ENVIRONMENTAL ¹²⁹I MEASUREMENTS

F. P. Brauer

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ENVIRONMENTAL ^{129}I MEASUREMENTS^(a)

F. P. Brauer

Battelle,
Pacific Northwest Laboratory
Richland, Washington 99352

ABSTRACT

Environmental levels of ^{129}I and natural ^{127}I have been measured by neutron activation analysis on samples from throughout the United States at locations near and remote from release points. Highest ^{129}I concentrations were observed near nuclear fuel reprocessing facilities. Levels of ^{129}I above natural iodine background were observed at all locations studied. The sample data establishes baseline levels of environmental ^{129}I for the expanding nuclear industry.

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F. P. Orauer

Battelle
Pacific Northwest Laboratory
Richland, Washington 99352

INTRODUCTION

Iodine-129 from natural and man-made sources has been measured in the environment. The production of ^{129}I in uranium ores by spontaneous fission and (α, n) induced fission was first measured by Purkayastha and Martin.⁽¹⁾ Studier, et al. initiated studies on the ^{129}I content of biological and environmental samples. Their measurements of the iodine concentration and the $^{129}\text{I}/^{127}\text{I}$ isotopic ratio were done by neutron activation analysis.⁽²⁾

The various processes which can release ^{129}I to the environment have been summarized by Edwards and co-workers.⁽³⁻⁵⁾ The principal natural ^{129}I production processes are spontaneous fission of uranium and cosmic-ray-produced spallation reactions with atmospheric xenon. Since the discovery of nuclear fission, man-produced fission reactions have resulted in ^{129}I released to the environment.

Radioactive iodine isotopes are produced by nuclear fission in reactors and nuclear weapons testing. Because of its volatility, iodine may be released to the atmosphere during nuclear reactor operation, irradiated fuel separation and nuclear waste handling. The major nuclear industry iodine releases to date have been associated with irradiated fuel separation facilities.⁽⁶⁻⁹⁾ Due to its mobility released iodine is locally, regionally and globally distributed. Iodine emissions are normally controlled by a combination of long fuel-cooling times prior to processing and off-gas treatment for iodine removal. These methods have been successful in reducing the emission of ^{131}I . Because of its long half-life (1.6×10^7 years), ^{129}I emissions are dependent on process operations and off-gas treatment and can not be reduced by radioactive decay.

Once ^{129}I is released to the environment it becomes a permanent contaminant as a result of its 1.6×10^7 year half-life. Measurement of ^{129}I in environmental samples have been reported by several laboratories.⁽⁹⁻¹⁹⁾ ^{129}I released to the environment can also be used as a tracer for various natural processes. The high analytical sensitivity for ^{129}I by activation analysis permits concentration measurements at levels much below those required for radiation protection. Such measurement are useful for detection and tracing of possible contamination problems before they reach significant levels and in time for control measures to be implemented.

With the projected growth of the nuclear power industry, baseline ^{129}I concentration and $^{129}\text{I}/^{127}\text{I}$ ratios should be established for both the total environment and local areas of increasing nuclear industry. The baseline data reported in this paper includes the results of several ^{129}I studies at our laboratory undertaken for surveillance, ecological, hydrological and meteorology purposes. Only data for samples collected within the last 6 years are included. Data on earlier samples collected and analyzed by our laboratory have been summarized elsewhere.⁽⁴⁻¹⁵⁾

METHOD

Collection of Iodine Samples

Several methods are used by our laboratory for concentration of iodine from large samples prior to analysis. Atmospheric iodine is collected by passing 3,000 to 60,000 cubic meters of air through a two-stage filter system.⁽¹⁵⁾ The first stage is a combustible mechanical filter for collection of particulate materials from the air stream. The second stage is a bed of activated charcoal

which absorbs and partially retains gaseous iodine from the air stream. Rain and snow have also been used to sample atmospheric iodine.

