

# The Fukushima Daiichi Accident

## Current status and marine impacts

February 2016

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The March 2011 Fukushima Daiichi nuclear accident led to the largest single release of radioactivity into the marine environment in history. In addition to the massive releases directly to the atmosphere, which deposited over a vast area of the North Pacific Ocean. Uncontrolled releases of radioactively contaminated water have entered into the ocean every day for nearly five years. The water crisis at Fukushima Daiichi was created in the first hours of the accident by the desperate need to maintain some cooling function for the hundreds of tons of reactor core fuel in units 1, 2 and 3, and the four spent fuel pools. Plant operator Tokyo Electric Power Company (TEPCO) opted to pump hundreds of tons of sea water in a desperate but doomed attempt to prevent multiple reactor core meltdown. In the five years since 2011, over one million tons of water has been pumped into the reactor cores of the Fukushima Daiichi plant. As a consequence, the Fukushima nuclear accident has created a radioactive water crisis unique in its scale and complexity, and with no prospects for a safe and effective solution in the coming years.

In addition to the radioactive contamination from the plant itself, the Japanese mainland, particularly the forests and mountains of Fukushima, are a source of radioactivity to the Pacific Ocean via rivers and streams. Due to the 30 year half life of one of the principal radionuclides released, Cesium-137, the flow of radioactivity from land to ocean will continue over a period of at least 300 years.

The Pacific Ocean is the world's largest body of water, with a surface area of 165.25 million square kilometers (63.8 million square miles) in area, or 46% of the Earth's water surface and about one-third of its total surface area, it is larger than the worlds combined land mass. Understanding the behavior and impacts of radioactivity from the Fukushima nuclear accident that has entered this vast marine environment is both highly complex but essential given how persistent the contamination will be. This is particularly important given the fact that the accident, in terms of uncontrolled releases of radioactivity into Pacific Ocean, is on going, and with the potential for additional major releases in the future. There is much that is already known from the extensive scientific research already conducted since 2011. Equally there are many things that remain to be understood.

In an effort to better understand the radio-ecological impacts of the worlds worst ever single release of radioactivity into the marine environment, an investigation team from Greenpeace has embarked on a radiation survey off the coast of Fukushima. Greenpeace has investigated marine contamination from nuclear facilities for over 25 years, including the impacts on the North-east Atlantic from the Dounreay, Sellafield and la Hague reprocessing plants in the UK and France. In 2016, working from a Japanese research vessel, and supported by the flagship, Rainbow Warrior III, during the month of February and first half of March, the survey teams will be conducting underwater seabed radiation measuring and sample collection. The areas of ocean we will be surveying include within the 20km radius of the Fukushima Daiichi plant, as well as areas to the north and south of the plant. The work will also focus on major coastal rivers of Fukushima which are an ongoing source of radioactive contamination. The Greenpeace survey team is working with radiation scientists from the independent ACRO laboratory in France, together with their partner laboratory in Tokyo.

Through this investigation, Greenpeace is aiming to further the understanding of the impact and future threats from the Fukushima Daiichi nuclear accident.

### **Fukushima Daiichi Plant Current Status**

After 5 years, still very little is known about the causes and effects of the Fukushima nuclear disaster. A whole five years have passed since the severe accident occurred, nonetheless, the

causes of the accident have yet to be clarified.<sup>1</sup> What was the main cause of the accident: the earthquake, or the tsunami? It is certain that both were implicated.<sup>2</sup> For many of the breakdowns that occurred in the reactors, it is still unknown how, for what reasons, and in what sequences they occurred.

At the site of the crippled Fukushima Daiichi plant, the thousands of workers are facing extreme challenges. The site remains highly contaminated with radioactivity, making direct investigations of the interior of reactor buildings, damaged facilities, as well as the location of molten fuel and its condition impossible. The underground areas of the turbine buildings and nearby facilities are submerged under highly contaminated radioactive water and cannot be investigated.

