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AIR-BORNE RADIONUCLIDE MEASUREMENTS AND PHYSICAL
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AIR-BORNE RADIONUCLIDE MEASUREMENTS AND
PHYSICAL CHARACTERISTICS DETERMINATION

R. W. Perkins, C. W. Thomas and J. M. Nielsen

Abstract

Newly developed counting techniques which employ multidimensional gamma-ray spectrometry have been employed for the direct measurement of a large group of radionuclides in fallout samples. This spectrometric counting method has made it possible to study the distribution of many of the trace constituents of fallout and also to improve the precision for the measurement of the longer lived fallout radionuclides. The concentrations of Be^7 , Na^{22} , Mn^{54} , Co^{60} , Y^{88} , Zr^{95} - Nb^{95} , Ru^{106} , Sb^{124} , Sb^{125} , Cs^{134} , Cs^{137} and Ce^{144} can be measured directly and their concentrations in air during the past 2-3/4 years are reported. The measured solubility of the fallout radionuclides is reported, and their deposition as dry fallout and as rain out is compared in the area of Richland, Washington. The distribution and movement of the tracer radionuclides Y^{88} , Sb^{124} both in the stratosphere and troposphere as well as that of Pu^{239} are discussed. Our discovery and the cosmic-ray produced radionuclides Cl^{38} and S^{38} is mentioned and their application along with other cosmic-ray produced radionuclides in atmospheric research is considered.

AIR-BORNE RADIONUCLIDE MEASUREMENTS
AND PHYSICAL CHARACTERISTICS DETERMINATION

by

R. W. Perkins, C. W. Thomas and J. M. Nielsen*

INTRODUCTION

The absolute and relative concentrations of the various air-borne radionuclides are of interest both in measuring their distribution and deposition rates and in studying the physical and chemical processes which occur in the atmosphere. The precise relative concentrations of a group of radionuclides is of particular value as it allows the relative deposition and circulation rates of each radionuclide to be followed. The accurate measurements of a large group of the air-borne radionuclides in a sample require extremely sensitive and selective analytical techniques which are often prohibitive in both cost and time. Measurements of the physical and chemical state of air-borne radionuclides requires fractionation into the desired species and adds further to the required analytical sensitivity.

Studies of the type mentioned and others dealing with the characteristics and behavior of air-borne radionuclides have become practical through our development of a highly sensitive and selective multidimensional gamma-ray spectrometer⁽¹⁾. This instrument uses the cascade gamma-ray decay characteristics of each radionuclide for its identification and measurement and employs anticoincidence techniques for background and Compton suppression. The instrument permits an air filter sample to be measured directly for the 12 radionuclides, Be⁷, Na²², Mn⁵⁴, Co⁶⁰, Zr⁹⁵-Nb⁹⁵, Y⁸⁸, Ru¹⁰⁶, Sb¹²⁴, Cs¹³⁴, Cs¹³⁷, and Ce¹⁴⁴. Measurements of the radionuclides after physical and chemical fractionation procedures are also possible. The use of these advance techniques plus conventional means have been applied in tropospheric and stratospheric distribution studies and in physical and chemical characteristics determinations.

*General Electric Company, Richland, Washington. Work performed under Contract No. AT(45-1)-1350 for the U. S. Atomic Energy Commission.

MULTIDIMENSIONAL SPECTROMETER

This instrument is described in detail elsewhere⁽¹⁾ but its basic operational characteristics and counting efficiency are covered here. The spectrometry system consists of a Nuclear Data 4096 channel analyzer used in a 64 x 64 channel grouping arrangement in conjunction with two anticoincidence shielded 4 inch thick by 6 inch diameter NaI(Tl) detectors (See Figure 1). One of the 4 inch by 6 inch detectors has a 4 inch light pipe of pure sodium iodide which serves to shield the detector from gamma radiation originating in its phototube. The anticoincidence annulus is a 11-1/2 inch diameter by 12-inch long NaI(Tl) crystal with a 6-1/2 inch diameter center hole to accommodate the principal detectors. The analyzer is equipped with an Optikon photographic printer which permits a readout of the entire memory in about four minutes. A Tally paper tape unit can be used as a readout for computer calculation. The sample to be measured is sandwiched between the two 6 inch diameter detectors. The signals from the two detectors are fed to the two separate analog to digital converters of the analyzer for energy and coincidence analysis and from there to the memory storage unit. When a single photon interacts with one of the detectors, the event is stored on the corresponding X or the Y axis of the memory. When two photons are emitted simultaneously, each interacting with a separate detector, the event is stored in an energy-energy plane at a point uniquely characteristic of the two energies. The spectra of Cu^{64} and Co^{60} illustrate (Figures 2 and 3) the manner of storage. The normal spectra of these radionuclides as seen by one of the detectors is shown for comparison. With a detection system of this type the unique decay characteristic of many radionuclides are readily resolvable thus permitting a far greater sensitivity for detection and direct measurement of many minor radioactive constituents. In addition a much lower background is obtained.

