Joint ICTP-IAEA Essential Knowledge Workshop on Deterministic Safety Analysis and Engineering Aspects Important to Safety

Trieste, 12-23 October 2015

Assessment of External Hazards

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Topics

- External Hazards- Important aspects
- Examples: Earthquake/Tsunami
- IAEA Safety Standards
- Seismic Evaluation Methods
- Earthquakes affecting NPPs and lessons learned

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External Hazards

- External hazards originate from sources located outside of the site of the nuclear power plant. External hazards are a fundamental part of NPP siting and a reason for **exclusion of the site**. The analysis of the site area for external hazards provides the input for the NPP design.
- Examples of external hazards include:
  - Seismic hazards
  - High winds and wind-induced missiles
  - External floods
  - Other severe weather phenomena (e.g., snow, ice)
  - Off-site transportation accidents
  - Off-site explosions
  - Releases of toxic chemicals from off-site storage facilities
  - External fires (e.g. fires affecting the site and originating from nearby forest fires)

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Importance – External Hazards

- External Hazards can often be the dominant contributor to the risk of plant failure (e.g., core damage, or significant radiological release)
  - For example, seismic events (earthquakes) are a particularly severe challenge to NPPs, and typically cannot be ruled at any location for return periods of interest (i.e., up to 10 million years)

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Special Considerations and Unique Challenges in External Hazards Assessment

- High Severity – Common Cause
  - Scenarios have the potential to adversely affect many components or, often, the entire plant
    - As in the Fukushima catastrophe
- High Uncertainty
  - Experience data is often lacking
- Broad and Diverse Phenomena
  - Covers several disciplines and areas of expertise
- Some external hazards, storms, heavy winds, etc. are large contributors to the LOOP (PIE), even if no further damage is caused

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Example: External Hazard (Earthquake)

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Example: External Hazard (Tsunami)

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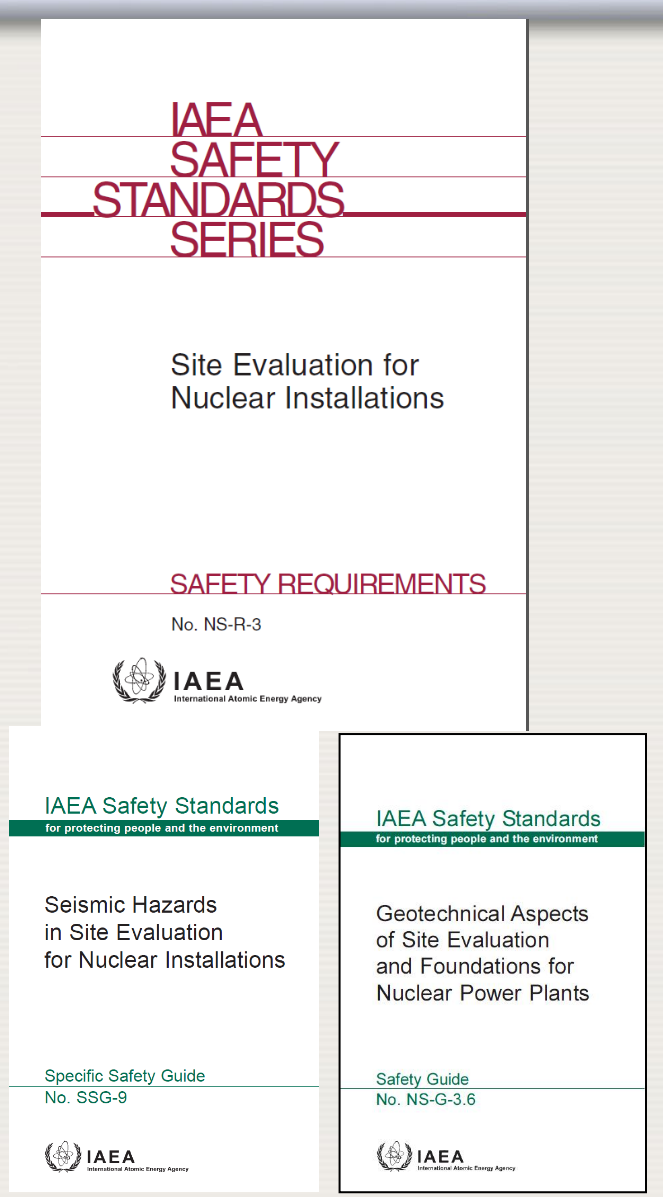
Safety Requirements for Siting (NS-R-3) Specific requirements for earthquakes

1. **Seismological, geological and geotechnical** conditions shall be evaluated.
2. **Information** shall be collected (prehistorical, historical, instrumental, etc.).
3. **Seismotectonic model** shall be performed to determine the seismic hazard.
4. **Seismic hazard assessment** shall be done taking into account seismotectonic model and site conditions. **Uncertainty** analysis shall be done.
5. Potential **surface faulting** shall be assessed.
6. A **fault is capable** if:
   a) Evidence of past movements
   b) Structural relationship with known capable faults able to produce movement at or near the surface
   c) Maximum magnitude is sufficiently large to produce movement at or near the surface.
7. Surface faulting is an **exclusion criterion**.



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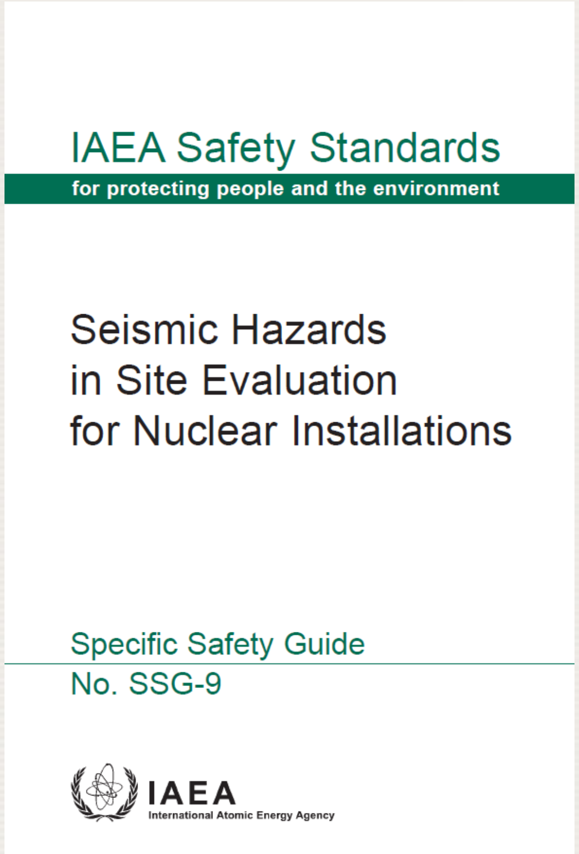
Safety Guide (SSG-9)

1. **General recommendations.**
2. **Necessary information: geological, geophysical, geotechnical and seismological database (GIS).**
3. **Seismotectonic model:** definition and characterization of seismic sources.
4. **Ground motion analysis :** parameters and ground motion models.
5. **Probabilistic seismic hazard assessment.**
6. **Deterministic seismic hazard assessment.**
7. **Potential for fault displacement :** probabilistic approach
8. **Design ground motion** (levels and definition: response spectra and time histories**).**
9. **Project Management.**


IAEA Safety Standards
for protecting people and the environment
Seismic Hazards in Site Evaluation for Nuclear Installations
Specific Safety Guide
No. SSG-9
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IAEA Safety Standards
for protecting people and the environment

Safety of
Nuclear Power Plants:
Design

Specific Safety Requirements
No. SSR-2/1

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SAFETY
STANDARDS
SERIES

Seismic Design
and Qualification for
Nuclear Power Plants

SAFETY GUIDE
No. NS-G-1.6

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IAEA Safety Standards
for protecting people and the environment

Evaluation of Seismic
Safety for Existing
Nuclear Installations

Safety Guide
No. NS-G-2.13

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Modern Seismic Evaluation Methods

- **Deterministic Approaches**
  - EPRI Seismic Margin Assessment (SMA)
    - Conservative deterministic failure margin (CDFM) approach for capacity assessment
    - Success paths approach for systems analysis
  - NRC Seismic Margin Assessment
    - Fragility analysis (FA) approach for capacity assessment
    - Simplified fault-tree approach for systems analysis
  - Full-scope, focused-scope, reduced-scope variations

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Modern Seismic Evaluation Methods

- **Principal Elements of SMA**
  - Determination of primary and alternate success paths
  - Seismic equipment list (SEL) from success paths
  - System & element selection walkdown
  - Seismic screening walkdown & anchorage review
  - Component-level seismic capacity analyses
  - Plant-level capacity assessment
    - e.g., Min-Max (Minimum component capacity in strongest success path)
- **Principal Results of SMA**
  - List of screened components
  - Component HCLPF (High-Confidence of Low-Probability of Failure) capacities
  - Plant-level HCLPF capacity

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Modern Seismic Evaluation Methods

- **Probabilistic Approach**
  - Seismic Probabilistic Safety Assessment (PSA)
    [a.k.a. Seismic Probabilistic Risk Assessment (PRA)]
    - Fragility analysis approach for capacity assessment
    - Full event-tree / fault-tree quantification
    - Full treatment of non-seismic failures and human errors
    - Point-estimate or full uncertainty analysis
      - Seismic CDF
      - Seismic large-early release frequency (LERF)

