^{137}Cs AND ^{134}Cs DISTRIBUTION IN SEDIMENT, WATER, AND BIOTA OF THE LOWER HUDSON RIVER AND THEIR DOSIMETRIC IMPLICATIONS FOR MAN

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Abstract

Since 1964, the magnitudes and distributions of natural, fallout, and reactor-produced radionuclides present in the Lower Hudson River Estuary have been under study.

Concentrations of the major radionuclides released to the estuary in liquid waste from a pressurized light water reactor have been measured in samples of water, sediment, and biota. These measurements have been combined with information related to site characteristics and human use of the environment to obtain estimates of the magnitudes and pathways of human radiation exposure from routine power reactor operation.

^{137}Cs and ^{134}Cs are presently the "critical" radionuclides in the lower estuary, and consumption of fish is the most important route of exposure for man. Based on measurements to date, releases from a PWR of 20 Ci/yr each of ^{137}Cs and ^{134}Cs would result in an annual total body dose to an avid local fish eater of about 0.2 mrem/yr.

Introduction

The radioecology of the Lower Hudson River Estuary has been under investigation by the Institute of Environmental Medicine since 1964. This research has been directed toward the identification of the types, sources, and magnitudes of radioactive materials present in the abiotic and biotic components of the estuary.

The region of the river which has been most intensively studied is centered about Indian Point, which is located 42 miles above the southern end of Manhattan and is the site of Consolidated Edison's Indian Point Nuclear Power Station (Fig. 1). Frequent upstream sampling is also conducted at Chelsea and Hyde Park, and selected samples have been collected as far south as the George Washington Bridge. Sample types include water, sediments, and the more abundant biota including fish, rooted plants, and plankton. Analysis for radionuclide content has been conducted by several techniques including gamma spectrometry, beta proportional counting, and liquid scintillation counting. Details of the analytical procedures employed are reported elsewhere.[1-4]

The spectrometric system employed for the quantitation of gamma emitting radionuclides consists of a 10 cm x 10 cm NaI(Tl) well geometry crystal coupled to a 512 channel pulse height analyzer (Nuclear Data). Estimates of the activities of gamma-emitting radionuclides in the sample are obtained by a computerized least squares fitting of standard reference spectra to the sample spectrum. Sensitivities obtainable with this analytical system have been found to be superior to those obtainable with typical large GeLi systems for all sample media except sediment.[2]

Radioactivity in the Hudson

Radionuclides which have been identified in the lower Hudson occur from natural sources, from fallout of weapons testing debris, and from liquid waste releases at a pressurized light water reactor (Indian Point # 1).

The predominant natural radionuclides are ^{40}K, ^{226}Ra, and ^{228}Ra. Potassium-40, which is present as a fixed proportion of all potassium in the environment, accounts for a major portion of the radioactivity in all sample types (Fig. 2). Radium-226 and ^{228}Ra occur in their highest levels in bottom sediments, where they are each found at a concentration of about 1.0 pCi/g dry weight.

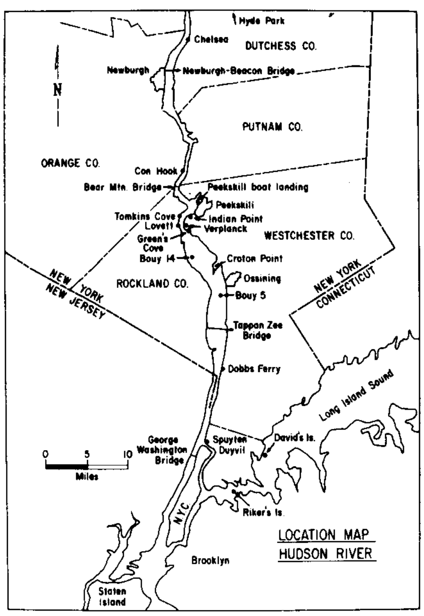

Fig. 1 Hudson River and Sampling Locations.