Iodine is removed from water and other aqueous samples by ion exchange. Dowex 1 anion resin is used both in the laboratory and in the field for iodine separation from up to several hundred liters of water.⁽¹²⁾

Animal thyroids have been used as natural iodine concentrators.⁽¹⁴⁾ Determination of the recent food source of the animals is often difficult. Thus analysis of directly collected vegetation and soil is desirable.

Laboratory Iodine Isolation

The procedure used for iodine isolation prior to neutron activation analysis is a modification of that published by Studier, et al.^(2,20) The sample to be processed may consist of filter, activated charcoal, ion-exchange resin, animal parts, vegetation or soil. Freeze drying can be used for moisture removal from the sample prior to analysis but is not required. The sample is spiked with ^{125}I which is used for estimation of the overall procedure yield. The iodine is separated by placing the sample in a quartz combustion apparatus and igniting the sample at high temperature (up to 1000°C) in a stream of oxygen. The off-gases are passed through a small bed of activated charcoal which retains the iodine.

Further purification of the iodine is accomplished by combusting the original charcoal trap in oxygen and trapping the released iodine on several milligrams of activated charcoal. The iodine is then removed from the charcoal by heating in a vacuum system, trapping the iodine in a quartz tube at liquid nitrogen temperature, and sealing the tube to make a quartz irradiation ampoule. The ^{125}I in the ampoule is determined by gamma-ray spectrometry⁽²¹⁾ to estimate the pre-irradiation yield. Typical yields range between 90 and 100%.

Iodine Activation Analysis

Quartz ampoules containing the iodine separated from the samples are irradiated with reactor neutrons for 8 to 24 hours. Comparator standards containing known ratios of ^{125}I , ^{127}I and ^{129}I are irradiated with each set of samples.

Following irradiation the carrier is added and the iodine samples are further purified by distillation and solvent extraction. The samples are finally precipitated as AgI and mounted on thin-plastic scintillators for counting.

The ^{126}I , ^{128}I and ^{130}I activities produced in the sample and produced in the comparator standard during irradiation, are estimated by gamma-ray spectrometry from several spectra collected over a period of time to obtain half-life information. Low level, beta-gated, multiple gamma-coincidence spectrometric techniques^(20,21) are used when required to measure very small amounts of activity and to discriminate against interfering activities.

The natural iodine is estimated from either the ^{126}I or ^{129}I activity produced in the sample; the induced ^{130}I is used to estimate the ^{129}I concentration.

The ^{125}I in the activated iodine sample is measured to determine the overall analysis yield. Such yields average about 50%. The ^{125}I in the comparator standard is measured to determine the amount of ^{127}I and ^{129}I in the comparator standard. The ^{127}I and ^{129}I concentration in the original sample are calculated from the counting, sample size and yield measurements. Corrections are made for laboratory and sampling blanks. The overall detection limit for ^{129}I is about 4×10^{-6} pCi per sample.

RESULTS AND DISCUSSION

The ^{129}I released to the environment to date contributes an insignificant radiation dose to human thyroids. However, studies of its environmental distribution are necessary for predicting its long term build-up with the growth of the nuclear industry. Environmental levels of ^{129}I and natural ^{127}I have been measured throughout the United States at locations near and remote from release points. Types of materials measured include air, water, soil, vegetation, milk and animal thyroids.

Measurements of atmospheric levels of iodine in the northwestern United States are listed in Table I. ^{129}I was detected at all locations sampled. Highest ^{129}I concentrations were observed at Richland, Washington near the AEC Hanford project. A significant fraction of the iodine was found to be gaseous at all locations sampled.

The iodine content of snow and rain samples from the northwestern United States is tabulated in Table II. The highest concentration of ^{129}I were observed at Richland, Washington as expected from the air concentration measurements.

Iodine removed from the atmosphere by precipitation is deposited on the soil. Studies at our laboratory have shown that ^{129}I retained in the soil is mostly found in the top few centimeters.⁽¹⁶⁾ Results of the iodine analysis of dry top soil are listed in Table III. ^{129}I was detected in all samples analyzed. Lower concentrations were observed at locations most distant from nuclear fuel separations plants associated with the Hanford and Savannah River AEC projects.

