DAMAGE ESTIMATE OF EARTHQUAKE, TSUNAMI AND HYDROGEN EXPLOSION FOR FUKUSHIMA NUCLEAR POWER PLANT

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ABSTRACT: The great earthquake occurred and gigantic tsunami waves damaged Fukushima Nuclear Power Plants. Emergency core cooling systems did not work, three reactors in Dai-ichi nuclear power plant became meltdowns and hydrogen exploded to break the buildings. Finally a big amount of radioisotopes were emitted to the sky. In this paper, time series of damages will be discussed for seismic oscillation, tsunami, and hydrogen explosions, which caused nuclear power plant collapse with radioisotope pollution. First, at 14:46, oscillation with seismic intensity 6 destroyed most constructions: roads and seawalls were broken; electricity and waterworks were broken. At 15:50, the great tsunami with 15 m of the wave height attacked the seawalls, and the emergent power was flooded and cut off. The emergent reactor cooling facility did not work and meltdown started. On March 12 to 16, five times hydrogen explosions occurred for Reactors 1 to 4. As a result, east Japan was polluted more than Chernobyl for the atmosphere, soils, vegetation and water body.

1. INTRODUCTION

At 14:46 on March 11, 2011, the great earthquake with magnitude of 9.0 occurred from a focus of Sanriku-oki. From Hokkaido to Kyushu, all Japan was attacked with a big shake and Tsunami. In record, it was the maximum in Japan and the greatest of the world with 20335 of victims. At 15:50, the great tsunami attacked Fukushima Daiichi and Daini Nuclear power Plants, Tokyo Electric Power Company. The emergent core cooling system did not work and lost cooling ability. Fukushima Daiichi had meltdown at Reactor 1, and a hydrogen explosion occurred, which made building structures falling to pieces and a big amount of isotopes leaking into the atmosphere. Reactors 2 and 3 also had meltdown in the same way. Reactor 4 was fired. At 13:10 on March 20, Reactor 3 had meltdown and isotope leak into the atmosphere again. On March 21, it rained in the Kanto plain, and high concentration of iodine 131 was detected from drinking water in waterworks in the Tone river watershed on March 22 and 23.

In this paper, time series of radioisotopes were estimated with hydrogen explosions at the nuclear power plants, and time series of pollution falling in the atmosphere was analyzed for the spatial distribution of radioisotopes in the watershed. Next, from meteorological data with rain on March 21, rainfall budget was analyzed for iodine concentration at the purification plant in the Tone river watershed.

Especially, time series of damages will be discussed for seismic oscillation, tsunami, and hydrogen explosions, which caused nuclear power plant collapse with radioisotope pollution. First, at 14:46, oscillation with seismic intensity 6 destroyed most constructions: roads and seawalls were broken; electricity and waterworks were broken. At 15:50, the great tsunami with 15 m of the wave height attacked the seawalls, and the emergent power was flooded and cut off. The emergent reactor cooling facility did not work and meltdown started. On March 12 to 16, five times hydrogen explosions occurred for Reactors 1 to 4. As a result, east Japan was polluted more than Chernobyl for the atmosphere, soils, vegetation and water body.

2. METHOD

2-1 Used data

Satellite data were THEOS/ Panchromatic/ Multispectral on March 18 and 28, 2011 and ALOS/PRISM/AVNIR-2 on May 20, 2009 and March 28, 2011. Meteorological data were 10 min rainfalls and winds from AMeDAS. Others were used from newspapers and internet references.

2-2 Rainfall analysis

From wind directions, flow directions of radioisotopes were determined each hydrogen explosion. The most wind directions were north and south. It was no rain in Kanto area till March 21, when the wind direction was north. Therefore, most of isotopes were emitted into the atmosphere during these days and the ones in the watershed ran off into the Tone River with rainfall.