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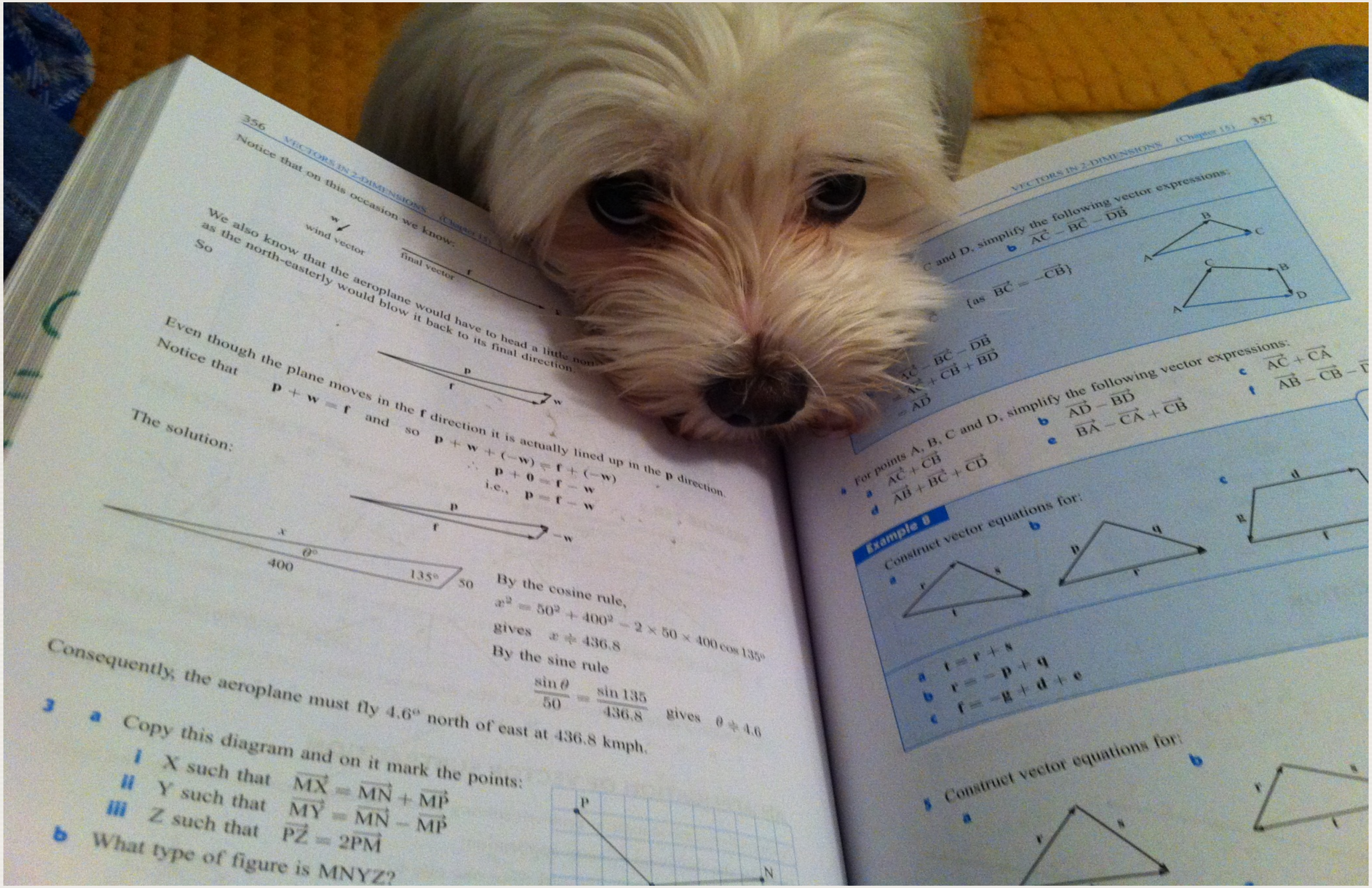
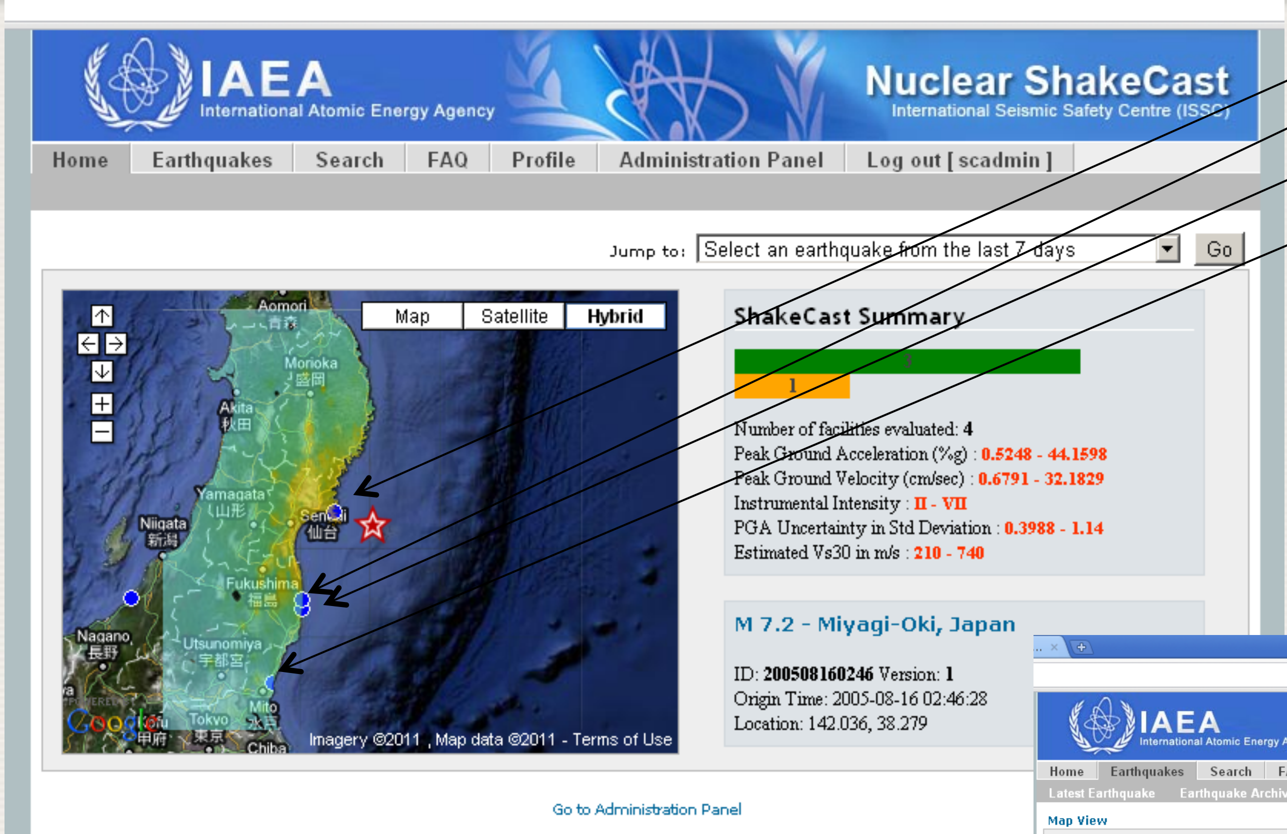
Lessons Learned & Lessons Forgotten from earthquakes affecting NPPs

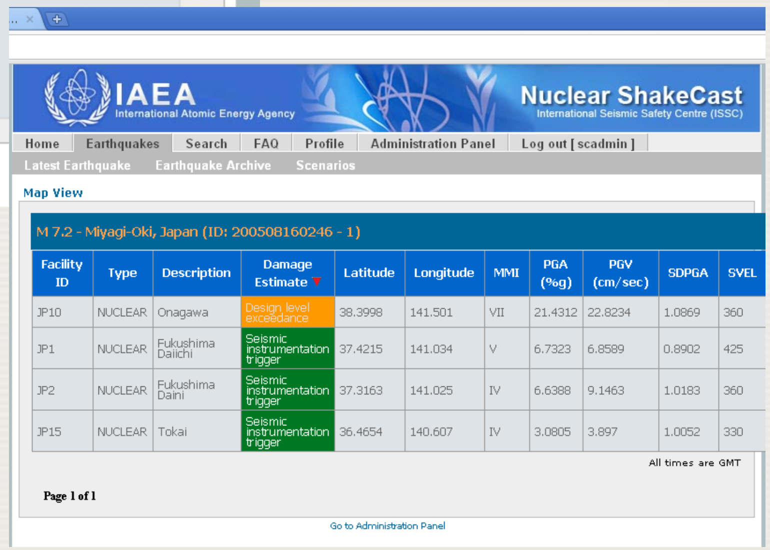


NPP sites affected by strong earthquakes

M 7.2 - Miyagi-Oki Japan: 16.08.2005



58km Onagawa
129km Fukushima Daiichi
137km Fukushima Daini
235km Tokai



M 7.2 - Miyagi-Oki, Japan (ID: 200508160246 - 1)

Facility ID	Type	Description	Damage Estimate	Latitude	Longitude	MMI	PGA (%g)	PGV (cm/sec)	SDPGA	SVEL
JP10	NUCLEAR	Onagawa	Design level exceedance	38.3998	141.501	VII	21.4312	22.8234	1.0869	360
JP1	NUCLEAR	Fukushima Daiichi	Seismic instrumentation trigger	37.4215	141.034	V	6.7323	6.8589	0.8902	425
JP2	NUCLEAR	Fukushima Daini	Seismic instrumentation trigger	37.3163	141.025	IV	6.6388	9.1463	1.0183	360
JP15	NUCLEAR	Tokai	Seismic instrumentation trigger	36.4654	140.607	IV	3.0805	3.897	1.0052	330

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Onagawa NPP (Tohoku Electric Power Co.)

Miyagi-Oki Earthquake, 2005-08-16		Situation at earthquake	First restart	Commercial Operation	Shutdown Period*
Onagawa Unit 1	BWR, 524MWe	A) 2005-08-16	2007-05-12	2007-08-01	634 days
Onagawa Unit 2	BWR, 825MWe	A) 2005-08-16	2006-01-10	2006-01-19	147days
Onagawa Unit 3	BWR, 825MWe	A) 2005-08-16	2006-03-14	2006-04-18	210 days

PO: Periodical Outage, A): Automatic Shutdown, *: Shutdown periods are from the earthquake or the shutdown to the first restart.