Many of the measuring instruments installed in the Fukushima Daiichi measuring system continue to malfunction as a result of the accident and there is no guarantee of the accuracy of values being measured. However, from the water temperature in the containment vessels and the spent fuel pools, and from the state of releases of Xenon-135, which is released when uranium undergoes fission, and other measurements, it can be estimated that the state of the molten fuel is stable.

Specific details on the location, status and condition of the hundreds of tons of molten reactor fuel in Fukushima Daiichi units 1, 2 and 3 remain unknown. What is confirmed is that the molten fuel has melted its way through the steel Reactor Pressure Vessels (RPV) in the three reactors.

## Water processing

While the Fukushima Daiichi accident is an on going nuclear crisis it is also a very unique water management crisis. A total of 316 tons of water is pumped into the Fukushima Daiichi units 1,2 and 3 each day as of January 28th 2016.<sup>3</sup> A total of 64,000 tons of contaminated water remains inside the reactors buildings 1-4 as of late January 2016. In the week to January 28<sup>th</sup> a total of 8,190 tons of water was treated to remove multiple radionuclides, including cesium and strontium, with a total volume of water processed amounting to 1.43 million tons since operations began in 2011.<sup>4</sup> The water still contains high levels of radioactive tritium which the fishing communities of Fukushima are opposed to discharging into the ocean.

Water storage – as of January 28<sup>th</sup> 2016, a total of 788,541 tons of treated water remains on the sites storage tanks. TEPCO appear to be treating around 1000 tons of highly contaminated water for removal of strontium each week, and a total of 4,200 tons per week for cesium and other radionuclide removal. The maximum storage capacity for treated water in late January was 613,900 tons – with 599,609 tons in storage tanks as of January 28<sup>th</sup>. At a weekly rate of increase of 4,200 tons, there was only sufficient capacity for 3 more weeks of storage. However, by February 18<sup>th</sup> TEPCO had increased storage tank capacity to 625,100 tons – an additional 12,000 tons of new welded tank capacity.<sup>5</sup> A total of 1,106 water storage tanks are currently on site, with an additional 20 tanks planned to be installed during 2016.<sup>6</sup>

## Contaminated Water Crisis

According to a 2012-13 estimate by TEPCO, roughly 800-1,000 m3 of groundwater was flowing onto the nuclear reactor site every day, with about 300 m3 flowing into the reactor buildings. TEPCO is currently implementing seven different kinds of measures in an attempt to reduce the flow of this groundwater:

<sup>1</sup> Current State of Post-Accident Operations at Fukushima Daiichi Nuclear Power Station July to December 2015 ~Nuke Info Tokyo No. 170, see <http://www.cnrc.jp/english/?p=3280>

<sup>2</sup> The National Diet of Japan Fukushima Nuclear Accident Independent Investigation Commission, 2012.

<sup>3</sup> □ "Situation of Storage and Treatment of Accumulated Water including Highly Concentrated Radioactive Materials at Fukushima Daiichi Nuclear Power Station (237th Release)" January 29, 2016 Tokyo Electric Power Company, see [http://www.tepco.co.jp/en/press/corp-com/release/betu16\\_e/images/160129e0201.pdf](http://www.tepco.co.jp/en/press/corp-com/release/betu16_e/images/160129e0201.pdf)

<sup>4</sup> □ "Situation of Storage and Treatment of Accumulated Water including Highly Concentrated Radioactive Materials at Fukushima Daiichi Nuclear Power Station (237th Release)" January 29, 2016 Tokyo Electric Power Company, see [http://www.tepco.co.jp/en/press/corp-com/release/betu16\\_e/images/160129e0201.pdf](http://www.tepco.co.jp/en/press/corp-com/release/betu16_e/images/160129e0201.pdf)

