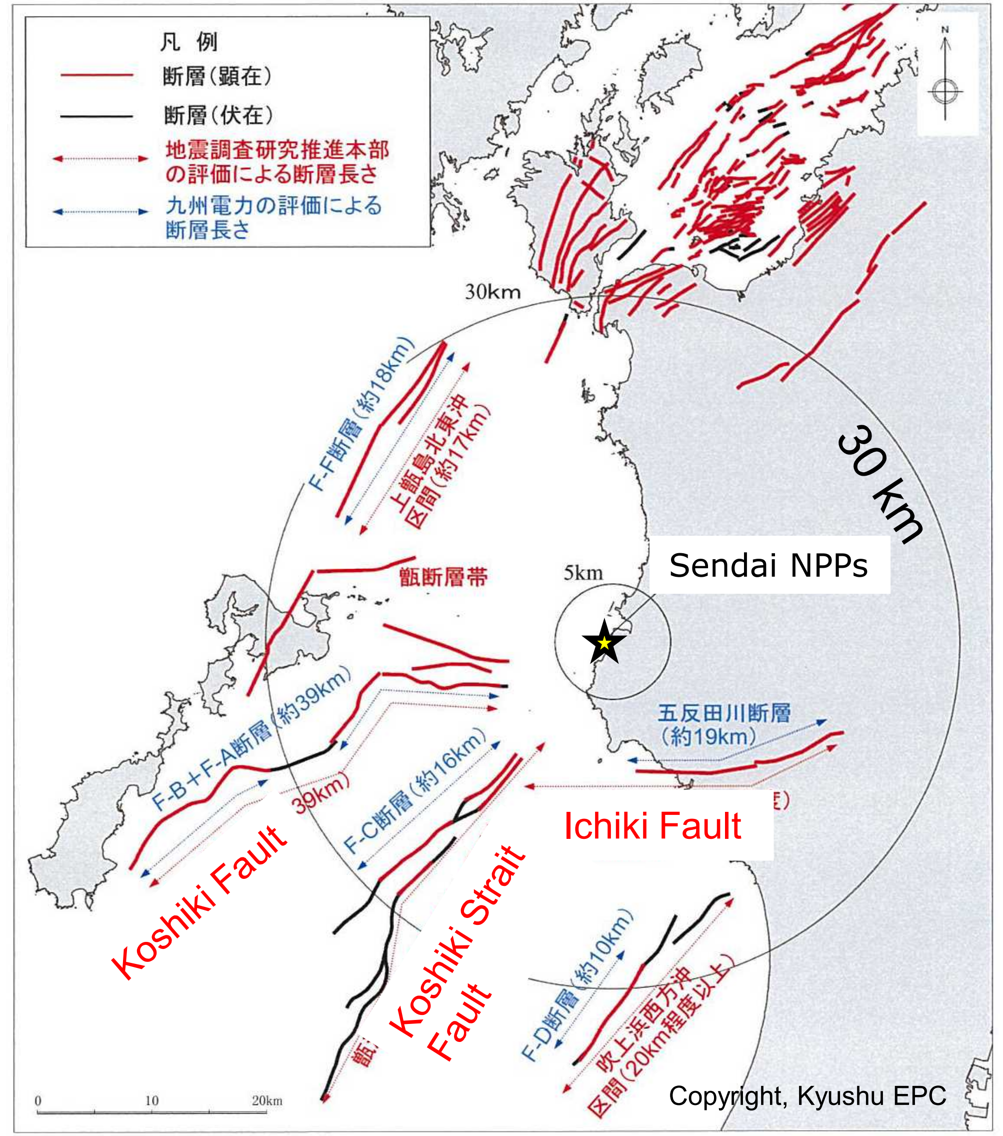


北薩地域の火山岩と金鉱床の分布（井澤,2004に加筆）

Izawa, E. (2004) Chishitsu News, 599, 49-54 (in Jpn.).

