25 years after Chernobyl

Fukushima-1: What happened, what's the present status, and what could be the impact?

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Woudschoten Natuurkunde Conferentie

Leeuwenhorst – Noordwijkerhout

17 December 2011

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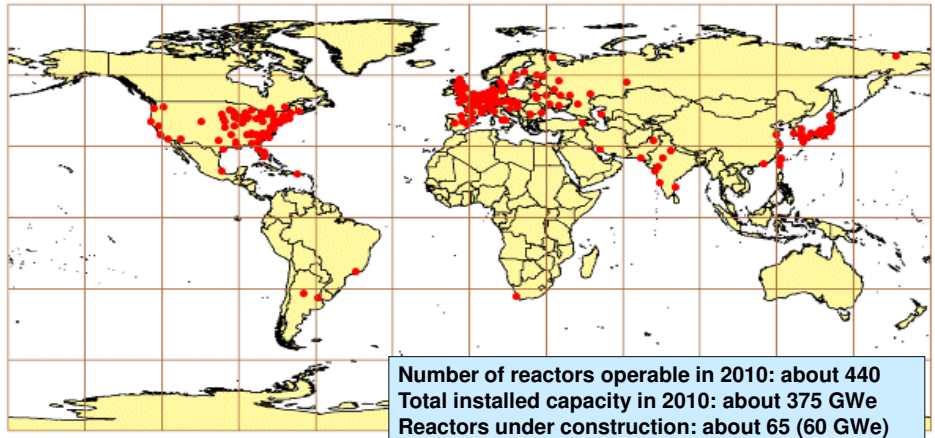
**) Ongeveer 20 sheets van deze presentatie zijn niet getoond tijdens de voordracht in Noordwijkerhout.*

Nuclear Power Sites of the World



Number of reactors operable in 2010: about 440
Total installed capacity in 2010: about 375 GWe
Reactors under construction: about 65 (60 GWe)
Generated electricity in 2010: about 2600 TWh
- about 14 % of global electricity production
- about 5 % of global primary energy demand

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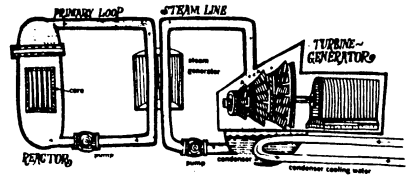
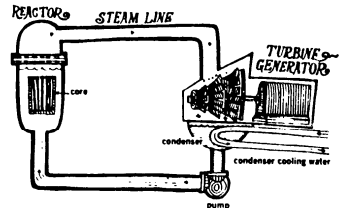
Light Water Reactors: PWR and BWR



PWR

Reactor 'Borssele' in NL



BWR

Reactor 'Doodewaard' in NL

American drawing of the principle of the PWR (above) and BWR (below)
Source: J.A. Goedkoop, 1975

Globally in 2011: about 90% of nuclear power reactors being LWR's

PWR = Pressurized Water Reactor; BWR = Boiling Water Reactor.

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Characteristics of PWR and BWR nuclear power plants

	PWR	BWR
Fuel	UO_2	UO_2
Enrichment (% U-235)	2,6	2,9
Moderator	H_2O	H_2O
Cooling medium	H_2O	H_2O
Electrical capacity (MW_e)	1150	1200
Temp. cooling medium out (˚C)	332	286
Max. fuel temperature (˚C)	1788	1829
Conversion efficiency (%)	34	34
Pressure inside reactor vessel (bar)	155	72
Specific capacity (MW_{th}/tonne fuel)	37,8	25,9

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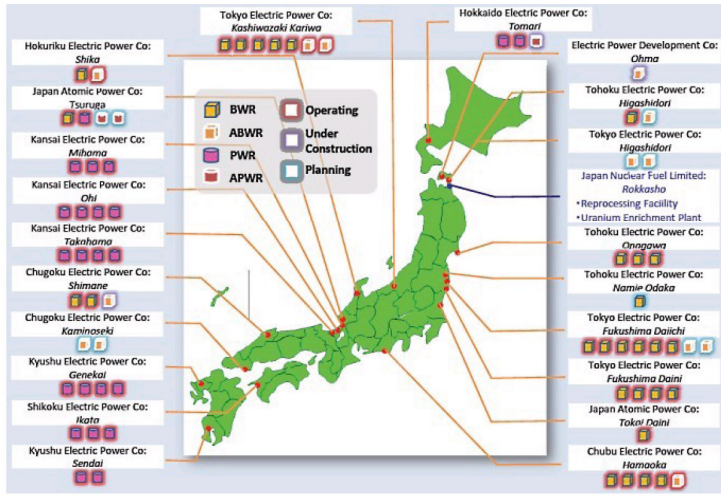
• The Boiling Water Reactor, and nuclear power in Japan

- Is het slim om kerncentrales te bouwen op een eiland als Japan?
- Is er een bouwtechnische reden waarom de reactor aan zee stond?
- Zijn er alternatieven voor de stroomvoorziening in Japan?
- Was van tevoren bekend dat de gevolgen zo groot zouden zijn?
- Zou zo'n ramp nog een keer kunnen voorkomen?
- Zou zo'n soort ramp ook in Nederland kunnen gebeuren?
- Hoe kan zo'n *kernexplosie* worden voorkomen in de toekomst?

About 30% of electricity production in 2010

Nuclear Power in Japan (February 2011)



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Source: World Nuclear Association, 24 February 2011

(28 October 2011)

Over 80% of Japan's reactors offline

"If none of the reactors restart, Japan will have no active nuclear power plants within several months".

(NHK, October 28, 2011)

- Forty-four of Japan's 54 nuclear reactors are currently idle, mainly for safety inspections *[Note WCT: At present (December 17) the number of reactors offline is 47].*
- Eighteen of them are undergoing stress tests mandated by the government. But none are expected to resume operations soon because the nuclear plant accident in Fukushima has raised safety concerns among local authorities hosting nuclear plants.
- Of the 10 reactors still running, 4 will be shut down for routine inspections by end 2011. The rest are scheduled to go offline by early 2012.

Source: JAIF (Japan Atomic Industrial Forum) / NHK (Japan Broadcasting Corporation), Friday, October 28, 2011

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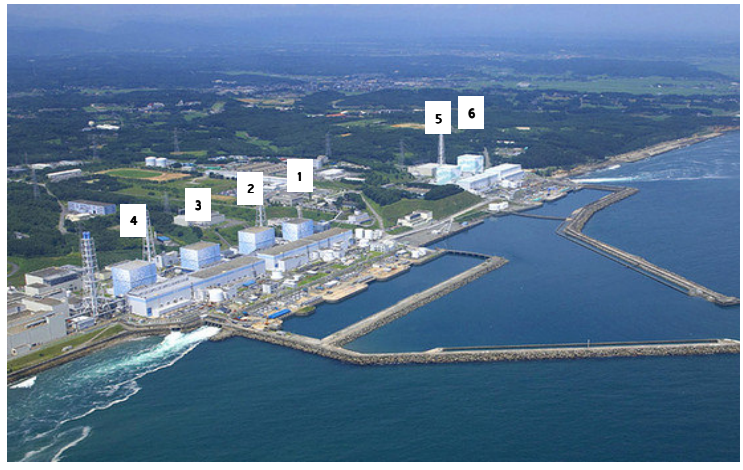
Reactors at Fukushima-1

Reactor	Type	Net capacity	Utility	Commercial Operation
Fukushima I-1	BWR	439 MWe	TEPCO	March 1971
Fukushima I-2	BWR	760 MWe	TEPCO	July 1974
Fukushima I-3	BWR	760 MWe	TEPCO	March 1976
Fukushima I-4	BWR	760 MWe	TEPCO	October 1978
Fukushima I-5	BWR	760 MWe	TEPCO	April 1978
Fukushima I-6	BWR	1067 MWe	TEPCO	October 1979

Source: World Nuclear Association, 24 February 2011

(2008)

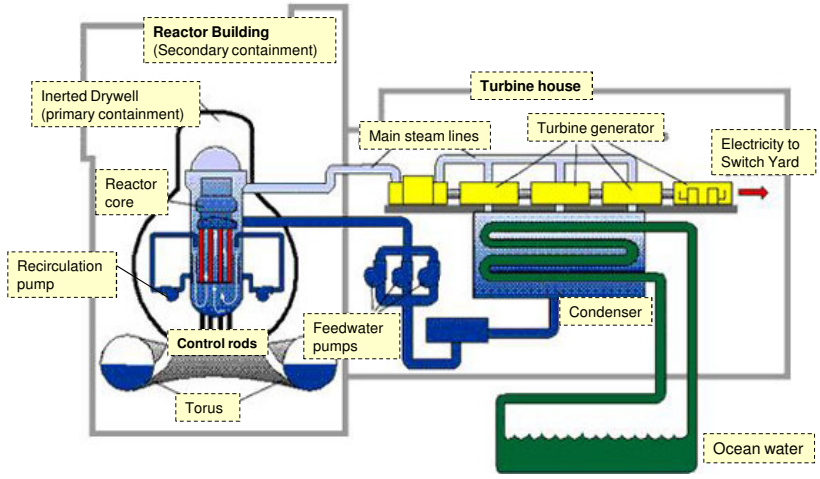
An aerial-view of the Japanese nuclear power plant Fukushima Daiichi, Japan



Zuma Press, 2008

Boiling Water Reactor, Mark I

System diagram 2



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Source: GE Reports "Imagination Daily" – accessed 9 April 2011

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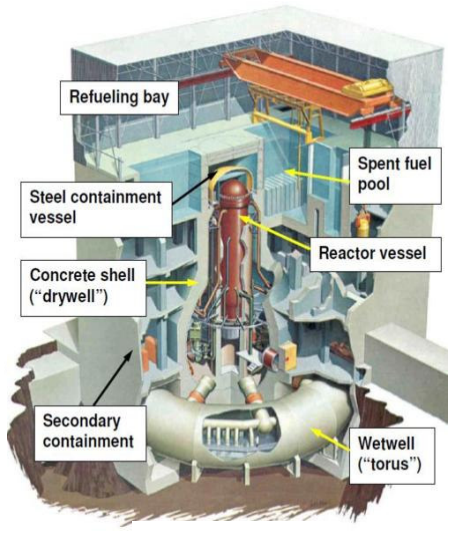
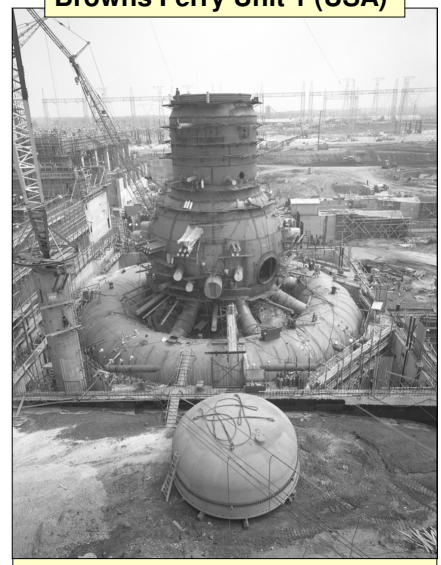
Mark I Containment



BWR/1, BWR/2, BWR/3 and some BWR/4

Browns Ferry Unit 1 (USA)



Browns Ferry Unit 1 drywell and wetwell under construction.
(a BWR/4 using the Mark I containment)

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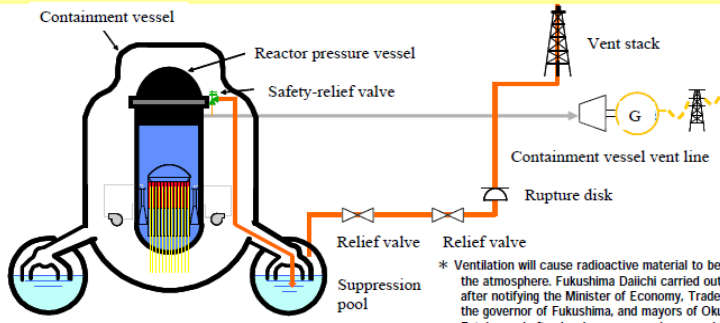
Source: FEPC
27 March 2011

How Containment Pressure is Reduced at Fukushima Daiichi NPP

•The action to gradually reduce pressure inside the containment vessel to prevent damage to the containment vessel is called ventilation (venting). The relief valves are opened to release gas from the containment vessel and then the gas is discharged from the vent stack after iodine and other radionuclides have been absorbed to some extent by the water in the pressure suppression pool. This action maintains the integrity and containment function of the containment vessel.



