

Engineering Ethics on Fukushima

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Abstract

In this paper, we discuss the problems of Tohoku earthquake in terms of engineering ethics. But as “engineers,” we also count seismologists. This is because, simply thinking, the recent disaster is partially attributable to seismologists. Through the discussion, including an overview of the earthquake, we reach the conclusion endorsing the abolition of nuclear power plants.

Key Words: Engineering ethics, Tohoku earthquake, the Fukushima Daiichi Nuclear Power Plant

1. Introduction¹

This paper tackles the issues of *Tohoku earthquake*, which assaulted Japan in 2011. For its analysis, we take a viewpoint of *engineering ethics*, narrowing our arguments down to the issues of technology and science. In particular, we think about the responsibility of seismologists.

Yet, seismologists are usually not taken “engineers.” So some supplementary explanation must be provided for that, first (§2). After the explanation, we overview the earthquake, picking out imminent problems around it (§3). As such, we shall take up the responsibility of engineers at the site (§4) and then, think about the current situation of seismology (§5).

2. Concept of Engineer

As just stated, we include seismologists in our arguments of engineering ethics. On what ground? Let me explain this respect first.

According to Harris et al, the concept of engineers is clarified in terms of *professions*, which is characterized by the following five items.

(1) *Five Characteristics of Profession* (Harris et al, 2004, pp.9-10)

1. Professionals are supposed to complete the education of their own fields. This education is usually given in universities, and it is this education that differentiates professionals from ordinary people. But the emphasis of the education is not put so much on the practical training as on the *intellectual* curriculums. Thus, the specific *knowledge* plays an essential role in becoming a professional.
2. Such educated professionals are indispensable for our society. We need their knowledge in terms of *division of labor* as well. (Consider lawyers’ role in litigation, doctors’ role for diseases, etc.)
3. These characteristics, 1 and 2, lead professionals to make *licensing systems* to monopolize their business.
4. A licensing system allows professionals to have *autonomy* even in case they belong to a large organization.
5. On the other hand, to inhibit themselves from abusing the licenses, professionals come to form a community, from which a *code of ethics* also emerges.

The noteworthy here is the first item, according to which the essence of professions consists not in practical training but in intellectual ability. So carpenters at construction sites, cooks in fast food shops, and the like are not considered to be professionals, how skillful they are.

¹ Each section is referred to as, e.g. “§1,” in the text.

Let us turn our eyes to the recent disaster. Who are to be counted as “professionals”? Following the preceding characterizations, we cannot simply count workers at the plant². But engineers who designed the reactors and controlled the systems are surely counted as such.

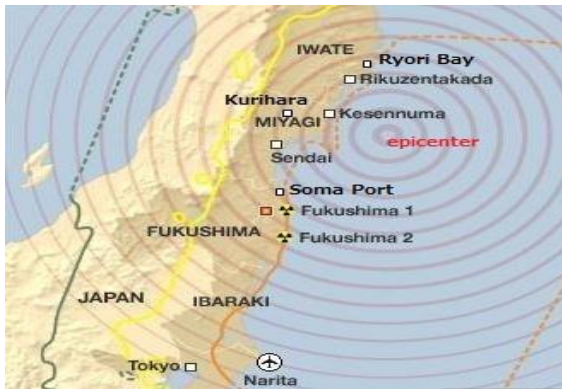
How about seismologists, then? In my opinion, they are also counted as professionals in this case. It is true they have no practical skills, but it is not so important when we think about professionals, as stated above; intellectual ability makes a difference, and particularly in that situation of emergency, it was the information they provided that should have played an important role³. For this reason, we include seismologists in our argument of engineering ethics⁴.

3. Overview of Tohoku Earthquake

This is the concept of engineers to be argued below. Based on it, next, we review the recent disaster itself, asking how engineers coped with the disaster, and in what respect they are to blame.

Tohoku earthquake and its accompanying disaster are described in the following way.

