Survey Report-1

Residual ^{137}Cs on the reefs close to the coastline of Fukushima

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June 2017

1. Introduction

The aim of this survey is to find out how much radioactive cesium remains on the shallow reefs which lie along the coastline of Fukushima.

On March 11, 2011 the Great East Japan Earthquake hit the Fukushima Daiichi Nuclear Power Plants (hereafter called F1NPP). Consequently, a huge amount of radioactive material was spewed into not only the atmosphere but also the ocean from the three crippled nuclear reactors. After the accident, Thornton *et al.*[1, 2] developed a towed gamma ray spectrometer and conducted in si-tu and continuous measurements to study the distribution of ^{137}Cs on the seafloor off the F1NPP. They have also revealed the existence of local anomalies in the levels of ^{137}Cs, as high as 40,000 Bq/kg-wet. In accordance with the achievement of these studies, concerted efforts[3-5] among National Maritime Research Institute, the University of Tokyo and Kanazawa University have been conducted, as a commissioned project sponsored by the Secretariat of the Nuclear Regulation Authority, to study the distribution of ^{137}Cs on the seafloor within 20km radius of the F1NPP by a sampling technique, and by the in-situ and continuous technique using the towed gamma ray spectrometer. The results have revealed that the average level of ^{137}Cs is a few hundred Bq/kg-wet. The technique of towing a gamma ray spectrometer has been particularly effective to map the continuous distribution of ^{137}Cs on the seafloor of sand, silt, clay or mixture of these sediment types. The towing technique, however, is rather difficult to be applied to the rugged reefs. Accordingly, in-situ and static technique must be employed for the systematic survey of radioactive material on the reefs near the F1NPP. Fig. 1 indicates the locations of the reefs surveyed in the present work.

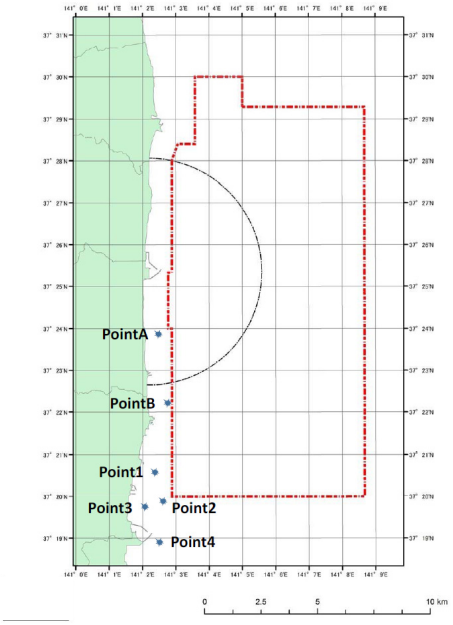

Fig.1. The area enclosed by the red dotted line is being surveyed by the work of Refs. 1-5. The blue stars indicate the reefs surveyed by the present work.

2. Instrumentation

The detector employed in the present work is a prototype CsI(Tl) gamma ray spectrometer developed by Kansai Electronics Co., Ltd.

Main specifications are as follows.

Scintillator :CsI(Tl) crystal of 1 in. ϕ × 1 in. in length.

Converter of optical signal to electronic signal: Photo Diode.

Energy resolution: 8.7% at 662 keV.

Detection efficiency: 20% at 662 keV.

Factor to convert the photoelectric peak counts per second to Bq/cm^2: 1 cps/6.32 Bq/cm^2 of ^{137}Cs.

Pressure tight vessel: Cylindrical aluminum case, 85 mmϕ × 240 mm in height, t=10 mm. An area of 40 mmϕ of the bottom of the case is thinned to 1 mm to serve as a window for incoming gamma rays.

The electronic signals from the photo diode are processed and are forwarded to a personal computer (PC) placed on a boat via a USB cable of 50 meter length. Three repeaters built in the cable can extend the total cable length to 50 meter. The block diagram for the signal processing is shown in Fig. 2.

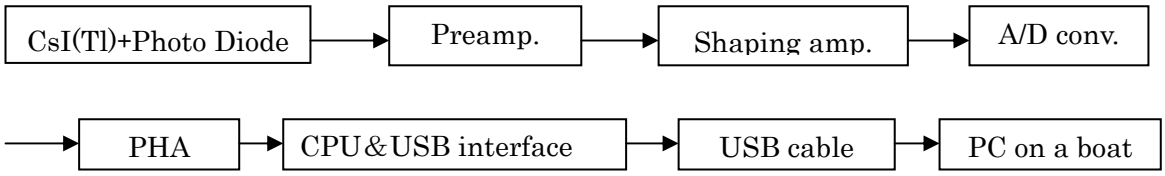

Fig. 2. Block diagram of signal processing

The detector and the pressure tight vessel are shown in Fig. 3.