* Ventilation will cause radioactive material to be released into the atmosphere. Fukushima Daiichi carried out ventilation after notifying the Minister of Economy, Trade and Industry, the governor of Fukushima, and mayors of Okuma and Futaba, and after issuing a press release, and it was confirmed that local residents had been evacuated.

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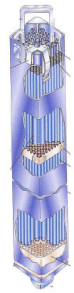
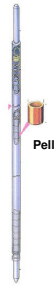
Fuel rod, fuel assembly and reactor assembly

Fuel Assembly

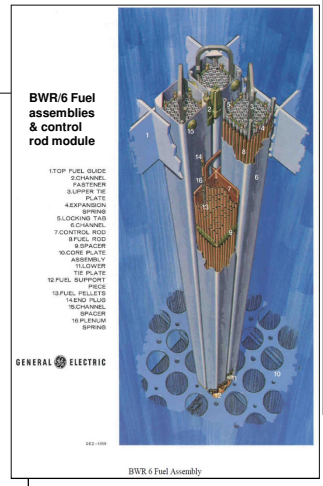
Fuel assembly



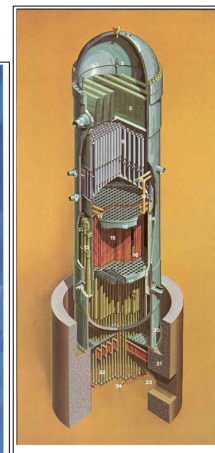
Fuel rod



BWR/6 Fuel assemblies & control rod module



BWR 6 Fuel Assembly



BWR/6
Reactor Assembly

1. VENT AND HEAD SPRAY
2. STEAM DRYER LIFTING LUG
3. STEAM DRYER ASSEMBLY
4. STEAM OUTLET
5. CORE SPRAY INLET
6. STEAM SEPARATOR ASSEMBLY
7. FEEDWATER INLET
8. FEEDWATER SPARGER
9. LOW PRESSURE COOLANT INJECTION INLET
10. CORE SPRAY LINE
11. CORE SPRAY SPARGER
12. TOP GUIDE
13. JET PUMP ASSEMBLY
14. CORE SHROUD
15. FUEL ASSEMBLIES
16. CONTROL BLADE
17. CORE PLATE
18. JET PUMP / RECIRCULATION WATER INLET
19. RECIRCULATION WATER OUTLET
20. VESSEL SUPPORT SKIRT
21. SHIELD WALL
22. CONTROL ROD DRIVES
23. CONTROL ROD DRIVE HYDRAULIC LINES
24. IN-CORE FLUX MONITOR

GENERAL ELECTRIC

BWR 6 Reactor Vessel

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Sources: Japan Nuclear Energy Society, 2005 & website General Electric (9 April 2011)

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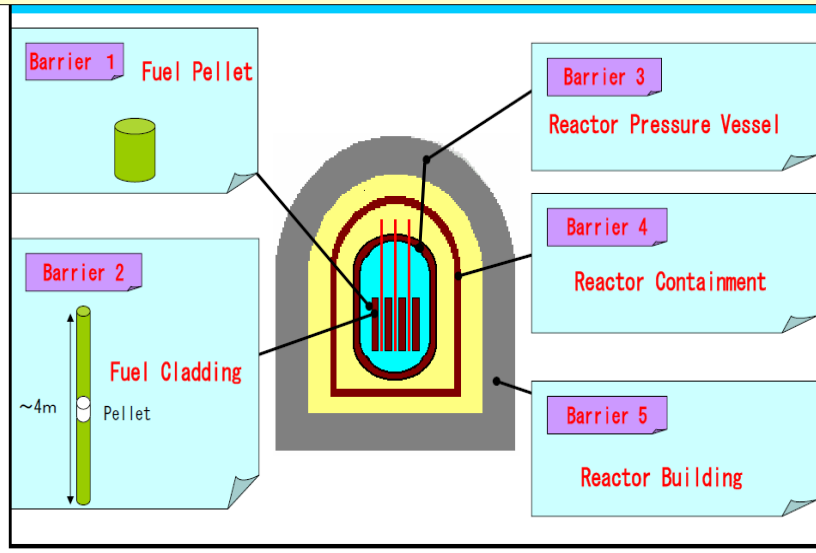
Protective Barrier for Containing Radioactivity

-Quintuple Barriers-

Source: Japan Nuclear Energy Safety organization (JNES), "Outline of Safety Design (Case of BWR)", Tokyo, Japan, 2005



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(31 March & 26 April):

"Probability nuclear disaster re-investigated"

- *"Caused by problems with the nuclear plant Fukushima-1 in Japan, all countries in the world having nuclear power plants are going to re-investigate and re-evaluate their calculation of the probability of a nuclear meltdown".* This statement was made by Piet Müskens, head of the Kernfysische Dienst (KFD) of the Netherlands (*comparable to NISA in Japan),* on March 31 during a meeting organized by the Parliament of the Netherlands about Fukushima accident. Müskens: "*I expect this item will be discussed globally. Everyone is making these calculations again*".
- Müskens reacted to questions of Diederik Samsom, a member of the Parliament, who indicated: *"In many countries it is stated that the probability of a getting a meltdown in a nuclear reactor is less than once in 100.000 years. But looking to the history, taking into account what happened in Japan, we have had 5 meltdowns in 14,000 reactor-years. This means a probability of once in 3,000 years instead of once in 100.000 years. This is a factor 30 difference. I wonder whether the promise made to the people is based on reality".*

Source: Reformatorisch Dagblad, 31 March 2011

Wim Turkenburg: *"We have had (at least) 8 meltdowns in 14,400 reactors-years; 2 in the US, 3 in Europe, and 3 in Japan. This means on average 1 meltdown in 2,000 reactor-years. Globally, 440 reactors are in operation at present. This means a high probability that a nuclear meltdown will happen again, somewhere, in the coming 25 years".*

Based on: Wim Turkenburg, De Volkskrant, 26 April 2011

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• The Earthquake and Tsunami at Friday 11 March 2011, and the Nuclear Crisis

- Wat is de oorzaak dat het fout ging?
- Waarom is hij ontploft?
- Hebben de Japanners fouten gemaakt?
- Hoe kunnen we kerncentrales bewapenen tegen natuurrampen?

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(15 September 2011)

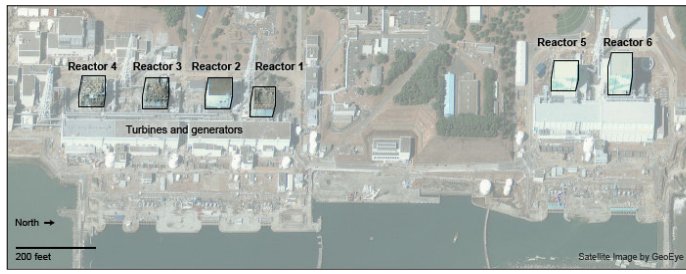
UN: *"Fukushima plant based on poor safety assessment"*

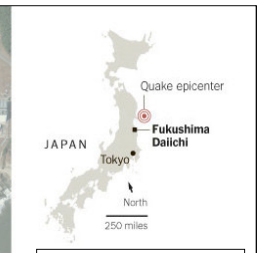
- UN Secretary General Ban Ki-moon has blamed the nuclear accident at the Fukushima-1 power plant on its design which, he says, was based on poor hazard assessments of natural disasters.
- The secretary general released a 43-page report on Wednesday, after studying the March accident with UN entities including the IAEA and the WHO.
- The report says it is necessary for nuclear power stations to strengthen their safety standards.
- It proposes the creation of a global system to allow the IAEA to internationally monitor radiation levels, citing the international impact of major nuclear accidents and emergencies.
- The report calls for an international emergency response framework in the event of nuclear accidents, to secure human health and food safety.

Source: JAIF / NHK, Thursday, September 15, 2011 16:40 +0900 (JST)

(11 March 2011)

Earthquake and tsunami at nuclear power plant Fukushima-1





Source: NYT, April 7, 2011

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Earthquakes that struck northern Japan

- **Friday, March 11, 2011**
  Magnitude: 9.0; Depth: 32 km
- **Thursday April 7, 2011**
  Magnitude: 7.1; Depth: 66 km
- **Monday April 11, 2011**
  Magnitude: 7.1; Depth: 10 km
- **Friday, August 19, 2011**
  Magnitude: 6.8; Depth: 20 km

TEPCO (*9 July 2011*): "The March 11 tsunami reached up to **13 meters** on the ocean side of the reactor and turbine buildings" (*9 April 2011: **15 m***).

The figure is far beyond the height of **5.7** meters assumed in TEPCO's risk analyses.

Sources: Kyodo News, 9 April 2011 & NHK,9 July 2011.

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Data on Tsunami's in Japan

Wave	Casualties	Date	Location	Magnitude
85 m	13,500	24.04.1771	Japan, Ryukyu Islands	7.4
38 m	26,360	15.06.1896	Japan, Sanriku	7.6
30 m	3,000	02.03.1933	Japan, Sanriku	8.4
28 m	3,000	24.12.1854	Japan, Nankaido	8.4
25 m	5,000	02.12.1611	Japan, Sanriku	8.0
17 m	31,000	20.09.1498	Japan, Nankaido	8.6
14.5 m	103	26.05.1983	Japan, Noshiro	7.7
12 m	2,144	01.09.1923	Japan, Tokaido	7.9
11 m	30,000	28.10.1707	Japan	8.4
10.5 m	5,200	31.12.1703	Japan, Tokaido-Kashima	8.2
10 m	40	07.12.1944	Japan, Off Southeast Coast Kii Peninsula	8.1
8 m	500	04.11.1677	Japan, Kashima	7.4
6.5 m	33	04.03.1952	Japan, Se. Hokkaido Island	8.1
6 m	26	23.08.1856	Japan, Se. Hokkaido Island	7.8

Source: http://www.tsunami-alarm-system.com/en/phenomenon-tsunami/phenomenon-tsunami-occurrences.html

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(5 October 2011)

Progress on improved nuclear plant seawalls

- In response to the accident at the Fukushima nuclear power plant, the government instructed the nation's power companies on March 30 to take urgent safety measures to prevent damage from tsunami.
- Hokuriku Electric Power Company started construction of a reinforced concrete seawall at the plant in Shika Town, Ishikawa Prefecture. The wall is 4 meters high, 700 meters long, and sits **11 meters** above the sea level

- 45 of the 54 reactors around the country are planning to build seawalls.
- Construction is expected to be completed as early as spring 2012, or in the next 3 years at the latest.

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Source: JAIF / NHK, Wednesday, October 05, 2011 18:54 +0900 (JST)

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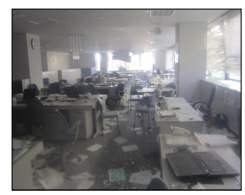
Fukushima
Fünfzehn-Meter-Welle traf Atomkraftwerk

Das Atomkraftwerk unmittelbar vor dem Tsunami

Wie die Flutwelle das Kraftwerk überschwemmt

Noch immer steht das Wasser im Kraftwerk, aber der Pegel ist gesunken



Verwüstung in der Büroetage

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FAZ.NET, 9 April 2011

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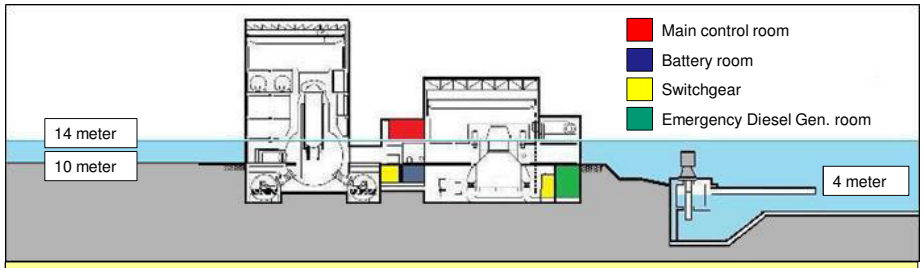
(11 March 2011)

General Elevations and Inundation Levels

The earthquake generated a series of seven tsunamis that arrived at the site starting at 15.27 h, 41 minutes after the earthquake. The first wave was approximately 4 meters high, the highest one approximately 14 m.
The tsunami inundated the area surrounding units 1-4 to a depth of about 4 meters above grade, causing extensive damage to site buildings and flooding of the turbine and reactor buildings. Intake structures at all six units were unavailable because of the damage. The damage resulted in a loss of the ultimate heat sink for all units.