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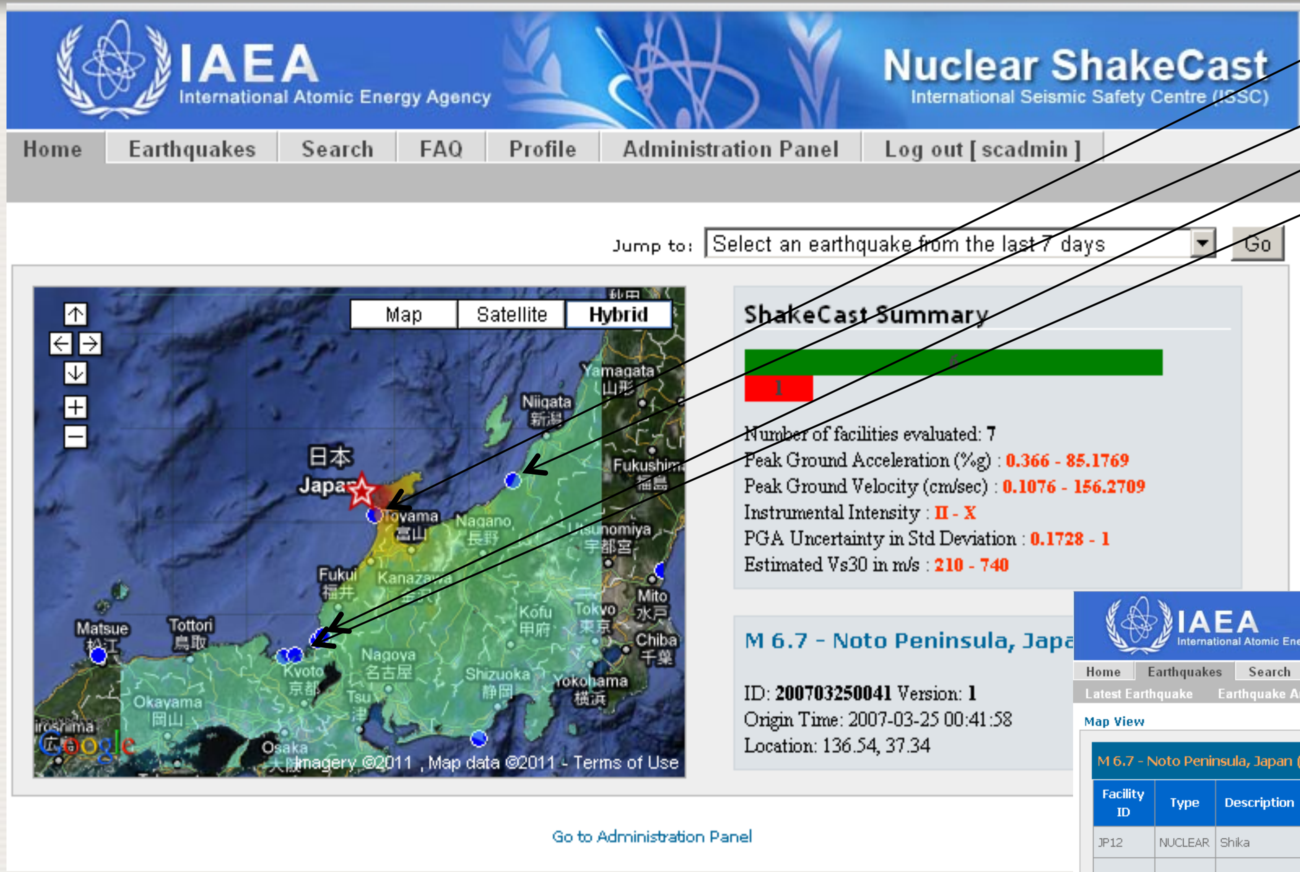
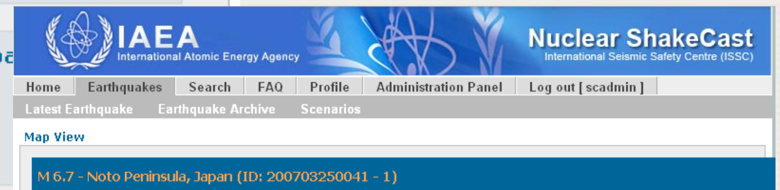
M 6.7 – Noto Peninsula, Japan: 25.03.2007



..km Shika
...km Tsuruga
..km Kashiwazaki Kariwa
...km Mhama



M 6.7 - Noto Peninsula, Japan (ID: 200703250041 - 1)

Facility ID	Type	Description	Damage Estimate	Latitude	Longitude	MMI	PGA (%g)	PGV (cm/sec)	SDPGA	SVEL
JP12	NUCLEAR	Shika	Damage expected	37.0602	136.727	VII	36.8401	38.9776	1	425
JP17	NUCLEAR	Tsuruga	Seismic instrumentation trigger	35.7505	136.023	IV	6.5263	1.92	1	360
JP7	NUCLEAR	Kashiwazaki - Kariwa	Seismic instrumentation trigger	37.4317	138.598	IV	6.5228	2.095	0.9107	360
JP8	NUCLEAR	Mihama	Seismic instrumentation trigger	35.7018	135.963	IV	6.1265	1.755	1	360
JP9	NUCLEAR	Ohi	Seismic instrumentation trigger	35.5409	135.653	IV	5.6193	1.3133	1	360
JP14	NUCLEAR	Takahama	Seismic instrumentation trigger	35.5223	135.504	IV	4.8905	0.8674	1	740
JP4	NUCLEAR	Hamaoka	Seismic instrumentation trigger	34.6242	138.14	IV	2.5971	0.9156	0.7709	360

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Shika NPP (Hokuriku Electric Power Co.)

Noto-Peninsula Earthquake, 2007-03-25		Situation at earthquake	First restart	Commercial Operation	Shutdown Period*
Shika Unit 1	BWR, 540MWe	PO)	2009-03-30	2009-05-13	736 days
Shika Unit 2	ABWR, 1206MWe	PO)	2008-03-26	2008-06-11	367 days

Shika-1 was out of operation since 2007-03-16 due to criticality accident cover-up.
Shika-2 was out of operation since 2006-07-05 due to cracks in low-pressure turbines.

PO: Periodical Outage, A): Automatic Shutdown, *: Shutdown periods are from the earthquake or the shutdown to the first restart.

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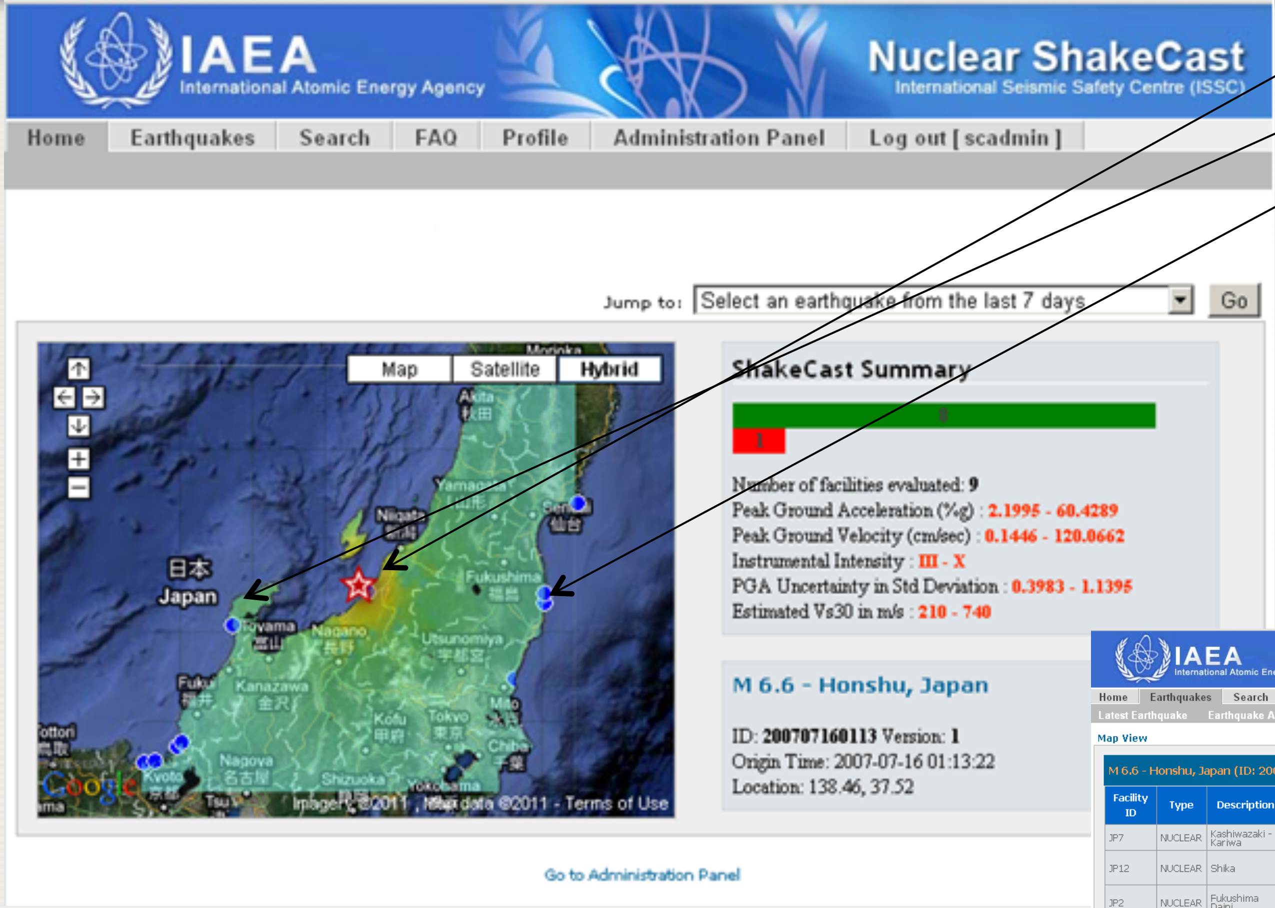
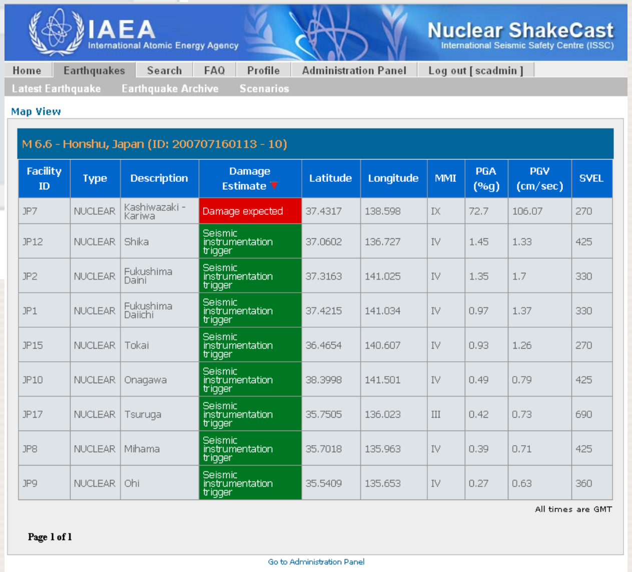
M 6.6 – Niigataken Chuetsu-Oki, Japan: 16.07.2007