(2) Overview of Tohoku Earthquake⁵



Date: Friday, March 11, 2011
Origin time: 14:46:18.1 (Japan time)
Epicenter: ca. 130 kilometers to the east of Sendai
Hypocenter: 24 kilometers (depth)
Magnitude: 9.0
Seismic Intensity (Shindo): 7 (Kurihara)
Tsunami: 40.1m Maximum run up height (Ryori Bay)
ca.9.3m (Soma Port)
Casualties: 15,868 deaths
6,109 injured
2,848 people missing

At 14:46 on March 11, 2011, *Tohoku earthquake* occurred on the northeast side of Japan. 50 minutes later, a tidal wave (tsunami) hit the *Fukushima Daiich Nuclear Power Plant* located at 22 Kitahara, Ottozawa, Ohkuma-machi, Futaba-gun, Fukushima Prefecture.

Inside the plant, soon (at 14:46 on March 11, 2011) at Unit1, Unit2 and Unit3⁶, so-called *reactor scrams*—the insertion of *control rods* among *fuel rods* to shut off the further *nuclear fission reactions*—was brought about by the shake of the earthquake itself.

² At the plant, foreign workers and seasonal workers were also employed (cf. Mizuno et al, pp.294f.).

³ Nature (2011) and Mizuno et al (2012, pp.311f.) also emphasizes the importance of scientists.

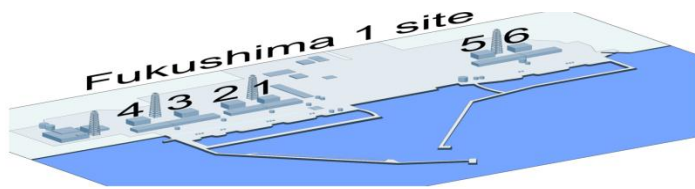
⁴ This course of argument would not impair the original intention of engineering ethics that Harris et al (1994) indicated, for example.

⁵ This figure is from <http://knowtsunami.blogspot.jp/p/tohoku-earthquake.html> (with a few additions by Kaneko). As for the information from Date to Tsunami, see JMA, 2011.

See also <http://earthquake.usgs.gov/earthquakes/eqinthenews/2011/usc0001xgp/>

<http://www.coastal.jp/tjt/index.php?%E7%8F%BE%E5%9C%B0%E8%AA%BF%E6%9F%BB%E7%B5%90%E6%9E%9C> As for Casualties, see NPA, 2012.

⁶ The description below is restricted to Unit1 alone. For further information, see Mizuno, 2012, pp.27-175.

(3) The Fukushima Daiich Nuclear Power Plant⁷

Around the same time (at 14:47 on March 11, 2011), the same quake caused the collapse of a *pylon*, which led to the *loss of offsite power (LOP)*. Because of this, the *emergency diesel generator (EDG)* began powering the plants' *cooling systems*, instead.

Approximately fifty minutes later (at 15:37 on March 11, 2011), however, a *13–15 meters maximum height tsunami* hit the entire plant, bringing about a *station black out (SBO)* of all the emergency diesel generator, which led to a halt of the cooling system of each unit.

According to primary reports from the engineers of the Tokyo Electric Power Company (TEPCO)⁸, since ca. 8:00 on March 12, 2011, the fuel rods inside Unit 1 got into “uncontrollable” states⁹, i.e. *no-water burning*, which led to *meltdown, the melt of the reactor core (fuel rods)* sooner or later.

Meltdown, accompanied by a rapid increase of temperature, causally increases the *pressure* inside the *primary containment vessel (PCV)* of the reactor, which finally leads to the explosion of PCV itself¹⁰. Ordinarily, to avoid it, a *vent*—a kind of valve each reactor is equipped with—is ordered to be opened; this, however, results in the release of *radioactive substances* into the air. We may identify this stage with the beginning of the actual nuclear disaster.

As far as Unit 1 is concerned, that order was made around 0:00 on March 12, 2011, by Masao Yoshida, the head of the plant¹¹. Following the order, TEPCO's staffs began evacuating inhabitants; in the meantime, also Prime Minister Kan prescribed evacuation to the inhabitants *within ten kilometers radius of the plant* at 5:44 on March 12, 2011.

Although the reactor's pressure was decreased, the heat of the fuel rods successively got higher, which meant the meltdown was still in process. In fact, the *fuel claddings* of the rods already began melting, and therefrom generated *zirconium*. Zirconium is the substance that *chemically reacts* with *vapor* from the water cooling fuel rods; this reaction produces *hydrogen*¹². This hydrogen further *chemically combines* with *oxygen* in the air, forming water¹³. This is why the *hydrogen explosion* occurred at Unit 1 at 15:36 on March 12, 2011¹⁴.