Mar. 19, 2014, Assessment Meeting #95
Doc. 2-1, Sendai NPPs (Kyushu EPC)

Capable faults (near site <30km)



Blue: Fault length assessed by Kyushu EPC

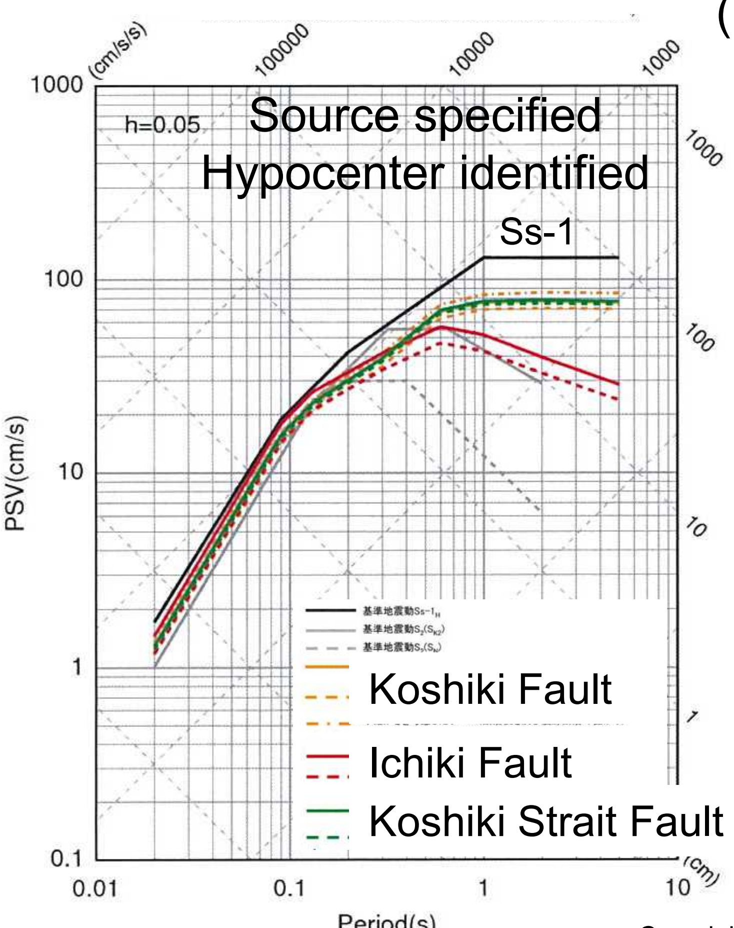
Red: Fault length assessed by the Headquarter for Earthquake Research Promotion (HERP)

NRA required to extend the length of faults to fit the length assessed by HERP

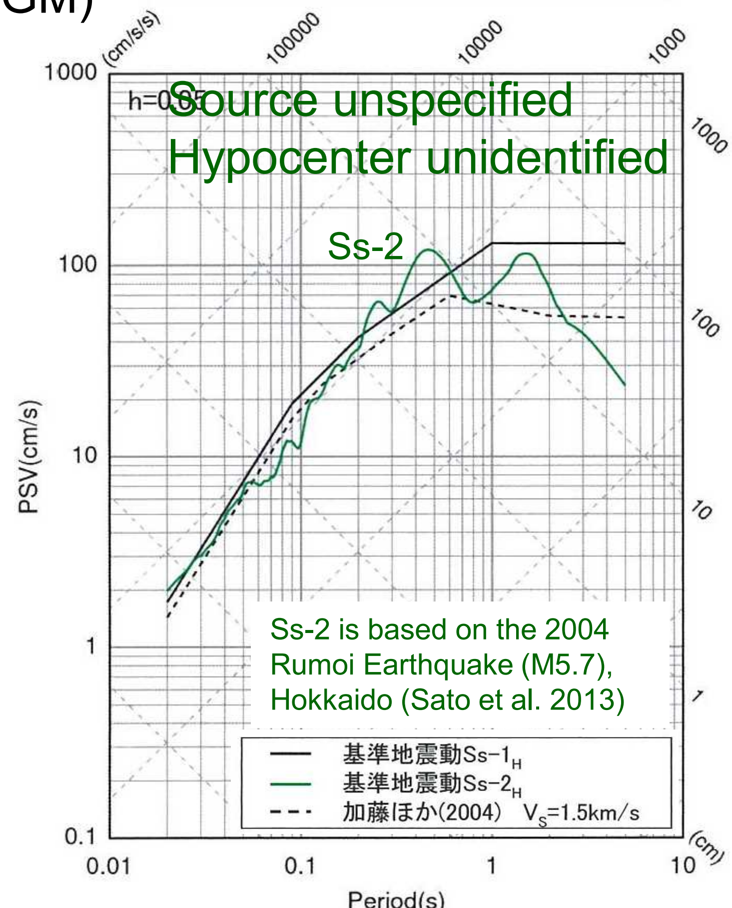
The nearest faults are used for calculation of Design Basis Ground Motion (DBGM)

(Mar. 12, 2014 Assessment Meeting #92. Copyright: Kyushu EPC)

Design Basis Ground Motion of Sendai NPPs (DBGM)



Horizontal movement



Horizontal movement

Ss-1 and Ss-2 are DBGMs for Sendai NPPs.

