

# Current Situation and Challenges at Fukushima: Hands-on Measurements of Radiation Contamination after Fukushima Daiichi Nuclear Power Plant Accident

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**Abstract** – An oceanographic investigation within 1.0km radius of Fukushima Daiichi nuclear power plant (FDNPP) was carried out in September 2013, independent of the Government of Japan. Samples of seawater and seafloor sand were collected near the sewage outlets and in front of the harbor at the FDNPP. The level of seawater radioactivity did not show evidence of immediate harm to the health of the people. However, sedimentation of radionuclides to the seafloor was estimated from the results of seafloor sand. We found strontium-90 at detectable levels in the sand samples of all three points. As far as the impact of biological concentration is concerned, it would be essential to monitor the radioactivity of seawater deeper down and seafloor sand rather than that of subsurface. Regulation for both total volume and concentration should be considered.

## I. INTRODUCTION

Following the magnitude 9.0 earthquake and tsunami that hit the Tohoku region of Japan on March 11, 2011, the Fukushima Daiichi Nuclear Power Plant (FDNPP) was severely damaged, resulting in three massive hydrogen explosions of its reactors the following day [1].

Restoration of the devastated and rubble power plant has been undergoing, but Tokyo Electric Power Company

(TEPCO), substantially nationalized in 2012, has still been struggling with high-radioactive water leaking from the reactors. As of August 19, 2014, The Japanese Government reported its failed attempt to shut the water leak by frozen soil walls built around the damaged reactors [2], and the number of the tanks to store the tainted water has swelled up to over a thousand today [3].

In August 2014, TEPCO started to inform local fisheries cooperation associations their plan to release the tainted water into the sea. It raised a significant concern about the safety of marine products. In fact, contaminated blue-fin tunas were found along the coast of California. It was confirmed that contamination was derived from the accident in Fukushima [4].

Efforts have been made to improve public communications, as Ministry of Education, Culture, Sports, Science and Technology (MEXT) and Nuclear Regulation Authority (NRA) disclose the monitoring results of the sea contamination on a regular basis [5]. But the monitoring of contamination within 20km radius from the power plant had been almost solely performed by TEPCO before November 21, when NRA started to conduct a monthly cross-check of seawater measurement by external agency [6]. The regular monitoring of NRA, especially of seafloor sand at nearby points of FDNPP, has still been performed under responsibility of TEPCO.

The UN special rapporteur stressed the importance of independent monitoring to facilitate compliance of international safety [7]. Given that affected communities are living with a sense of uncertainty, an investigation was conducted to provide a third party view.

## II. METHODS

With a view to assess the contamination of seawater from Fukushima Daiichi, an oceanographic investigation was conducted within 1.0 km radius of the power plant on September 19, 2013, which was completed as a third party body for the very first time. Assistance and permission were obtained from a local Fishery Cooperative and, for security reasons, the Japan Coast Guard.

### A. Sampling

Samples of seawater and seafloor sand were collected at three locations (Figure 1): 1) near the sewage outlets north of the plant (F-1), 2) at the approach of the harbor surrounded by breakwaters (F-2), and 3) at another sewage outlet south of the plant (F-1) 1). Latitude and longitude were as follows; F-1: N37.431519 and E141.038216, F-2: N37.423156 and E141.041571, F-3: N37.418163 and E141.037331, respectively. Water depth was 3.3m at F-1, 9.0m at F-2, 3.5m at F-3. Air dose rate at 2.0m above sea surface was 0.11 $\mu$ Sv/h at F-1, 0.11 $\mu$ Sv/h at F-2, 7.5 $\mu$ Sv/h at F-3.

Sewage outlets are located outside the harbor, and the contaminated water flows out directly to the ocean. Water samples were collected at 1.5m below the sea surface. Additionally, we were able to collect a sample of water above 1.5m from the seafloor at F-3, allowing us to examine if the depth is associated with the level of contamination. Besides, dose at the seafloor and its spectrum of radioactivity was measured when sampling the seafloor sand, by a gamma spectroscopy developed for underwater measurement. Measurement time for dose and spectrum was 300 seconds.

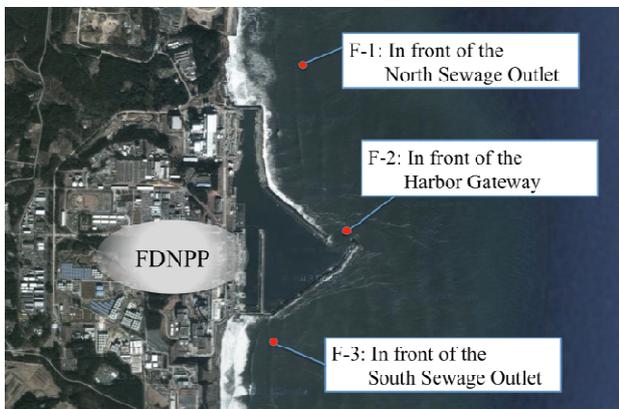


Figure 1. Map of Sampling Locations.