Because of these—the venting and the hydrogen explosion¹⁵, large quantities of radiation substances were released into the air.

⁷ Letter, e.g. “1” means Unit 1. This figure is from the following address: <http://ja.wikipedia.org/wiki/%E7%A6%8F%E5%B3%B6%E7%AC%AC%E4%B8%80%E5%8E%9F%E5%AD%90%E5%8A%9B%E7%99%BA%E9%9B%BB%E6%89%80>

⁸ Cf. Mizuno et al, 2012, pp.34f.

⁹ Cf. Mizuno et al, 2012, p.19 note4.

¹⁰ Cf. Mizuno et al, 2012, pp.32f., p.45.

¹¹ Cf. Mizuno et al, 2012, pp.47f.

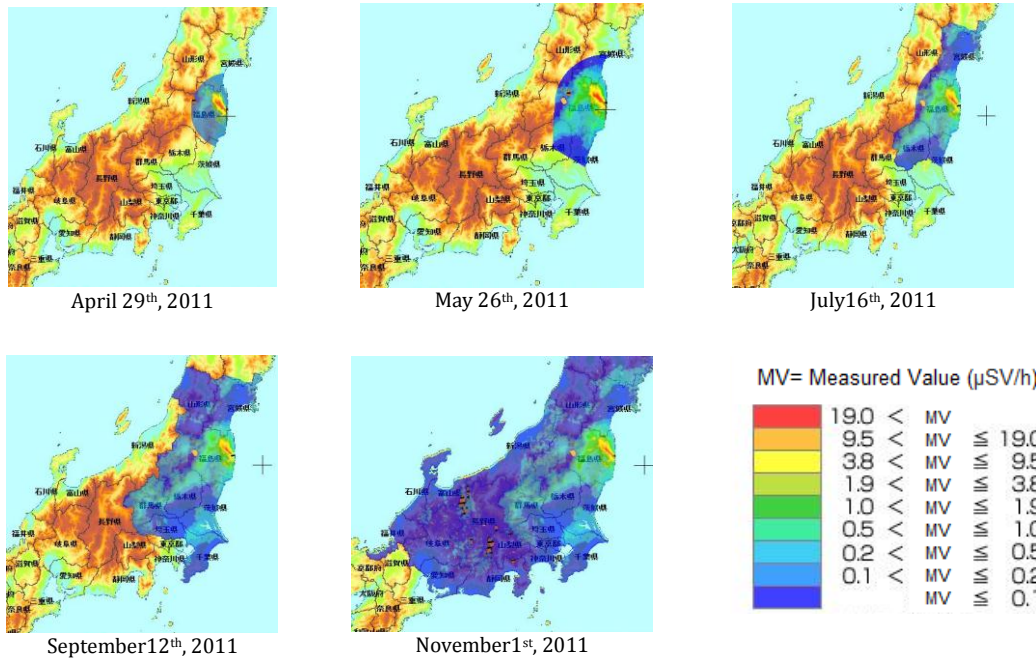
¹² This is an *oxidation-reduction reaction*: $Zr + 2H_2O \rightarrow ZrO_2 + 2H_2$.

¹³ Simply, $2H_2 + O_2 \rightarrow 2H_2O$. As is well known, the explosion in this case is a kind of *oxidation*.

¹⁴ As for this explanation, see Ishibashi, 1997 and AESJ, 2011.

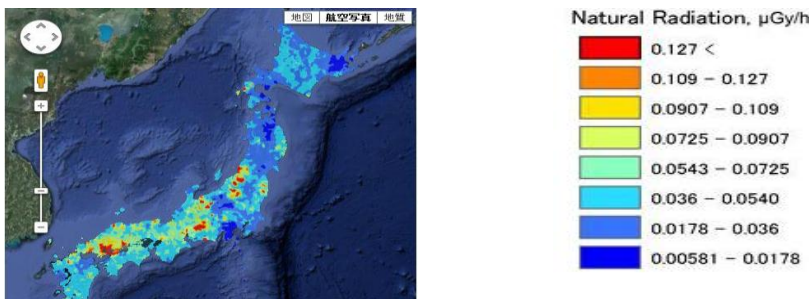
¹⁵ The main reason was these two. See Matsumura et al, 2011, p.152.