In Figure 4 the background of the single 4 inch thick by 6 inch diameter crystal without light pipe or anticoincidence is compared with that of the two

detectors in the multidimensional detector system separated by a 1 inch thick lead absorber. The background shown for the multidimensional detector system is for an energy diagonal from 0 to 3 Mev and therefore represents the case of 0 to 3 Mev adsorption by each detector. These curves can also be used to compare the background that would be obtained with two crystals used in a summing arrangement with that shown for the two crystals in the multidimensional arrangement. In this case the background at a given energy on the top curve should be doubled and compared with a point of half that energy on the bottom curve. By either this method of comparison or that shown in Figure 4, the background with multidimensional analysis is three to five orders of magnitude lower.

The sensitivity for the measurement of a given radionuclide is dependent on the instrument's counting efficiency as well as the background counting rate and the Compton interference from other radionuclides. In Figure 5 the efficiency for total absorption by either crystal for gamma-rays originating in the sample is plotted as curve $2E$. The curve $2E^2$ gives the efficiency for two coincidence gamma rays to be totally absorbed - one each by the two detectors. This curve thus gives the probability that a coincidence event in the sample will be stored in a total absorption peak (either one of the two) in the energy-energy plane. It is plotted for the special case where the two gamma rays have equal energy but it does serve to illustrate the change in efficiency with energy.

It is evident that with this relatively high geometry system coincidence counting rates can be measured with a reasonably high efficiency. This fact, coupled with the extremely low backgrounds and the elimination of most of the Compton interference, makes the device an extremely sensitive and selective instrument.

EXPERIMENTAL RESULTS AND DISCUSSION

Measurement of the Air-Borne Radionuclides Near Ground Level

Air sampling⁽²⁾ near ground level was performed with a continuously operating vacuum pump which pulled air at 100 cfm through a membrane filter of 5 μ pore size (AM-1, Gelman Instrument Company). These membrane filters have been shown to be essentially absolute for the collection of fallout radionuclides⁽²⁾. The filters are composited on a monthly or semimonthly basis, pressed into a standard geometry of 1/2 inch thick by 1 inch diameter and counted on the multidimensional gamma-ray spectrometer. The air samples were obtained at a point 15 ft. above the ground, 6 miles north of Richland, Washington. The annual precipitation in this area is only about 8 inches and dry deposition accounts for a significant fraction of the fallout. In Figure 6 the concentration in air of 13 radionuclides are recorded for the period 1962 through three quarters of 1964. All of these radionuclides except Pu^{239} were measured by the direct spectrometric analysis. With the exception of Pu^{239} which is a residue of the nuclear devices these radionuclides result from fission and neutron activation during atomic tests, and from cosmic ray interactions with the atmosphere. The radionuclides Zr^{95} - Nb^{95} , Ru^{106} , Sb^{125} , Cs^{137} , and Ce^{144} are fission products and presumably this is their main source in the atmosphere; Mn^{54} , Co^{60} , Y^{88} , Sb^{124} , and Cs^{134} are formed as neutron activation products during testing, while Be^7 and Na^{22} are produced continuously in the atmosphere by interactions of cosmic rays. The fallout rates of many of the fission products are measured at sampling locations the world over⁽³⁾ and perhaps their main value here is to serve as a base line for comparing the concentrations of less abundant radionuclides in the atmosphere.

The radionuclide Na^{22} was first reported to be present in the atmosphere by Marquez⁽⁴⁾ in 1957 who found it in rain water at Rio de Janeiro in a concentration of 0.017 disintegration min^{-1} liter $^{-1}$. It is produced naturally by cosmic-ray spallation of argon in the atmosphere but also results from the reaction $\text{Na}^{23}(\text{n}, 2\text{n}) \text{Na}^{22}$ during tests of nuclear weapons. Its potential value as a tracer of

atmospheric circulation has been recognized, and recently reported measurements for this purpose of air filters collected prior to the last test series⁽⁵⁾ have shown air concentrations ranging from 1 disintegration min^{-1} 10^6 ft^3^{-1} below the tropopause to 460 disintegration min^{-1} per 10^6 ft^3 above the tropopause. Our measurements show concentration ranging from 4 - 40 disintegrations min^{-1} 10^6 ft^3^{-1} in the troposphere to 12,000 disintegrations min^{-1} 10^6 ft^3 in the stratosphere. This suggests that a large amount of Na^{22} was injected into the atmosphere during the past series of tests.

The Cs^{134} appears to be produced in nuclear detonations mainly by an n, γ reaction on Cs^{133} but is also produced directly by fission⁽⁶⁾. The ratio of Cs^{134} to Cs^{137} during the past 2-1/2 years has not shown a pronounced drop; however, our biological studies⁽⁷⁾ have shown that the ratio of these radionuclides in Alaskan caribou flesh dropped by a factor of 4 during the period from just prior to the last test series (October 1961) through July 1963. This suggests that a major injection of Cs^{134} into the atmosphere occurred prior to this last test series.

