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# Preface: Migration of radionuclides from the Fukushima Daiichi Nuclear Power Plant accident

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On March 11 in 2011, a great earthquake hit the eastern part of mainland Japan. It triggered several gigantic tsunami waves that destroyed the coastal areas in Tohoku and north Kanto districts, which face the Pacific Ocean. The earthquake that was coupled with a tsunami fatally damaged the Fukushima Daiichi Nuclear Power Plant (FDNPP), which was operated by the Tokyo Electric Company, taking over the nuclear reactors. When the backup electricity supply was lost, nuclear fuels were partly melted, causing a couple of hydrogen explosions that eventually released a large amount of radioactive materials into the environment. Radioactive nuclides, mostly produced by the nuclear fission of $^{235}$U, were detected in a wide area, not only in the immediate vicinity surrounding the FDNPP but also in remote areas such as the Kanto district and metropolitan Tokyo. Subsequently, some radioactive nuclides were detected in the United States and in some European countries. Apparently, radioactive materials released into the atmosphere and oceans are carried by global atmospheric and oceanic circulations all over the world.

The Geochemical Society of Japan (GSJ) initiated several actions soon after the earthquake and the FDNPP accident. For instance, in response to the society's appeal, many GSJ members joined the project to map the distribution of several radioactive nuclides in soil samples in the Fukushima Prefecture under the supervision of the Cabinet Office and Ministry of Education, Culture, Science, Sport and Technology (MEXT). The members' contributions led to the creation of several distribution maps of radioactive nuclides, such as $^{134,137}$Cs, $^{131}$I, and $^{132}$Te, trapped in soils in Fukushima (MEXT, 2011). The GSJ members also performed several experiments from various aspects individually or in groups in collaboration with researchers from neighboring fields. Considering these situations, the GSJ proposed to organize special sessions on research activities related to the FDNPP accident on the occasions of the 2011 Goldschmidt Conference and 2011 Annual Meeting of the GSJ.

For the Fukushima Review session of the 2011 Goldschmidt Conference in Prague, nine papers (all invited) were orally presented on August 16, 2011. After the session, a statement (Supplementary Materials) was appealed by the presidents of three societies, Drs. Mitsuru Ebihara, Bernard Bourdon, and Samuel Mukasa, on behalf of the GSJ, the European Association of Geochemistry, and the Geochemical Society, respectively (Society Presidents' Joint Statement on Fukushima, 2011). In this statement, the disclosure of monitoring data on radioactive material, continued monitoring of the spread of radioactive materials, and international alliance of researchers for the global monitoring of radioactive materials were strongly appealed. In total, 15 papers were presented (i.e., 12 oral and 3 poster presentations) in the session entitled "Geochemistry of environmental pollution and revival from a great disaster" on September 14, 2011 during the 2011 Annual Meeting of the Geochemical Society of Japan held at Hokkaido University, Sapporo. This special issue was made to accommodate the selected papers presented in these two special sessions. The title of this volume was named after the session held at the 2011 Goldschmidt Conference.

Here, we introduce the contributions and compare them with those already reported in the literature on the migration of radionuclides emitted from the FDNPP. The FDNPP accident caused a number of radioactive nuclides to be dispersed in the environment. Haba *et al*. (2012) report the one-year monitoring data of 11 airborne radionuclides (i.e., $^{140}$Ba, $^{137}$Cs, $^{136g}$Cs, $^{134g}$Cs, $^{133g}$I, $^{132}$Te, $^{131}$I, $^{129m}$Te, $^{110m}$Ag, $^{99}$Mo, and $^{95g}$Nb) collected in Wako, Saitama, Japan. The information may be important in the characterization of the FDNPP accident in terms of the

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damage to the nuclear reactor, fuel condition, and release mechanisms of radionuclides. The results are comparable with those of Endo *et al*. (2012) and Tagami *et al*. (2011) that identify various radionuclides, such as $^{95}$Nb, $^{110m}$Ag, $^{129m}$Te, $^{132}$Te, $^{131}$I, $^{132}$I, $^{134}$Cs, $^{136}$Cs, $^{137}$Cs, $^{140}$Ba, and $^{140}$La, in soils collected from highly contaminated areas in the Fukushima Prefecture.

Among these radionuclides, $^{131}$I (half life: 8 days), $^{134}$Cs (half life: 2 years), and $^{137}$Cs (half life: 30 years) are highly concerned in terms of radiation exposure to the public (Chino *et al*., 2011). More than two-thirds of the papers presented in this issue describe the distribution of $^{134}$Cs and $^{137}$Cs in the environment. Watanabe *et al*. (2012) report $^{134}$Cs and $^{137}$Cs concentrations in soil samples systematically collected from the southern part of the Miyagi Prefecture, which is adjacent to the northern part of the Fukushima Prefecture. Although this area is close to the FDNPP, systematic surveys on radioactive nuclides, such as those conducted in the Fukushima Prefecture, have not been conducted. This study complements that of Kinoshita *et al*. (2011), which describes the distribution of radionuclides in the Fukushima and Ibaraki Prefectures. The distribution of radionuclides in wide areas helps to construct the precise modeling of the emission and deposition of radionuclides on land (Morino *et al*., 2011).