2-3 Pollution model

From the Stokes equation, relationship between particle falling velocity and its size was obtained for isotopes.

$$v = D^2\rho g/18\mu \qquad (1)$$

where v: a falling velocity, D: a particle size, ρ: a specific weight, g: the gravity constant, and μ: a viscosity coefficient.
The specific weight of isotopes varies widely from gas to solid state. As the falling time is reverse proportional to the specific weight, direct contaminants should be isotopes in solid state and ones adhering solid such as sand. This hypothesis leads to the next equation from Equation (1).

$$L = v_w t = 18\mu h v_w/D^2\rho g \qquad (2)$$

where L: an approach distance, v_w: a wind velocity, t: a floating time, h: the maximum height. If radioactivity is proportional to the mass of the particle, the next equations were derived from Equation (2).

$$I = 9*2^{1/2}N_a(1-2^{-1/T})\ (\mu h v_w)^{3/2}\alpha/(\rho^{1/2}g^{3/2}w_a L^{3/2}) \qquad (3)$$

$$I \propto L^{-3/2} \qquad (4)$$

where I: radioactivity, N_a: Avogadro number, T: a half-life, w_a: an atomic weight, α: the weight ratio of an isotope to the carrier (=1 if the carrier is an isotope).

2-4 Hydrogen explosions

Hydrogen exploded in the reinforced steel concrete buildings, and radioisotopes such as iodine 131 emitted into the atmosphere. If the initial velocity at explosion is 340 m/s, the next equation holds.

$$\rho_a\pi D^2 v_a^3 t/4 = \rho\pi D^3 v_0^2/6 \qquad (5)$$

where ρ_a: an air density (1.29 kg/m3), v_a: a velocity at the explosion (340 m/s), t: the mean flying time of particles in the building, v_0: a velocity at the exit of the building.
The building volume is 75000 m^3, and the mean distance between the center and the wall in the building is 56.1 m. thus,

$$t = 56.1 / 340 = 0.165 \text{ s}$$

Therefore, the velocity at the exit of the building for particles is the next equation.

$$v_0 = (3\rho_a v_a^3 t / 2\rho D)^{1/2} = 68.8\ D^{-1/2} \qquad (6)$$

With air resistance $\rho_a\pi D^2 v^2 c / 8$ and the gravity, the approach altitude will be the next equation as the first approximation by integration.

$$H \sim \beta v_0 \sim D^{-1/2} \qquad (7)$$

where c: a resistance coefficient (0.2), β: a coefficient(>1).

3. RESULTS

3-1 Damage by seismic oscillation

At 14:46, the oscillation with seismic intensity 6 (a severe shock) attacked the nuclear power plant. Because of limitation of the earthquake-proof design, most constructions were broken. Roads, harbors, electricity, and waterworks were damaged. At this point, the emergency power started. Most structures were still recovered so far.

3-2 Damage by Tsunami

At 15:50, the great tsunami with 15 m of the wave height attacked. As shown in Figure 3, all the facilities were ponding, and electricity power became out of service.

3-3 Damage by hydrogen explosion

Because of reduction of the water level in Reactors 1 to 3, the fuel bars lost water and meltdown started. Hydrogen flowed from the reactors into pressured vessels and their buildings. On March 12, hydrogen explosions started. As shown in Table 1, five-times explosions were in a different magnitude and isotopes diffused in different meteorological conditions.