The figure shows the general elevations (typical for units 1-4) and the approximate inundation level.
The grade level of units 1-4 is 10 meters above mean sea level (and 13 meters at units 5 and 6).
The intake structures were at an elevation of 4 meters for all units.

Source: INPO 11-005, November 2012

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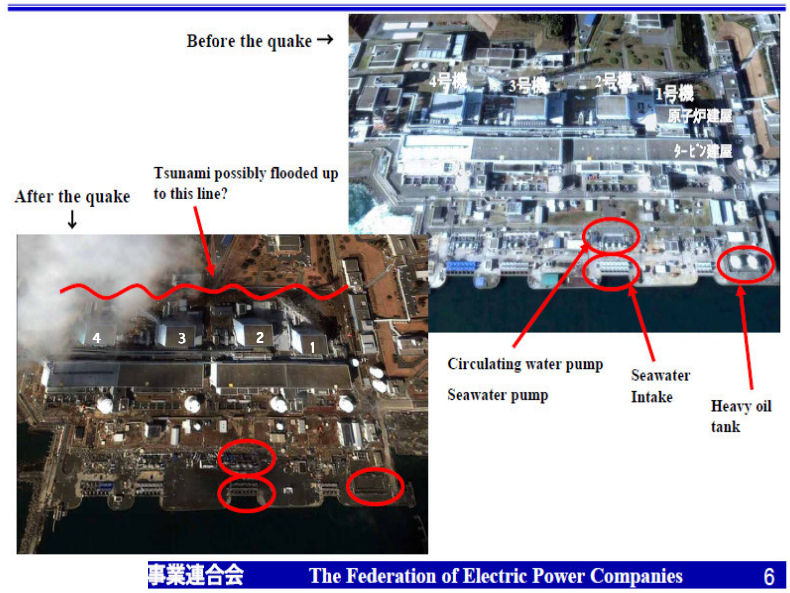
Source: FEPC
27 March 2011

27 March 2011

Current Status of Fukushima Daiichi NPP



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• What Happened with the Reactors Number 1, 2, 3, and 4 of Fukushima-1?

- Wat is de oorzaak dat het fout ging?
- Hoe is het 'gestopt'?
- Hebben de Japanners fouten gemaakt?
- Hoe komt een melt down tot stand en wat houdt deze precies in?
- Hoe erg / dodelijk is het?

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(21 April 2011)

"Fukushima accident likely caused by blackouts"

- National Nuclear Safety Commissioner **Osamu Oyamada**: ''the crisis at the Fukushima Daiichi nuclear power plant was likely caused by electricity blackouts as a result of tsunami and not by shock of the earthquake".
- Referring to accounts of the accident by the plant manager and workers, Oyamada said the reactors were apparently shut down without any hitch.
- He said the reactors and their buildings did not likely incur serious damage caused by the quake itself and that they were intact immediately after it. *[note: other view in May 2011!]*

Source: NHK, Thursday, April 21, 2011 00:34 +0900 (JST)

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(24 October 2011)

NISA: *"TEPCO did not envision such a power failure or any kind of prolonged power loss"*

- The Nuclear and Industrial Safety Agency (NISA) has made public a large portion of TEPCO's procedural manuals for nuclear accidents.
- The documents show that TEPCO had not made sufficient preparations to cope with critical nuclear accidents.
- In the March 11th tsunami, almost all electricity sources for the reactors at Fukushima Daiichi were lost.
- The documents reveal that TEPCO did not envision such a power failure or any kind of prolonged power loss. It assumed that in a serious incident, emergency power sources would be available to vent pressure in the reactor containment vessels or to carry out other safety procedures.
- NISA decided to make the manual public because transparency is necessary to find the cause of the Fukushima nuclear accident and to establish better safety measures for the future.

Source: JAIF / NHK, Monday, October 24, 2011 21:10 +0900 (JST)

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(16 May 2011)

"Quake hurt reactors before tsunami"

- High radiation readings taken in the Nr. 1 reactor building the night of March 11 suggest **it was the quake rather than the loss of cooling that critically damaged the Fukushima Nr. 1 power plants.**
- On March 11, the nuclear plant shut down automatically just after 2.46 p.m., when the magnitude 9 quake occurred. Within an hour it was hit by at least two tsunami. The external power supply then shut down, stopping the emergency cooling system at 4.36 p.m.
- Workers entered the building during the night to assess the damage only to hear their dosimeter alarms go off a few seconds later, sources of TEPCO said. Since the building was filled with highly radioactive steam, the workers decided to evacuate.
- Based on the dosimeter readings, the radiation level was about 300 mSv per hour, suggesting that a large amount of radioactive material had already been released from the core.
- "The quake's tremors may have caused damage to the pressure vessel or pipes, before the tsunami", a TEPCO official said.

Source: The Japan Times, Monday, 16 May 2011

Reactor 1

Outer building is damaged and there was a meltdown. Radioactivity has been vented and leaked. 100% of fuel rods melted, partly also through reactor vessel. Operators have trouble cooling down the reactor. Activities to prevent second hydrogen explosion, inside containment. The reactor has (had) 400 fuel assemblies and the spent fuel pool has 292.

March 11:	An earthquake sparks a tsunami. The reactor shuts down automatically, though its fuel continues to produce large amounts of heat. Due to earthquake probably breakdown cooling system. Operators shut down emergency cooling system for some time. After tsunami, backup diesel generators for running the plant's cooling systems fail. Meltdown 5 hours after the earthquake
March 12:	Operators start injecting water into the reactor to cool it. Melt down of the core. The pressure-suppression pool stops working properly. Hydrogen explosion blows the roof and top walls off the reactor building. Reactor containment vessel seems not significantly damaged. Radioactive materials, including Iodine-131, are detected. Workers start flooding the reactor with seawater in a desperate effort to cool it.
March 18:	Japanese authorities raise the assessment of severity of the accident to a **5** out of 7 on the international nuclear event scale INES.
March 19:	Pressure within the reactor containment vessel appears to be stable.
March 21:	Radioactive isotopes of cobalt, iodine and cesium are found in seawater near the discharge canal of the reactor.

Based on: New York Times (NYT), April 7, 2011, and NHK messages thereafter

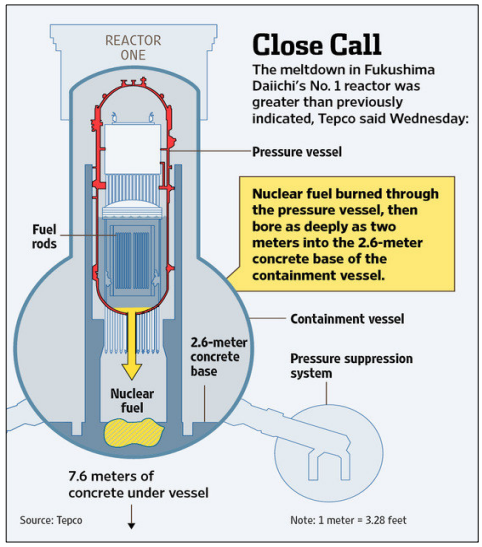
(12 March 2011)

Explosion at reactor 1 of Fukushima-1

Source: Reuters

(1 December 2011)

Reactor Core Melted Fully, TEPCO Says



- For the first time, TEPCO said that nuclear-fuel rods in the complex's No. 1 reactor had likely melted completely, burning through the pressure vessel and then boring through concrete at the bottom of a second containment vessel.
- TEPCO estimates the fuel then eroded about 65 centimeters (about two feet) deep into the 2.6-meter (8.5-foot) concrete bottom. The government model estimated the erosion at up to 2 meters.
- The molten core stopped short of reaching the vessel's steel casing, under which lies an additional 7.6 meters of concrete foundation, TEPCO said.
- *Note WCT: other sources mentioned a thickness of 1 m instead of 2.6 m*

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Source: The Wall Street Journal, December 01, 2011

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(17 May 2011)

TEPCO: Nuclear plant cooling system manually shut down

- TEPCO says workers may have manually shut down the No.1 reactor's emergency cooling system in order to prevent damage to the reactor. It says pressure inside the reactor dropped sharply from 75 to 40 atm. after the earthquake struck the plant on March 11th.
- TEPCO on Monday disclosed records of its operations at the plant. They show that the reactor automatically halted operations after the earthquake. The emergency cooling system was automatically activated but stopped about 10 minutes later and remained off for about 3 hours until after the tsunami arrived.
- The system is designed to cool the reactor even if all external sources of power are lost, but the move to shut it down temporarily means that it did not (fully) function. The decision may have been made based on a manual to prevent damage to the reactor.

Source: JAIF / NHK, Tuesday, May 17, 2011

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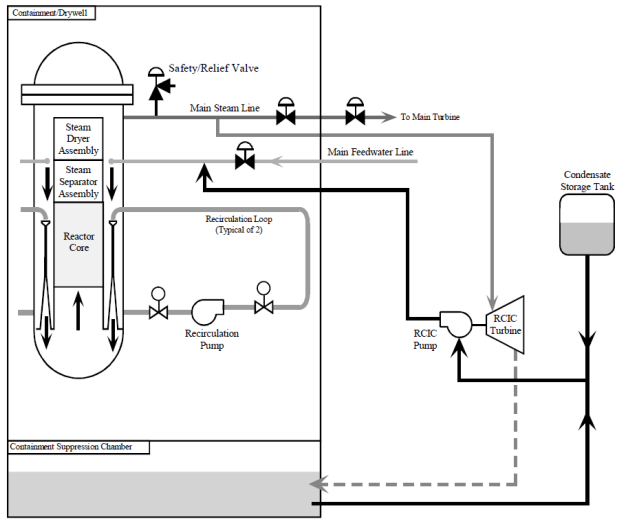
Reactor Core Isolation Cooling (RCIC)



- The reactor core isolation cooling (RCIC) system provides water to the reactor for core cooling when normal supply of water is lost.
- The system consists of a turbine driven pump, piping, and valves.
- The turbine is *driven by the steam* supplied by the main steam lines. The turbine exhaust is routed to the suppression pool.
- The turbine driven pump supplies water from the *condensate storage tank* or the *suppression pool* to the *reactor vessel* via the feed water piping.

 Source: US-NRC Technical Training Center, "Reactor Concepts Manual", Rev 0200

Universiteit Utrecht

(22 May 2011)

TEPCO didn't follow Fukushima emergency manual

- *It is highly likely that the operator of the Fukushima-1 nuclear power plant did not follow the procedures to prevent a hydrogen explosion.*
- *A failure of the cooling system causes the pressure inside the reactor's container vessel to rise.*
- *The manual calls for releasing steam from the vessel when the pressure is projected to rise to 853 kilopascals -- double the operating limit. A venting operation is necessary to prevent the vessel from being damaged, which could lead to the leakage of a large amount of radioactive substances.*
- *The pressure inside the vessel was close to the level that requires a venting operation 13 hours before the explosion occurred. But TEPCO did not start the operation until 6 and a half hours before the explosion, and the operation was carried out just one and a half hours before the blast because it was hampered by high-level radioactivity.*

 Source: JAIF / NHK, Sunday, May 22, 2011 23:18 +0900 (JST)

Reactor 2

The fuel and the reactor core severely damaged resulting in a (partial) meltdown. Some fuel may have leaked out of the reactor vessel into the primary containment vessel, which was damaged in an explosion. Broken fuel rods have been found outside the reactor, maybe from the spent fuel pool.
The reactor has 548 fuel assemblies and the spent fuel pool has 587.

March 11: An earthquake sparks a tsunami. The reactor shuts down automatically, though its fuel continues to produce large amounts of heat. Back-up diesel generators for running the plant's cooling systems fail.
March 12: Operators start injecting water into the reactor to cool it.
March 14: Water level in the reactor is found to have fallen and continues to fall over next few hours. Holes are made in the reactor building to prevent a hydrogen explosion in the reactor building.
March 15: After a (partial) meltdown of the core, an explosion was heart near the pressure-suppression pool, causing damage to the containment vessel around the reactor.
March 18: There is an uncontrolled steam release from the reactor. Japanese authorities raise the assessment of severity of the accident to a **5** out of 7 on the international nuclear event scale.
March 19: Power line from an external power substation is connected.
March 20: Fourty tons of seawater is pumped into the building to cool the spent fuel pool. March 21: White smoke starts rising from the building. Though power is partly restored, engineers discover that they do not have enough of it to fully run the cooling and pressure systems. Radioactive isotopes (cobalt, iodine and cesium) found in seawater near discharge canal.