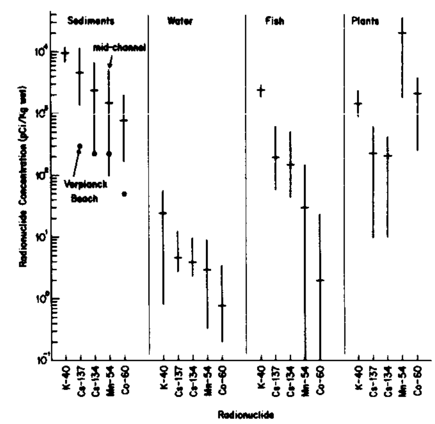

Fig. 2 Means and Ranges of Radionuclide Concentrations Observed in Sediment, Water and Biota at Indian Point (1971-1972).

Major introductions of manmade radionuclides to the Hudson River occurred as a result of the large scale weapons testing by the U. S. and U. S. S. R. during 1961-1962. Radionuclides which were introduced in significant quantities from this source include ^{90}Sr, ^{137}Cs, ^{3}H, ^{144}Ce, ^{141}Ce, ^{106}Ru, ^{103}Ru, ^{131}I, $^{95}ZrNb$, ^{125}Sb, ^{140}Ba, ^{140}La, ^{54}Mn, ^{60}Co, ^{65}Zn, and ^{55}Fe. Due to the Nuclear Test Ban Treaty, fallout levels have greatly decreased since 1963. As a result, those radionuclides with relatively short half-lives are now, in most cases, below detectable levels in samples collected from the river, and at present the major fallout components are ^{137}Cs and ^{3}H.

The major intermediate to long-lived activity discharged in liquid waste from the light water reactor at Indian Point consists of fission products (^{137}Cs, ^{3}H), and nuclides produced by activation (^{134}Cs, ^{54}Mn, ^{60}Co, ^{58}Co). The relative activities of these radionuclides in liquid reactor waste during 1971 indicate that the two cesium isotopes, ^{137}Cs and ^{134}Cs, comprise the major portion of the non-tritium activity released.[5] Cesium-134 has not been a significant component of fallout, and its occurrence in the Hudson River environment is, therefore, indicative of the presence of radioactivity discharged from Indian Point # 1. During 1971, a total of 22.5 Ci of ^{137}Cs and 16.5 Ci of ^{134}Cs were released to the Hudson in liquid waste discharges from the reactor.

Evaluation of the Radiation Dose to Man from Indian Point # 1 Aquatic Releases

Observed environmental distributions of radionuclides in the Hudson have been combined with information relating to specific site characteristics and human use of the environment in order to assess the important pathways and magnitudes of human radiation exposure attendant to low level liquid waste releases to an estuary from an operating light water reactor. Based upon measurements of the radionuclide content of environmental media in the vicinity of Indian Point, estimates of the whole-body doses resulting from reactor discharges and from fallout are presented for the pathways in Table 1. The pathways can generally be divided into those resulting in internal exposure through consumption of food and water, and external exposures from radionuclides present in water and shoreline soils.

Table 1. Summary of Estimated Doses to Man from Reactor* and Fallout Radionuclides in the Hudson River (1971-1972)

Pathway	Annual Whole-Body Dose (mrem/yr) Reactor	Fallout	% Reactor Dose from Radiocesium
Fish Consumption 30 g/day	0.19	0.01	98%
Sunbathing 200 hr/yr	0.06	0.01	80%
Swimming 200 hr/yr	0.01	0.001	65%
Drinking Water (2.2 l/day)	0.003	0.08	90%

*Indian Point # 1 Nuclear Power Station

The radiation doses to man in the Indian Point area resulting from natural sources has also been determined. These doses are based on 19 measurements with a pressurized ion chamber at a number of locations in the vicinity of Indian Point. They can be categorized into those resulting from external exposure to cosmic and terrestrial radiations (~94 mrad/yr), and those caused by radioactivity occurring naturally within the body (~20 mrad/yr). The total mean natural radiation dose amounts to more than 114 mrad/yr, which for purposes of this paper will be considered equal to 114 mrem/yr.