<sup>5</sup> □ "Situation of Storage and Treatment of Accumulated Water including Highly Concentrated Radioactive Materials at Fukushima Daiichi Nuclear Power Station (239th Release)", February 12, 2016 Tokyo Electric Power Company, [http://www.tepco.co.jp/en/press/corp-com/release/betu16\\_e/images/160212e0101.pdf](http://www.tepco.co.jp/en/press/corp-com/release/betu16_e/images/160212e0101.pdf)

<sup>6</sup> "PHOTO: More than 1,100 water storage tanks at Fukushima plant ... and counting", Asahi Shimbun, February 13, 2016, <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201602130025>

Groundwater pumping wells have been installed on the mountain side of the site to pump up groundwater and release it into the ocean after measuring its contamination level. This “groundwater bypass” for reducing the inflow of groundwater began operation in April 2014. A total of 154,021 m<sup>3</sup> of water has been released into the Pacific (up to December 21, 2015). In October 2015, TEPCO estimated that, combined with the water suppression measures taken at the high-temperature incinerator building, this operation reduced the groundwater inflow by 80 m<sup>3</sup> per day.)

Installation of the impermeable seaside water barrier to prevent contaminated water leaking out with groundwater. The construction work was completed in October 2015, but due to a rise in the level of groundwater, which now had no outlet, the water barrier warped and a fissure appeared between the ground and the barrier. Repairs were completed on December 5 2015, but it raises questions about the long term viability of this barrier.

Groundwater is being pumped up from the pumping wells, known as sub-drains, that have been dug around the buildings, and this being released into the ocean after processing at the water processing facility for water from the sub-drains and other locations. This measure began operation in September 2015. Around 360 m<sup>3</sup>/day of water is being pumped up and a total of 36,376 m<sup>3</sup> had been released as of December 21, 2015.

Groundwater is being pumped up from pumping wells known as groundwater drains, five of which were dug in the vicinity of the sea side water barrier, and is being released into the ocean after processing at the water processing facility for water from the sub-drains and other locations. This operation began in November 2015, when the groundwater level rose. Around 90 m<sup>3</sup>/day are pumped up. The groundwater level is being adjusted in combination with groundwater pumping (80 m<sup>3</sup>/day) using well points which began operation in August 2013.

Construction of an inland water barrier (the so called ice wall, consisting of 1,568 refrigeration pipes to a depth of 30 meters and 359 temperature measuring tubes at set intervals around Units 1 to 4.) The preparation for freezing was completed on the three inland sides on September 15<sup>th</sup> 2015 and the work to install the refrigeration pipes of the remaining sea side was completed on November 9<sup>th</sup> 2015. Trial freezing, which began in April last year at 18 locations using 58 freezing tubes, showed differences in freezing temperature.

Implementation of removal of highly contaminated water flowing from the buildings into trenches on the sea side. Work on Unit 4 to stop water flows and to remove contaminated water, was conducted in two stages and completed on in 2015 on April 28 and December 21, for Unit 2 on July 10, and for Unit 3 on August 27.

TEPCO estimates that they have reduced the inflow of groundwater into the buildings by 200 m<sup>3</sup>/day. However, the plan to release treated groundwater has had to be abandoned because the groundwater pumped up was found to be so highly contaminated with tritium above the maximum of 1500 Becquerels per liter - that it could not be processed by the water processing facility for water from the sub-drains and other locations. An additional 300 tons of water is now being pumped into the reactor buildings as a `temporary measure`. To compound the problem, the seaside walls have also significantly raised groundwater levels, forcing the utility to pump a lot more groundwater than it originally planned.<sup>7</sup> As a result, the volume of water transferred to the building for treatment by ALPS is increasing (around 400 m<sup>3</sup>/day as of December 18<sup>th</sup> 2015). The total inflow to the reactor buildings increased to 600 tons per day.

TEPCO has stated that it suspects the high levels of radiation found in the groundwater from the wells is due to the water being exposed to highly contaminated soil near the plant's coastal embankment.<sup>8</sup> This was predictable yet TEPCO has not been transparent on exactly how this is occurring, with no plans announced on how they intend to process this water.