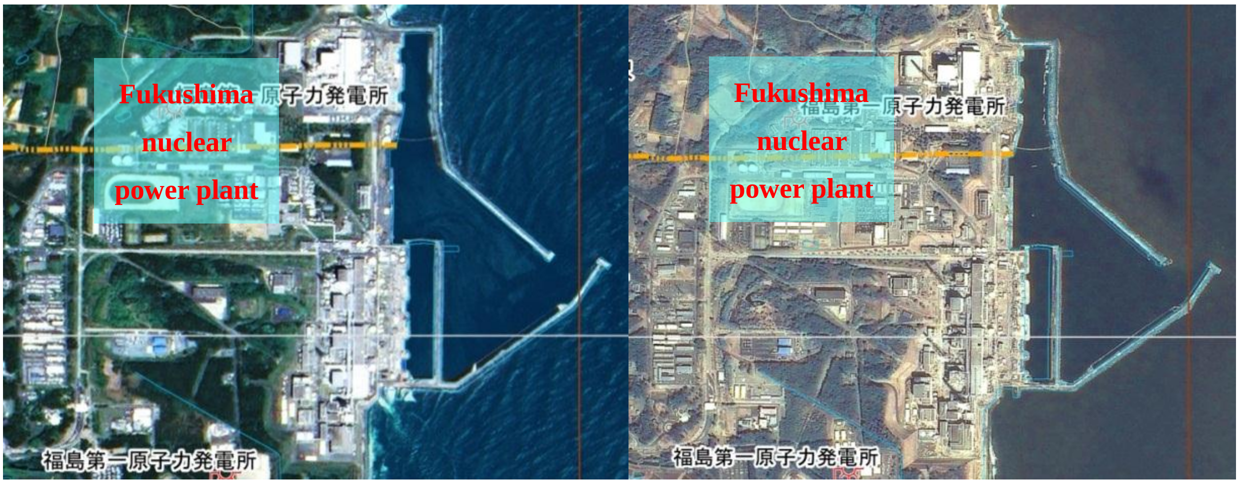


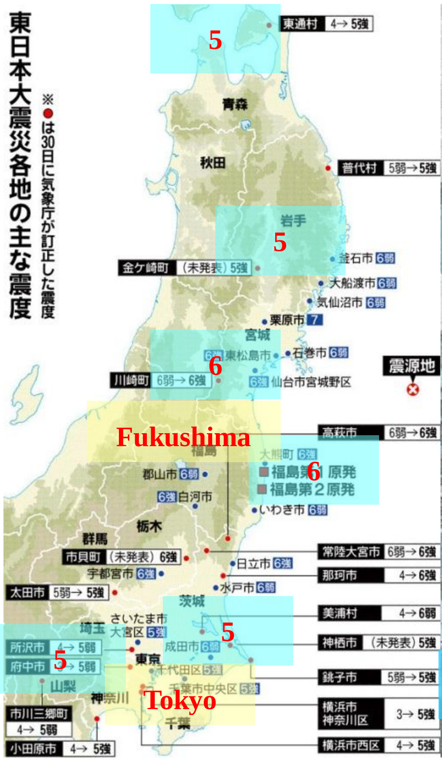
Figure 1 Satellite images of Fukushima nuclear power plant before (Left: ALOS, May 20, 2009) and after (Right: THEOS, March 18, 2011) the earthquake (RESTEC).

Table 1 Time series of hydrogen explosion

Date/Time	Reactor	Max Dose	Time Lag*	Dose Estimate**	Wind Direction
3/12; 15: 36	1	1204 μ Sv/h	16h57m	$4.3x10^4$TBq	South
3/14; 11: 00	3	3130 μ Sv/h	11h37m	$2.3x10^6$TBq	South east
3/15; 6: 14	2	11992 μ Sv/h	2h46m	$4.3x10^5$TBq	North
3/15; 20: 00	4	8124 μ Sv/h	?	$2.9x10^5$TBq	South
3/16; 5: 45	3	10850 μ Sv/h	6h45m	$3.9x10^5$TBq	East Northeast

*Observation at MP4.