Fish Consumption

Since no edible shellfish populations exist in the Hudson and the aquatic plants present are not consumed by man, fish consumption is the primary pathway by which radionuclides can be recycled to man through the aquatic food web.

Over 200 samples of Hudson River fish have been collected and analyzed during 1971 and 1972. These samples included 20 different species, ranging from anadromous fish such as the striped bass and shad to indigenous types such as white perch, sunfish, catfish, and largemouth bass.

Indigenous fish species in the Indian Point area have been observed to contain about fourfold higher concentrations of reactor-produced radionuclides than those species migrating into the river to spawn. Over 90% of the content of manmade gamma-emitting radionuclides in these fish is comprised by the two cesium isotopes, ^{137}Cs and ^{134}Cs (Fig. 2). It is interesting to note that fish discriminate against the uptake of manganese and cobalt isotopes from vegetation upon which they feed. This phenomenon makes these nuclides insignificant to considerations of human radiation exposures by this route. Concentrations of ^{54}Mn and ^{60}Co in fish are 2 to 3 orders of magnitude less than the concentrations occurring in vegetation. This observation is in direct contradiction to the popular assumption that all aquatic contaminants are, in effect, concentrated by transfer to a higher trophic level (a process generally referred to as biomagnification). Recent scientific assessments of the existing literature indicate that, in fact, biomagnification of metals is probably an infrequent occurrence in nature.[6]

The dose to man from fish consumption was calculated using the mean radionuclide concentrations observed in indigenous fish at Indian Point during 1971 (^{137}Cs = 219 pCi/kg; ^{134}Cs = 182 pCi/kg), and using the ingestion/dose rate model of ICRP 2. The year 1971 was the year in which the highest concentrations of reactor-produced radionuclides in fish were observed since observations began in 1964. The total variation in radiocesium content among fish collected at Indian Point was approximately a factor of 10; with maximum concentrations (3-5 times the mean value) observed in fish caught at the reactor outfall. The dose calculation assumes a continuous daily ingestion of 30 grams of fish (about 15% of total meat intake for an adult), and is considered to give a conservative estimate of the dose since year-round consumption of fish caught solely in the Indian Point area is unlikely. Of the total dose calculated to result from fish consumption (0.2 mrem/yr), about 0.08 mrem is attributable to the presence of ^{137}Cs and about 0.12 mrem to ^{134}Cs.

Drinking Water

The water in the vicinity of Indian Point is sufficiently brackish throughout the year to prevent its use as a potable water supply. Estimates of the doses from drinking water have, therefore, been calculated using radionuclide concentrations measured at the Chelsea pumping station, which is located 22 miles upstream from Indian Point. This station serves as an auxiliary water supply for New York City and is only 1.5 miles north of the public water supply closest to Indian Point, the Veteran's Administration Hospital at Castle Point.

Due to the hydrological characteristics of the estuary, the concentrations of reactor-produced radionuclides in water tend to decrease exponentially with distance north of Indian Point. Thus, as shown in Table 1, the reactor contribution to radiation dose from consumption of water at upstream, freshwater sites is minute, and insignificant in relation to exposures by other pathways.

Swimming

Although the water near the reactor site is not suitable for drinking, it is used for recreational purposes. The maximum external exposure from radionuclides present in water can be expected to occur to persons immersed while swimming.

Calculation of the swimming dose was made using the mean radionuclide concentrations measured in water samples collected continuously at Verplanck (Fig. 2), which is about one mile downstream from the reactor discharge and represents the nearest publicly used beach. Since the water samples from Verplanck are collected continuously, they are assumed to provide reasonable estimates of average radionuclide concentrations occurring at that site.