<sup>7</sup> “Fukushima Daiichi NPS Prompt Report (Jan 08,2016) Recent Topics: Tepco Stores Rather Than Discharges From Groundwater Drain After Monitoring Detects Higher Contamination Levels”, see [http://www.tepco.co.jp/en/press/corp-com/release/2016/1265513\\_7763.html](http://www.tepco.co.jp/en/press/corp-com/release/2016/1265513_7763.html)

<sup>8</sup> □ “TEPCO confronts new problem of radioactive water at Fukushima plant”, Asahi Shimbun, December 26 2015, see <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201512260045>

## Ice Wall Doubts

Construction of the ice barrier at Fukushima Daiichi began in June 2014, with the project having cost 34.5 billion yen (\$300 million) as of January 2016.<sup>9</sup> TEPCO had planned to begin the freezing operation in March 2015 for a period of six years – the time they say that will be required to seal the reactors from environment. In addition to looking like an unrealistic schedule, there are significant doubts about the effectiveness of the ice wall plan.<sup>10</sup> The actual rate of ground water migration, geology, soil movement (including seismic risks) and surface temperature are all issues that raise questions over the prospects for the ice wall barrier's effectiveness. In December 2015, the Nuclear Regulation Authority (NRA) requested to TEPCO that they consider operating the ice wall only in places where contaminated water is unlikely to leak into the ground. In February 2016, further doubts led the NRA to first put a stop to TEPCO's plans to operate the ice wall completely,<sup>11</sup> and then to backtrack to allow limited operation only on the seaside of the plant. The NRA stated in February 2016 that contaminated water accumulated in the reactor buildings could leak into the groundwater if the ground water level inside the frozen soil wall drops too much. TEPCO has maintained that once the soil is frozen, it will form a circular barrier and reduce the flow of groundwater into the reactor buildings; and that, in turn, will prevent water contaminated with radioactive substances from accumulating.

*"TEPCO is scattering a strange illusion that the problem of contaminated water can be solved completely if a frozen soil wall is constructed,"* NRA chairman Shunichi Tanaka.<sup>12</sup>

## Radioactivity releases to the Pacific Ocean

With no prospect of an end to the water crisis at the Fukushima Daiichi plant, the radioactive threat to the Fukushima prefecture coastline, the communities that live there and the Pacific Ocean is a major concern to Greenpeace. As a result of the Fukushima Daiichi accident, there are three principle sources of radioactivity that have and are contaminating the ocean:

- the initial atmospheric and direct liquid marine discharges in 2011;
- the on going direct uncontrolled releases from the Fukushima Daiichi site, including groundwater;
- land based pollution from Fukushima prefecture via rivers and watercourses.

Radioactive cesium is largely soluble in the marine environment, being carried by ocean currents, but also a small fraction attaches to marine sediments. This particle associated cesium is important as a potential source for the higher levels of cesium found in specific benthic invertebrates and demersal fish. It is this particulate cesium that is associated with contamination of the seabed in the near shore area of the Fukushima Daiichi plant. The levels of cesium in this area, including the 20km radius of the plant far exceeds the general level in Japanese waters as a whole.<sup>13</sup>

As observed in 2011, due to the overall amount of radioactivity released from Fukushima, *"the concentrations of Cs in sediments and marine biota near the nuclear power plant plant may be quite large and will continue to remain so for at least 30-100 years due to the longer half life of cesium-137"*.<sup>14</sup>

<sup>9</sup>

"NRA calls a halt to TEPCO's plan to freeze soil at Fukushima plant", Asahi Shimbun, February 10, 2016, see <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201602100079>

<sup>10</sup> [http://www.huffingtonpost.com/2014/05/02/fukushima-ice-wall\\_n\\_5252868.html](http://www.huffingtonpost.com/2014/05/02/fukushima-ice-wall_n_5252868.html), accessed January 29<sup>th</sup> 2015.

