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Estimations of direct release rate of ^{137}Cs and ^{90}Sr to the ocean from the Fukushima Dai-ichi Nuclear Power Plant for five-and-a-half years

Daisuke Tsumune (1), Michio Aoyama (2), Takaki Tsubono (1), Kazuhiro Misumi (1), and Yutaka Tateda (1)

(1) Central Research Institute of Electric Power Industry, Abiko, Japan (tsumune@criepi.denken.or.jp), (2) Institute of Environmental Radioactivity, Fukushima University, Fukushima, Japan (r706@ipc.fukushima-u.ac.jp)

A series of accidents at the Fukushima Dai-ichi Nuclear Power Plant (1F NPP) following the earthquake and tsunami of 11 March 2011 resulted in the release of radioactive materials to the ocean by two major pathways, direct release from the accident site and atmospheric deposition. Additional release pathways by river input and runoff from 1F NPP site with precipitation and were also effective for coastal zone in the specific periods before starting direct release on March 26 2011. Direct release from 1F NPP site is dominant one year after the accident. We estimated the direct release rate of ^{137}Cs and ^{90}Sr for more than five-and-a-half years after the accident by the Regional Ocean Model System (ROMS).

Direct release rate of ^{137}Cs were estimated for five-and-a-half years after the accident by comparing simulated results and measured activities adjacent to the 1F NPP site(at 5,6 discharge and south discharge). Directly release rate of ^{137}Cs was estimated to be the order of magnitude of 10^{14} Bq/day and decreased exponentially with time to be the order of magnitude of 10^{9} Bq/day by the end of September 2016. Estimated direct release rate have exponentially reduced with constant rate since November 2011. Apparent half-life of direct release rate was estimated to be 346 days. The estimated total amounts of directly released ^{137}Cs was 3.7$\pm$0.7 PBq for five and a half years. Simulated ^{137}Cs activities attributable to direct release were in good agreement with observed activities, a result that implies the estimated direct release rate was reasonable. Simulated ^{137}Cs activity affected off coast in the Fukushima prefecture. We used the measured ^{137}Cs activities by the Tokyo Electric Power Company (TEPCO) for the estimation of direct release. The sea water samples were corrected from the coast. The averaged ^{137}Cs activities from November 2013 to June 2016 were 391 and 383 Bq/m^3 at 5,6 discharge and south discharge, respectively. The averaged ^{137}Cs activities measured by the Nuclear Regulation Agency (NRA) is about five times smaller than the one by the TEPCO because the NRA corrected seawater samples at 300-500m offshore by ship. Horizontal resolution of the model was 1km x 1km, therefore it is important to consider the difference of activities in the sub-grid scale for the detailed estimations of direct release.

^{90}Sr/^{137}Cs activity ratio measured adjacent to the 1F NPP is variable with time. The ^{90}Sr/^{137}Cs activity ratio was 0.62 due to the global fallout before the accident. The ^{90}Sr/^{137}Cs activity ratio decreased to 0.01 after the accident before April 2011. And the ratio increased to 1 by September 2013. And then the ratio decreased to 0.1-1. After October 2015, the ratio decreased to 0.1-0.2. Directly release rate of ^{90}Sr was estimated to be the order of magnitude of 10^{12} Bq/day and decreased to the order of magnitude of 10^{8} Bq/day by the end of September 2016. The estimated total amounts of directly released ^{90}Sr was 35 $\pm$ 7 TBq.