18km Kashiwazaki Kariwa
161km Shika
229km Fukushima Daiichi
229km Fukushima Daini



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Map View

M 6.6 - Honshu, Japan (ID: 200707160113 - 10)

Facility ID	Type	Description	Damage Estimate	Latitude	Longitude	MMI	PGA (%g)	PGV (cm/sec)	SVEL
JP7	NUCLEAR	Kashiwazaki - Kariwa	Damage expected	37.4317	138.598	IX	72.7	106.07	270
JP12	NUCLEAR	Shika	Seismic instrumentation trigger	37.0602	136.727	IV	1.45	1.33	425
JP2	NUCLEAR	Fukushima Daini	Seismic instrumentation trigger	37.3163	141.025	IV	1.35	1.7	330
JP1	NUCLEAR	Fukushima Daiichi	Seismic instrumentation trigger	37.4215	141.034	IV	0.97	1.37	330
JP15	NUCLEAR	Tokai	Seismic instrumentation trigger	36.4654	140.607	IV	0.93	1.26	270
JP10	NUCLEAR	Onagawa	Seismic instrumentation trigger	38.3998	141.501	IV	0.49	0.79	425
JP17	NUCLEAR	Tsuruga	Seismic instrumentation trigger	35.7505	136.023	III	0.42	0.73	690
JP8	NUCLEAR	Mihama	Seismic instrumentation trigger	35.7018	135.963	IV	0.39	0.71	425
JP9	NUCLEAR	Ohi	Seismic instrumentation trigger	35.5409	135.653	IV	0.27	0.63	360

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Kashiwazaki-Kariwa NPP (Tokyo Electric Power Co.)

Niigataken Chuetsu-Oki Earthquake, 2007-07-16		Situation at earthquake	Current status	First restart	Commercial Operation	Shutdown Period*
Unit 1	BWR, 1100MWe	PO	Commercial Operation	2010-05-31	2010-08-04	1050 days
Unit 2	BWR, 1100MWe	A) 2007-07-16	Equipment test			
Unit 3	BWR, 1100MWe	A) 2007-07-16	Equipment test			
Unit 4	BWR, 1100MWe	A) 2007-07-16	Equipment test			
Unit 5	BWR, 1100MWe	PO	Commercial Operation	2010-11-18	2011-02-18	1221 days
Unit 6	ABWR, 1356MWe	PO	Commercial Operation	2009-08-26	2010-01-19	772 days
Unit 7	ABWR, 1356MWe	A) 2007-07-16	Commercial Operation	2009-05-09	2009-12-28	663 days

PO: Periodical Outage, A): Automatic Shutdown, *: Shutdown periods are from the earthquake or the shutdown to the first restart.

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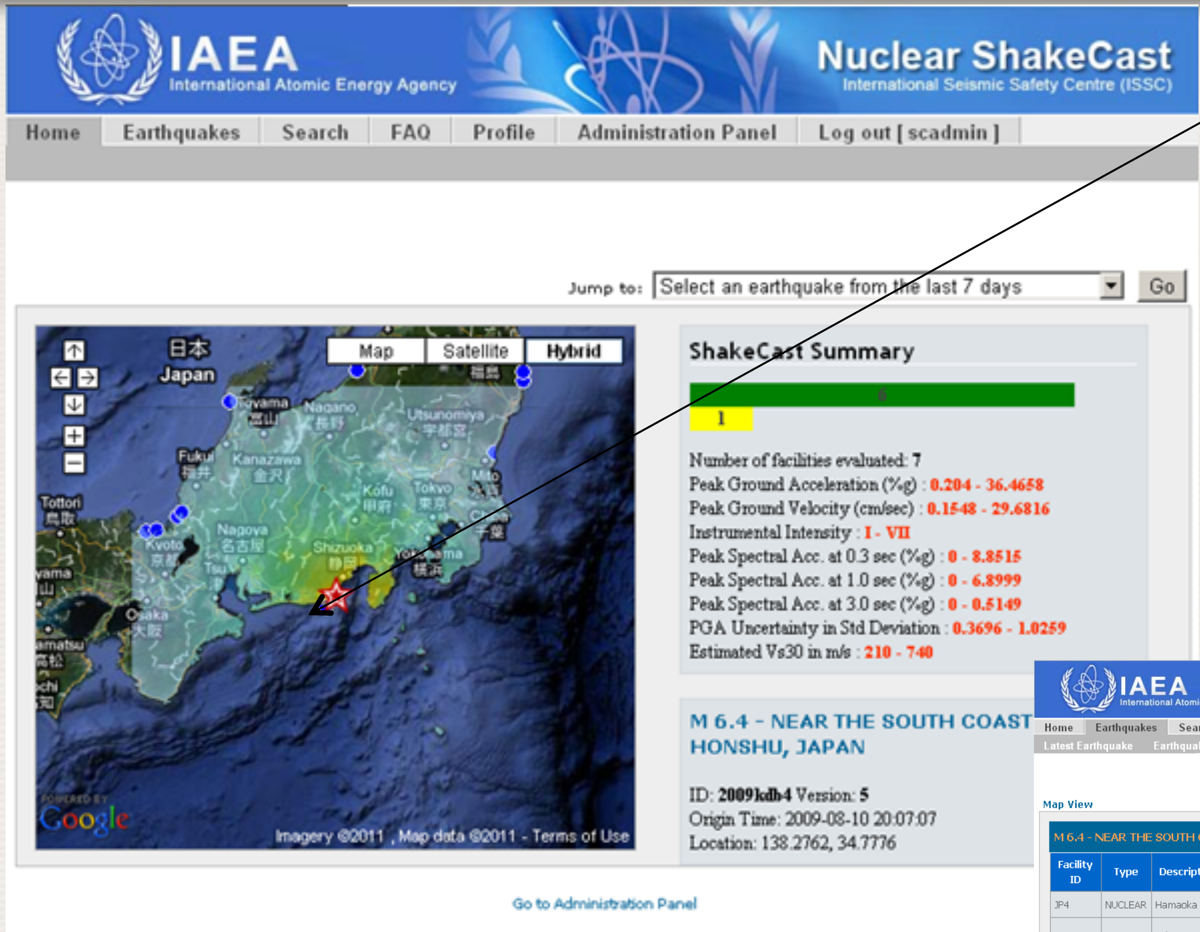
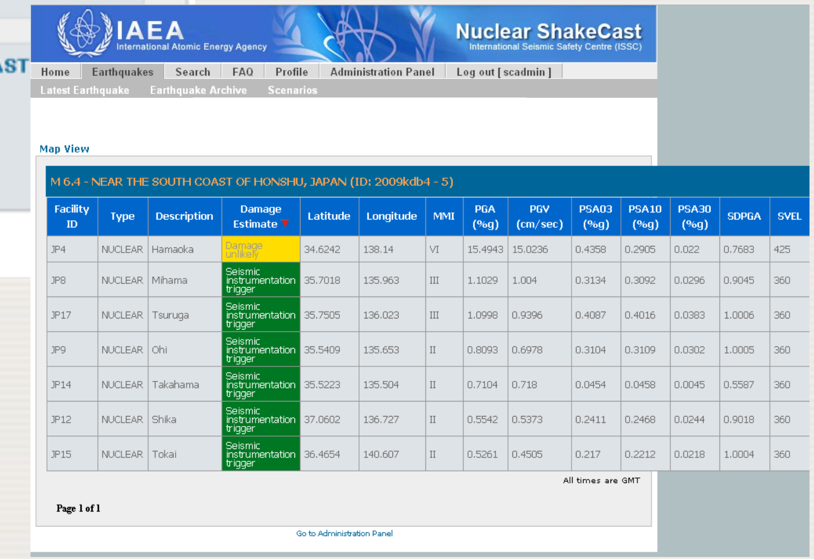
M 6.4 – South cost of Honshu, Japan: 10.08.2009

...km Hamaoka





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Map View

M 6.4 - NEAR THE SOUTH COAST OF HONSHU, JAPAN (ID: 2009kdb4 - 5)

Facility ID	Type	Description	Damage Estimate	Latitude	Longitude	MMI	PGA (%g)	PGV (cm/sec)	PSA03 (%g)	PSA10 (%g)	PSA30 (%g)	SDPGA	SVEL
JP4	NUCLEAR	Hamaoka	Damage unlikely	34.6242	138.14	VI	15.4943	15.0236	0.4358	0.2905	0.022	0.7683	425
JP8	NUCLEAR	Mihama	Seismic instrumentation trigger	35.7018	135.963	III	1.1029	1.004	0.3134	0.3092	0.0296	0.9045	360
JP17	NUCLEAR	Tsuruga	Seismic instrumentation trigger	35.7505	136.023	III	1.0998	0.9396	0.4087	0.4016	0.0383	1.0006	360
JP9	NUCLEAR	Ohi	Seismic instrumentation trigger	35.5409	135.653	II	0.8093	0.6978	0.3104	0.3109	0.0302	1.0005	360
JP14	NUCLEAR	Takahama	Seismic instrumentation trigger	35.5223	135.504	II	0.7104	0.718	0.0454	0.0458	0.0045	0.5587	360
JP12	NUCLEAR	Shika	Seismic instrumentation trigger	37.0602	136.727	II	0.5542	0.5373	0.2411	0.2468	0.0244	0.9018	360
JP15	NUCLEAR	Tokai	Seismic instrumentation trigger	36.4654	140.607	II	0.5261	0.4505	0.217	0.2212	0.0218	1.0004	360

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Hamaoka NPP (Chubu Electric Power Co.)