(4) Expansion of Air Dose Rate (MEXT, 2012a)



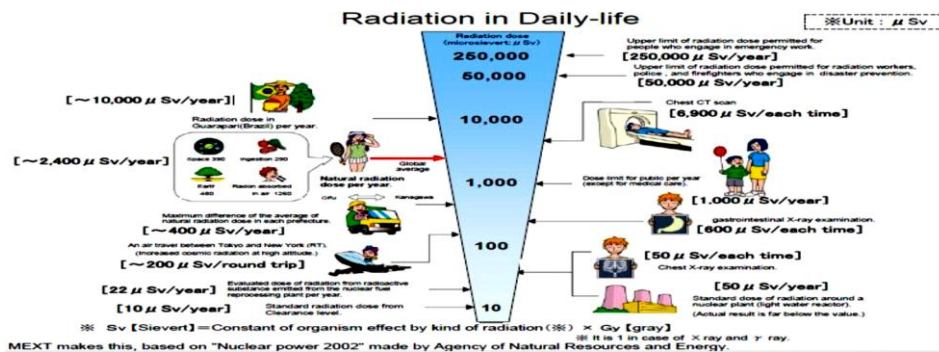
Comparing these with the data below, we realize how large the *radioactive contamination* was.

(5) Natural Radiation in Japan (JGS, 2011)



In addition to the air, TEPCO released 10,393-ton radioactive contaminated water into the sea from April 4th to 10th, 2011; the amount of radioactive substances was estimated to be 150,000,000,000 Bq, which means we will be *exposed to 0.6 mSv/y of radiation* in case we eat marine products in the sea (TEPCO, 2011). The scale of this exposure is imaginable from the following figure.

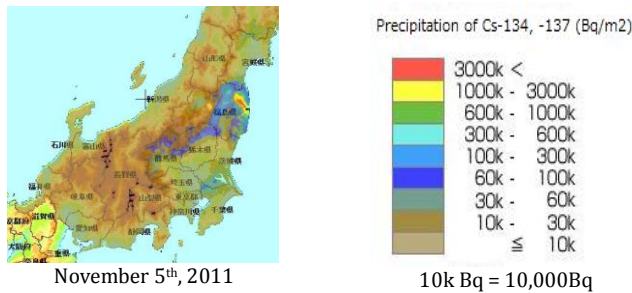
(6) Radiation in Daily-life (MEXT, 2012b)¹⁶



¹⁶ $1\mu\text{SV} = \frac{1}{1000}\text{mSV}$, $1\mu\text{SV} = \frac{1}{1,000,000}\text{SV}$, $1\text{mSV} = \frac{1}{1000}\text{SV}$

The *radionuclides*¹⁷ diffused from the damaged reactor was at least seven¹⁸: *Tellurium-132* (¹³²T), whose half-life period is around three days; Iodine-131 (¹³¹I), around eight days; Iodine-132 (¹³²I), around two hours; Xenon-133 (¹³³Xe), around five days; Caesium-134 (¹³⁴Cs), around two years; Caesium-136 (¹³⁶Cs), around thirteen days; Caesium-137 (¹³⁷Cs), around thirty years. In terms of the half-life period, real threat for us is the existence of ¹³⁴Cs and ¹³⁷Cs; it is overviewed in the following figure.

(7) *Expansion of Caesium-134 plus Caesium-137*



The density (precipitation) of radioactive caesium before the disaster was estimated to be 32.5 Bq/m² to 9100 Bq/m² at most¹⁹.

4. Responsibility of Engineers

This is an overview of the recent disaster. Who are to blame for it? Recently, some critics began to focus on the negligence of the *management side* in TEPCO (Mizuno et al, 2012; Yamaguchi, 2011). They say a decisive factor of this disaster consists in the misjudgment of the managers. At that time, the managers hesitated to order their subordinates to pour *seawater* onto the cores (fuel rods) merely to preserve the expensive reactors. If, however, this order had been made by ca. 8:00 on March 12 —before the no-water burning of the fuel rods began, we could have avoided the nuclear disaster (Mizuno et al, 2012, pp.46f.).

This remark is crucial, but we do not treat it, because our present interest is in engineering ethics. We ask instead: What about engineers at the site? Did they take proper action?