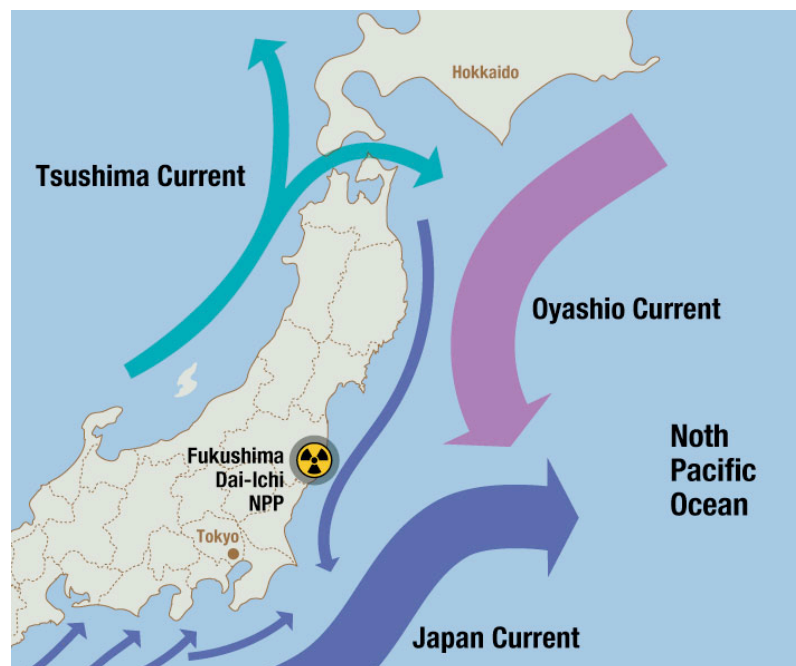
<sup>11</sup> "NRA to allow part of frozen soil wall at Fukushima plant" Asahi Shimbun, February 15, 2016, <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201602150062>

<sup>12</sup> "NRA calls a halt to TEPCO's plan to freeze soil at Fukushima plant", Asahi Shimbun, February 10, 2016, see <http://ajw.asahi.com/article/0311disaster/fukushima/AJ201602100079>

<sup>13</sup> "Tracking the fate of particle associated Fukushima Daiichi Cesium in the Ocean off Japan", K. Buessler, C. German, M. Honda, S. Otsuka, E. Black, H. Kawakami, S. Manganin, S. Pike, Woods Hole Oceanographic Institute, Japan Agency for Marine Earth Science and Technology, Japan Atomic Energy Agency, Environmental Science and Technology, July 9 2015.

<sup>14</sup> "Impacts of the Fukushima Nuclear Power Plants on Marine Radioactivity", Ken Buessler, Michio Aoyama and Msao Fukasawa, Environmental Science and Technology, American Chemical Society, 2011.

The total releases of cesium remains uncertain, ranging from 4-90 Pbq, with most estimates in the 15-30PBq range for each cesium isotope.<sup>15</sup> Estimates suggest that the releases to the Pacific Ocean through atmospheric deposition and direct discharges was around 11PBq.<sup>16</sup>



### Dispersal and concentration in coastal sediments

Ocean currents off the coast of Japan transported contaminated water southward via the Oyashio current as well as northwards largely as a result of wind driven surface shifts. The cesium concentrations in seawater near the coasts of Fukushima and Ibaraki prefectures during spring 2011 rose dramatically from a pre-accident background level of 1-2 becquerels per cubic meter to concentrations of up to 60 million becquerels per cubic meter, “high enough to cause reproductive and health effects in marine animals.”<sup>17</sup>

During the intervening five years, the cesium released at that time has both dispersed and settled out due to horizontal and vertical mixing, and generally radioactive contamination of ocean seawater dispersed rapidly, particularly compared to contamination of soil on land. However, evidence of the on-going releases from the Fukushima Daiichi plant was demonstrated during May and June 2011 when concentration levels in seawater did not decline as expected. For the period through 2012, the radioactivity remained at a relatively high level in close proximity to the Fukushima Daiichi plant, clear evidence of continuous releases from the plant.<sup>18</sup> Cesium has the potential to be taken up in plankton and the marine food chain as well as deposited with organic material and biominerals.<sup>19</sup> A fraction of this has settled on the sea floor.