Ohno *et al*. (2012) study the vertical and horizontal distributions of radiocesium and radioiodine mainly in the agricultural fields in the Fukushima Prefecture. Although their vertical profiles were already studied in Kato *et al*. (2012) and Tanaka *et al*. (2012), Ohno *et al*. (2012) revealed that the horizontal distribution of radionuclides can be different among rice paddy fields, orchards, and cedar forests. Qin *et al*. (2012) investigate the host phase of radiocesium in soil and sediment samples contaminated with radiocesium in the Fukushima Prefecture by sequential extraction and extended X-ray absorption fine structure (EXAFS) spectroscopy. The local structure of cesium adsorbed on the soil and the sediment can explain the strong retention of radiocesium on the surface of the soil layer already observed in several studies previously mentioned.

After the deposition of radionuclides on land, the redistribution of such radionuclides can occur through transport in the atmosphere and hydrosphere (Yamauchi, 2012; Yoshida and Takahashi, 2012). As for the river system, Oura and Ebihara (2012) identify a short-lived nuclide $^{131}$I that was determined from river water samples collected from several major rivers flowing through the Tokyo metropolis area and compare its concentration change with those of $^{134}$Cs and $^{137}$Cs. As regards migration in the marine system, Inoue *et al*. (2012) report their concentrations in sea water samples collected not only from the local area close to the FDNNP but also from the sea surrounding Japan. Aoyama *et al*. (2012) examine the temporal variation of radiocesium activity along the coastline near the FDNPP. The results show that the peak of the radiocesium activity at the Hasaki station (180 km south of the FDNPP) was observed in June 2011, a two-month delay from the peak at the FDNPP. The results should be interpreted in the future by numerical simulation, as was already conducted by Yasunari *et al*. (2011), Honda *et al*. (2012) and Masumoto *et al*. (2012). Subsequent migration of radiocesium into the marine food web was also discussed in Yoshida and Kanda (2012).

Two studies focus on radiosulfur and radioiodine, respectively, emitted through the FDNPP accident. Danielache *et al*. (2012) estimate the amount of radioactive $^{35}$S emitted into the atmosphere by the accident using a numerical simulation global transport. Possibly, $^{35}$S can be an important tracer for future studies on the geochemical cycle of sulfur on the earth's surface. Similar discussion was also found in Priyadarshi *et al*. (2011) based on the measurement of $^{35}$S in California. Miyake *et al*. (2012) determine $^{129}$I/$^{131}$I ratios in several soil samples from Fukushima by accelerator mass spectrometry and estimate $^{129}$I/$^{131}$I = 31.6 ± 8.9 as of March 15, 2011. The distribution of $^{131}$I is very important, particularly for the radiological dose assessment of the accident. However, data on $^{131}$I are limited because of its short half life. Thus, the determination of $^{129}$I is important as a complement to the study on the distribution of $^{131}$I if we assume that the $^{129}$I/$^{131}$I ratio emitted from the FDNPP is constant, as indicated in the $^{134}$Cs/$^{137}$Cs ratio, which is almost constant at 1.0 as of March 11, 2011 (Haba *et al*., 2012; Aoyama *et al*., 2012).

In this issue, three manuscripts related to the possible emission of plutonium, which is also of high concern because of its toxicity to the human body, are included. Yamamoto *et al*. (2012) report the $^{239}$Pu+$^{240}$Pu concentrations aside from those of $^{131}$I, $^{134}$Cs, $^{136}$Cs, $^{137}$Cs, $^{129m}$Te, $^{129}$Te, and $^{140}$La in the soil samples collected from several areas in the Fukushima Prefecture, including the evacuation area near the FDNPP site. Sakaguchi *et al*. (2012) also report the concentrations of $^{239}$Pu as well as those of $^{134}$Cs and $^{137}$Cs in river water, paddy field water, and sea water in some selected areas close to the FDNPP. Moreover, they present the $^{236}$U and $^{238}$U concentrations in these samples. Zheng *et al*. (2012a) study the distribution of Pu isotopes in marine sediments in the Pacific Ocean 30 km off the FDNPP. The results show that Pu contamination from the FDNPP accident was not observed in marine sediments outside the 30 km zone. These studies on the distribution and concentration of Pu isotopes show that Pu isotopes were fortunately dispersed only in a limited area with a limited quantity, as suggested by Zheng *et al*. (2012b).

In conclusion, we would like to thank all those who

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## Supplementary Materials

Society Presidents' Joint Statement on Fukushima (2011) URL (http://www.terrapub.co.jp/journals/GJ/archives/data/46/MS223.pdf)