Table IV lists results obtained for tree bark and dry grass samples. Highest concentrations were observed near the nuclear fuels separation plant at West Valley, New York. The closest sampling point was Riceville, New York. Additional studies of the ^{129}I levels in the environment of this facility have been reported by several authors.^(6,9,17,18,19) Grass samples collected near the AEC facilities which contain fuel processing plants such as Hanford, Savannah River and the National Reactor Test Site also contained higher concentrations of ^{129}I than the more distant samples. This was expected from results previously reported on cattle thyroids.⁽¹⁴⁾

Milk samples from various locations in the northwestern United States have been analyzed to follow the iodine pathway from air to grass to milk to man (Table V). All samples were obtained from small local dairies. The ^{129}I concentrations per liter of samples were found to be similar to those observed in rain. However, the natural iodine content of the milk was much greater than that observed in rain.

Water from rivers and lakes was also analyzed for ^{129}I (Table VI). Increased ^{129}I concentrations due to the West Valley, New York plant operations was observed in water from the mouth of the Cattaraugus Creek outflow. No increase in the ^{129}I content of the Columbia River was detected as the result of Hanford Operations liquid effluent discharges as shown by comparison of the results obtained upstream at Vernita and the other Columbia River samples collected near Richland, Washington. The ^{129}I concentration and $^{129}\text{I}/^{127}\text{I}$ isotope ratios observed in the northwestern United States were less for river and lake waters than for rain water.

Iodine measurements on silt and seaweed samples are listed in Table VII. The highest ^{129}I concentrations in silt were from the same locations where high water sample concentrations were observed downstream from the West Valley, New York plant. Silt from the Columbia River above (Priest Rapids Dam) and below (McNary Dam) the Hanford project yielded essentially identical results indicating no effect from Hanford. The seaweed samples show the very low $^{129}\text{I}/^{127}\text{I}$ ratios which exist in the marine environment.

Groundwater flow and contamination patterns beneath the Hanford project reservation have been studied since the early days of the project. Groundwater samples from a number of wells on or near the Hanford reservation have been analyzed for ^{129}I . These analyses, which provide high sensitivity for groundwater studies, have been reported elsewhere.⁽¹²⁾ Typical results for background underground waters are given in Table VIII. The Cold Creek well is an old artesian well upstream from the Hanford project. The higher levels observed in the Troutdale well are the result of the greater portion of atmospheric water which charges the well although the well is remotely located from nuclear fuel processing facilities. Measurement of ^{129}I in underground water can serve as a method for monitoring nuclear waste storage facilities for many

years. Its long half-life, high measurement sensitivity and anionic form give it many of the same advantages as tritium. It will remain after the tritium has decayed or been evaporated.

A comparison of values observed for various types of samples collected near nuclear fuel separation facilities and background areas is given in Table IX and shown in Figure 1. Iodine-129 losses near nuclear fuel separations facilities were observed.

CONCLUSION

The occurrence of ^{129}I in the United States near and remote from nuclear facilities is summarized in this paper. Highest concentrations were observed near nuclear fuel reprocessing facilities. Measurements above natural mineral iodine levels were found at all locations studied.

None of the radiation doses estimated as the result of these studies are significant in comparison to the existing radiation standard of 1500 mrem-yr to the thyroid or in comparison to the annual dose of about 100 mrem from natural background radiation. (14,16)

These results can be used for comparison with future measurements to determine the rate of increase in environmental ^{129}I with the growth of the nuclear industry and to detect contamination problems well before they reach significant levels.

Since ^{129}I can be lost as a gas but interacts with the environment, gaseous losses can be detected at some time after the emission by analysis of ground level samples. Aqueous losses of iodine travel considerable distance due to its anionic nature. Thus it can serve as an ideal nuclide for detection of suspected aqueous effluent.

