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Plutonium Released by the Nagasaki A-bomb: Mobility in the Environment

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The first and second environmental releases of man-made $^{239+240}Pu$ came from nuclear explosions at Alamagordo and Nagasaki in 1945. The release at Nagasaki was more serious than at Alamagordo, because it happened in an area with a high population density. Unfissioned $^{239+240}Pu$ and various fission products (e.g. ^{90}Sr and ^{137}Cs) have been interacting here with various environmental materials (soils, sediments, and plants) under wet and temperate conditions for more than 45 years. To assess the environmental mobility of $^{239+240}Pu$, the distributions of radionuclides from this release were investigated at Nishiyama (3 km east of the hypocenter) where heavy black rain containing unfissioned plutonium and fission products fell 30 minutes after the nuclear explosion. The vertical distributions of ^{90}Sr, ^{137}Cs and $^{239+240}Pu$ were determined in unsaturated soil cores up to 450 cm deep. Most radionuclides were found in the soil column 30 cm from the ground surface (95% of ^{90}Sr, 99% of ^{137}Cs and 97% of $^{239+240}Pu$). However, ^{90}Sr and $^{239+240}Pu$ were detected in the groundwater as well below a depth of 200 cm. No ^{137}Cs was found below 40 cm from the ground surface or in groundwater. These observations reveal that about 3% of the total $^{239+240}Pu$ has been migrating in the soil at a faster rate than the remaining $^{239+240}Pu$. Sharp peak of ^{137}Cs and $^{239+240}Pu$, indicating heavy deposition from the Nagasaki local fallout of 1945, were found in sediment cores collected from the Nishiyama reservoir. On the other hand, since ^{90}Sr is mobile in fresh water sediments, there was no 1945 ^{90}Sr peak in the sediment cores. $^{239+240}Pu$ peaks were unexpectedly discovered in pre-1945 sediment core sections. Although ^{90}Sr was found in these sections, no ^{137}Cs was found. By contrast to the distribution in sediment cores, ^{137}Cs in tree rings had spread by diffusion from the bark to the center of the tree without holding a fallout deposition record. Most of the $^{239+240}Pu$ was distributed in the tree rings following a similar deposition record to that found in sediment cores. Furthermore, a very small amount of $^{239+240}Pu$ (about 1%) was found unexpectedly in pre-1945 tree rings. The only reasonable explanation for these unexpected discoveries is the existence of mobile $^{239+240}Pu$ in the environment.

Introduction

Plutonium (atomic number 94) was first produced and discovered after an artificial nuclear reaction in 1942. Only 3 years later, plutonium was released into the environment as a result of the Nagasaki A-bombing. Plutonium has two important features: it may provide fertile energy through use in fast breeder reactors, and it is a very hazardous material. Environmental release of $^{239+240}Pu$ started at Alamagordo in New Mexico and at Nagasaki in Japan in 1945. Nagasaki has a mild humid climate with 2000 mm of precipitation a year. The migration, transfer and interaction of $^{239+240}Pu$ in the environment is faster at Nagasaki than at Alamagordo which is very dry with low precipitation. Data collected at Nagasaki can help to evaluate long-term environmental effects caused by $^{239+240}Pu$ released by nuclear accidents like Chernobyl.

To restore an environment polluted by $^{239+240}Pu$, we must assess its mobility based on data collected *in situ* and under laboratory conditions. The mobility of plutonium in various environments has been discussed by many researchers. Koide *et al.* (1975), Livingston and Bowen (1979), Bondietti and Trabalka (1980), Santschi *et al.* (1980), Bowen *et al.* (1980), Carpenter and Beasley (1981), Aston and Stanners (1981), Nelson and Lovett (1978), Lovett and Nelson (1981), Karshaw *et al.* (1983), Karshaw *et al.* (1990), Sholkovitz (1983), Sholkovitz and Mann (1984), Cochran (1985), Pentreath *et al.* (1986), and Mahara *et al.* (1988) have described mobility in marine and freshwater environments. Rhodes (1957), Hajek (1966), Sanchez *et al.* (1981), Sanchez *et al.* (1982), Sanchez *et al.* (1985), Cleveland and Rees (1981), Nelson *et al.* (1985), Bondietti (1982), Olsen *et al.* (1986), Mahara and Miyahara (1984), Mahara and Matsuzuru (1989), and Price (1991) have described underground mobility. However, long-term *in situ* migration of $^{239+240}Pu$ has been discussed only by Mahara and Miyahara (1984), Mahara *et al.* (1988), and Price (1991). Unfortunately, the data investigated by Price were collected at the Hanford site under semi-arid conditions and the production rate of mobile $^{239+240}Pu$ is thought to be less than that at Nagasaki.

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