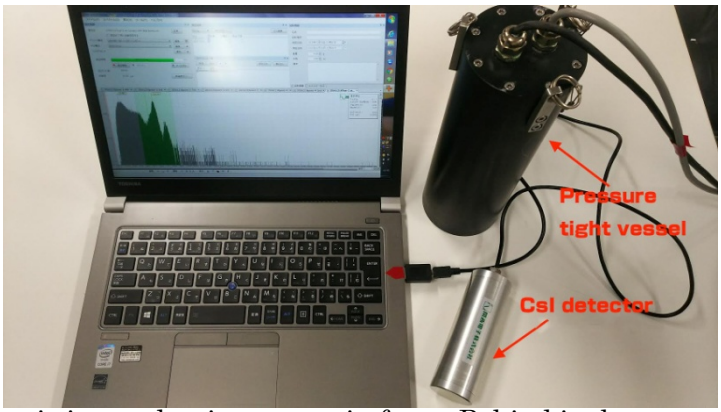

Fig.3. Detector is in an aluminum case in front. Behind is the pressure tight vessel.

The efficiency of the detector mentioned above is measured by a standard method using a point source of ^{137}Cs. In actual measurements, however, the detector contacts with a contaminated surface of a rock which can be regarded as a two-dimensionally extended source. To take into account effects of this extended nature of the source, this situation is simulated by putting the detector in the pressure tight vessel on a rectangular plate source of ^{137}Cs, 10 cm×10 cm in size which is large enough compared with the diameter of the CsI(Tl) crystal. The plate source has a density of 100 Bq/cm^2 (calibrated on Dec. 1, 2011). The gamma ray spectrum of ^{137}Cs is recorded and the count rate per second (cps) is determined from the area under the photoelectric peak after subtraction of the background. The obtained relation of the count rate to amount of ^{137}Cs under the detector is 1 cps to 6.32 Bq/cm^2.

Fig. 4 shows the detector in a cage with two water tight video cameras and flashlights, and one GoPro to observe the surroundings of the cage and to watch drift of the cage, if any, due to a current on the seafloor. Lead of about 7 kg is mounted near the bottom of the cage as weights which can keep the cage upright.

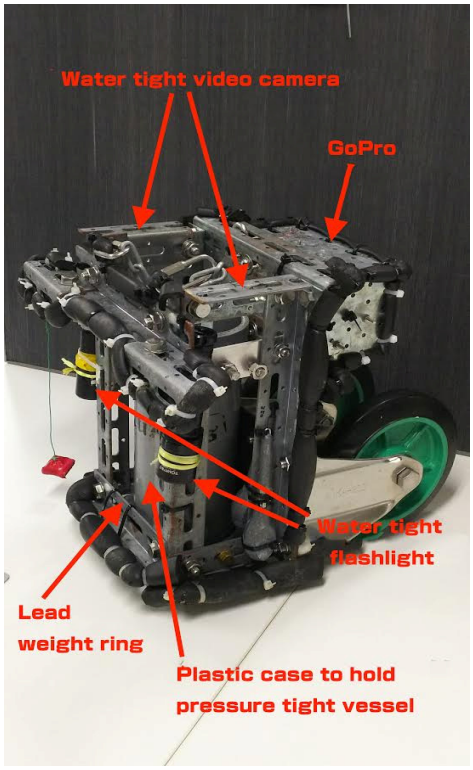

Fig. 4. The cage to support the pressure vessel, the video cameras and the water tight flashlights, and a GoPro.

3. In-situ and static measurements

Fig. 5 illustrates schematically the present in-situ and static method. The cage is lowered by a thick rope. The signal cable, the power supply line, and video signal cable are bundled together. While a gamma ray spectrum is being collected, the rope and the bundle of cables are kept so loose as not to drag the cage. The boat naturally drifts due to a surface current and wind. The position where the cage is lowered from the boat is marked on a GPS display placed on the boat. The boat is constantly brought back to the marked position with engine and steering.

When a current on the seafloor is strong, it pushes the bundled cables toward downstream and, as a result, the cage is dragged in the same direction. In this case the bundled cables are anchored to the bottom before they are pulled up to the boat.