**Relative radioactive dose to Reactor 2.



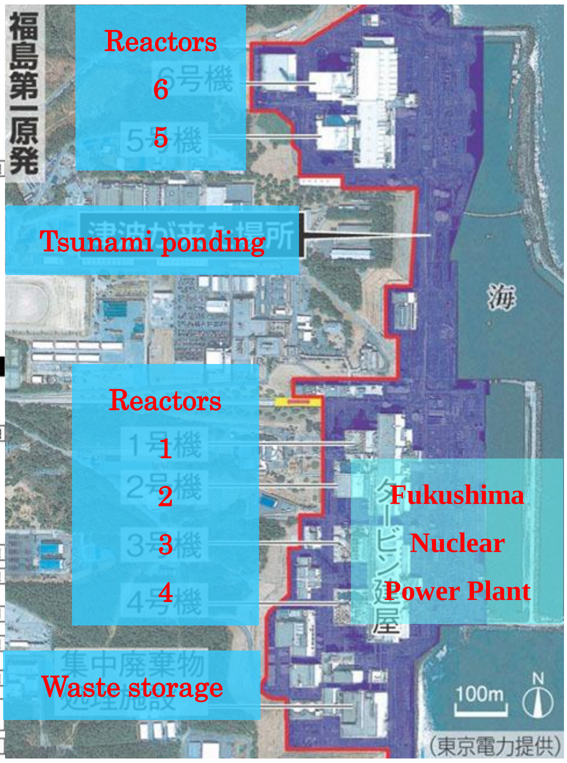
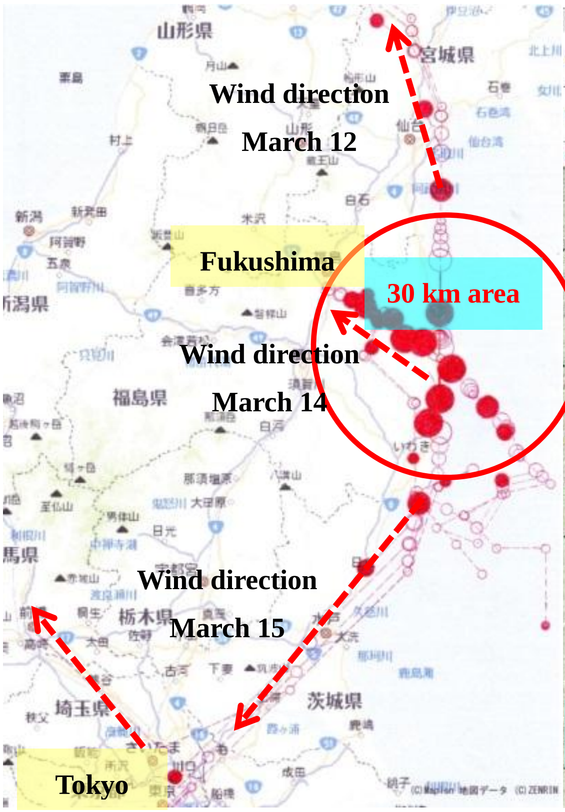


Figure 2 East Japan Great Earthquake Seismic intensity. 4: a weak shock, 5: a strong shock, 6: a severe shock. (Japanese Meteorological Agency)

Figure 3 Tsunami ponding area (TEPCO)



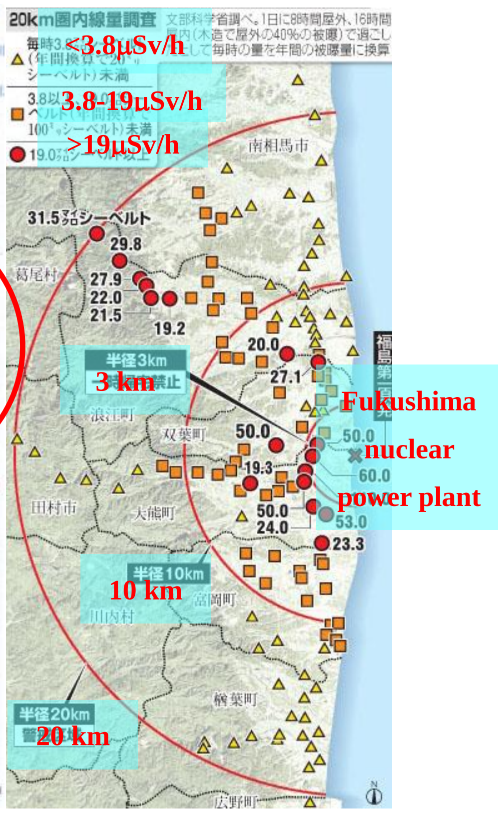


Figure 4 Hydrogen explosions and its pollution
Red circles show relative pollution of radioisotopes.