Mainly based on: NYT, April 7, 2011 and NHK, May 25, 2011

(25 May 2011)

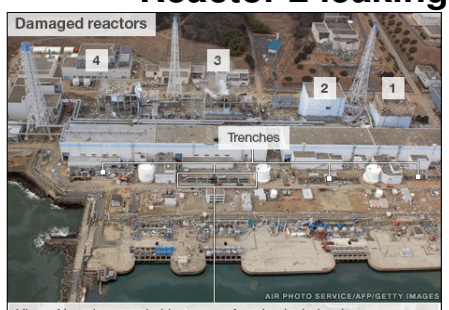
Reactor 2 and 3: meltdown, holes and cracks

- TEPCO says fuel meltdowns are believed to have occurred at the No.2 and No.3 reactors within a few days after the March 11th earthquake and tsunami.
- This is likely to have created holes and cracks at the bottom of the pressure vessels protecting the reactor cores and damaged the containment vessels.
- The utility said holes and cracks equivalent to 10 centimeters in diameter may have formed in the Number 2 reactor's containment vessel about 21 hours after the quake.
- It said a similar amount of holes could have been created in the suppression pool chamber by an explosion heard coming from there on March 15th.
- **Masanori Naito** of the **Institute of Applied Energy** says TEPCO should have been done the analysis much earlier, as it would have provided important clues to long-term cooling and other measures.

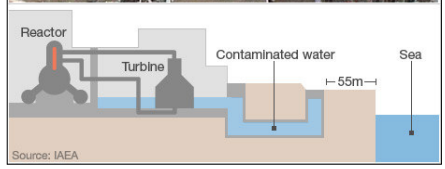
Source: JAIF / NHK, 25 May 2011

(6 April 2011)

Reactor 2 leaking radioactive water



View of trenches - probable source of contaminated water



- Radioactive water and steam has been flowing from the core into the reactor housing and through cracks in the water-filled suppression chamber beneath the reactor.
- Radioactive water in a tunnel underneath the reactor and the turbine building prevents workers from gaining access. This tunnel emerges at the front of the building as a trench, just 55 metres from the sea.
- For some days, water with high levels of radiation is leaking into the sea.
-TEPCO announced April 6 *a leak* of radioactive water had been stopped. They said engineers had injected chemical agents to solidify soil near a leaking crack, 20cm long.
- Earlier attempts to plug the leak had failed.

Based on: BBC News Asia-Pacific, 7 April 2011

***Note WCT*: July 1, about 120,000 tons high-level radioactive water had accumulated at the plant. In April 2011 about 520 tons leaked into the sea.**

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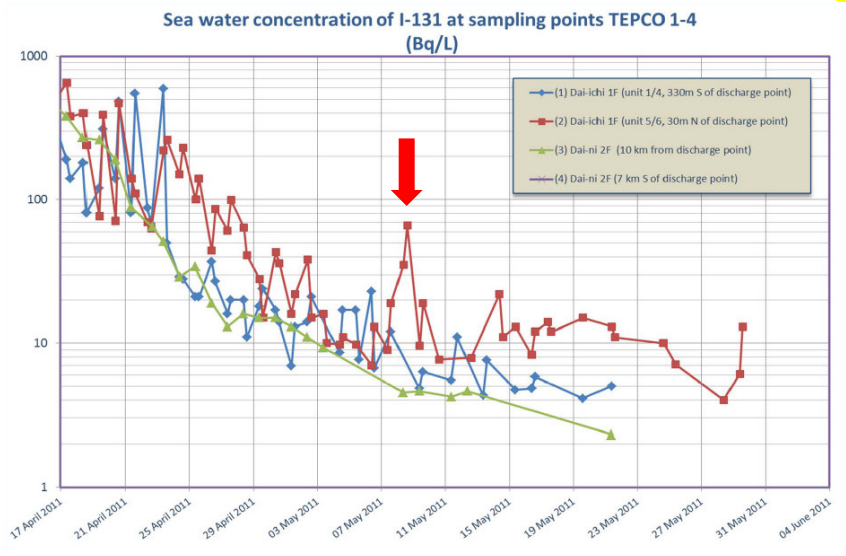
(20 May 2011)

IAEA: Status Seawater Monitoring

- The activity concentrations of I-131, Cs-134 and Cs-137 in seawater close to the Fukushima Daiichi plant at the screen of **Unit 2** have been measured every day since 2 April.
- Concentrations of Cs-134 and Cs-137 decreased from initial values of more than 100 MBq/L to less than 5 kBq/L on 7 May.
- The concentrations increased to levels of around 20 kBq/L on 16 May, and to about 10 kBq/L on 17 May.
- There was a significant increase in levels of I-131 from about 8 to 80 kBq/L from 10 to 11 May, in parallel with the increase for both radio-cesium isotopes. **This indicates that there is still some production of fission products (!!)**.
- The I-131 levels decreased to about 20 kBq/L on 17 May.

Source: IAEA, "Fukushima Nuclear Accident Update Log", IAEA website, 20 May 2011

(17 April - 1 June 2011)



Source: IAEA website, 4 June 2011

(8 December 2011)

Radioactivity in seawater and seabed: latest news

- Sea water: Small amount of radioactive substance was detected in the samples taken from the sea *off the coast*.
- Sea bed: Soil samples taken at the plant port in late November contained as many as 870,000 becquerels of cesium-137 per kg of soil and 730,000 becquerels of cesium-134 per kg of soil. Radioactive substance such as Cs, Te, Ag and Nb was detected in the soil samples taken from the seabed *beyond 30 km* off *the coast* of Miyagi, Fukushima and Ibaragi prefectures
- Marine plankton: 700 Becquerel/kg of radioactive Cesium was found in animal plankton collected in an area *3 kilometers off Iwaki City* on July. (News of Oct 15)
- Fishily: All fishermen's associations in Fukushima decided not to start fishing activities again in this year due to the fact that radioactive substance in excess of provisional standard has been continuously found in fishes caught at the coast. (News of Nov. 28)

Source: JAIF, "Environmental impact caused by the nuclear power accident at Fukushima Daiichi nuclear power station, as of December 8th, 2011"

Reactor 3

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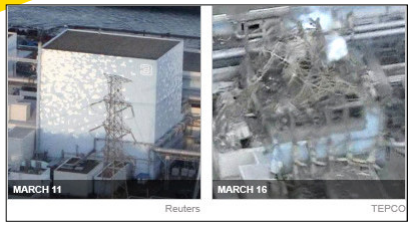

The reactor used uranium and plutonium (MOx), which may produce more toxic radioactivity. The reactor containment vessel may have been damaged and the spent fuel pool may have become uncovered. (Most?) fuel rods have been melted down.
The reactor had 548 fuel assemblies and the spent fuel pool has 514.

March 11: An earthquake sparks a tsunami. The reactor shuts down automatically, though its fuel continues to produce large amounts of heat. Back-up diesel generators for running the plant's cooling systems fail.
March 12: Operators start injecting water into the reactor to cool it. A safety valve is opened to reduce pressure and seawater containing boric acid is injected in the reactor.
March 13: Injection of water fails. Officials warn that an explosion is possible. Plant operators detect increasing levels of radioactive material.
March 14: (Partial) meltdown of the core. A hydrogen explosion damages the reactor building and the primary containment vessel. Eleven workers are injured.
March 17: Helicopters make four passes to dump water on the building in an effort to cover the spent fuel, which may have been exposed to the air. Water cannon trucks spray water on the reactor building for an hour, though it is unknown if it has any effect.
March 18: Trucks are again used to try to hose down the building and the spent fuel pool. Japanese authorities raise the assessment of severity of the accident to a **5** out of 7 on the international nuclear event scale.

Mainly based on: NYT, April 7, 2011 and NHK, May 25, 2011

Reactor 4

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Spent fuel rods in a water pool may have become exposed to air, emitting radioactive gases. An explosion and fire have damaged the building and (probably) also the spent fuel pool.
There are no fuel assemblies in the reactor; 548 were removed for maintenance and are part of 1,535 in the spent fuel pool.

March 11: An earthquake hits just off the coast, sparking a tsunami. The reactor was already shut down for maintenance.
March 14: Temperature in the spent fuel pool is 84 degrees Celsius.
March 15: A hydrogen-gas explosion, probably caused by hydrogen from reactor 3, damages the building. A fire also breaks out. Temperature in the spent fuel pool is measured to be 84 degrees Celsius (normal is 25 degrees).
March 16: A fire is reported in the building. An inspection 30 minutes later finds no sign of a fire.
March 17: The chairman of the U.S. Nuclear Regulatory Commission says the water covering the spent fuel rods may have boiled off. Engineers say the spent fuel pool appears to be leaking as water is disappearing too quickly to be only caused by evaporation.
March 20: Trucks begin spraying the building to cool the spent fuel. Trucks spray water on the building for more than an hour.
March 21: Trucks begin spraying water on the building. They finish at 8:40 AM. Workers finish laying a cable in an effort to restore power. Radioactive isotopes of cobalt, iodine and cesium are found in seawater near the discharge canal of the reactor.

Mainly based on: NYT, April 7, 2011 and WNN, 17 May 2011

(10 May 2011)

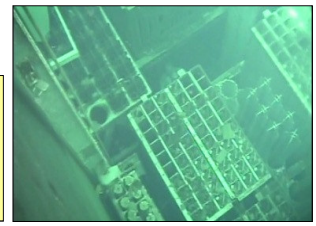
Spent fuel pool Nr 3 and 4

Pool reactor 3

Debris litters the fuel pond of reactor 3 (picture 10 May)

Pool reactor 4

There seems to be little damage to the assemblies in fuel pond of reactor 4 (picture 10 May)



- Spent fuel pools (SFP) are storage pools for spent fuel from nuclear reactors. *Typically about 12 m deep, with the bottom 4-5 m equipped with storage racks designed to hold fuel assemblies removed from the reactor.* These fuel pools are situated at the reactor site.

- In many countries, the fuel assemblies, after being in the reactor for 3 to 6 years, are stored underwater for 10 to 20 years before being sent for reprocessing or dry cask storage. *The water cools the fuel and provides shielding from radiation.*

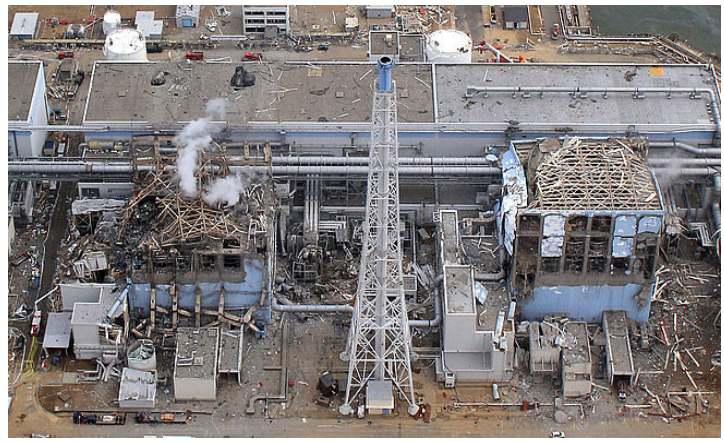
- *About 2.4 m of water is needed to keep radiation levels below acceptable levels.* The extra depth provides a safety margin and allows fuel assemblies to be manipulated without special shielding to protect the operators.