With regard to the action taken by the *engineers as subordinates* in TEPCO, we may say, they did their best in contrast with their managers. This is clear from the preceding description (§3). Moreover, as early as 2006, TEPCO reported that they had got enough training not only for business ethics but also for engineering ethics (Ono&Soraoka, 2006). Then, looking back to the disaster, let us ask: What about the *designers* of the reactors?

Yet, around this question, the argument becomes somewhat confusing, because the designers are not specified in a simple manner; TEPCO outsourced the designs to other companies.

It is American big company, General Electric (GE), that is often mentioned in this context. Indeed, the designs depended on ideas of GE's, especially concerning PCV termed *Mark I* (TEPCO, 2012a). Some Japanese engineers recently confessed that they did not have enough knowledge to criticize GE's idea at that time (The Hokkaido Shimbun, 2011).

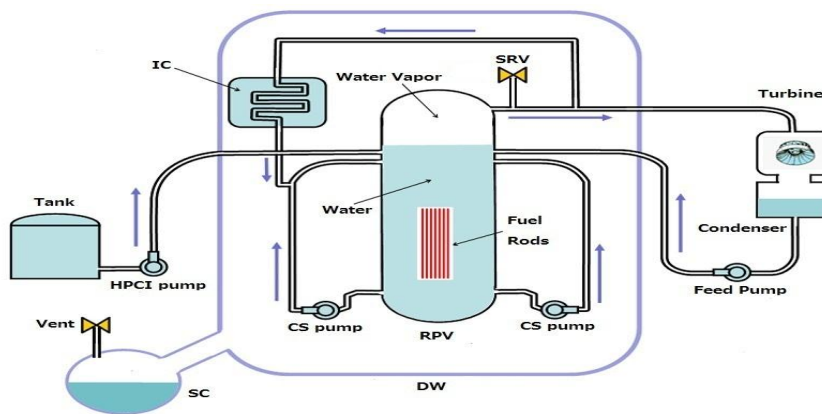
¹⁷ The substance generating from nuclear fission. E.g., ${}^{235}_{92}\text{U} + {}^1_0\text{n} \rightarrow {}^{141}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 3{}_0^1\text{n}$. This formula means: Uranium-235 splits into Ba-141, Kr-92, and three neutrons when it absorbs one neutron. Here, Ba and Kr are called radionuclides. Aside from that, there seems no change brought about in this reaction, since the sum of nucleons (shown as the upper-left superscripts) on the left side (=236) is equal to that on the right side. However, there actually occurs a so-called *mass defect* between them, which amounts to ca. 200 MeV. 200 MeV is equal to 3.2×10^{-11} J, and so to ca. 7.6×10^{-12} cal. This amount seems quite small. But it actually means: if only we prepare 1kg of uranium (=ca. 2.6×10^{24} atoms), then as much as ca. 2.0×10^{13} cal of energy is to be produced, which heats 1000 m³ of water up to 2.0×10^4 °C higher. It is this thermal energy that is used in the nuclear power plant. (This information is gained from my textbook of physics for high school students.)

¹⁸ As to the description below, see KEK&RIKEN, 2011 and Matsumura et al., 2011.

¹⁹ Cf. MAFF, 2012. The density of radioactive caesium all over Japan (as to farmlands) was 0.5 Bq/kg to 140 Bq/kg. The values in the text, 32.5 Bq/m² to 9100 Bq/m², were the results of multiplying those values by "65." This calculation is based on: <http://radi-info.com/?s=Bq%2Fkg+Bq%2Fm2&x=0&y=0> (Japanese)

Nevertheless, in general, we may say the designers did their best. They could be positively appraised. Let us check this point out along the design of the reactor.

(8) *The Inside of the Reactor* (Yamaguchi, 2011; see also Mizuno et al, 2012, pp.29f.)



This is the inside structure of Unit1. *Primary Containment Vessel (PCV)* mentioned above is constituted of two parts: the main body called *Drywell (DW)*, and the attached part called *Suppression Chamber (SC)*. The core is located in DW, called *Reactor Pressure Vessel (RPV)*. A blue-colored arrow “→” stands for a direction of a stream of fresh water.

Yamaguchi Eiichi highly evaluates this design, saying as follows.