### B. Measurements

Water samples and sand samples were first analyzed by germanium semiconductor detector (GMX30-70-LB-B-HJ, ORTEC) to measure the level of gamma-ray emitting radionuclides, with measuring time of 86,400 seconds for seawater and 28,800 seconds for dried seafloor sand.

For water samples, following tests were performed respectively: Cerenkov counting, tritium in distilled water, tritium in benzene prepared using original water, total alpha ( $\Sigma\alpha$ ) and total beta ( $\Sigma\beta$ ) activity. For these measurements, two modern ultra-low level liquid scintillation spectrometers called Quantulus 1220TM (s/n 200040 and s/n 220491) were used. Water samples were pre-concentrated from 280ml into 20 ml, for measuring of  $\Sigma\alpha$  and  $\Sigma\beta$  activities, and for Cerenkov counting 20 ml undisturbed water was used. As for Cerenkov all samples were measured at least twice. In tritium measurement, two approaches were applied using; 1) 8 ml of distilled water in plastic vial with 12 ml of Optiphase Highsafe 3 from Perkin Elmer Inc. and 2) benzene from analyzed water according to chain of chemical transformation, to confirm consistency.

For sand samples, the level of strontium-90 and plutonium was measured at Japan Chemical Analysis Center. Strontium-90 was measured after chemical separation using low-background beta-ray measurement device (LBC-471Q, Hitachi-Aloka Medical, Ltd.), with measuring time of 3,600 seconds. Plutonium was measured after separation and purification using silicon semiconductor detector (BU-020-450-AS, ORTEC), with measuring time of 80,000 seconds. Those manipulations were worked out according to the method manuals for radiation measurement, issued by MEXT.

## III. RESULTS

### A. Dose rate at the seafloor

Dose rate at the seafloor measured when sampling took place is shown in Table 1. Considering that the air dose rate was 0.11 $\mu$ Sv/h at F-1 and F-2, the presence of contamination in underwater environment was confirmed.

Table 1. Dose rate at the seafloor of three sampling points within 1.0km radius from FDNPP.

	Sampling Points		
	F-1	F-2	F-3
Dose rate at the seafloor ( $\mu$ Sv/h)	0.262-0.280	0.636-0.654	0.005-0.234

An example of gamma-ray spectrum measured at the seafloor at F-2 is shown in Figure 2. Peaks of cesium-134 and cesium-137 were detected. Similar-shaped spectrum was also found at F-1 and F-3, and peaks of cesium-134 and cesium-137 were detected at both sampling points.

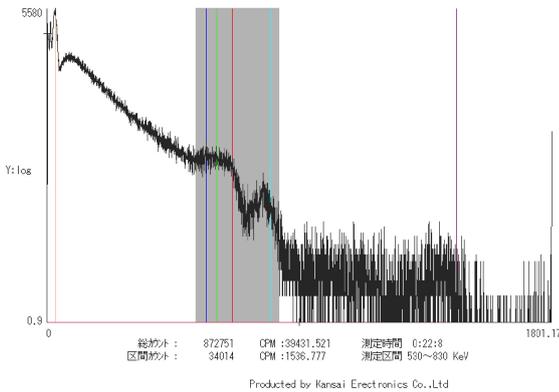


Figure 2. Example of gamma-ray spectrum measured at the seafloor of F-2.

### B. Water contamination

Radioactivity concentrations of cesium-134, cesium-137, tritium, and the level of Cerenkov, total alpha and total beta in the water samples are shown in Table 2. Additionally, a sample of water 1.5m above the seafloor at F-3 was examined, and its radioactivity concentration was  $2.06 \pm 0.30 \text{ Bq/L}$  for cesium-134 and  $4.01 \pm 0.34 \text{ Bq/L}$  for cesium-137. Compared with the sample within 1.5m from sea surface of F-3, the sample from deeper down had about 8 times higher concentration of radioactive cesium.

All samples contained cesium-134, cesium-137 and tritium at detectable level. The level of contamination in water was the highest at the point F-2. Radioactivity profiles for three samples presented similar patterns.