Based on: http://en.wikipedia.org/wiki/Spent_fuel_pool

Source: WNN, 10 May 2011

(5 April 2011)

At the Fukushima Daiichi nuclear plant, reactors No. 3, left, and No. 4, right, have been damaged



Source: NYT, 5 April 2011

(19 and 20 March 2011)

Trucks spraying water

19. und 20. März: Mit Wasserwerfern und Feuerwehrequipment werden die Reaktoren gekühlt. In einem 13-stündigen Einsatz hatte ein Feuerwehrfahrzeug Wasser aus dem Meer auf Block 3 gepumpt. Auf den erheblich beschädigten Block sind vermutlich mehr als 2000 Tonnen Wasser niedergegangen. Auch Block 4 wurde für zunächst etwa eine Stunde mit Wasser bespritzt. Ziel war es, den Wasserstand des Abklingbeckens mit abgebrannten Kernbrennstäben zu erhöhen. (Foto: AFP)

Source: http://www.tagesschau.de/multimedia/bilder/japan548.html

(2 August 2011)

Highest radioactivity level detected at nuke plant

- TEPCO says it has detected 10,000 millisieverts of radioactivity per hour at the plant. The level is the highest detected there since the nuclear accident in March.
- Workers of TEPCO, on Monday measured the extremely high level of radioactivity near pipes at the bottom of a duct between the No.1 and neighboring No.2 reactor buildings.
- *According to the science ministry's brochure, if a human received 10,000 millisieverts, they would likely die within a week or two.*
- The utility says the high level of radioactivity was detected because the pipes were used to vent air containing radioactive substances from the crippled No.1 reactor on March 12th.
- TEPCO, said that the level in a room on the second floor of the No.1 reactor building was 5,000 millisieverts per hour.
- The utility had detected a maximum of 1,000 millisieverts per hour outdoors in debris.

Source: JAIF / NHK, Tuesday, August 02, 2011 (JST)

4

• TEPCO Road Map to Cool Down Fukushima-1: present status

- Hoe is de situatie nu? Je hoort er zo weinig over.
- Welke maatregelen zijn er getroffen?
- Hoe vordert de bouw van de doos om de reactoren? Uit welk materiaal bestaat deze doos?
- Kan straling in de toekomst nog problemen geven als het omhulsel erom zit?
- Hoe lang duurt het voordat alle problemen bij Fukushima zijn opgelost?
- Hoe gaan ze het weer opbouwen? Gaan ze het überhaupt opbouwen?

(Sunday, 17 April 2011)

TEPCO finalizes roadmap to cool down

***IAEA**:* On 17th April, TEPCO has issued a "**Roadmap towards Restoration from the Accident at the Fukushima Daiichi Nuclear Power Station**". The roadmap outlines **63 measures to be taken in two steps over a period of six to nine months**. TEPCO declared they will "make every effort to enable evacuees to return to their homes and for all citizens to be able to secure a sound life".

Source: IAEA, 18 April 2011

The operator of the crippled Fukushima-1 nuclear power plant has finalized a roadmap to cool down the troubled reactors in 6-9 months

1) ***In 1st phase***, TEPCO will install a new cooling system. It plans to first pump contaminated wastewater outside the turbine buildings where it is cooled (*air cooling*) and filtered. Radioactive substances and salt are removed and a continuous supply of treated water is circulated to gradually cool down the reactors.
TEPCO is scheduled to start operating the new cooling system by summer 2011.

2) TEPCO will contain radioactivity leakage from reactor(s) by patching the damaged section(s).

3) ***In 2nd phase***, TEPCO plans to lower the temperature of the fuel in the reactors to below 100 C to stabilize its condition (*April 17: 1=200 C; 2=150 C; 3=120 C*).

4) The firm also plans to cover the reactor buildings with giant covers with filters to prevent the release of radioactive substances into the air.

Source: NHK, Sunday, April 17, 2011

(20 July 2011)

TEPCO is now moving to Step 2

Documents for restoration show that TEPCO has met the conditions of **Step 1**, summarized as 'stable cooling' on schedule.

It is now moving to **Step 2**, described as 'more stable cooling'. This covers in a three to six month period:

1. *Cold shut down.*
2. *Ensuring the robustness of water injection and treatment facilities.*
3. *Installation of heat exchangers for the used fuel ponds of units 1 and 4.*
4. *A detailed investigation of groundwater conditions, and preventing a release of contaminated water to the ocean.*
5. *Expansion of water treatment and management of the sludge produced.*
6. *Installation of the cover on unit 1.*
7. *Removal of debris from the roofs of units 3 and 4.*
8. *Beginning 'full-fledged' decontamination.*

Source: World Nuclear News (WNN), 20 July 2011

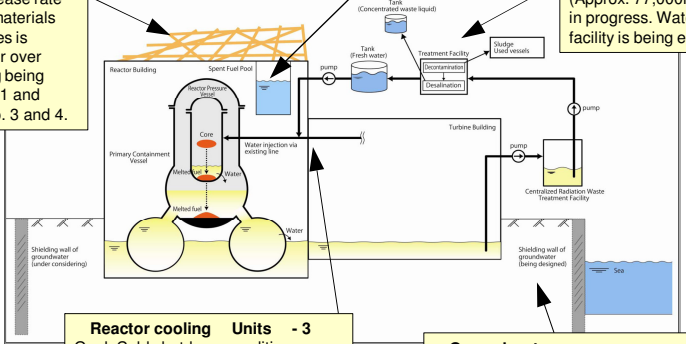
(27 October 2011)

Overview of the status of countermeasures at Fukushima-1, Unit 1-4

Radioactive materials in the atmosphere / soil
Goal: Mitigation of dispersion of radioactive materials.
Status: The release rate of radioactive materials from the facilities is declining. Cover over reactor building being installed for no.1 and designed for no. 3 and 4.

Spent Fuel Pool cooling (Unit 1-4)
Goal: More stable cooling (achieved).
Status: Circulation cooling with heat exchanger and desalination of pool water in progress.

Accumulated water
Goal: Reduction total amount of contaminated water.
Status: Treatment of high level radioactive wastewater (Approx. 77,000m3 [Oct.25]) in progress. Water treatment facility is being enhanced.



Reactor cooling Units - 3
Goal: Cold shutdown condition.
Status: Circulating injection cooling in progress (Further diversification of the core injection system is being planned).

Ground water
Goal: Mitigation of contamination in the ocean.
Status: Monitoring the radioactive materials in the groundwater. Design of shielding wall completed.

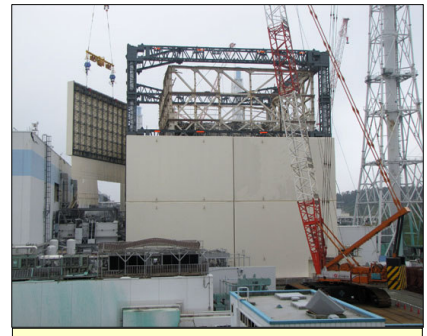
Source:
JAIF website,
October 27, 2011

(12 & 19 September 2011)

Current state of enclosure around unit 1

Picture: Kyodo News

TEPCO has finished the steel framework for the heavy-duty plastic enclosure around reactor building 1. Completion of the structure to seal off the atmosphere from any possible unit 1 airborne releases, is scheduled for the end of October. Once unit 1 is "wrapped up", work will begin to provide units 3 & 4 with the same sort of enclosure.



September 19, The Japan Times posted a picture of the current state of construction on the enclosure around the unit 1 reactor building. TEPCO expects to be finished by mid-late October.

Copernicus Institute

Source: www.hiroshimasyndrome.com/fukushima-accident-updates.html (Updates 12 & 19 September 2011)

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(17 October 2011)

Polyester covering installed at No.1 reactor

- A covering of thick polyester sheets has been attached to steel frames at the damaged No.1 reactor building at the Fukushima Daiichi nuclear plant. TEPCO plans to complete the covering and verify its effectiveness by the end of October.
- The work which began in late June is designed to decrease the release of radioactive materials into the air.
- The utility company will conduct a test-run to see how the system captures radioactive materials from the building with a filter.
- TEPCO estimates **the system should be able to remove about 90 percent of the radioactive materials**.
- TEPCO is considering installing covers on the No. 3 and 4 reactors which were also damaged.

Copernicus Institute

Source: JAIF / NHK, Monday, October 17, 2011 05:54 +090-0 (JST)

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(28 September 2011)

3 Fukushima reactors cooled below 100 degrees

- Temperatures at the Number 1 and 3 reactors have been maintained below 100 degrees Celsius since August.
- TEPCO says the temperature in the lower area of the Number 2 reactor stood at 99.4 degrees at 5 PM on Wednesday, September 28.
- The utility says its cooling efforts have achieved results although it is too early to say that it has attained a state of cold shutdown for all 3 troubled reactors.
- **Cold shutdown** is a state where *temperatures below 100 Celsius are sustained* and *the situation remains stable.*
- The utility now says it is important to ensure a reliable cooling system to achieve cold shutdown.

Source: JAIF / NHK, Wednesday, September 28, 2011 20:23 +0900 (JST)

(14 December 2011)

Gov't to declare cold shutdown at Fukushima plant

- The Japanese government will declare December 16 that a state of *cold shutdown* has been achieved for all the reactors at Fukushima-1.
- The announcement will mean the achievement of the second phase of the road map to bring the plant under control. The government has now confirmed that all the conditions are met.
- It says *temperatures* at the bottom of the reactor pressure vessels and inside the containment vessels have basically fallen below 100 degrees Celsius.
- The amount of *radioactive materials emitted* has also dropped, with radiation levels on the compound's border falling below 1mSv/year.
- The government says stable *circulatory cooling of the reactors* can be achieved with contaminated water, as alternative methods have been secured against malfunctions or accidents.
- The gov't will also release a *medium-to-long term timetable* which includes decommissioning, and helping residents to return home.

Source: JAIF / NHK, Wednesday, December 14, 2011 08.43 +0900 (JST)

(15 December 2011)

Still major challenges at Fukushima-1

Many problems and questions remain after announcement *cold shut down*:

1) Radiation levels are too high to get close to the reactors; as a result "we don't know what is happening inside the plant" – therefore we don't know the exact temperatures inside the reactors.
2) The unknowns are so great that authorities aren't sure how to start tackling some of the biggest problems, which include *locating and stopping the flow of toxic water* and *removing the melted nuclear fuel.*
3) Fukushima Daiichi is hemorrhaging enough radiated water each month to fill four Olympic-size swimming pools. "There's not enough land to store the radioactive water inside the plant compound".
4) Bits of highly radioactive debris and dust around the compound could still be scattered by wind and rain.
5) Another urgent challenge is keeping the complex's vulnerable reactors protected and separated from the outside world. TEPCO commissioned a vinyl covering for unit 1. "The whole structure will likely need to be replaced with something more robust in a few years".

Source: The Wall Street Journal, 15 December 2011

(16 December 2011)

Plant decommissioning to take 40 years

- With a condition of cold shutdown achieved, the focus now shifts to scrapping the crippled reactors of the Fukushima-1 plant, after removing the melted nuclear fuel. The job may take up to 40 years.
- The industry ministry and TEPCO have drawn up a new timetable to decommission the reactors.
- Under the plan, workers will remove *spent nuclear fuel rods* from a pool at the No.4 reactor within 2 years.
- *Melted nuclear fuel* inside reactors Nos.1, 2 and 3 is due to be recovered within 25 years.
- *Work to scrap the reactors* and the outer buildings would then proceed, with completion expected in 40 years at most.
- All these challenges are unprecedented in human history. Workers would have to pinpoint breaches in the reactor containment vessels and repair damage while dealing with massive continuous outflows of radioactive water.

Source: JAIF / NHK, Friday, December 16, 2011 19.06 +0900 (JST)

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5
• Release of radioactivity

- Is Fukushima erger dan Tsernobyl?
- Hoe lang duurt het voordat de schadelijke straling weg is?
- Wat is het meest radioactieve element dat is vrijgekomen?
- Wat is het bereik van de vrijgekomen radioactiviteit en van de straling?
- Wat is straling eigenlijk?
- Is het schadelijk voor Nederland?
- Zijn er gevolgen voor ons als scholieren?