The Ss-2 “hypocenters-unidentified” earthquake is assumed to occur in the earth’s crust just beneath the NPPs.

The Ss-2 is larger than the Ss-1 in some periods.

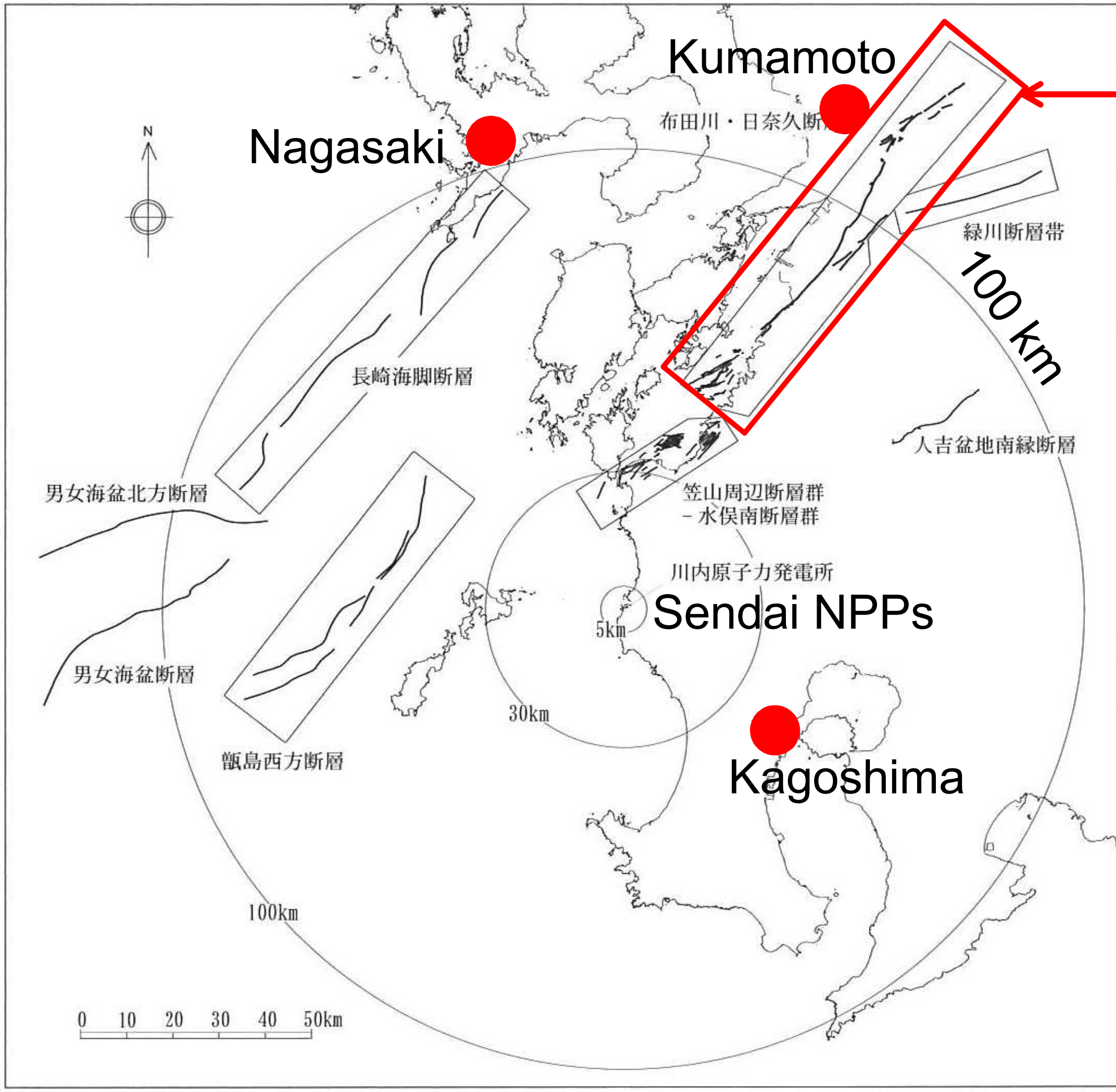
Seismic accelaration of DBGM: (gal = cm/s^2)

- Sendai: 540 gal (Appl.) >>> 620 gal (Reassess.)
- Ikata: 570 gal (Appl.) >>> 650 gal (Reassess.)
- Takahama: 550 gal (Appl.) >>> 700 gal (Reassess.)
- Mihama: 750 gal (Appl.) >>> 993 gal (Reassess.)