<sup>15</sup> See for example, “<sup>131</sup>I and <sup>137</sup>Cs Accidentally Discharged from the Fukushima Daiichi Nuclear Power Plant into the Atmosphere”, Chino, M.; Nakayama, H.; Nagai, H.; Terada, H.; Katata, G.; “Preliminary Estimation of Release Amounts of 1129–1134”, J. Nuclear Science and Technology 2011, 48 (7), Yamazawa, H.; Tsumune, D.; Tsubono, T.; Aoyama, M.; Uematsu, M.; Misumi, K.; Maeda, Y.; Yoshida, Y.; Hayami, H. One-year, regional scale simulation of <sup>137</sup>Cs radioactivity in the ocean following the Fukushima Daiichi Nuclear Power Plant accident. Biogeosciences 2013, 10 (8), 5601–5617.

<sup>16</sup> “Source term estimation of atmospheric release due to the Fukushima Dai-ichi Nuclear Power Plant accident by atmospheric and oceanic dispersion simulations”, Kobayashi, T.; Nagai, H.; Chino, M.; Kawamura, H.. J. Nuclear Science and Technology, 2013, 50, 255–264.

<sup>17</sup> “Radioisotopes in the Ocean What’s there? How much? How long?”, Woods Hole Institution, David Pacchioli, May 1, 2013, see <http://www.whoi.edu/oceanus/feature/radioisotopes-in-the-ocean>

<sup>18</sup> “Continuing <sup>137</sup>Cs release to the sea from the Fukushima Daiichi nuclear power plant through 2012”, J Kanda, Department of Ocean Sciences, Tokyo University of Marine Science and Technology, Tokyo, September 26 2013, Biogeosciences.

<sup>19</sup> As described by FUKUDA - In soil and sediments, the radiocaesium activities for finer grain sizes tends to be higher because specific surface areas of smaller grains are larger (e.g. He and Walling, 1996). Therefore, it is necessary to consider the differences of grain size composition in sediments in order to compare distributions of lateral and vertical radiocaesium activities and inventories in coastal sediments, which are commonly of several grain sizes. Sediments off the coast of Fukushima are divided into four classes based on grain sizes using several mesh sizes: granules (grain size larger than 2 mm); very coarse to coarse sand particles (1 to 2 mm); coarse to very fine sand particles (0.063 to 1 mm); and silt particles (smaller than 0.063 mm). Radionuclides were measured for each grain size class using high-purity gamma ray spectrometry and then corrected to the sampling date. In collected sediments, the only artificial radionuclides detected were radiocaesium. In the surface layer of sediments (0-5 cm), the percentage ranges were: granules, 0 to 23 %; very coarse to coarse sand particles, 0 to 39 %; coarse to very fine sand particles, 38 to 98 %; and silt particles, 0 to 46 %. The <sup>137</sup>Cs activities for coarse to very fine sand particles and silt particles ranged from 8.5 to 609 Bq kg<sup>-1</sup>-dry and 18 to 1487 Bq kg<sup>-1</sup>-dry, respectively and the latter particle activities were higher than those for the former particles in most layers. The <sup>137</sup>Cs inventories for coarse to very fine sand particles ranged from 972 to 3285 Bq m<sup>-2</sup> and those in the water depth range of 100 to 150 m were highest. The <sup>137</sup>Cs inventories for silt particles ranged from 1387 to 31321 Bq m<sup>-2</sup> and they decreased with increasing water depth – as described in “The



It is the processes affecting the distribution of sedimentary cesium<sup>20</sup> in the nearshore environment along the Fukushima coastline that is a focus of the Greenpeace investigations in February / March 2016.