(9) *Japanese engineers tend to work on the basis of social justice and ethics, rather than the order of an organization of which they happen to belong to. This means that Engineers generally plan out counter-measures in such a way to ensure that there is a fail-safe for any kind of situation, in this case it was their “last fortification” to protect against the unknown. With this in mind, it is hard to imagine that they would design the power plant without some kind of back up emergency power support plan to protect against power loss or malfunction* (Yamaguchi, 2011; see also Mizuno et al, 2012, p.16).

“Last fortification” here mentioned is the part “IC” in (8), which stands for *Isolation Condenser* (Yamaguchi, 2011; see also Mizuno et al, pp.16f.).

The cooling system of Mark1 (=8) can be described as follows (cf. Mizuno et al, 2012, pp.29f.). Its most normal course²⁰ is that via *Feed Pump*, through which the vapor cooled down in *Condenser* returns back into RPV. By this, the loss of fresh water inside RPV and the no-water burning of the fuel rods are avoided.

The first stage of an accident is the malfunction of this normal system. In that case, the pump of *High Pressure Coolant Injection System* called *HPCI Pump* starts working, which draws fresh water from Tank, putting it into RPV, to cool down the fuel rods, instead of the normal system.

Together with that via HPCI, the system via the pump of *Core Spray System* called *CS Pump* also starts working, which draws fresh water from CS, spraying it onto the fuel rods.

However, there could be a worse case in which even these supporting systems also stop working. Even in that case, however, *Safety Relief Valve (SRV)* automatically opens, through which the vapor inside RPV is released into DW; this provides a relief measure temporarily.

But there remains a problem: all these cooling systems require electrical power²¹. Thus, in the case of a station black out, they all stop working.

²⁰ Review how nuclear power plants works, which was described in note17.

²¹ Not only the systems using a pump—those via Feed Pump, via HPCI Pump, and via CS Pump—but also SRV (TEPCO, 2012b).

This is, presumably, the worst. Most of the engineers do not prepare for that. Yet, the engineers at the Fukushima Plant did. They installed “last fortification,” Isolation Condenser (IC) stated above, in the reactor, which does not require any electrical power. In this very respect, Yamaguchi highly evaluates their work (Mizuno et al, 2012, p.32). The worst case actually occurred in that earthquake. Then, in fact, IC properly functioned (Mizuno et al, 2012, pp.37f., pp.123f.). So we cannot blame the designers.

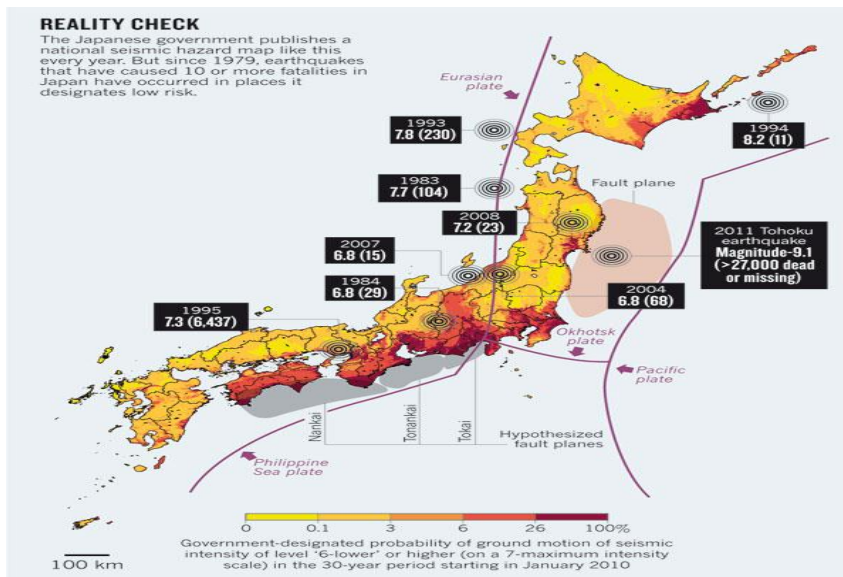
5. Responsibility of Seismologists

This is how we can prove the innocence of the designers. How about other people concerned, then? At the beginning of this paper, we counted *seismologists* not only in the people concerned but also in main engineers (§2). So now, let us proceed to consider their responsibility.