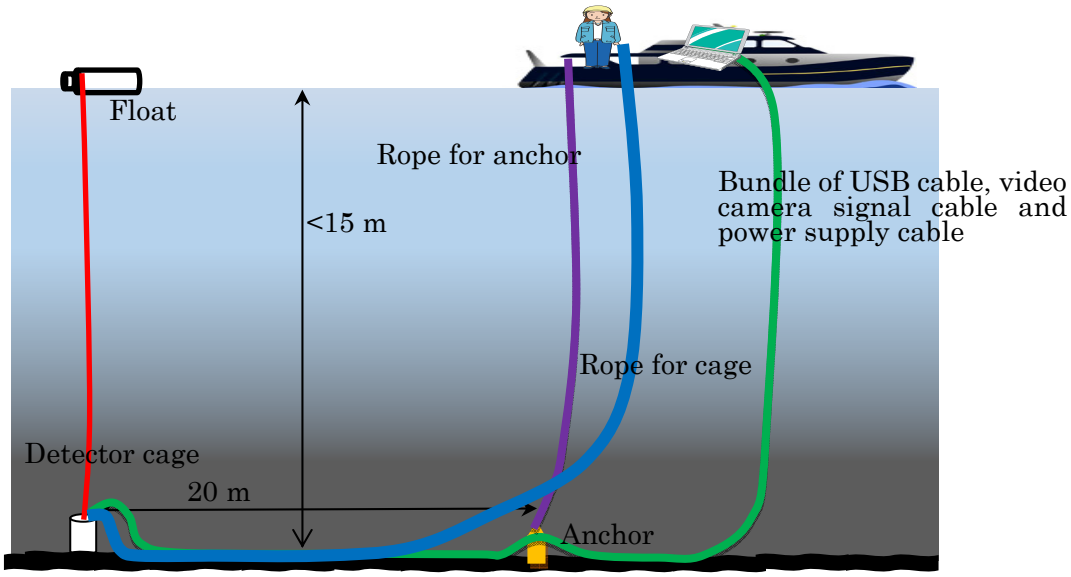

Fig. 5. Illustration of in-situ and static measurement

4. Data processing

A commercially available software, Origin of Origin Lab Co., is used to extract information from the measured gamma ray spectra. Since the aim of the present survey is to quantify the amount of residual ^{137}Cs on rocks of the reefs, we examine the spectra in an energy range between 500 keV and 920 keV which covers 605 keV peak of ^{134}Cs, 662 keV peak of ^{137}Cs, and 796 keV peak of ^{134}Cs. Firstly the background is determined by the B-spline. Then the three peaks are fitted with three Gaussian functions with the same width which is determined by an independent measurement using a test source of

^{137}Cs. The position of each peak is also fixed at that determined from the channel-energy calibration. Therefore, the actual fitting parameters are the heights of the three peaks.

Plausibility of the fitting results is examined by taking a ratio of an area under 796 keV peak of ^{134}Cs and that of 662 keV peak of ^{137}Cs. The theoretical ratio is calculated from the half-life of ^{134}Cs and that of ^{137}Cs, the date of the measurements, and the number of gamma rays emitted from 1 Bq of each nuclide. It is widely accepted that the amount in units of Bq of each nuclide is the same when they were spewed from the crippled nuclear reactors. Only qualitative comparison between theory and measurement could be made because the signal to noise ratio of the 796 keV peak of ^{134}Cs is not high enough to quantify the intensity of the 796 keV peak of ^{134}Cs. Therefore, the measured amount of ^{137}Cs in units of Bq/cm^2 determined from the intensity of the 662 keV peak of ^{137}Cs are given in Table 1 below.

	Point	GPS coordinates		^{137}Cs
		N	E	Bq/cm^2
1st Expl. 2015/9/4	1	37.20.553	141.02.399	1.2
	1	37.20.506	141.02.182	1.3
	2	37.19.918	141.02.584	1.2
	3	37.19.825	141.02.043	4.3
	4	37.18.930	141.02.526	0.85
2nd Expl. 2015/12/20	1	37.20.703	141.02.667	1.8
	2	37.19.918	141.02.587	0.47
3rd Expl. 2016/5/21	1	37.20.498	141.02.387	2.7
	3	37.19.899	141.02.602	2.4
	4	37.19.814	141.02.054	2.9
4th Expl. 2016/7/16	A	37.23.850	141.02.501	2.4
	1	37.20.557	141.02.395	2.5
	2	37.19.900	141.02.601	1.4
	3	37.19.811	141.02.050	1.3
	4	37.18.933	141.02.533	2.6
5th Expl. 2016/12/18	1-3	37.20.060	141.02.417	1.7
	1-4	37.20.555	141.02.405	4.3
	1-5	37.20.560	141.02.425	2.1
	1-6	37.20.562	141.02.423	2.3
	3	37.19.810	141.02.077	1.5
	4	37.18.950	141.02.538	0.97
	4-2	37.18.953	141.02.542	1.5

Table 1. Coordinates by GPS and amount of residual ^{137}Cs in units of Bq/cm^2. As for errors involved, see the text.