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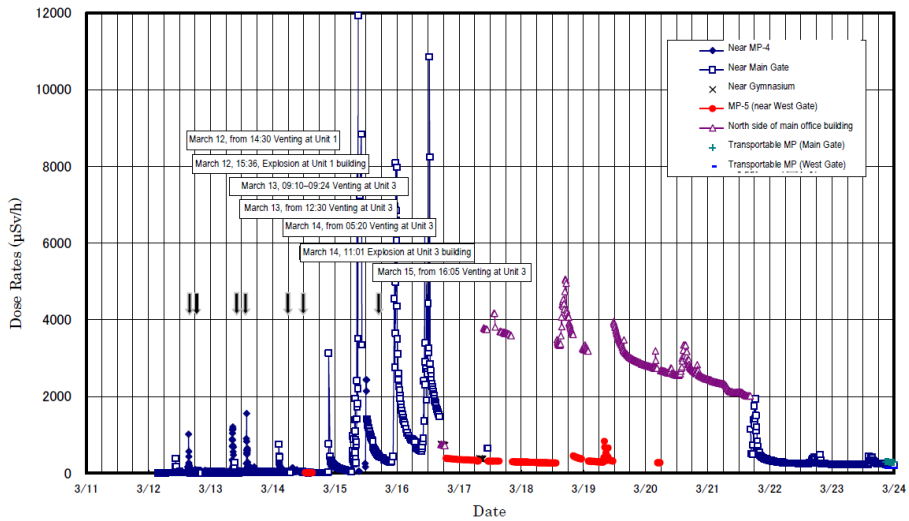
Measurement (by monitoring car) of dose rates at Fukushima-1, March 11-24, 2011



Source: Additional Report of the Japanese Government to the IAEA, September 2011

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(4 June 2011)

NISA didn't release radiation data after accident

- The Japanese government's Agency NISA has expressed regret for not disclosing some important results of the radiation monitoring conducted near the Fukushima-1 nuclear plant soon after the accident.
- The central and Fukushima prefectural governments collected the data to determine evacuation measures as well as food and water restrictions.
- A reading on March 12th shows that radioactive tellurium was detected 7 km away. Tellurium is produced during the melting of nuclear fuel.
- Three hours before the data was collected, the government expanded the radius of the evacuation area around the plant from 3 km to 10 km. But NISA reported several hours later that *the fuel was intact*.
- NISA also failed to disclose the high radiation levels in weeds 30 to 50 km from the plant. On March 15th, 123 million becquerels of J-131 per kg were detected 38 km northeast of the plant.
- The nuclear safety agency NISA says it deeply regrets not releasing the data.
- Prof. Yasuyuki Muramatsu of Gakushuin University says that if the data had been released earlier, children could have been protected better.

Source: JAIF / NHK, Saturday, June 04, 2011 15:27 +0900 (JST)

(17 November 2011)

70-80% of radioactive materials from Fukushima-1 fell into sea: study

- Between 70 and 80 percent of the radioactive cesium from the Fukushima -1 power plant had fallen into the sea by April, with the rest having fallen on land, according to the simulation done by the Meteorological Research Institute in Tsukuba, Ibaraki Prefecture, and other researchers.
- The simulation showed they largely completed a trip around the globe in roughly 10 days after first crossing the Pacific.
- Once released into the atmosphere, the materials were dispersed mostly northbound and reached the western coast of the mainland United States around March 17 after passing through eastern Russia and Alaska, according to the simulation.
- Most of the radioactive materials fell with rain as they got carried through the atmosphere, the study showed, saying that about 65 percent of the cesium released has since fallen into the sea.

Source: The Mainichi Daily News, Thursday, November 17,

(28 August 2011)

NISA: **Radioactive emission Fukushima** about one-sixth of Chernobyl

- The amount of radioactive cesium ejected by the Fukushima reactor meltdowns is about 168 times higher than that emitted in the atomic bombing of Hiroshima, the government's nuclear watchdog NISA said Friday.
- NISA provided the estimate at the request of a Diet panel but noted that making a simple comparison is problematic.
- The report said the crippled Fukushima No. 1 plant has released 15,000 tera-becquerels of Cesium-137, which lingers for decades and can cause cancer, compared with the 89 tera-becquerels released by the U.S. atomic bombing of Hiroshima.
- The report estimated each of the 16 isotopes released by the "Little Boy" bomb and 31 of those detected at the Fukushima plant. NISA has said the radiation released at Fukushima was about one-sixth of that released during the 1986 Chernobyl disaster.

Source: The Japan Times, Sunday, August 28, 2011

(29 October 2011)

Study: **Fallout Cs-137 reaching 40% of Chernobyl disaster**

- The Fukushima nuclear accident released double the amount of Cesium-137 into the atmosphere than the government initially estimated, reaching 40 percent of the total emitted during the Chernobyl disaster, a preliminary report said.
- The estimate of much higher levels of Cesium-137 comes from a worldwide network of sensors. Report coauthor Andreas Stohl, of the Norwegian Institute for Air Research, said the government estimate didn't include emissions blown out to the Pacific Ocean.
- In the summer, the government estimated that Fukushima-1 released 15,000 terabecquerels of cesium.
- The new report estimates the crippled plant spewed about 36,000 terabecquerels from the start of the crisis on March 11 through April 20. That's about 42 percent of the Cesium-137 estimated to have been released during the Chernobyl catastrophe.

Source: The Japan Times, October 29, 2011

(30 September 2011)

Plutonium detected 45 kilometers from nuke plant

- Small amounts of plutonium have been detected in samples of soil taken at locations including a spot 45 kilometers away from the troubled Fukushima Daiichi nuclear plant.
- The science ministry announced on Friday that the plutonium was detected in samples taken from 6 locations in the towns of Futaba and Namie, and Iitate Village in Fukushima Prefecture -- all located northwest of the nuclear plant. The radioactive substance is believed to have been released by the nuclear plant disaster.
- The ministry says the samples taken from a location in Iitate, farthest among the 6, contained 0.82 becquerels per square meter of plutonium-238 and a total of 2.5 becquerels of plutonium-239 and -240. The ministry had collected soil samples at 100 locations within an 80-kilometer radius of the plant in June and July.
- Ministry officials say that possible exposure to the detected plutonium is believed to be very low.

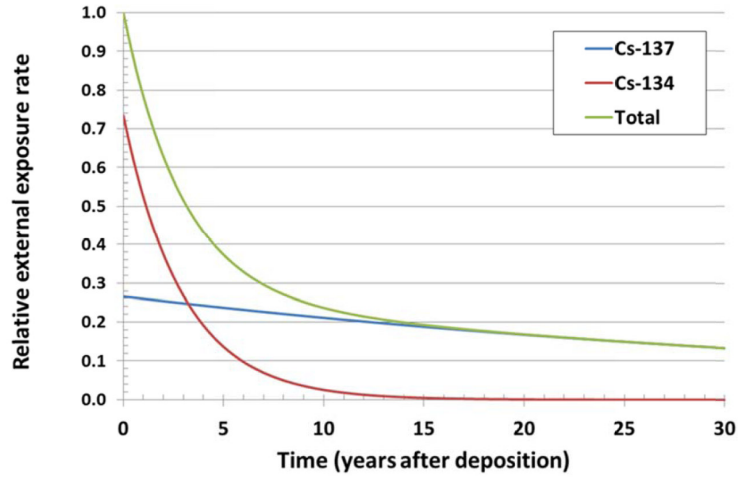
Source: JAIF / NHK, September 30, 2011 21:14 +0900 (JST)

Some important radioactive isotopes, half-life of these isotopes, and kind of radiation

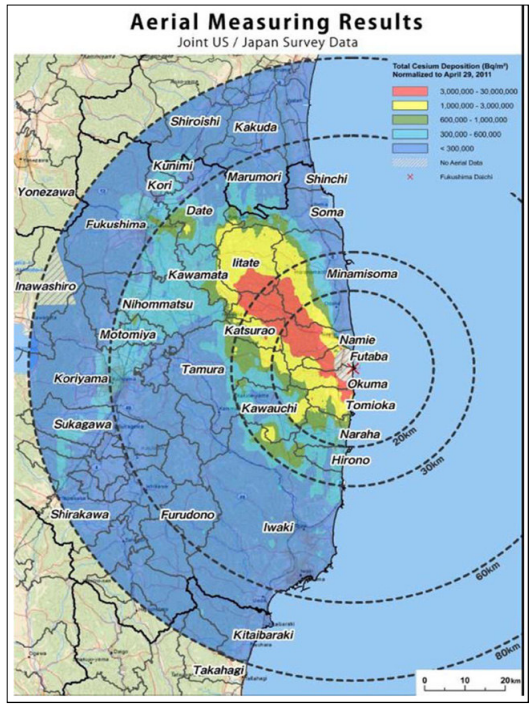
(1) Iodine-131: …….. 8.02 days (beta emitter)
(2) Cesium-134: …… 2.065 years (beta emitter)
(3) Cesium-137: …… 30.23 years (beta emitter)
(4) Strontium-90: …….. 28.9 years (beta emitter)
(5) Plutonium-239: …… 24,000 years (alpha emitter)

Note: in addition (in general) also gamma rays are emitted

Reduction of the relative external exposure rate subsequent to deposition of Cs-134 and Cs-137 (ratio = 1) due to radioactive decay



Source: IAEA, "Final Report of the IAEA International Mission on Remediation of Large Contaminated Areas Off-site the Fukushima Dai-ichi NPP", Geneva, 15 November 2011



(20 May 2011)

Map of deposition of radio-caesium (sum of Cs-134 and Cs-137) for the land area within 80 km of the Fukushima-1 plant (reported by the Japanese authorities)

The values represent the sum of Cs-134 and Cs-137. The areas in green show a deposition of these two radionuclides of between 0.6 and 1 MBq/m2. The areas in yellow indicate a deposition of between 1 and 3 MBq/m2. The areas in red indicate a deposition of between 3 and 30 MBq/m2. All are normalized to 29 April 2011

Source: IAEA, briefing 20 May 2011

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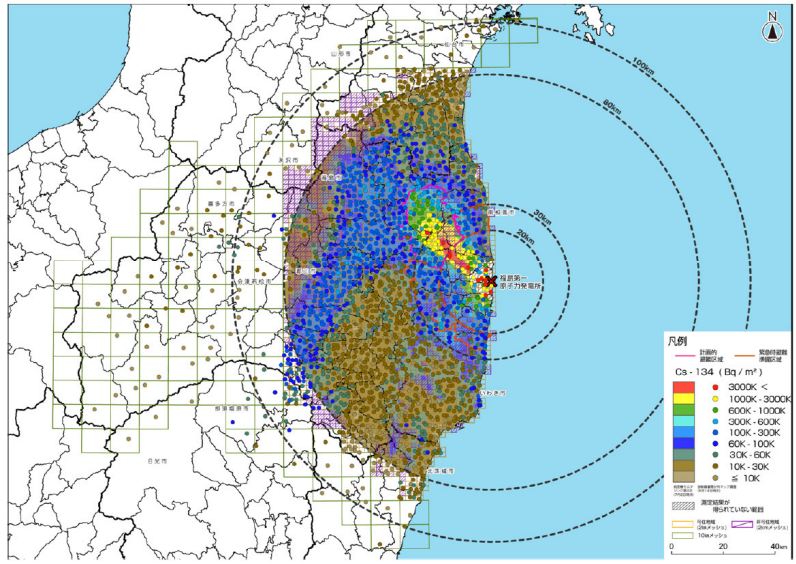
Overview Cesium-134 data (Bq/m²) September 22, 2011

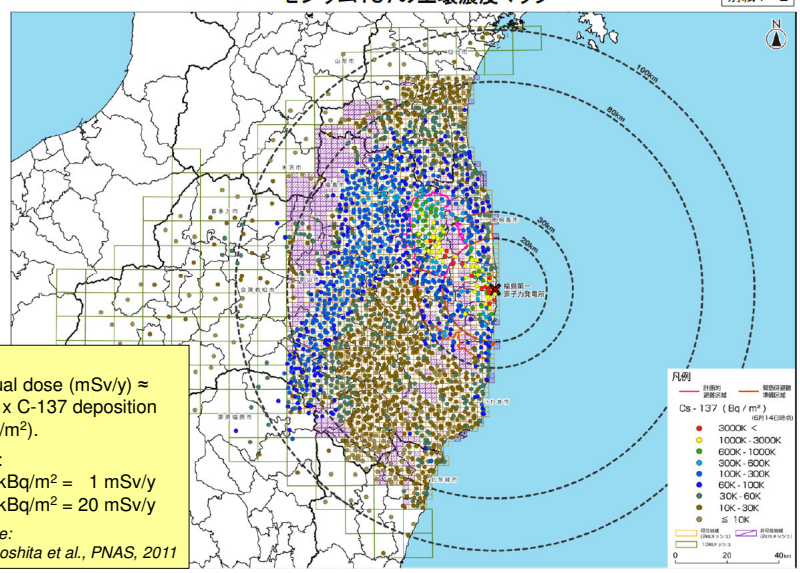
第3次航空機モニタリング結果とセシウム134の土壌濃度マップの比較について　別紙６



Source: http://radioactivity.mext.go.jp/ja/distribution_map_around_FukushimaNPP/0002/11555_0830.pdf

Overview Cesium-137 data (Bq/m²) September 22, 2011

セシウム137の土壌濃度マップ　別紙4－2



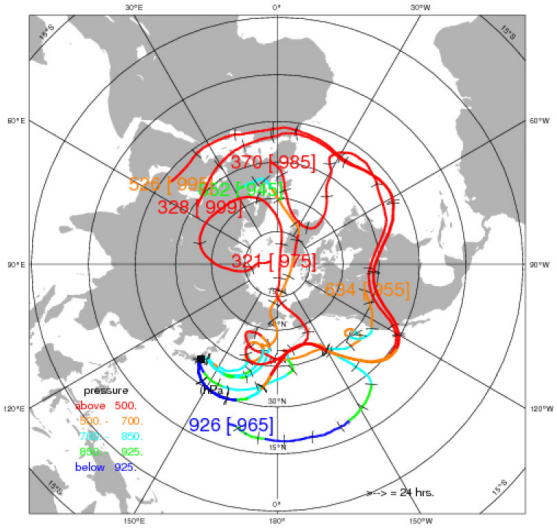
Note:
Annual dose (mSv/y) ≈ 0.06 x C-137 deposition (kBq/m²).