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Figure 1. COMPARISON OF $^{129}\text{I}/^{127}\text{I}$ AT SEVERAL LOCATIONS

TABLE I
ATMOSPHERIC LEVELS OF IODINE IN
NORTHWESTERN UNITED STATES

Location	Date (mo/yr)	Particle Filter		Charcoal Filter	
		¹²⁷ I (ng/m ³)	¹²⁹ I (pCi/m ³)	¹²⁷ I (ng/m ³)	¹²⁹ I (pCi/m ³)
Neah Bay, WA	8/68	1.0	4x10 ⁻⁹	2.1	5x10 ⁻⁸
	4/69	1.0	7x10 ⁻⁹	1.4	6x10 ⁻⁸
	2/70	.7	2x10 ⁻⁷	1.8	5x10 ⁻⁸
	11/70	2.1	2x10 ⁻⁷	2.8	2x10 ⁻⁷
Troutdale, OR	5/69	.7	3x10 ⁻⁸	1.8	1.4x10 ⁻⁷
Richland, WA	11/70	1.0	1.1x10 ⁻⁴	2.8	2x10 ⁻⁴
	3/71	.7	2x10 ⁻⁶	2.1	1.4x10 ⁻⁵
	8/72	.4	4x10 ⁻⁶	3.2	5x10 ⁻⁵
	10/72	.7	2x10 ⁻⁶	2.1	1.1x10 ⁻⁵
	2/73	.14	7x10 ⁻⁷	.7	1.1x10 ⁻⁵
	4/73	1.1	4x10 ⁻⁶	1.4	5x10 ⁻⁶
	1/74	.4	1.4x10 ⁻⁶	1.1	1.8x10 ⁻⁵
Spokane, WA	8/72	.6	7x10 ⁻⁷	2.1	1.1x10 ⁻⁶
Great Falls, MT	9/68	.5	4x10 ⁻⁸	.8	1.1x10 ⁻⁷
	4/69	.7	4x10 ⁻⁸	1.1	7x10 ⁻⁸
	2/70	.7	4x10 ⁻⁸	.7	6x10 ⁻⁸
	11/70	.6	7x10 ⁻⁸	.7	1.8x10 ⁻⁷
	3/72	1.1	7x10 ⁻⁸	.7	7x10 ⁻⁸
	4/73	.6	3x10 ⁻⁸	1.1	7x10 ⁻⁸
Barrow, AK	1/71	1.2	1.1x10 ⁻⁷	12	3x10 ⁻⁷

TABLE II
IODINE CONTENT OF SNOW AND RAIN SAMPLES
FROM NORTHWESTERN UNITED STATES

Location	Date (mo/yr)	¹²⁷ I (ng/g H ₂ O)	¹²⁹ I (pCi/g H ₂ O)	¹²⁹ I/ ¹²⁷ I (Atom ratio)
SNOW				
White Pass, WA	4/69	640	6x10 ⁻⁴	5x10 ⁻⁶
Richland, WA	1/70	1100	4x10 ⁻³	2x10 ⁻⁵
Bend, OR	1/70	830	1.2x10 ⁻⁴	8x10 ⁻⁷
Hurricane Ridge, WA	2/70	310	6x10 ⁻⁶	1x10 ⁻⁷
Bogus Basin, ID	1/70	500	7x10 ⁻⁶	8x10 ⁻⁸
Pullman, WA	12/71	570	1.8x10 ⁻³	1.8x10 ⁻⁵
Barrow, AK	9/73	620	5x10 ⁻⁶	4x10 ⁻⁸
RAIN				
Copalis, WA	4/69	3600	3x10 ⁻³	4x10 ⁻⁶
Troutdale, OR	5/69	4200	1x10 ⁻³	1.5x10 ⁻⁶
Richland, WA	6/71	1800	3x10 ⁻²	8x10 ⁻⁵
Richland, WA	6/71	360	1.2x10 ⁻²	1.8x10 ⁻⁴
Richland, WA	10/71	490	1.8x10 ⁻²	2x10 ⁻⁴
Richland, WA	5/72	420	2x10 ⁻³	3x10 ⁻⁵