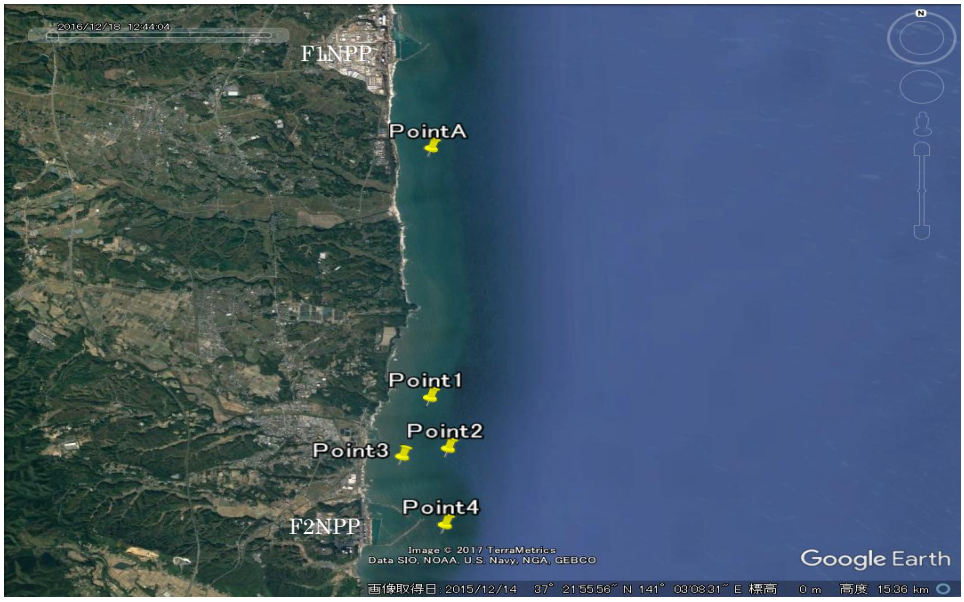

Fig. 6. F1NPP and F2NPP, and reefs surveyed in this work.

5. Uncertainties involved in the measured values

The largest uncertainty involved is in that the bottom of the pressure tight vessel (hereafter called PTV) may not firmly contact with a surface of rock as it did the plate source when the relation between cps and Bq/cm^2 was obtained. Theoretically, a gap of 5mm filled with seawater between a rock surface and the bottom of the PTV reduces the count rate by 4.4%. Seaweed caught between a rock surface and the bottom of the PTV also reduces the count rate by several per cent. The video cameras failed to show how firmly the bottom of the PTV was touching a rock surface. Therefore, there is no way to quantitatively evaluate this sort of uncertainty. A current sways the cage, which makes the gap open and close. This also reduces the count rate. All of these mentioned above work to reduce the count rate, and thus the measured values in the Table 1 must be assumed as the minimum value at each designated point. That is, at least this much of ^{137}Cs remains there. This is the reason why the values in Table 1 do not carry a usual expression of error. The cage was occasionally dragged by an intermittent strong current. Then, the measured value represents an average value of a certain area.

Conclusion

Residual ^{137}Cs on the reefs which lie along the coastline of Fukushima was surveyed by an in-situ and static method. Because of unquantifiable uncertainties in touching of the detector to rock surfaces the values obtained in this study must be considered as the minimum values. Although the present static method is time consuming, further efforts

shall be made toward mapping of distribution of ^{137}Cs on the reefs close to the coastline of Fukushima. Time dependence of the distribution in a short term and a long term shall also be pursued.

Acknowledgments

We thank Professor Arakawa of Tokyo University of Marine Science and Technology and Mr. Tomihara of Aquamarine Fukushima for providing us precious information about the present status of the sea off Fukushima, measuring techniques, and how to find a proper fishing boat. We also thank Iwaki Fishery Cooperative for understanding of the aim of our survey and for introducing us Captain Ishii and his fishing boat Choeimaru. We appreciate Captain Ishii's knowledge of reefs and skill to keep his boat at a designated point against wind and current.

References

1) Thornton, B., Ohnishi, S., Ura, T., Odano, N., Fujita, T., 2013. Continuous measurement of radionuclide distribution off Fukushima using a towed sea-bed gamma ray spectrometer. Deep sea Res. pt. 1(79), 10-19.
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