Calculation is based on Irikura and Miyake (2001; *J. Geogr.*, **110**, 849-; 2011; *Pure Appl. Geophys.*, **168**, 85-)

原子力規制委員会 Nuclear Regulation Authority

Capable faults (near site <100km)



Kyushu EPC's evaluation of Futagawa-Hinagu Fault is 93 km long and M8.1, assuming a full-length rupture. Equivalent epicenter distance from Sendai NPPs is 104 km.

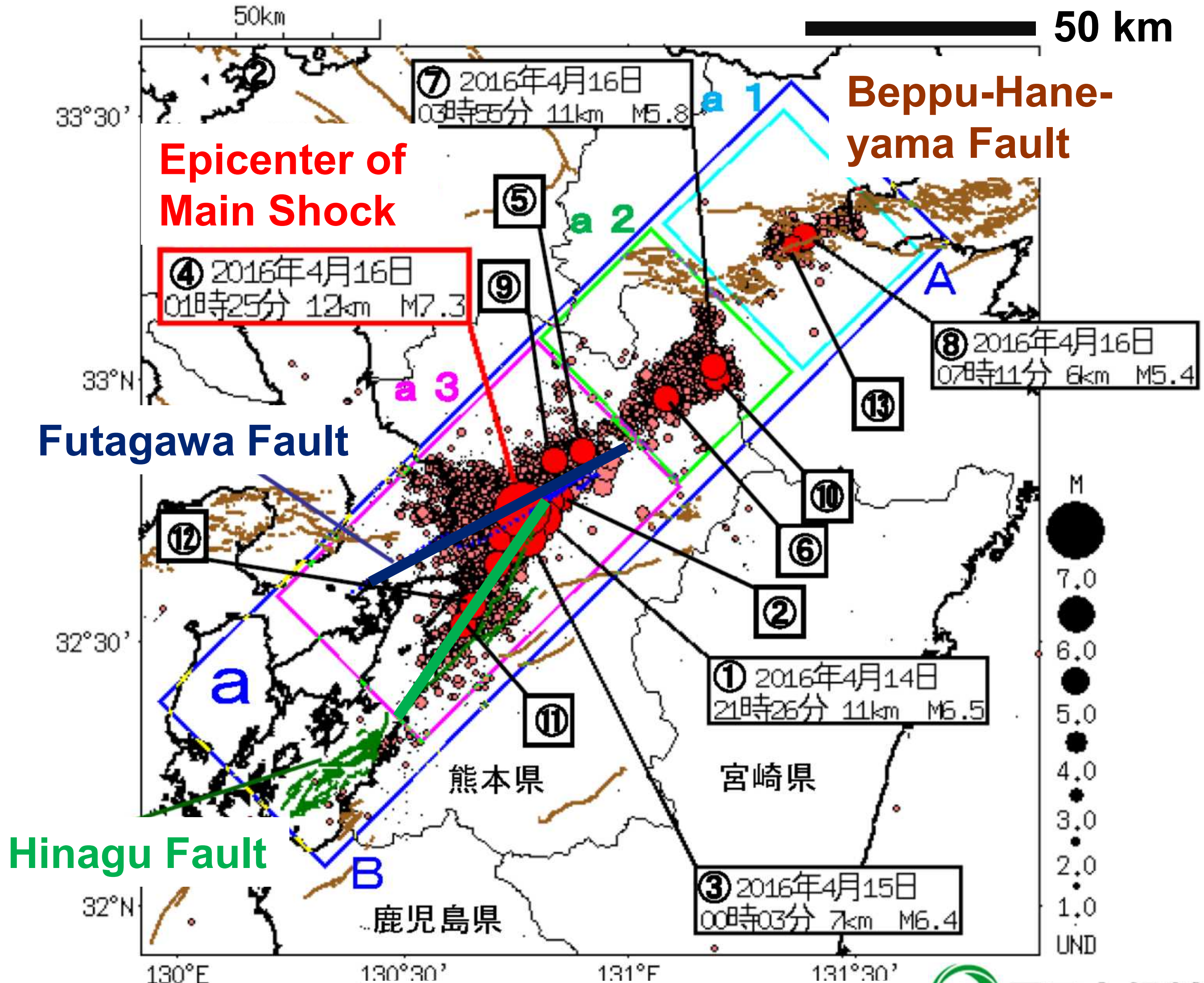
The Futagawa-Hinagu Fault caused M7.3 Kumamoto earthquake on Apr. 16, 2016 and associated numerous disastrous earthquakes.