TABLE III
IODINE CONTENT OF SOIL SAMPLES

Location	Date (mo/yr)	^{127}I (ng/g)	^{129}I (pCi/g)	$^{129}\text{I}/^{127}\text{I}$ (Atom ratio)
Hoh River, WA	4/68	4500	8×10^{-6}	9×10^{-9}
Great Falls, MT	4/68	470	2×10^{-5}	3×10^{-7}
Missoula, MT	4/68	670	5×10^{-6}	4×10^{-8}
Wallace, ID	4/68	130	8×10^{-6}	3×10^{-7}
Hoh River, WA	7/68	2900	2×10^{-6}	4×10^{-9}
Augusta, GA	5/71	2600	5×10^{-4}	1.1×10^{-6}
Jackson, SC	5/71	760	6×10^{-4}	4×10^{-6}
Madison, GA	5/71	4400	2×10^{-5}	3×10^{-8}
Beverly, WA	6/71	29	5×10^{-5}	1.0×10^{-5}
Pasco, WA	6/71	190	2×10^{-4}	7×10^{-6}

TABLE IV
IODINE CONTENT OF VEGETATION SAMPLES

Location	Date (mo/yr)	^{127}I (ng/g)	^{129}I (ng/g)	$^{129}\text{I}/^{127}\text{I}$ (Atom ratio)
TREE BARK				
Wallace, ID	4/68	570	3×10^{-4}	3×10^{-6}
Missoula, MT	4/68	540	1.1×10^{-4}	1.1×10^{-6}
Chelan, WA	9/69	250	2×10^{-4}	5×10^{-6}
Priest Lake, WA	9/69	230	2×10^{-4}	5×10^{-6}
Riceville, NY	10/69	1100	5×10^{-2}	2×10^{-4}
East Avon, NY	10/69	2300	2×10^{-4}	5×10^{-7}
Albany, NY	9/70	1600	3×10^{-5}	9×10^{-8}
Lexington, MA	9/70	1400	3×10^{-5}	1×10^{-7}
Elmira, NY	9/70	2300	1.4×10^{-4}	3×10^{-7}
DRY GRASS				
Missoula, MT	4/68	200	6×10^{-5}	1.6×10^{-6}
Hoh River, WA	4/68	640	7×10^{-6}	6×10^{-8}
Great Falls, MT	4/68	930	2×10^{-4}	1×10^{-7}
Wallace, ID	4/68	640	1.4×10^{-4}	1.2×10^{-6}
Hoh River, WA	7/68	200	3×10^{-6}	7×10^{-8}
Great Falls, MT	9/68		1.4×10^{-5}	
Riceville, NY	10/69	3800	1.0×10^{-1}	1.4×10^{-4}
Rochester, NY	10/69	2500	3×10^{-4}	7×10^{-7}
Oyster Creek, NJ	5/70	790	3×10^{-5}	2×10^{-7}
Philadelphia, PA	5/70	71	1.2×10^{-5}	9×10^{-7}
Morris, IL	5/70	1800	1.6×10^{-5}	5×10^{-8}
Lexington, MA	9/70	5300	3×10^{-5}	3×10^{-8}
Elmira, NY	9/70	1900	1.6×10^{-4}	5×10^{-7}
Albany, NY	9/70	2800	4×10^{-5}	7×10^{-8}
Colfax, WA	2/71	650	1.1×10^{-3}	1.0×10^{-5}
Humptulips, WA	2/71	2200	4×10^{-5}	1.0×10^{-7}
Augusta, GA	5/71	14000	1.5×10^{-4}	6×10^{-8}
Jackson, SC	5/71	440	9×10^{-4}	1.2×10^{-5}
Madison, GA	5/71	510	1.7×10^{-5}	1.2×10^{-7}
Beverly, WA	6/71	410	7×10^{-4}	1.0×10^{-5}
New Meadows, ID	6/71	160	1.3×10^{-5}	5×10^{-7}
Atomic City, ID	6/71	230	9×10^{-5}	2×10^{-6}
Sage, NY	6/71	1500	1.9×10^{-5}	7×10^{-8}
Pasco, WA	6/71	950	1.5×10^{-3}	9×10^{-6}
Sisters, OR	7/71	360	8×10^{-5}	1.2×10^{-6}
Barrow, AK	9/73	5200	5×10^{-6}	5×10^{-9}