Thus:
17 kBq/m² = 1 mSv/y
340 kBq/m² = 20 mSv/y

Source:
N. Kinoshita et al., PNAS, 2011

Source: http://radioactivity.mext.go.jp/ja/distribution_map_around_FukushimaNPP/0002/11555_0830.pdf

Hoe verliep het luchttransport van Japan naar Europa ?



- Berekende 14-dagen voorwaartse trajectorieën (paden van lucht-pakketjes door de atmosfeer), gestart op een vijftal hoogtes in de onderste 500 m boven de kerncentrale vanaf de explosie en brand in reactor 4 op 15 maart.
- De hoogte van de pakketjes wordt in kleur aangegeven (van laag naar hoog: van donkerblauw via groen, lichtblauw, en oranje, naar rood).
- Dagen worden aangegeven met dwarsstrepen langs de trajectorieën.
- We zien dat in ieder geval op 26-27 maart, dus na 12 dagen, lucht uit Fukushima boven Nederland aanwezig was.

Bron: KNMI, 2011

Bron: R. Overwater e.a., "Metingen in buitenlucht op het RIVM terrein te Bilthoven na het Fukushima kernongeval in maart 2011", RIVM, Briefrapport 610891001/2011

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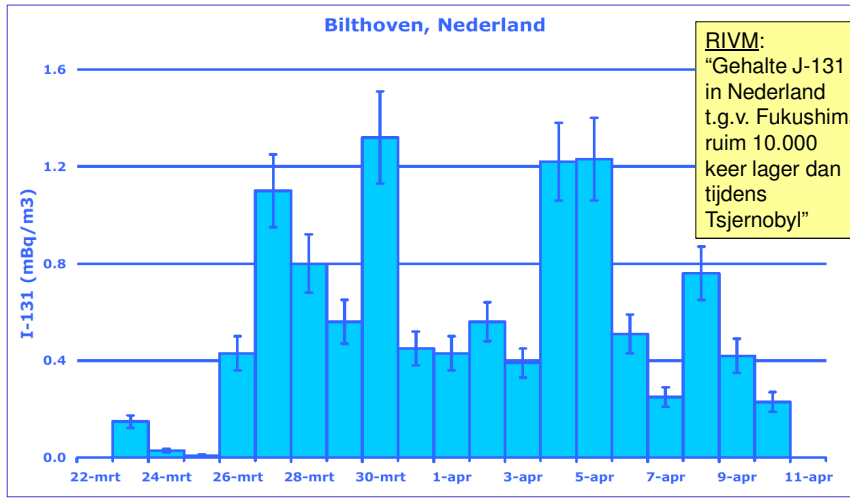
(22 maart – 11 april)

Activiteitsconcentratie van stofgebonden J-131 in buitenlucht Bilthoven [10^{-3}Bq/m^3]



RIVM: "Gehalte J-131 in Nederland t.g.v. Fukushima ruim 10.000 keer lager dan tijdens Tsjernobyl"

Bron: R. Overwater e.a., "Metingen in buitenlucht op het RIVM terrein te Bilthoven na het Fukushima kernongeval in maart 2011", RIVM, 2011

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6

• Exposure to radiation, Evacuation and Decontamination activities

- Kan je erheen?
- Ga je dood als je er gaat wonen?
- Hoe schadelijk is straling?
- Is er sprake van mutaties?
- Wat zijn de merkbare gevolgen op korte termijn voor de omgeving?
- Hoe lang zullen de gevolgen in de omgeving nog merkbaar zijn?
- Hoe lang duurt het voordat de schadelijke straling weg is?
- Wanneer mogen bewoners weer terug naar de plaats van de ramp?
- Hoeveel generaties zullen er last van hebben?

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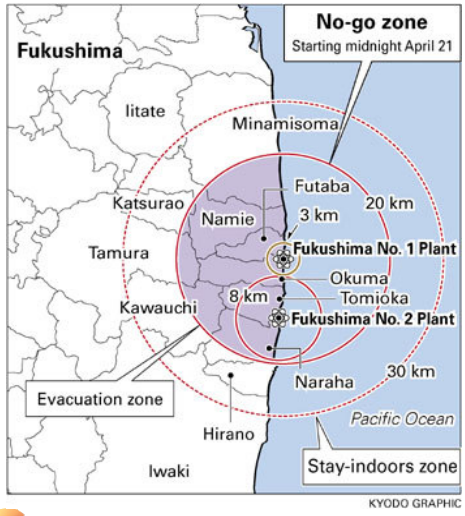
(22 April 2011)

20-km evacuation area now declared a *no-go* zone



- The government declared the 20-km evacuation area around the radiation-spewing Fukushima No. 1 nuclear plant a no-go zone Thursday, urging residents to abide by the order for their own safety or possibly face fines or detention.
- Nearly 80,000 residents left when the area was evacuated March 12.

Source: The Japan Times, 22 April 2011

1) Restricted Area,
2) Deliberate Evacuation Area,
3) Evacuation-Prepared Area in case of Emergency,
4) Evacuation Recommendation Spots.

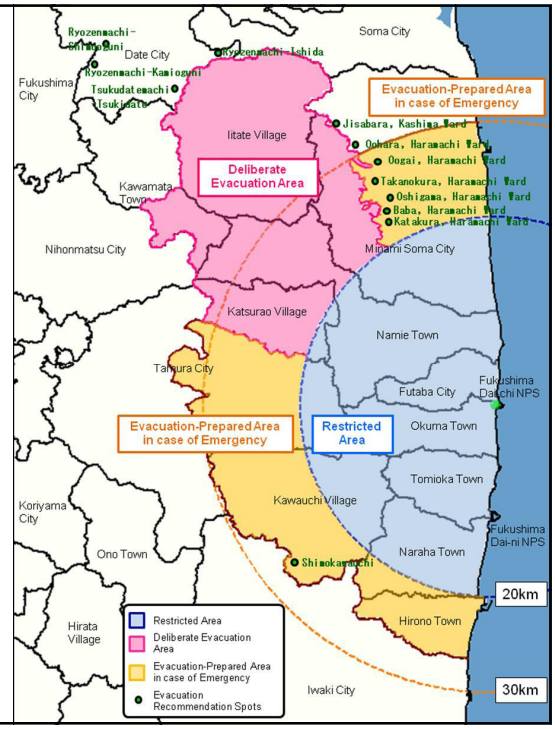
Restricted / Evacuation Area: *Area within 20 km.*

Deliberate Evacuation Area: *Area in which more than 20 milliSv/year of radiation is detected within 30 km and beyond 20 km.*

Evacuation Prepared Area in case of Emergency: *Area which is not Evacuation Area or Deliberate Evacuation Area within a 30-kilometer radius.*

Specific Spots Recommended for Evacuation: *Specific spots estimated to exceed an integral dose of 20mSv over a one year outside 30km radius.*

Source: Additional Report of the Japanese Government to the IAEA, September 2011



(30 April 2011)

Nuclear advisor protests against 20 millisievert norm

- University of Tokyo Professor Toshiso Kosako, nuclear advisor to Prime Minister Naoto Kan, has resigned to protest what he called the government's impromptu handling of the nuclear crisis. Also he said that the government has belittled the law.
- Kosako criticized the education ministry for allowing students at primary schools in Fukushima Prefecture to perform outdoor activities if the level of radiation of the school ground does not exceed 20 millisieverts per year.

- The nuclear scientist said he cannot agree on that figure as an upper limit for children.
- Chief Cabinet Secretary Yukio Edano said that the ministry's decision seeks to reduce exposure to radiation and that it does not mean the government will allow the limit of 20 millisieverts per year for children.

Source: NHK, Saturday, April 30, 2011 15:10 +0900 (JST)

Effecten straling (1)

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Deterministische effecten (ook wel *"weefselreacties"* genoemd):

- Weefselreacties zijn het gevolg van gemeenschappelijke schade aan aanzienlijke aantallen cellen in de getroffen weefsels.
- Effecten treden op boven een bepaalde drempeldosis.
- Voorbeelden: *afname bloedvorming, steriliteit, huidverbranding, ontharing, gezichtsverlies.*

Stochastische effecten (een kans proces: het effect treedt wel of niet op):

- De stochastische effecten kunnen het resultaat zijn van schade aan slechts één cel of een klein aantal cellen.
- Voorbeelden: *Leukemie, andere vormen van kanker, genetische effecten.*

*N.B.: Het bestaan van een stimulerend herstel effect (**hormese**) van lage doses ioniserende straling wordt beschreven in de literatuur maar thans niet algemeen aanvaard, ook niet door de Gezondheidsraad.*

Bron: Gezondheidsraad, 2007

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Effecten straling (2)

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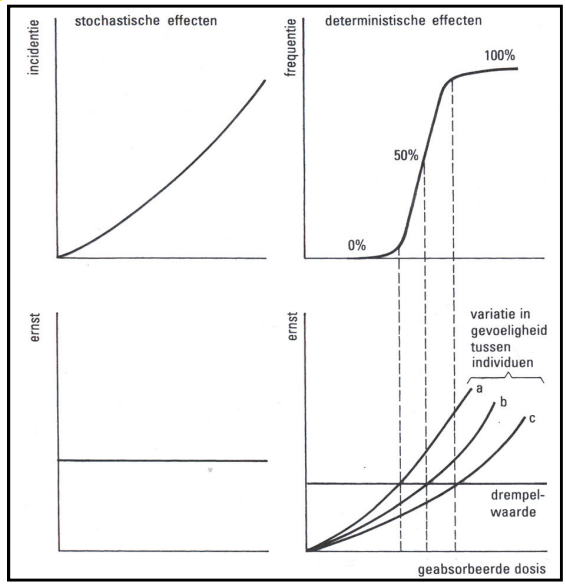

- ***Deterministische effecten*** treden op boven een bepaalde drempeldosis.
Hoe hoger de dosis, hoe sterker het effect.

- Het optreden van ***stochastische effecten*** is een kans proces: het effect (bijvoorbeeld kanker) treedt wel of niet op. Hoe hoger de dosis, hoe groter de kans op gezondheidsschade.

Bron: Gezondheidsraad, 2007

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ICRP-2007:
Fatal risk coefficient of 5% per Sv

- **Von Hippel**: "When distributing 20 Sievert in total to many people, one of them will die, due to cancer caused by the radiation".
- **Bijwaard**: "According to the ICRP-103 report (2007), the '*20 Sievert calculation rule'* is still valid (to calculate number of death)":
- ***ICRP**: "It is therefore the recommendation of the Commission that the approximated overall **fatal risk coefficient of 5% per Sv,** on which current international radiation safety standards are based, continues to be appropriate for the purposes of radiological protection". (See page 55 of ICRP-103, published in 2007).*
- **Bijwaard**: *"Note, however, that the calculation rule is meant for radiation protection, not to calculate afterwards the number of death of an accident, as there are many uncertainties".*

Source: Private comm. with (1) Frank von Hippel, Princeton University, 14 April 2011, and (2) Harmen Bijwaard, RIVM, 22 April 2011

(August – November 2011)

Gov't radiation limit at schools and kindergartens

- MEXT (Ministry of Education, Culture, Sports, Science and Technology) will lower the *threshold* for cumulative external radiation permitted at schools and kindergartens to a maximum annual exposure of 1 mSv. (News of August 24).
- *Integral dosimeters* has been distributed to every school and other applicable institutions throughout Fukushima Prefecture.
- All preschools and schools are closed in *Evacuation Area* or *Deliberate Evacuation Area*.
- Schools in *Evacuation Preparation Area in case of Emergency* reopened on Oct 18 in some area following the restriction lift of September 30th.

