Radiocaesium in the North Pacific Ocean derived from atmospheric weapons tests and Fukushima accident: A review of past and present

*Michio Aoyama[1]

1. Institute of Environmnetal Radioactivity, Fukushima University

1, Two major sources terms of radiocaesium to the Ocean from the Fukushima accident and fallout from atmospheric weapons tests before the accident

The ^{137}Cs derived from atmospheric weapons test conducted late 1950s and early 1960s and the inventory in the North Pacific Ocean in 1970 was 290 +- 30 PBq (Aoyama et al., 2006). Some portion of the ^{137}Cs in the North Pacific Ocean were transported to South Pacific Ocean and Indian Ocean and also radioactive decay occurred with a half-life of 30.7 years, the ^{137}Cs inventory in the North Pacific Ocean before the FNPP1 accident decreased to 69 +- 7 PBq as of 2011 (Aoyama et al., 2016).

There are two major sources of radionuclides to the environment derived by the TEPCO Fukushima Dai-ichi Nuclear Power Plant (FNPP1) accident in 2011. The largest and earliest source of artificial radionuclide was atmospheric release from FNPP1, which led to atmospheric deposition on both land and in the ocean. Atmospheric release peaked mid of March 2011 and total amount of atmospheric release of ^{137}Cs was estimated to be 15.2-20.4 PBq and same amount of ^{134}Cs was also released because activity ratio of ^{134}Cs vs. ^{137}Cs was almost 1(Aoyama et al., 2016). About 20 % of released radiocaesium fell on land and 80% of released radiocaesium fell on the ocean. Therefore 11.7-14.8 PBq of ^{137}Cs was injected in the North Pacific Ocean as atmospheric deposition.

Second largest source was the direct discharge of contaminated waters to the ocean since 26 March 2011 and peaked on 6 April 2011 based on analysis of 131I vs. ^{137}Cs activity ratio (Tsumune et al., 2012). Total amount of released ^{137}Cs was estimated to be 3.5 +- 0.7 PBq. A combined input to the North Pacific Ocean of ^{137}Cs from both atmospheric deposition and direct discharge was therefore estimated to be 15.2 –18.3 PBq.

2, Three major pathways of FNPP1 derived radiocaesium in the North Pacific Ocean

The fastest pathway of FNPP1 derived radiocaesium might be surface pathway. FNPP1-derived radiocaesium injected at north of Kuroshio front by atmospheric deposition and direct discharge spread eastward in surface water up to 200 meters by the North Pacific Current across the mid-latitude North Pacific (Aoyama et al., 2016). In 2013 main body of FNPP1 radiocaesium in surface layer was already in the eastern Pacific. A model simulation (Tsubono et al., 2016) also shows good agreement with the observed radiocaesium activities in the Pacific Ocean reported by several studies.

The second pathway is subduction of central mode water (CMW). A maximum of radiocaesium activity in June/July 2012 was observed at potential densities of 26.1–26.3 at 34 deg. N–39 deg. N, 165 deg. E, which correspond to 400 meters depth. The density is in a range of density of CMW and radiocaesium activity was higher than those in the surrounding waters, including STMW. In June-July 2015 and June 2016 at 36˚N–44˚N along 165˚E, there are only very week signal of subduction of FNPP1 radiocaesium. This means that subducted radiocaesium might move eastward from this region. Before the Fukushima accident, ^{137}Cs maximum corresponding CMW region was observed, however, it located at 20˚N, 165˚E because it was 40 years after subduction (Aoyama et al., 2008).

The third pathway is subduction of subtropical mode water (STMW). FNPP1-derived radiocaesium injected at south of Kuroshio front by atmospheric deposition transported to southward rapidly due to subduction of STMW at potential densities of 25.1–25.3. In 2015 along 165 deg. E, FNPP1 radiocaesium corresponding STMW spread entire subtropical gyre and a part of them reached 2 deg. N and recirculated in the subtropical gyre and reached Japanese coast.

3, Mass balance of FNPP1 radiocaesium in the North Pacific

134Cs inventory was estimated to be 8 PBq in surface layer in summer 2012 (Inomata unpublished). Kaeriyama et al. (2016) estimated that 134Cs inventory in STWM in 2012 was about 4 PBq. We believe that FNPP1 derived 134Cs injected in the North Pacific was 15.2 - 18.3 PBq. Therefore 134Cs inventory can be estimated 3-6 PBq in CMW at this moment based on a mass balance of FNPP1 radiocaesium. The ^{137}Cs inventory in the North Pacific Ocean before the FNPP1 accident, which was derived mainly from nuclear weapons testing, was 69 PBq at the end of 2010. Thus, the FNPP1 accident increased the ^{137}Cs inventory of 15.2 - 18.3 PBq by as much as 22 - 27%.

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