TABLE V
IODINE CONTENT OF MILK SAMPLES
FROM NORTHWESTERN UNITED STATES

Location	Date (mo/yr)	^{127}I (na/l)	^{129}I (pCi/l)	$^{129}\text{I}/^{127}\text{I}$ (Atom ratio)
Hoquiam, WA	4/69	400000	6×10^{-3}	8×10^{-8}
Portland, OR	12/70	1200000	2×10^{-2}	1.0×10^{-7}
Chehalis, WA	2/71	1100000	3×10^{-2}	1.8×10^{-7}
Pullman, WA	3/71	1700000	3×10^{-2}	1.7×10^{-7}
Richland, WA	5/71	4800000	8×10^{-2}	1.7×10^{-7}
Halla Walla, WA	5/73	470000	1.5×10^{-2}	1.8×10^{-7}
Richland, WA	1/74	1600000	2.1×10^{-3}	7×10^{-9}
Yakima, WA	1/74	880000	1.5×10^{-3}	1.7×10^{-8}

TABLE VI
IODINE CONTENT OF RIVER AND LAKE WATER SAMPLES

Location	Date (mo/yr)	^{127}I (na/l)	^{129}I (nCi/l)	$^{129}\text{I}/^{127}\text{I}$ (Atom ratio)
Lake Pend Oreille, ID	9/69	2100	4×10^{-5}	1×10^{-7}
Priest Lake, ID	9/69	560	4×10^{-5}	4×10^{-7}
Cattaraugus Cr., NY	10/69		2×10^{-2}	
Lake Erie, NY	10/69	2900	1.6×10^{-3}	3×10^{-6}
Lake Ontario, NY	10/69	2400	1.9×10^{-4}	4×10^{-7}
* Columbia River, WA	3/71	1200	9×10^{-5}	4×10^{-7}
* Columbia River, WA	4/71	1900	9×10^{-5}	3×10^{-7}
* Columbia River, WA	6/71	860	6×10^{-5}	4×10^{-7}
Columbia River (Vernita), WA	6/71	1100	5×10^{-5}	3×10^{-7}
* Columbia River, WA	6/71	990	4×10^{-5}	2×10^{-7}
* Columbia River, WA	7/72	290	1.7×10^{-4}	3×10^{-6}
* Columbia River, WA	7/72	530	3×10^{-5}	4×10^{-7}
Humptulips River, WA	2/71	950	1.7×10^{-5}	1×10^{-7}
Lake Chelan, WA	9/69	450	2×10^{-5}	3×10^{-7}
Queets River, WA	7/69	520	2×10^{-6}	2×10^{-8}
Snake River, WA	6/71	2600	1.6×10^{-5}	4×10^{-8}
Snake River, WA	6/72	600	4×10^{-5}	4×10^{-7}
Yakima River, WA	6/71	4100	6×10^{-5}	8×10^{-8}
Yakima River, WA	6/72	890	1.2×10^{-4}	1.2×10^{-6}