(Mar. 12, 2014 Assessment Meeting #92. Copyright: Kyushu EPC)

2016 Kumamoto Earthquake

Apr. 14, M6.5 and Apr. 16, M7.3; 50 deaths, >2,000 injuries and >180,000 evacuees.

Surface Fault Rupture:
Futagawa: 28 km
Hinagu: 6 km



Sendai NPP●

Japan Meteorological Agency

Fault Length by Satellite-based Ground Movement:
Futagawa E: 5 km
Futagawa W: 20 km
Hinagu: 10 km
(Data from Japan Meteorological Agency)

Kyushu EPC's evaluation of the Futagawa-Hinagu Fault in the Sendai NPP Reassessment:
93 km, M8.1

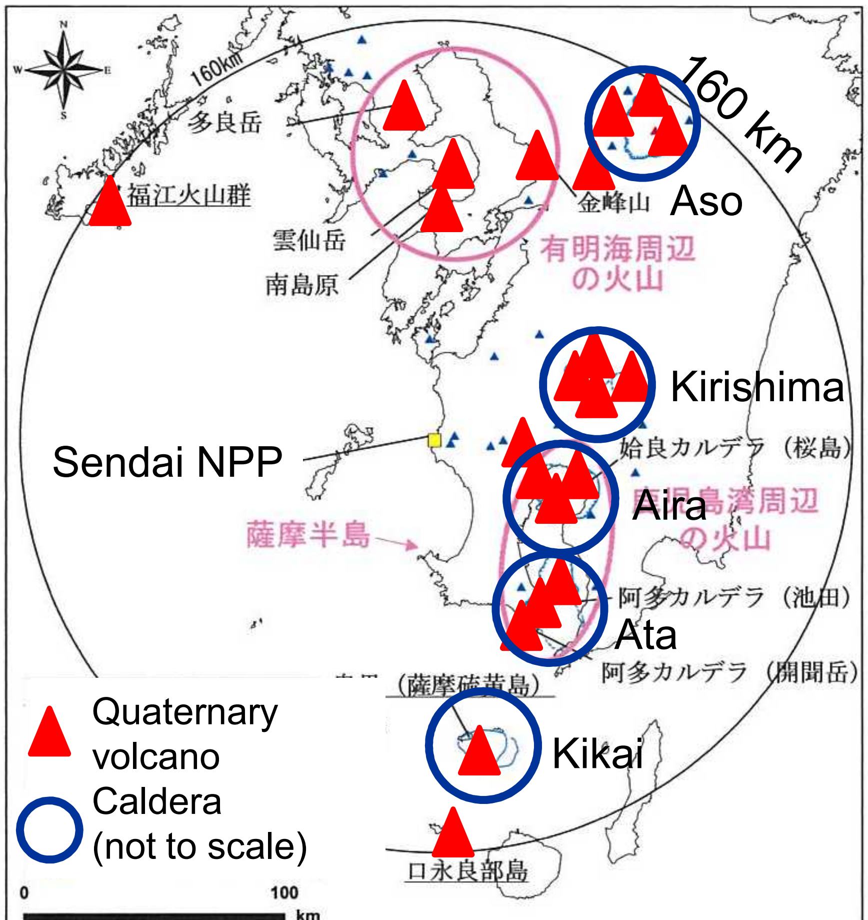
原子力規制委員会 Nuclear Regulation Authority

Protection of NPPs from volcanic hazards

Utility companies should survey Quaternary volcanoes within 160 km from the NPP, and assess their eruption histories, geothermal activities, distribution of lavas, pyroclastic flows and ash, etc.

(Apr. 23, 2014 Assessment Meeting #107 Sendai NPPs, Kyushu EPC)

In case if a pyroclastic flow reached the NPP site in the geologic past, the company should conduct seismic and geodetic monitoring of the source caldera volcano. This is the case for Sendai NPPs.



Evaluation of volcanic ash to be deposited in the NPP site during its operation:

NPP	Ash
Sendai	15 cm
Ikata	15 cm
Takahama	10 cm
Mihama	10 cm

原子力規制委員会
Nuclear Regulation Authority

Conclusion (Action Principles of NRA)

- Protect human life & environment – our goal
- Independent scientific & technical decisions
- Field-based, effective regulation
- Open & informed regulation processes
- Professional moral & ability by daily studies
- Immediate & organized action at crisis
- Enhance nuclear safety & security culture

Thank you for your kind attention.