Figure 5 Surface pollution of radioisotopes (MEXT, Japan).
Triangles: <3.8μSv/h, Squares: 3.8-19μSv, Circles: >19μSv/h

4. DISCUSSION

4-1 Chemical reaction of hydrogen explosion

Zirconium that was used for covers of fuel bars reacts with water and hydrogen occurred.

$$Zr + 2\,H_2O \rightarrow ZrO_2 + 2H_2$$

By this reaction, a big amount of hydrogen occurred in the reactors and leaked out of reactors and exploded inside the buildings. In this case, the amount of hydrogen was shown as next. Parenthesis values are total one including used fuels in the building.

Reactors 2 and 3: generated 3.1×10^5 mols of H_2 (total: 3.3 and 2.9×10^5)
Reactor 1: 2.3×10^5 mols of H_2 (1.7×10^5)
Reactor 4: 5.5×10^5 mols of H_2

Final partial pressure: reactor 1= 0.07 (total: 0.12), reactor 2 = 0.09 (0.19), reactor 3 = 0.09 (0.17), reactor 4 = 0.16 atm

Thus, at 3000^{o}C, 0.07~2.1 atm

Final partial pressure of hydrogen and generated water became at most 2 atm, reinforced concrete buildings could not be broken with less than 10 to 20 atm. Therefore, the zirconium-water reaction cannot produce enough hydrogen to explode the buildings. Most hydrogen might be produced by radiation damage for water or high temperature contact with fuel bars.

4-2 Radioisotope carrier

SPEEDI calculates diffusion simulation from reactors to the atmosphere each isotope. However, actual isotope performances are categorized to two patterns. Most isotopes adhered sands and concrete debris, and diffused into the atmosphere, which explained the observation of isotope doses very well. By the observation of radioactive doses, after the hydrogen explosion in a few hours a single or some peaks were shown, which means isotopes fell down. Even most isotopes were 20 kinds, maybe more than 200 kinds of isotopes leaked outside and diffused. As a carrier of sands or concrete debris, diffusion with a limited particle size distribution explains the results of observation. Sands in the atmosphere and concrete debris generated by hydrogen explosions diffused in the sky, and leaked isotopes caught them to fly into the sky and fell down from a certain elevation each particle size according to the wind velocity and directions. Therefore, the spatial distribution of pollution was similar to the particle size distribution for east Japan. On the other hand, fine particles or gas like materials departed from a carrier and moved with the wind, and fell down to the earth by rainfall. Thus, these two ways were the form of isotopes movement. All the isotopes with a carrier fell down to east Japan and the Pacific Ocean.

5. CONCLUSIONS

(1) The damages by the earthquake were most construction collapse at 14:46 with seismic intensity 6 (a severe shock) because of limitation of the earthquake-proof design for nuclear power plant. Roads, harbors, electricity, and waterworks were broken. At this point, the emergency power started. But broken facilities were not recovered so far.

(2) The damages by tsunami were most constructions, at 15: 50 with wave height of 15 m by the great tsunami. All the facilities were ponding and electricity became out of service.

(3) The damage by the hydrogen explosions were Reactors 1 to 4. With reduction of the water level the fuel rods became meltdown out of water, and hydrogen leaked into the pressured vessels and started to explode on March 12. Five-times explosions were in a different magnitude and isotopes diffused in different meteorological conditions to pollute in Fukushima prefecture mainly more than Chernobyl.

(4) The hydrogen reaction cannot be explained by the water-zirconium reaction. Water decomposition at high

temperature or radiation damage seemed to be rather reasonable.

(5) With a carrier of isotopes, their diffusions into the atmosphere were categorized into two types. Isotopes with a carrier polluted over the east Japan very widely. On the other hand, isotopes departed from a carrier and diffused widely and fell down by rainfall.

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