### **Seabed Cesium Anomalies within 20km of Fukushima Daiichi nuclear plant**

*“The lack of information raises concerns regarding our ability to predict the effects of the accident on the marine ecosystem...”<sup>21</sup>*

Due to the complex challenges of marine investigations limited understanding exists on the local distribution of Cs137 in proximity to the Fukushima Daiichi plant. The research that has been conducted has identified considerable variation in the distribution and concentration of Cs137. Prior to the 2011 accident, concentrations in seafloor sediment off Fukushima were in the range of 0.68-1.7Bq/kg (dry weight) according to the Ministry of Education, Culture, Sports, Science and Technology (MEXT), levels post 2011 are commonly several hundreds of Bq/kg.<sup>22</sup>

Survey work conducted in late 2012 and early 2013 identified anomalies where the maximum levels of Cs137 were higher than a few hundred Bq/kg within a 20km radius of the Fukushima Daiichi plant. The measured anomalies were in scale from a few meters to several hundreds of meters in length. The survey researchers concluded that the size and distribution of cesium sedimentary anomalies appeared to be closely related to meter scale features of the seafloor terrain, and that the **existence of these anomalies should be taken into account when planning future survey efforts, and when considering the potential effects of 137Cs on marine ecology.**

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distributions and behavior of radiocaesium according to grain sizes in sediments after the FDNPS accident”, FUKUDA, Miho ; YAMAZAKI, Shinnosuke; AONO, Tatsuo ; YOSHIDA, Satoshi ; NAGANUMA, Sho ; KUBO, Atsushi ; SHIMADA, Keishi ; TAKASAWA, Nobue ; HOSAKA, Takuji ; SATO, Kenichiro ; YAMAGUCHI, Seiya ; ITO, Yukari ; ISHIMARU, Takashi ; KANDA, Jota, National Institute of Radiological Science (NIRS), Tokyo University of Marine Science and Technology, Marine Works Japan.

<sup>20</sup> “Vertical and Lateral Transport of Particulate Radiocaesium off Fukushima”, Shigeyoshi Otsuka, Takahiro Nakanishi, Takashi Suzuki, Yuhui Satoh, and Hisashi Narita Research Group for Environmental Science, Japan Atomic Energy Agency, Fukushima Environmental Research Group, Japan Atomic Energy Agency, and the Japan School of Marine Science and Technology, Tokai University, dx.doi.org/10.1021/es503736d | Environmental Science and Technology, 2014, 48, 12595–12602, October 13 2014.

<sup>21</sup> Distribution of local 137Cs anomalies on the seafloor near the Fukushima Dai-ichi Nuclear Power Plant”, Blair Thornton, Seiki Ohnishi, Tamaki Ura, Naoteru Odano, Shun Sasaki, Tsuneo Fujita, Tomowo Watanabe, Kaoru Nakata, Tsuneo Ono, Daisuke Ambe, Institute of Industrial Science, The University of Tokyo, National Maritime Research Institute, Fukushima Prefectural Fisheries Experimental Station, National Research Institute of Fishery Science, Fisheries Research Agency, Marine Pollution Bulletin, 2013

<sup>22</sup> “Distribution of local 137Cs anomalies on the seafloor near the Fukushima Dai-ichi Nuclear Power Plant”, Blair Thornton, Seiki Ohnishi, Tamaki Ura, Naoteru Odano, Shun Sasaki, Tsuneo Fujita, Tomowo Watanabe, Kaoru Nakata, Tsuneo Ono, Daisuke Ambe, Institute of Industrial Science, The University of Tokyo, National Maritime Research Institute, Fukushima Prefectural Fisheries Experimental Station, National Research Institute of Fishery Science, Fisheries Research Agency, Marine Pollution Bulletin, 2013