South cost of Honshu Earthquake, 2009-08-10		Situation at earthquake	First restart	Commercial Operation	Shutdown Period*
Unit 1	BWR, 540MWe	D (since 2009-01-30)	Not applicable.	n.a.	n.a.
Unit 2	BWR, 840MWe	D (since 2009-01-30)	n.a.	n.a.	n.a.
Unit 3	BWR, 1100MWe	PO	2009-10-01	2009-10-30	51 days
Unit 4	BWR, 1137MWe	A) 2009-08-11	2009-09-15	2009-10-16	35 days
Unit 5	ABWR, 1267MWe	A) 2009-08-11	2011-01-25	2011-02-23	532 days
Unit 6	ABWR, 1400 MWe class	New built, expected to be operational in 2020s	n.a.	n.a.	n.a.

D: Decommissioning Stage, PO: Periodical Outage, A): Automatic Shutdown, *: Shutdown periods are from the earthquake or the shutdown to the first restart.

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Lessons learned from the effect of NCO earthquake at Kashiwazaki Kariwa NPP

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The NCO Earthquake

"NIIGATAKEN-CHUETSU OKI" – MAIN SHOCK:

- **Magnitude: 6.8 I_{JMA} (6.6 Moment Magnitude)**
- **Epicentre: N37.5 , E138.6**
- **Time: 16 July 2007, 10:13(JST), i.e. 10:13 in the morning**
  National Holiday in Japan, 120 staff in plant (1000).
- **Depth: 17 km**
- **Distance to KK NPP:**
  - **Epicentre: 16 km**
  - **Hypocentre: 23 km**

Total output

8,212 MW

Biggest NPP in the world

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The NCO Earthquake

Magnitude-Shindo Number (Shindo Number in Japanese) / *Meter reading*	Effects on people	Indoor situations	Outdoor situations	Residences	Other buildings	Lifelines	Ground and slopes	Peak ground acceleration[11]
0 (0) / *0–0.4*	Not felt by all or most people.	Indoor objects will not shake.			Buildings will not receive damage.			Less than 0.008 m/s²
1 (1) / *0.5–1.4*	Felt by only some people indoors.	Objects may swing/rattle very slightly.			Upper sections of multi-story buildings may feel the earthquake.			0.008–0.025 m/s²
2 (2) / *1.5–2.4*	Felt by many to most people indoors. Some people awake.	Hanging objects such as lamps swing slightly.		Homes and apartment buildings will shake, but will receive no damage.	No buildings receive damage.			0.025–0.08 m/s²
3 (3) / *2.5–3.4*	Felt by most to all people indoors. Some people are frightened.	Objects inside rattle noticeably and can fall off tables.	Electric wires swing slightly. People can feel it outdoors.	Houses may shake strongly. Less earthquake-resistant houses can receive slight damage.	Buildings may receive slight damage if not earthquake-resistant. None to very light damage to earthquake-resistant and normal buildings.	No services are affected.		0.08–0.25 m/s²
4 (4) / *3.5-4.4*	Many people are frightened. Some people try to escape from danger. Most sleeping people awake.	Hanging objects swing considerably and dishes in a cupboard rattle. Unstable ornaments fall occasionally. Very loud noises.	Electric wires swing considerably. People outside can notice the tremor.	Less earthquake-resistant homes can suffer slight damage. Most homes shake strongly and small cracks may appear. The entirety of apartment buildings will shake.	Other buildings can receive slight damage. Earthquake-resistant structures will survive, most likely without damage.	Electricity may go out shortly.	No landslides or cracks occur.	0.25–0.80 m/s²
5-lower (5弱) / *4.5-4.9*	Most people try to escape from danger by running outside. Some people find it difficult to move.	Hanging objects swing violently. Most unstable items fall. Dishes in a cupboard and books fall and furniture moves.	People notice electric-light poles swing. Occasionally, windowpanes are broken and fall, unreinforced concrete-block walls collapse, and roads suffer damage.	Less earthquake-resistant homes and apartments suffer damage to walls and pillars.	Cracks are formed in walls of less earthquake-resistant buildings. Normal and earthquake resistant structures receive slight damage.	A safety device can cut off the gas service in some residences. Sometimes, water pipes are damaged and water service is interrupted. Electricity can be interrupted.	Cracks may appear in soft ground, and rockfalls and small slope failures take place.	0.80–1.40 m/s²
5-upper (5強) / *5.0–5.4*	Many people are considerably frightened and find it difficult to move.	Most dishes in a cupboard and most books on a bookshelf fall. Occasionally, a TV set on a rack falls, heavy furniture such as a chest of drawers fall, sliding doors slip out of their groove and the deformation of door frames makes it impossible to open doors.	Unreinforced concrete-block walls can collapse and tombstones overturn. Many automobiles stop because it becomes difficult to drive from the shaking. Poorly installed vending machines can fall.	Less earthquake-resistant homes and apartments suffer heavy/significant damage to walls and pillars and can lean.	Medium to large cracks are formed in walls. Crossbeams and pillars of less earthquake-resistant buildings and even highly earthquake-resistant buildings also have cracks.	Gas pipes and water mains are damaged. (Gas service and/or water service are interrupted in some regions.)	Cracks may appear in soft ground. Rockfalls and small slope failures would take place.	1.40–2.50 m/s²
6-lower (6弱) / *5.5–5.9*	Difficult to keep standing.	A lot of heavy and unfixed furniture moves and falls. It is impossible to open the door in many cases. All objects will shake violently.	Strongly and severely felt outside. Light posts swing, and electric poles can fall down, causing fires.	Less earthquake-resistant houses collapse and even walls and pillars of other homes are damaged. Apartment buildings can collapse by floors falling down onto each other.	Less earthquake-resistant buildings easily receive heavy damage and may be destroyed. Even highly earthquake-resistant buildings have large cracks in walls and will be moderately damaged, at least. In some buildings, wall tiles and windowpanes are damaged and fall.	Gas pipes and/or water mains will be damaged. Gas, water and electricity are interrupted.	Small to medium cracks appear in the ground, and larger landslides take place.	2.50–3.15 m/s²
6-upper (6強) / *6.0–6.4*	Impossible to keep standing and to move without crawling.	Most heavy and unfixed furniture moves and becomes displaced.	Trees can fall down due to violent shaking. Bridges and roads suffer moderate to severe damage.	Less earthquake-resistant houses will collapse or be severely damaged. In some cases, highly earthquake-resistant residences are heavily damaged. Multi-story apartment buildings will fall down partially or completely.	Many walls collapse, or at least are severely damaged. Some less earthquake-resistant buildings collapse. Even highly earthquake-resistant buildings suffer severe damage.	Occasionally, gas and water mains are damaged. (Electrical service is interrupted. Occasionally, gas and water service are interrupted over a large area.)	Cracks can appear in the ground, and landslides take place.	3.15–4.00 m/s²
7 (7) / *6.5 and up*	Thrown by the shaking and impossible to move at will.	Most furniture moves to a large extent and some jumps up.	In most buildings, wall tiles and windowpanes are damaged and fall. In some cases, reinforced concrete-block walls collapse.	Most or all residences collapse or receive severe damage, no matter how earthquake-resistant they are.	Most or all buildings (even earthquake-resistant ones) suffer severe damage.	Electrical, gas and water service are interrupted.	The ground is considerably distorted by large cracks and fissures, and slope failures and landslides take place, which can change topographic features.	Greater than 4 m/s²

KK NPP: Fire at in-house electrical transformer

The fire was extinguished by an External Fire Brigade:

- **Fire started at about 10:15 (smoke detected)**
- **Fire fighting: started at 11:30 (~75 min later)**
- **Fire extinguished at 12:10 (in ~40 min)**

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Flooding of Spent Fuel Pool in Unit 3