*Downstream from Hanford

TABLE VII
IODINE CONTENT OF SILT AND SEAWEED SAMPLES

Location	Date (mo/yr)	^{127}I (ng/g)	^{129}I / (pCi/g)	$^{129}\text{I}/^{127}\text{I}$ (Atom ratio)
<u>SILT</u>				
Elk River, ID	5/68	250	5×10^{-7}	1×10^{-8}
Lake Chelan, WA	9/69	260	5×10^{-6}	1×10^{-8}
Priest Lake, ID	9/69	950	3×10^{-5}	2×10^{-7}
Lake Pend Oreille, ID	9/69	37	9×10^{-7}	1.3×10^{-7}
Cattaraugus Cr., NY	10/69	2000	3×10^{-2}	7×10^{-5}
Lake Erie, NY	10/69	89	1.1×10^{-4}	7×10^{-6}
Lake Ontario, NY	10/69	86	3×10^{-6}	2×10^{-7}
Puget Sound, WA	11/69	430	2×10^{-7}	3×10^{-9}
Mission Bay, CA	12/59	5800	7×10^{-7}	7×10^{-10}
McNary Dam, WA	5/70	2500	2×10^{-5}	5×10^{-8}
Priest Rapids Dam, WA	6/71	1500	1.2×10^{-5}	4×10^{-8}
<u>SEAWEED</u>				
Kalaloch, WA	7/68	80000	3×10^{-6}	2×10^{-10}
Mouth of Hoh River, WA	2/70	240000	2×10^{-5}	4×10^{-10}

TABLE VIII
IODINE CONTENT OF UNDERGROUND WATER SAMPLES

Location	Date (mo/yr)	^{127}I (ng/l)	^{129}I (nCi/l)	$^{129}\text{I}/^{127}\text{I}$ (Atom ratio)
Troutdale, WA	5/69	1700	2×10^{-5}	6×10^{-8}
Cold Creek, WA	1/70	12000	2×10^{-6}	1.1×10^{-9}
Thousand Springs, ID	3/70	2000	8×10^{-7}	2×10^{-9}
Cold Creek, WA	1/72	14000	2×10^{-6}	7×10^{-10}
Troutdale, WA	4/72	3700	2×10^{-4}	3×10^{-7}

TABLE IX
SELECTED VALUES OBSERVED NEAR AND FAR
FROM NUCLEAR FUEL SEPARATIONS FACILITIES

Sample Type	Near Nuclear Fuel Separations		Background	
	^{129}I (a) (nCi/unit)	$^{129}\text{I}/^{127}\text{I}$ (Atom ratio)	^{129}I (a) (nCi/unit)	$^{129}\text{I}/^{127}\text{I}$ (Atom ratio)
Air Particle Filter	1.1×10^{-4}	6×10^{-4}	2×10^{-9}	2×10^{-8}
Air Charcoal Filter	2×10^{-4}	4×10^{-4}	5×10^{-8}	1.6×10^{-7}
Snow	4×10^{-3}	2×10^{-5}	5×10^{-6}	4×10^{-8}
Rain	3×10^{-2}	8×10^{-5}	7×10^{-5} (14)	3×10^{-7} (14)
Soil	3×10^{-1} (16)	4×10^{-4} (16)	2×10^{-6}	4×10^{-9}
Bark	5×10^{-2}	2×10^{-4}	3×10^{-5}	1×10^{-7}
Leaves	9×10^{-2}	3×10^{-4}	5×10^{-6}	1.2×10^{-8}
Pine Needles			1×10^{-5}	3×10^{-7}
Grass	1×10^{-1}	1.4×10^{-4}	3×10^{-6}	7×10^{-8}
Milk	8×10^{-2}	1×10^{-7}	6×10^{-3}	8×10^{-8}
Cattle Thyroid	1.2 (14)	4×10^{-6} (14)	1×10^{-4} (14)	4×10^{-7} (14)
River Water	2×10^{-4}		2×10^{-5}	1×10^{-7}
Lake Water	2×10^{-3}	3×10^{-6}	2×10^{-5}	3×10^{-7}
Seaweed			3×10^{-6}	2×10^{-10}
Silt	3×10^{-2}	7×10^{-5}	2×10^{-7}	3×10^{-9}
Deep Well Water			8×10^{-7}	2×10^{-9}
Mineral Iodine				$< 5 \times 10^{-14}$ (14)

(a) Unit of measure is grams for solid samples, liters for liquid samples and cubic meters for air samples.