Sunbathing

Radiocesium accumulations in near-shore submerged sediments have been determined by analysis of cores collected during 1972 in the vicinity of Indian Point. Cumulative activities ranged between 180 and 545 mCi/km^2 for ^{137}Cs and between 40 and 405 mCi/km^2 for ^{134}Cs.

Estimates of the total accumulations of reactor radionuclides in sediments at the river shoreline have also been obtained by analysis of core samples collected at six selected sites north and south of the reactor outfall.

Cumulative depositions of radiocesium per unit release from Indian Point # 1 have been calculated on the basis of activity measured in submerged and shoreline sediments 1-2 miles south of the reactor outfall. For submerged sediment approximately 15-20 mCi/km^2 was accumulated per Ci released, while for shoreline sediments the value was only about 2 mCi/km^2-Ci.

The dose to a sunbather at the nearest public beach was calculated using the observed accumulations and depth distributions of radionuclides in shoreline sediment at this site. Since the emissions from radionuclides accumulated in submerged sediments are effectively shielded by the overlying water, calculations of the dose to man were based on measurements of the shoreline accumulations.

Radiation Dose to Biota

Radiation standards for the release of radioactive materials to the environment are based upon limiting the radiation dose to man. This has been presumed to be a reasonable philosophy in view of the fact that man is one of the most radiosensitive organisms known. However, it is relevant to ask whether or not biota are being exposed to higher doses than man, and whether or not these doses are radiobiologically significant.

Accordingly, from the measurements of radionuclides in biota, water, and sediment, it is possible to calculate the radiation dose being received by several classes of aquatic biota present in the vicinity of Indian Point. The results of such calculations for fish and benthos are shown in Table 2, where it can be seen that the largest exposure, both natural and manmade, occurs to organisms immersed in the top portions of local sediments. The additional dose rate from the reactor is about equal to that from the natural background in these sediments, about 180 mrads/yr. Accordingly, benthic organisms (including fish) might accumulate doses on the order of 0.2 of a rad/yr. Auerbach (1970) has suggested that the lowest dose rates at which observable biological effects can be noted are approximately one rad/d, or roughly 400 rads/yr.[7] The dose to biota in the vicinity of Indian Point is at least two thousandfold below this. Thus, the results of environmental measurements to date give good reason to believe that no perceptible deleterious effects on the biota will occur as a result of the radiological releases at Indian Point.

Table 2. Estimated Doses to Fish and Benthos from Reactor Releases and from Natural Potassium

Biota	Method of Exposure	Dose Rate (mrad/yr) K-40	Reactor
Fish	Internal	17	3
Fish	External - water	0.2	0.2
Benthos	External - sediments	100	180

Summary

Examination of the magnitudes of the estimated doses indicates that consumption of fish represents the "critical pathway" for radiation exposure of man due to routine aquatic discharges from a light water reactor on an estuary. Furthermore, as indicated in Table 1, the cesium (^{137}Cs and ^{134}Cs) isotopes deliver the majority of the dose by all exposure pathways, and are especially important in determining the dose from fish consumption.

The total whole body dose to the maximally-exposed individual from an annual liquid waste discharge of 39 Ci of ^{137}Cs and ^{134}Cs (1971) is estimated to be about 0.2 mrem/yr.[1] This dose amounts to .04% of the internationally accepted dose limits (ICRP - 500 mrem/yr) and about 0.2% of the natural background dose in the reactor area.

Radiation doses to biota resulting from reactor liquid waste discharges to the Hudson estuary are largest for organisms inhabiting the surface layers of local sediments. These doses, which may be as high as 0.2 rad/yr, are radiobiologically insignificant. Thus, it appears that discharge of radioactive waste to the Hudson River Estuary from a light water reactor in operation more than a decade neither presents any limitation upon human use of the estuary, nor constitutes a hazard to the river biota.

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