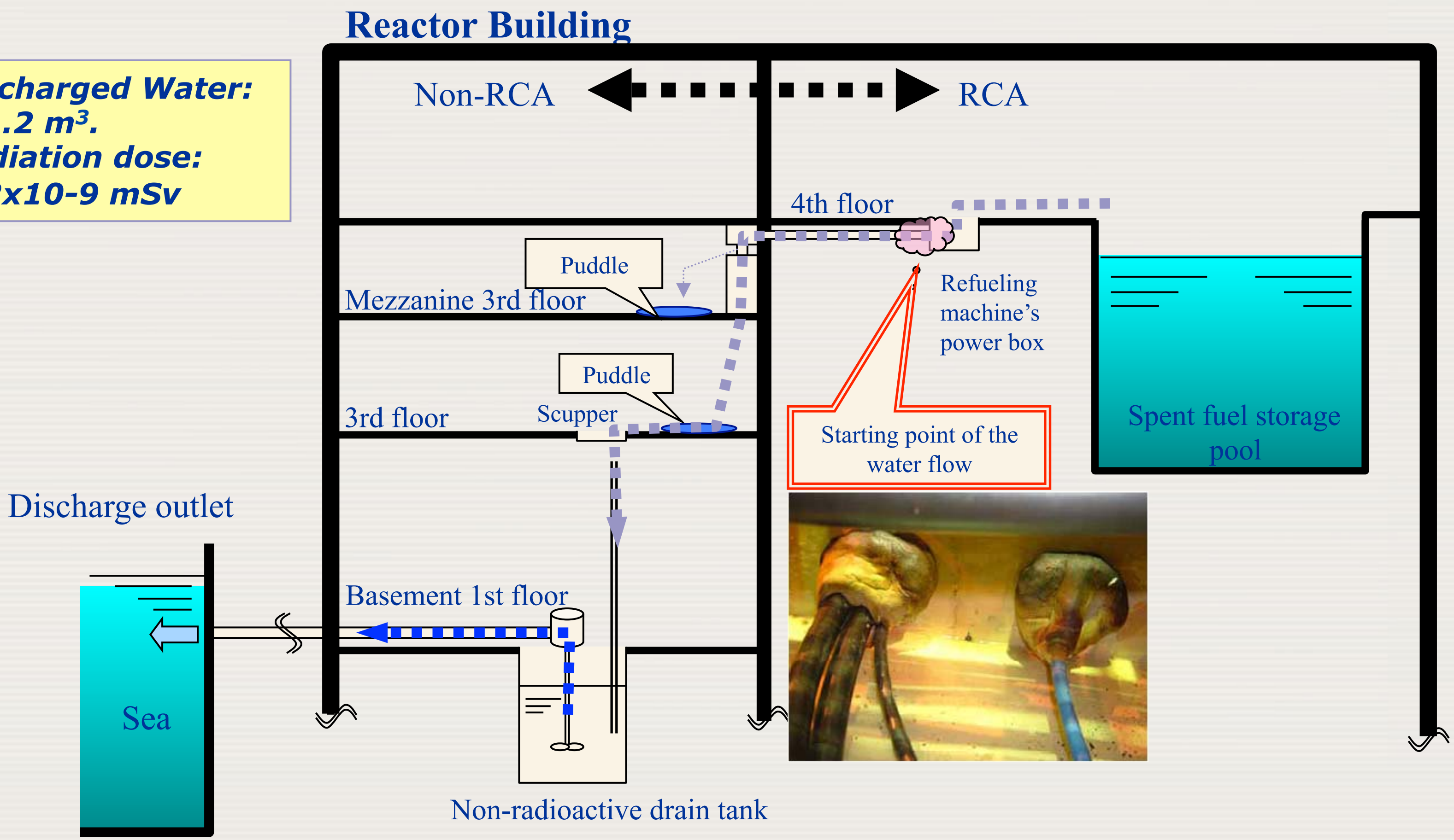
Normal Condition

During Earthquake

Plant Condition

Leakage of Radioactive Water

Discharged Water:
1.2 m³.
Radiation dose:
2x10-9 mSv



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Plant Performance

- **Satisfactory plant behaviour during and after the earthquake**
- **Fundamental safety functions preserved:**
  - **very small and insignificant releases observed**
- **Design basis (S2) ground motions largely exceeded:**
  - **Seismic Hazard: ground motions, used for estimating dynamic response, were underestimated.**
  - **Conservatism in the seismic design criteria used compensated the uncertainties in the data/methods at the time of design.**

Plant Performance

- No loss of off-site power (2 out of 4 transmission lines fully available)
- Soil failures:
  - Large. Generally, non-safety consequences
  - Fire protection piping failure led to water and soil intrusion in RB Unit 1
  - Oil leaks in several transformers.
- Fire fighting capability:
  - Water sources were lost
  - Delayed off-site fire brigade

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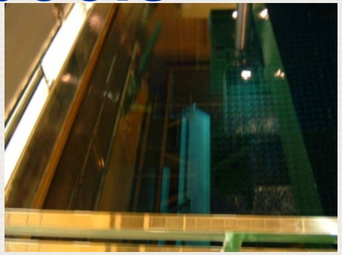
Plant Performance

- Seismic systems interaction:
  - Falling:
    - Control room ceilings Units 6, 7 and 3
    - “Temporary” platform in spent fuel pools



  - Flooding:
    - Damage of Fire suppression piping (RB 1)
    - Condenser (rubber connection failure).

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Plant Performance

- Anchorage failures (non-safety service water tanks)
- Very small radioactive releases:
  - Sloshed water leaked into non-control area, pumped into the sea. Failure of leak-tigthness of cable penetrations .
  - To air, from the exhaust fan in the turbine gland steam ventilator - operator error.

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Lessons Learned - Integrity Assessment (1)

Basic Integrity Assessment Policy:

- **A specific and integrated basic policy to investigate and assess the integrity of the NPP structures, systems and components and (SSCs) was developed by NISA using a combination of inspection and analyses.**
- **Considering that there are no international standards to be used as guidance for this development -with respect to this kind of extreme events that significantly exceed the original design basis- it was felt that the inspection plan developed to comply with the basic policy should be made available to the international nuclear community.**

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Lessons Learned - Fire Safety (1)

- Seismically induced fires are frequent events after an earthquake in urbanized areas.
- Experience from the Niigataken Chuetsu-Oki earthquake event in KK NPP, shows that seismically induced fires should be considered during the design of fire protection systems at nuclear power plants. Soil failures.
- The fire protection program should provide for reasonable fire fighting capacity to cope with this common cause, especially for multi-unit plants.
- All this experience and lessons are being reflected in the revision of current regulations in Japan as presented to the mission.
- A fire brigade is now at the site.

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The Great Japanese Earthquake on March 11, 2011

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The Great Japanese Earthquake on March 11, 2011

- Date and Time: 11 March 2011 14:46 JST (05:46 UTC)
- Magnitude: 9.0 (interim value; the largest earthquake recorded in Japan)
- Hypocenter: N38.1, E142.9 (130km ESE off Ojika Peninsula) Depth 24km (interim value)

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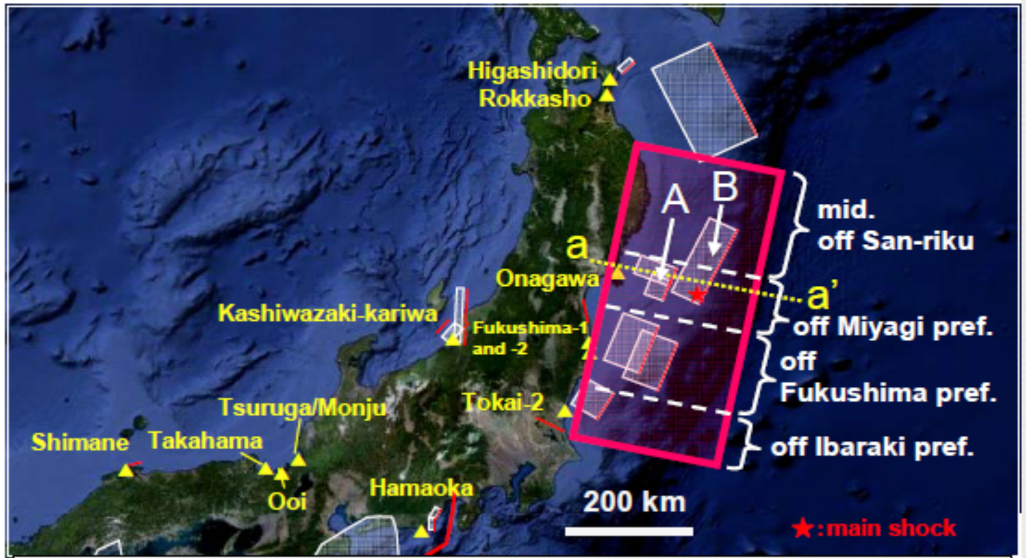
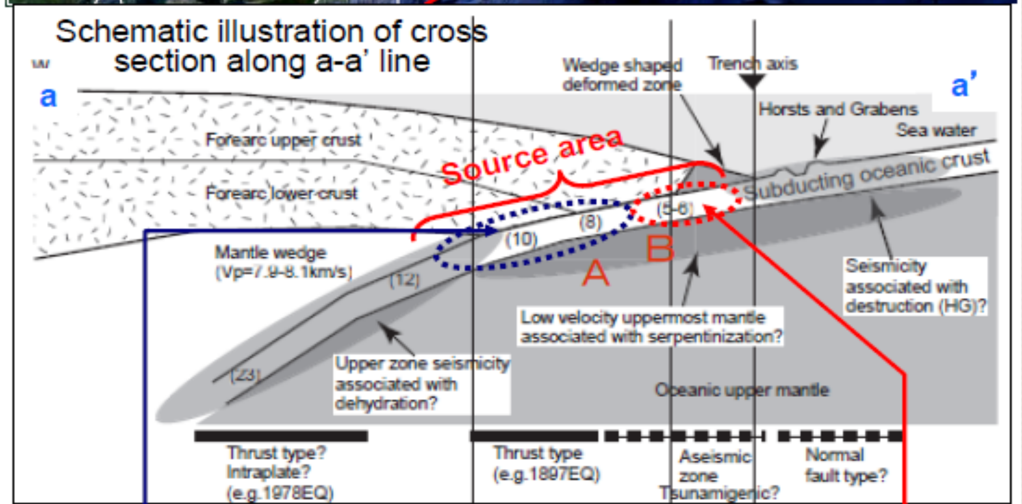
March 11, 2011 Tohuku Earthquake

■ The source area & the multi-segment rupture

- The hypocenter was located in the Off Miyagi area. It is inferred that a multi-segment rupture started from the hypocenter, then propagated to the north (the sea area off Iwate Pref.), and to the south (the sea area off Fukushima Pref. and Ibaraki Pref.).
- Rupture around the hypocenter: this quake ruptured the shallow portion along Japan trench, close to the source area of the scenario earthquakes A and B.
- Multi-segment rupture: rupture propagated to the deep part (A) as well as the shallow part east to B. (The lower figure plots a cross-sectional view of the source area)
- Large slip was estimated to occur in the shallow part along Japan trench from the water area off the Northern Sanriku to the area off the Boso, with the largest value above 20m.