In face of Tohoku earthquake, not a few seismologists mentioned their defeat (The Asahi Shimbun, 2012). Kouketsu Kazuki is one of them²². He points out that now is the time when seismologists admit the limitation of their science: unpredictability of an earthquake.

Robert Geller is a vanguard of this opinion (Geller, 2011; Geller, 2012). He mentions *National Seismic Hazard Maps* of Japanese government, criticizing it as useless.

(10) *National Seismic Hazard Maps* (Geller, 2011; see also Headquarters, 2012)



According to this map, the most risky region is said to be the Tokai district—so-called “Tokai earthquake.” However, Geller spurns this prediction, simply because earthquakes are not predictable.

In 1960s, *plate tectonics* became the fundamental paradigm of geoscience (Geller, 2011)²³. It is the theory to explain phenomena on the earth in terms of plates, the upper parts of mantles. In reality, it has worked well as a theory to explain earthquakes *in the past*; but explanation of the past is one thing, and prediction *of the future* is another.

Nevertheless, seismologists have applied it in both manners. Geller criticizes it.

(11) *Researchers in several countries made efforts to combine plate tectonics with seismicity data to make long-term forecasts of large earthquakes. The idea was very simple. It was hypothesized that zones where no large earthquakes had occurred for a while, dubbed 'seismic gaps', were ripe for imminent large events. However, the seismic-gap hypothesis failed the test of reality* (Geller, 2011).

²² He recalls receiving many defamatory mails at the time of the Great Hanshin-Awaji Earthquake (Kouketsu, 2011).

²³ According to Kouketsu, around this time, Japanese seismology was surpassed by the United States (Kouketsu, 2011).

Thus, “the prediction boom” died out (Geller, 2011). But some “die-hard holdouts” have continued the application; Japan is a representative. Every year, a large amount of money is spent in huge facilities to predict earthquakes. Geller repudiates it, saying, “[T]he Japanese government should admit to the public that earthquakes cannot be reliably predicted” (Geller, 2011).

All the seismologists were able to support this view²⁴; and their warning could have led engineers in another direction. But there was no such movement. If all the seismologists had cooperatively supported Geller’s view, the best option would have become *the abolition of the nuclear power plants*—since we do not know where an earthquake will occur in the Japanese archipelago, forever.

6. Conclusion

Actually, some seismologists began to bolster the abolition of nuclear power plants. Katsuhiko Ishibashi’s argument is the most famous²⁵. His analysis of the nuclear disaster combined with an earthquake is highly evaluated as the anticipation of the recent case (Mizuno, 2012, pp.191f.).

So now, it is time for seismologists to inform the public of the unpredictability of the earthquake, supporting the movement toward the abolition of nuclear power plants.

I do not mean seismology is useless. Unpredictability of earthquakes does not imply uselessness of seismology. It is quite significant to recognize, in an objective, scientific way, why we cannot predict earthquakes with pinpoint accuracy (consider the significance of Heisenberg’s uncertainty principle in physics). Again, even if a scientific explanation is provided only *after* an earthquake occurs, it is as significant for people who want to know the cause of the affair at that time (consider the explanation of economists after a financial crisis).

The abolition of nuclear power plants could be a consequence from modern seismology. It is true the construction of nuclear power plants is essentially not concerned with the researches of seismology. However, as far as we count seismologists in related fields, the information they can provide, like unpredictability of earthquake now argued, is to be terribly significant. In terms of engineering ethics, they must play such an important role.

²⁴ Of course, there are actually many seismologists who oppose Geller’s stance. Ide Satoshi, for example, claims that the task of seismologists’ is not to *predict* an occurrence of an earthquake with pinpoint accuracy in a *deterministic* way, but to *foresee* it *probabilistically* (Ide, 2012). Hence, Ide says, the following foresight should be highly evaluated.

“The probability that an earthquake with a magnitude of 7.5 occurs off Miyagi prefecture within thirty years from 2007 onwards is 99%.” (Headquarters, 2009, p.23)

Koizumi Naoji also criticizes Geller as “unfair,” because the prediction in a strict sense was not made in the case of Tohoku earthquake (Koizumi, 2012, p.38).

²⁵ Cf. Ishibashi, 1997 and Geller, 2011. Ironically, Ishibashi is a supporter of Tokai earthquake and the prediction of earthquakes.

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