Source: JAIF, "Environmental impact caused by the nuclear power accident at Fukushima Daiichi nuclear power station, as of December 8, 2011"

(27 May 2011)

Fukushima begins to decontaminate school grounds

- Fukushima begins to decontaminate school grounds
- Work has begun to remove radioactive contaminated topsoil from school grounds in Fukushima Prefecture.
- The decontamination work began in 26 elementary and junior high schools in Fukushima City on Friday.
- In one, Watari Elementary School, the top 5 centimeters or so of soil will be scraped off and replaced with uncontaminated earth.

Source: NHK, Friday, May 27, 2011 19:45 +0900 (JST)

The municipality says it expects the removal of the topsoil to substantially lower radiation levels at the school to about 0.6 microsieverts per hour from Friday's reading of 3.0 microsieverts per hour.

(29 November 2011)

High radioactivity detected in Fukushima rice

- Fukushima Prefecture is set to expand its testing of rice crops, after higher-than permissible levels of radioactive cesium were detected from more post-harvest samples.
- Prefectural officials said on Monday that rice from 3 farms in Date City contained cesium above the government's safety limit of 500 becquerels per kilogram. The highest measurement reached 1,050 becquerels per kg.
- Date City is located over 50 kilometers from the Fukushima Daiichi nuclear power plant. The city is close to the Onami district, where excess levels of cesium first turned up in rice in mid-November.
- The discovery in Onami prompted the prefecture to test crop samples in Date and other radioactive hot spots.
- Prefectural officials say they will now expand the testing to cover more than 2,300 farms in other nearby municipalities, where radiation levels are relatively high.

Source: JAIF / NHK, Tuesday, November 29, 2011 12:43 +0900 (JST)

Regulatory levels for radioactivity in Japan since March 2011

Limits for Iodine-131 (half-life 8 days):

- *Drinking water:* 100 bq/liter *(assuming 1 liter = 1 kg).*
- *Seawater:* 40 bq/liter.
- *Spinach / rice:* 2000 bq/kg *(possibly a general standard for food).*

Limits for Cesium-137 (half-life 30 years):

- *Drinking water:* 200 bq/liter *(assuming 1 liter = 1 kg).*
- *Seawater:* 90 bq/liter.
- *Spinach / rice:* 500 bq/kg *(possibly a general standard for food).*
- *Soil:* less than 5000 bq/kg *(guideline for rice planting in Sept. 2011).*

Notes:

(1) 1 bq = 1 becquerel = 1 disintegration per second (1 tera-bq = 10^{12} bq = 27 Curie).

(2) Limits are based on "less than 5 mSv per year from drinking and food".

Sources: *(1) http://en.wikipedia.org/wiki/Radiation_effects_from_Fukushima_I_nuclear_accidents#Iodine-131.*
(2) http:// www.jaif.or.jp/english/news_images/pdf/ENGNEWS01_1316677149P.pdf.
(3) JAIF, "Environmental impact caused by the accident of Fukushima -1 NPS, as of December 8, 2011".

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Human internal exposure (mSv) when applying guideline levels Japanese Gov't

- **$E = GL(A) \cdot M(A) \cdot e_{ing}(A) \cdot F$**
  - E = Exposure (mSv)
  - GL(A) = Guideline level (Bq/kg)
  - M(A) = age-dependent mass of food consumed per year
  - $e_{ing}(A)$ = age-dependent ingestion dose coefficient (mSv/Bq)
  - F = Fraction of food consumed per year that is contaminated (dimensionless)
- As an example, dose assessments are calculated for the first year of consuming Cs-137 contaminated food:
  - For adults: E = 500 Bq/kg · 550 kg · $1.3 \cdot 10^{-5}$ mSv/Bq · 1 = 3.5 mSv
  - For infants: E = 500 Bq/kg · 200 kg · $2.1 \cdot 10^{-5}$ mSv/Bq · 1 = 2.0 mSv

Based on: "Codex Guideline Levels for Radionuclides in Foods (…)", CAC/GL 5-2006

Copernicus Institute

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7

• Physical consequences of Chernobyl disaster and meltdown Fukushima-1

- Wat zijn de overeenkomsten met Tsernobyl?
- Is Fukushima erger dan Tsernobyl?
- Hoeveel mensen zullen er op lange termijn sterven?
- Zijn er mensen overleden die betrokken waren bij de reddingsactie?

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Chernobyl disaster

26 April 1986

- The Chernobyl disaster was a nuclear accident that occurred on 26 April 1986 at the Chernobyl Nuclear Power Plant in the Ukrainian SSR (now Ukraine).

- An explosion and fire released large quantities of radioactive contamination into the atmosphere, which spread over much of Western Russia and Europe.

- About 5.2 million terabecquerels radioactivity have been emitted

- It is considered the worst nuclear power plant accident in history, and is one of only two classified as a level 7 event on the International Nuclear Event Scale – INES (the other one being the Fukushima-I accident).

Mainly based on: Wikipedia, 19 April 2011

Physical consequences of the Chernobyl accident

- Death of about 30 emergency workers from radiation illness within weeks (1).
- Exposure to high radiation fields of 600,000 civilian and military "liquidators" (2).
- Radioactive contamination of an area of about 3,000 km^2 by the 30 year half-life gamma emitter Cesium-137 to levels that resulted in its long-term evacuation (2).
- A still growing epidemic of thyroid cancer among people in the region from ingested and inhaled radio-iodine, with probably several thousands of death (2).
- Other radiogenic cancers are suspected but undetectable in a much larger background of cancers due to other courses. One recent theoretical estimate is typical: 4,000 extra cancer death among the 600,000 Chernobyl liquidators, 5,000 among the 6 million living in "contaminated areas" (above 37kBq/m^2 of Cs-137) and about 7,000 in the 500 million population of the rest of Europe (3).
- From UNSCEAR-2008, a total figure of 12,000-15,000 cancer death is calculated (4). (*Note WCT: According to RIVM, about 100 cancer death in the Netherlands.*)

(1) UN-OCHA (2001), ***Heath effects of the Chernobyl Accident: Results of 15-Year Follow-up Studies.***
(2) UNSCEAR (2000), ***Sources and Effects of Ionizing Radiation***, Vol. II, Annex J.
(3) E. Cardis et al. (2006), ***Estimates of the Cancer Burden in Europe from Radioactive Fallout from the Chernobyl Accident***, International Journal of Cancer, Vol. 119, No. 6, pp. 1224-35.
(4) UNSCEAR (2011), ***Sources and Effects of Ionizing Radiation***, Vol. II, Annex C, D and E.

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(November 2011)

Rough estimates health effects of Fukushima-1 meltdown

- *No death within weeks due to radiation; about 3 death due to other reasons.*
- *Till October 2011: Exposure to radiation of about 8,000 workers, about 98% of them to values below 100 mSv, 2% between 100 and 250 mSv, and some above 250 mSv (up to 650 mSv).*
- *Status December 16: between 11 March and 11 December 2011, about 14,000 people worked at the plant in total. Based on the radiation levels received in total, about 5 workers will die from radiogenic cancer.*
- *Radioactive contamination of an area of about 1,000 km^2 to levels that may result in its long-term evacuation.*
- *Not many thyroid cancers to be expected, because of timely evacuation (apart from some areas) and provision of iodine tablets.*
- *Radiogenic cancers are suspected (but undetectable in a much larger background of cancers due to other courses). A first rough estimation: up to 1,000 death among people living in "contaminated areas" (above 37kBq/m^2 of Cs-137) and maybe up to 5,000 death in the rest of Japan.*
- *A number of people died as a result of stress caused by the accident and due to the evacuation and uncertainty.*

Based on: Wim C. Turkenburg, De Volkskrant, 26 April 2011, and JAIF / NHK announcements thereafter

8

- **The 'Safety Myth';**

(dis)functioning of the Nuclear Regulatory Authority NISA;

failure of scientists to take proper actions

- Hoe heeft het kunnen gebeuren?
- Hebben de Japanners fouten gemaakt?

(1 June 2011)

IAEA experts point to tsunami risks and regulatory body independence

- Nuclear safety experts from the International Atomic Energy Agency pointed to **an underestimated tsunami hazard** and the importance of ensuring the **independence of nuclear regulatory authorities** in their preliminary assessment of the Fukushima nuclear crisis submitted Wednesday to Japan.
- The Japanese government will take the report seriously and will seek to reorganize the country's regulatory bodies, said Goshi Hosono, a special adviser to Prime Minister Naoto Kan on the crisis, apparently mindful of criticism about having the promoter of nuclear power and safety regulators exist in the same organization.
- The summary was issued following a week-long mission in Japan by a team of nearly 20 experts from countries around the world, who plan to deliver a final report on their findings at an IAEA ministerial meeting on nuclear safety to be held in Vienna from June 20 to 24.

Source: Kyodo News, June 1, 2011

(24 June 2011)

'Safety Myth' Left Japan Ripe for Nuclear Crisis (1)

- Over several decades, Japan's nuclear establishment has devoted vast resources to persuade the Japanese public of the safety and necessity of nuclear power.
- Plant operators built lavish, fantasy-filled public relations buildings that became tourist attractions. Bureaucrats spun elaborate advertising campaigns through a multitude of organizations to advertise the safety of nuclear plants. Politicians pushed through the adoption of government-mandated school textbooks with friendly views of nuclear power.
- The result was the widespread adoption of the belief — called the "safety myth" — that Japan's nuclear power plants were absolutely safe. Japan single-mindedly pursued nuclear power even as Western nations distanced themselves from it.
- The belief helps explains why the Japanese acceptance of nuclear power was so strong that the accidents at Three Mile Island and Chernobyl barely registered.

Source: Norimitsu Onishi, New York Times, June 24, 2011

(24 June 2011)

'Safety Myth' Left Japan Ripe for Nuclear Crisis (2)

- As the Japanese continue to search for answers to the disaster at the Fukushima Daiichi plant, some are digging deep into the national psyche and examining a national propensity to embrace a belief now widely seen as irrational.
- Because of the widespread belief in Japanese plants' absolute safety, plant operators and nuclear regulators failed to adopt proper safety measures and advances in technology, like emergency robots, experts and government officials acknowledge.
- "In Japan, we have something called the 'safety myth' ", Banri Kaieda, who runs the Ministry of Economy, Trade and Industry, which oversees the nuclear industry, said at a news conference at an IAEA meeting in Vienna on Monday. "It's a fact that there was an unreasonable overconfidence in the technology of Japan's nuclear power generation."
- As a result, he said, the nuclear industry's "thinking about safety had a poor foundation."

Source: Norimitsu Onishi, New York Times, June 24, 2011

(26 November 2011)

"Several areas in which scientists in Japan had failed to take proper action"

- In a speech, the president of the Atomic Energy Society of Japan (AESJ), Satoru Tanaka, identified several areas in which scientists in Japan had failed to take proper action before the NPS accident. They had failed to prepare for external events, such as:
  1) Foreseeing the scale of the tsunami;
  2) Taking measures to prevent flooding within structures;
  3) They did not develop measures to deal with the loss of all the power sources simultaneously;
  4) Scientists had not fully determined safety targets, regulations and design;
  5) They did not properly prepare for managing a severe accident;
  6) They failed to foresee the probability of hydrogen explosions at the NPS;
  7) They did not carry out sufficient safety-related R&D.
- As to why Japan had not adopted global safety standards, Tanaka suggested the lack of an orderly process to reflect new knowledge and knowhow in safety standards, also citing the great resistance to efforts to improve the safety of things already deemed "safe."

Source: Japan Atomic Industrial Forum (JAIF), December 05, 2011

Thanks!

Wim Turkenburg
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The Netherlands