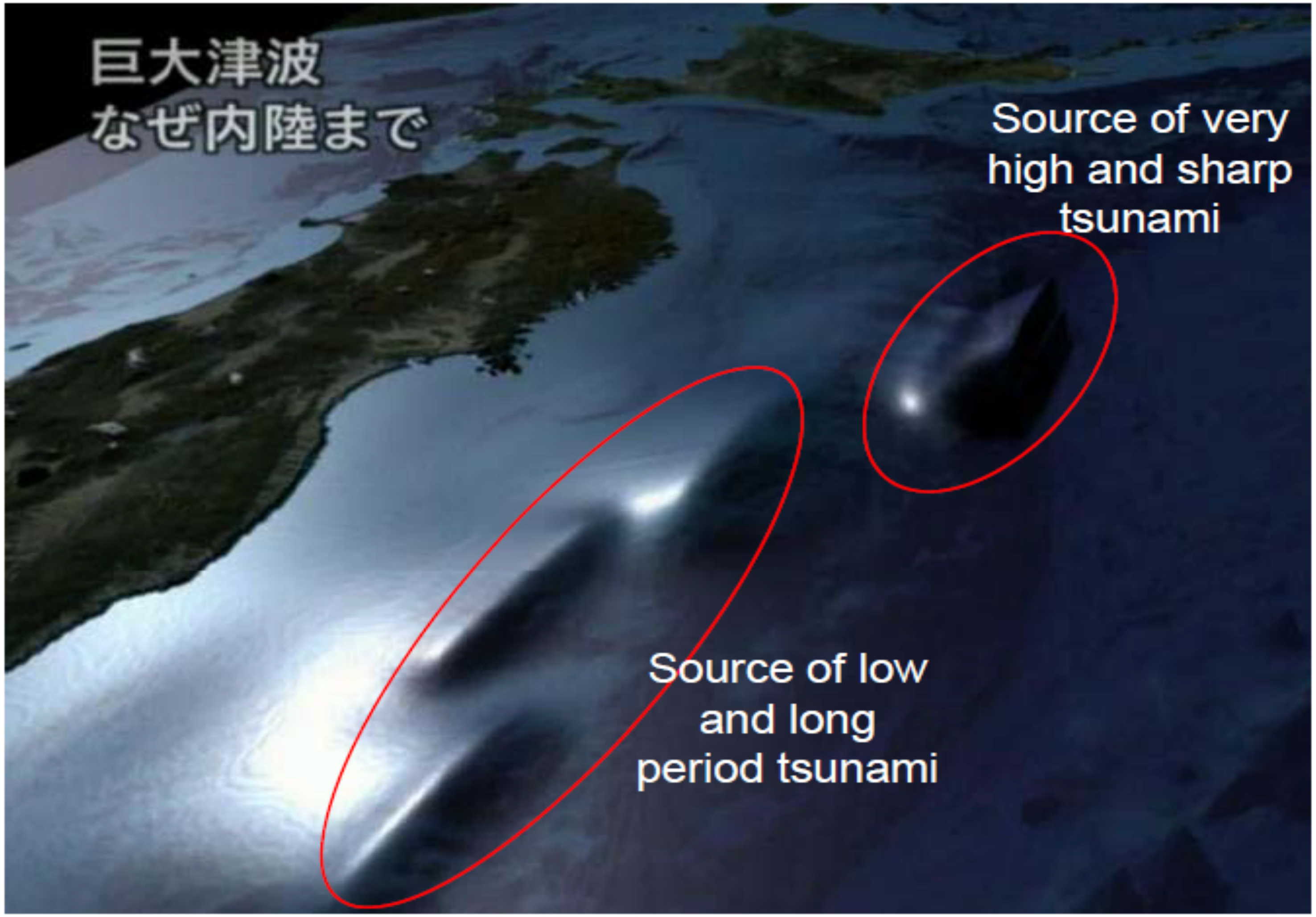


Deep potion of interplate: smaller slip than that at shallower potion and generating strong motion due to near land

Shallow potion of interplate: Large and slow slip and generating great tsunami

March 11, 2011 Tohuku Earthquake

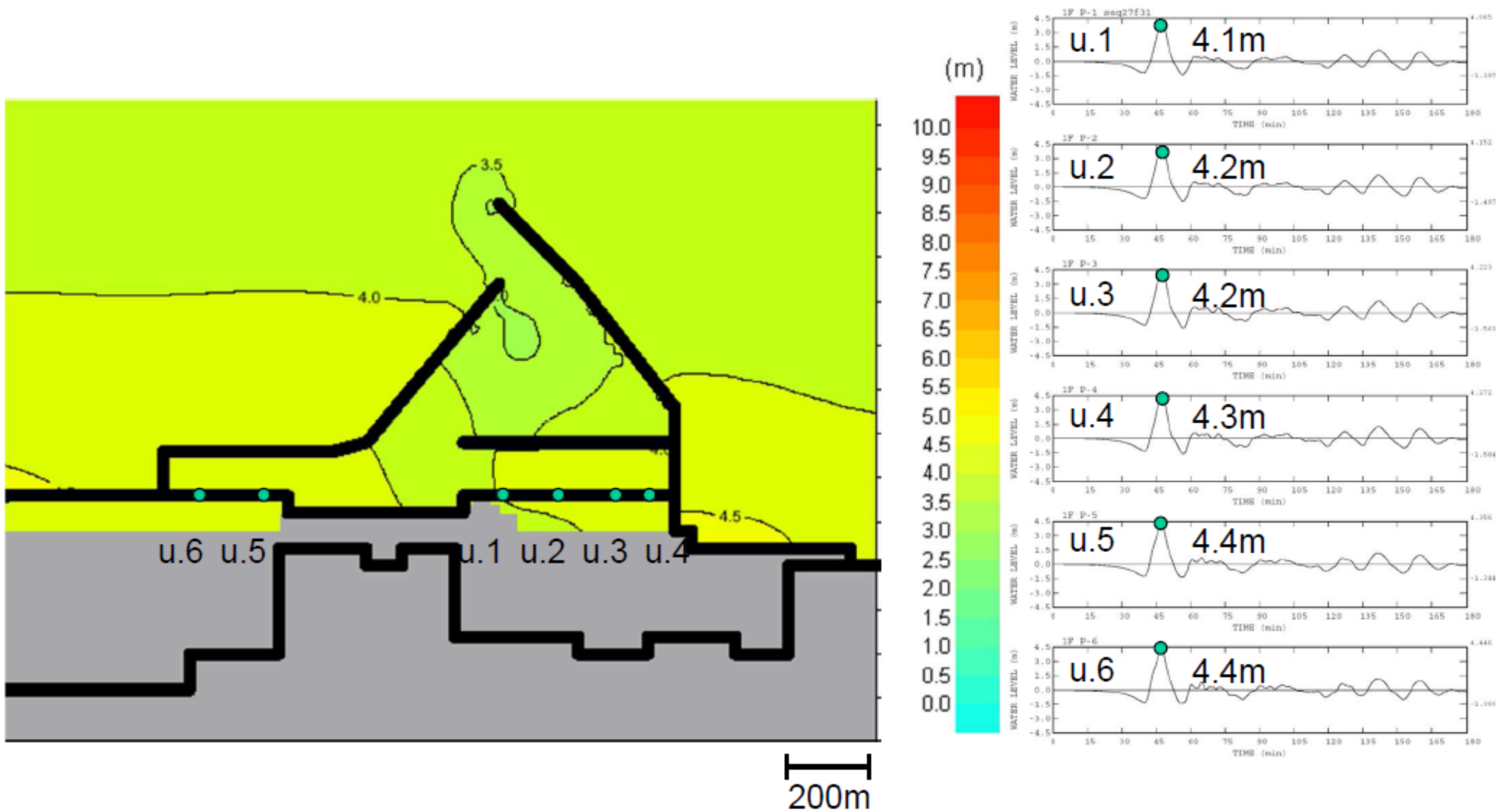
Tsunami Model by Dr.Fujii (Fuji Tokoha Univ.)



From NHK TV on May 10

Estimated Tsunami Height at Back check

Maximum Water Level by Near Field Tsunami

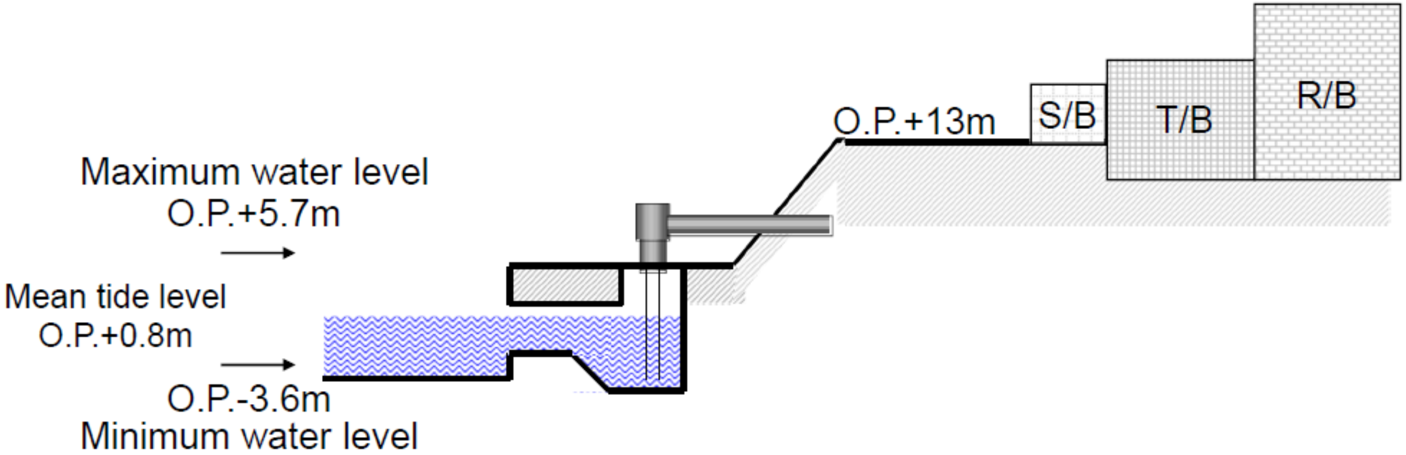


Estimated Tsunami Height at Back check

Summary of Evaluation

Maximum water level = 4.4 + O.P.+1.3 = O.P.+5.7m

Minimum water level = -3.6 – O.P.0.0 = O.P.-3.6m



Plant levels

• Fukushima Daiichi Unit 1-4	OP+10m
• Fukushima Daiichi Unit 5,6	OP+13m
• Fukushima Daini	OP+12m
• Onagawa	OP+14.8m

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Field Data Collection During Structures and Systems Walkdowns: Medium Voltage Switchgears

__Operating Status at the Time of the Earthquake__: All switchgear assemblies were energized with breakers closed on operating trains as Unit 3 was on line. Station power at 6.9-kV was retained as Unit 3 continued to be supplied through an off-site 275-kV line.