Table 2. Radioactivity concentration in seawater samples

	Sampling Points		
	F-1	F-2	F-3
Cs-134 (Bq/L)	$0.0821 \pm 0.0160$	$1.154 \pm 0.032$	$0.1989 \pm 0.0198$
Cs-137 (Bq/L)	$0.1848 \pm 0.0185$	$2.553 \pm 0.045$	$0.529 \pm 0.024$
H-3 (Bq/L)	$0.5 \pm 0.5$	$8.9 \pm 0.5$	$1.5 \pm 0.5$
Cerenkov (CPM)	7.2	10.3	7.2
$\Sigma\alpha$ (Bq/L)	0.18	0.29	0.21
$\Sigma\beta$ (Bq/L)	8.4	15.9	6.9

### C. Sand contamination

Radioactivity concentration of cesium-134, cesium-137, strontium-90, plutonium-238 and the sum of strontium-239 and 240 in the three seafloor sand samples were listed in Table 3. The highest concentrations of cesium-134 ( $1161.2 \pm 8.2 \text{ Bq/kg}$ ) and cesium-137 ( $3596.2 \text{ Bq/kg}$ ) were found at F-2. Since plutonium-238 with 87.7 years of half-life was under detectable level, plutonium-239 and 240 derived from natural fallouts, not from Fukushima Daiichi.

The levels of contamination were almost consistent with the result of water samples taken at the same sampling points, however, radioactivity concentration of strontium-90 at F-3 was significantly higher.

Table 3. Radioactivity Concentration in sand samples

	Sampling Points		
	F-1	F-2	F-3
Cs-134 (Bq/kg)	$376.2 \pm 3.2$	$1161.2 \pm 8.2$	$239.0 \pm 2.8$
Cs-137 (Bq/kg)	$841.7 \pm 4.9$	$3596.2 \pm 12.5$	$550.8 \pm 4.3$
Sr-90 (Bq/kg)	$0.21 \pm 0.068$	$8.8 \pm 0.33$	$34 \pm 0.6$
Pu-238 (Bq/kg)	*(0.009)	*(0.008)	*(0.009)
Pu-239+240 (Bq/kg)	$0.15 \pm 0.012$	$0.28 \pm 0.017$	$0.21 \pm 0.016$

\*Below under limit (value of the under limit)

## IV. DISCUSSIONS

### A. Summary of contamination

The level of seawater radioactivity did not show evidence resulting in an immediate harm to the health of the people. Sedimentation of high levels of radionuclides to the seafloor was, however, suggested from the results of seafloor sand. Concentration of cesium-134 and 137 in seawater was higher at deeper down in the water. Besides, we found strontium-90 at detectable levels in the sand samples of all three sampling points.

One of the potential concerns is that the level of radioactivity concentration was the highest at F-2 for cesium-134, cesium-137 and tritium. Although F-2 is in front of the harbor, which was declared as “completely sealed (thus no lead to the open water)” by the Government in September 2013 [8], there is a possibility that the contamination persists for some time, according to our result. In fact, the harbor gateway is not closed for passage and, according to an estimate, 44% of the seawater in the harbor is exchanged with outside seawater every day [9].

The level of radioactivity concentration may be attenuated in this sense, if released at high level.

### B. Legal Loophole of Radioactive Substances Released from Fukushima Daiichi

Current Japanese regulations including Ordinance on Prevention of Ionizing Radiation Dangers stipulate regarding prevention of exposure to harmful radioactive substances. However, these did not assume a possibility of emergency situations when first drafted, such as the FDNPP accident. Technically, radioactive substances are considered a danger if and only they exceed the regulatory limit for both volume and concentration, according to the current regulations [10]. Thus even if an extremely large volume of diluted radioactive substances exists, it is still outside the scope of regulation. In this sense the regulations overall are fragile in terms of managing radioactive substances in such a catastrophic

nuclear accident.

Given that there was at least 3.7Bq/L of cesium activity in the seawater at the entrance of the harbor (F-2), there were at least total amount of 11.1 billion Bq of radioactive nuclides in the 0.3 square-kilometer area seawater (depth was set as 10.0m). Based on the estimation that 44% of the seawater in this area is exchanged with outside seawater every day, 4.88 billion Bq would be released to the sea daily. This exceeds the 220 billion Bq, the voluntary total annual emission criteria [11] of usual status (excluding tritium) easily.

As far as the impact of biological concentration is concerned, it would be essential to monitor the radioactivity of seawater deeper down and seafloor sand rather than that of subsurface. Moreover, the monitoring activity should be performed by a third party organization rather than TEPCO, which is obviously an interested party.

On the other hand, inspections of radioactive nuclides in fishery products have widely been conducted by Fisheries Agency of Japan and local Fishery Cooperative Associations, based on the Basic Policy for Inspections on Radioactive Materials in Fishery Products. By conducting field investigations that we have been involved in, we have learned a value of community collaborations [12][13]. In this case, we should continue to take advantage of the efforts for food security taken by the local Fishery Corporate Association of Futaba which voluntarily monitors and samples fish in the area to examine the level of contamination in the ocean.

Since this is the largest accidental source of radioactive nuclides to the ocean at this point, and decommissioning is said to be a 40-year long process, we should reconsider the line between ordinary circumstances and those of a nuclear disaster. The total volume and concentration should be simultaneously monitored.

## V. ACKNOWLEDGMENTS

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