__Basis for Assuming Post-Earthquake Operability__: All switchgear was reported as undamaged and operable. As some systems have presumably not been tested since the unit has not restarted.

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Field Data Collection During Structures and Systems Walkdowns

Summary of the interviews with plant operators and technical personnel

Comments

- Evaluation of Tsunami hazard from the 869 Jougan earthquake was on going to reassessed. Nevertheless, magnitude of the 2011 Tohoku earthquake is larger than the Jougan earthquake.
- In addition, three Tsunami deposit before the Jougan earthquake were detected.
- More than 8m of the tsunami heights were observed at permanent tidal measurement stations.
- The maximum Tsunami height record is 38.9m.
- Pulse like wave form of Tsunami was recorded at offshore stations.

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Comments

- Observed motions on the base mat were close to the response of the DBGM. However, around 0.3 second of predominant period, observed motions were exceeded at some units.
- Concerning Tsunami the difference of consequence between Unit 1-4 and Unit 5-6 is remarkable, but the difference of the plant ground levels is slight as 3m. This may cause the consequence.
- Tsunami height at Onagawa NPP was 13m and it did not reach to the plant level.

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Some of the main preliminary findings and lessons learned

- The **tsunami hazard for several sites was underestimated**. Nuclear designers and operators should appropriately evaluate and provide protection against the risks of all natural hazards, and should periodically update these assessments and assessment methodologies in light of new information, experience and understanding.
- Defence in depth, physical separation, diversity and redundancy requirements should be applied for extreme external events, particularly those with common mode implications such as extreme floods.
- Nuclear regulatory systems should address extreme external events adequately, including their periodic review, and should ensure that regulatory independence and clarity of roles are preserved in all circumstances in line with IAEA Safety Standards.

Some of the main preliminary findings and lessons learned

- Severe long term combinations of external events should be adequately covered in design, operations, resourcing and emergency arrangements.
- The Japanese accident demonstrates the value of hardened on-site Emergency Response Centres with adequate provisions for communications, essential plant parameters, control and resources. They should be provided for all major nuclear facilities with severe accident potential. Additionally, simple effective robust equipment should be available to restore essential safety functions in a timely way for severe accident conditions.

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Some of the main preliminary findings and lessons learned

- Hydrogen risks should be subject to detailed evaluation and necessary mitigation systems provided.
- Emergency arrangements, especially for the early phases, should be designed to be robust in responding to severe accidents.

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CONCLUSIONS - EARTHQUAKE

- Earthquakes provide valuable “lessons learned” – the major steps of progress in earth sciences and earthquake engineering have always occurred after major earthquakes.
- For Japan, the Great Kanto Earthquake of 1923, the Kobe Earthquake of 1995, the Niigataken-Chuetsu Oki Earthquake of 2007, the Tohoku Earthquake of 2011 provided many lessons to earth scientists and engineering community and established milestones for scientific and technical progress and development.
- IAEA with the ISSC is, precisely, committed to disseminate all those lessons to the international nuclear community.

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CONCLUSIONS - EARTHQUAKE

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

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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 possibly due to conservatisms in the various steps of the design process.
- 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.

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CONCLUSIONS - EARTHQUAKE

- **At the moment, it is very difficult to separate earthquake damage from others**; i.e. tsunami, 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.

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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.

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CONCLUSIONS - TSUNAMI

- 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 tsunami hazard was underestimated.

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CONCLUSIONS - TSUNAMI

- **The <u>tsunami warning and notification system</u>, 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.**

- **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 issues have prevented this expertise to be applied to practical cases at the three NPPs affected.**

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LESSONS LEARNED - TSUNAMI

1) There is need to incorporate large safety factors to estimate tsunami run up for NPP sites.
2) 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).

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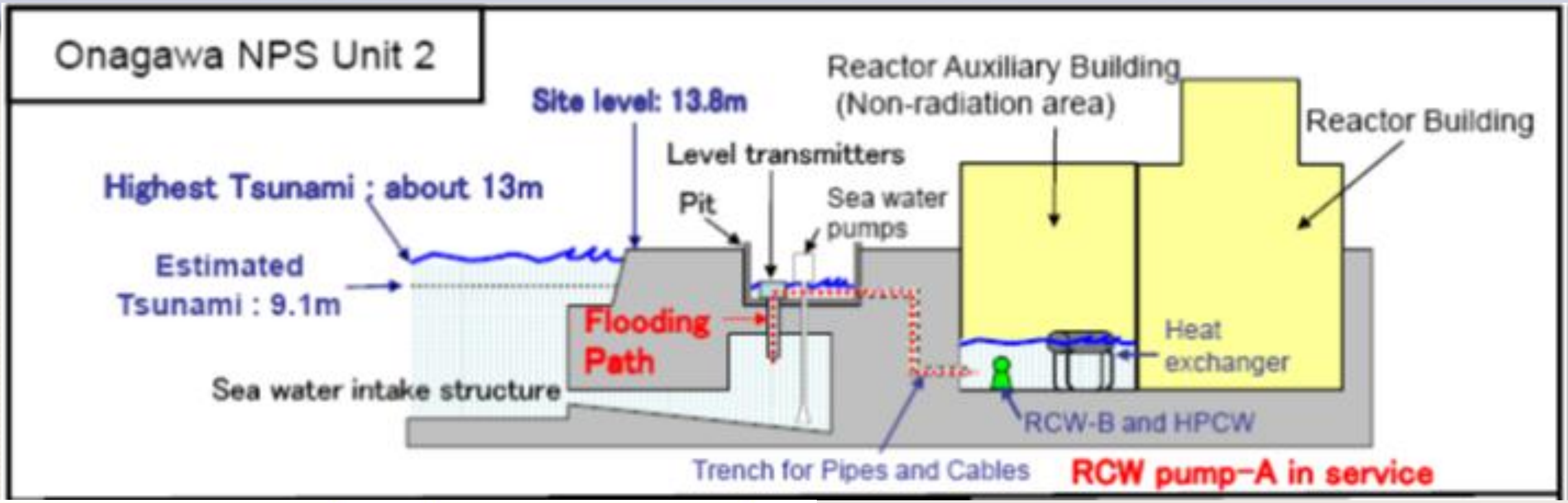
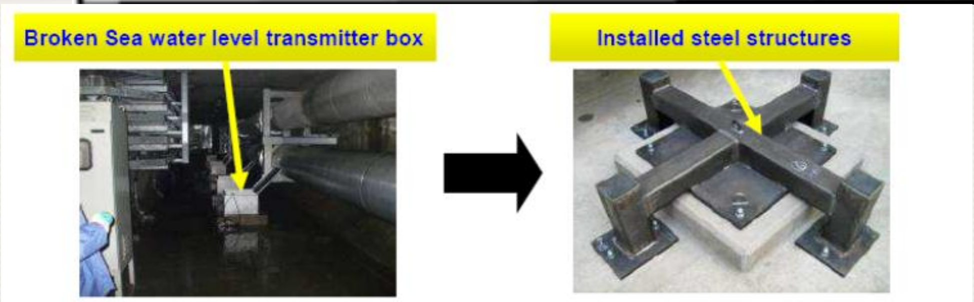
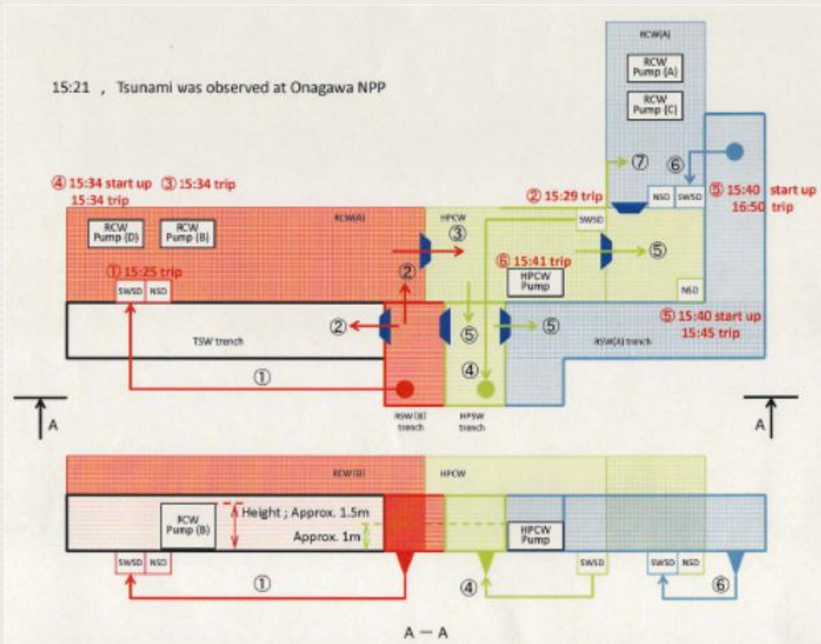
LESSONS LEARNED - TSUNAMI







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LESSONS LEARNED - TSUNAMI

2) 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 from Lessons Learned

Lessons learned from the Kashiwazaki-Kariwa experience provided extremely valuable improvements to the emergency response at all the plants.

- The so called ‘seismically isolated’ building (which is also has charcoal filtered ventilation, shielded and located at a high elevation) provided a safe haven to all plant personnel during this disaster and expedited emergency and recovery actions.
- The on site fire brigade was also extremely valuable even though there was no fire at the sites. The fire engines were used for injecting water to various structures to provide cooling.

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…Thank you for your attention

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