The radionuclides Co^{60} and Mn^{54} were reported to be present in the atmosphere in 1958 by Marquez, et al⁽⁸⁾ who found them in rain water collected between June 1957 and March 1958. Their presence was attributed to thermonuclear testing. It was recently reported⁽³⁾ that a number of activation products including Mn^{54} , Fe^{55} and Sb^{124} were produced in relatively high abundance in the high yield detonations carried out by the USSR at Novaya Zemlya in the fall of 1961 and that Y^{88} and Sb^{124} were produced in USSR tests in late 1962. These tests appear to be the major source of the Mn^{54} , Co^{60} , Y^{88} , Sb^{124} . The radionuclides Y^{88} and Sb^{124} were first observed in our studies during November 1962 and January of 1963 respectively. Both Mn^{54} and Co^{60} showed a sharp rise during January and February of 1963 indicating an additional injection of these radionuclides.

The Be^7 is produced by cosmic ray spallation reactions in the atmosphere and

its presence was first reported in the atmosphere by Arnold and Al-Salih in 1955⁽⁹⁾ who chemically separated it from rain water samples. Measurements of its concentration in the atmosphere at various altitudes and latitudes have since been reported^(5, 10, 11). Only recently have we begun to study the concentration of Be^7 in the atmosphere. It is interesting that, unlike other fallout radionuclides, Be^7 has not shown a large seasonal concentration change.

The Pu^{239} was separated chemically from the air filters after the gamma-ray spectrometric analysis. Its concentration change with time is somewhat similar to that of Cs^{137} (see Figure 6) but does show a larger increase during 1962.

The ratios of Pu^{239} to Cs^{137} as a function of time are tabulated in Table I and do show a relatively large peak with its maximum in October of 1962. Alpha energy analysis of the plutonium separated from the air filters has shown the ratio of Pu^{238} to Pu^{239} is less than 0.02.

TABLE I

PLUTONIUM-239 TO CESIUM-137 RATIO IN
GROUND-LEVEL AIR AT RICHLAND, WASHINGTON
DURING 1962 - 1964

(Ratio $\times 10^3$)

Month	1962	1963	1964
1		5.5	4.3
2		6.2	4.0
3		4.6	3.2
4	5.8	2.6	3.5
5	7.6	3.9	3.6
6	8.2	3.7	3.0
7	8.2	4.5	
8	10.0	3.0	
9	8.9	5.2	
10	13.0	4.1	
11	9.0	3.0	
12	9.6	2.4	

It is both interesting and significant that the activation products Y^{88} (105 d) and Sb^{124} (60 d) reached concentrations this year which are comparable with those 1 year ago while the fission product $Zr^{95}-Nb^{95}$ (65 d) is lower by about a factor of 20. Also, the fission product Cs^{137} (30 y) reached a concentration comparable with that last year and the Ru^{106} (1 y) and Ce^{144} (285 d) reached about half their last year's concentrations. Since there have been no atomic detonations above ground during 1963 and 1964⁽¹²⁾, all of these radionuclides entered the atmosphere prior to 1963 and their reservoir in the atmosphere has decreased with their respective half-lives since that time. This points to an obvious difference in the source of Y^{88} and Sb^{124} relative to most of the $Zr^{95}-Nb^{95}$, and the other fission products. In Figure 7 the air concentrations of Y^{88} and Sb^{124} have been decay corrected to the time of their probable injection into the atmosphere⁽³⁾ and are compared with Cs^{137} . The large increase in the fallout rates of Y^{88} and Sb^{124} relative to Cs^{137} clearly point to a different origin.

AIR PROFILES OF RADIONUCLIDES

During the past nuclear weapons testing period a few sampling flights were made with the Hanford AEC twin-engine Beachcraft. The flights were planned with the object of measuring air profiles under specific meteorological conditions. Air was drawn through a membrane filter of 5 μ pore size which was followed by an activated charcoal trap for collection of gaseous radioiodine. These flights were limited to 12,000 feet but they did serve to show that significant variations in radionuclide concentrations did exist at these low altitudes. Figure 8 gives a typical profile of the concentrations of 5 radionuclides as a function of altitude showing the comparatively high concentrations at 12,000 feet.

The availability of stratospheric air filters which were supplied by Isotopes, Inc., of Westwood, New Jersey has made it possible to compare the air concentrations observed near ground level at our geographical position with those present in the

stratosphere above. In Figure 9, the ratio of the radionuclide concentrations for stratospheric to ground level air are compared for 12 radionuclides. These measurements were made on samples collected during January of 1964. It is interesting that these ratios range from about 1500 to 3000 for all the radionuclides except Y^{88} , Sb^{124} and Cs^{134} . The high stratospheric concentrations of Y^{88} and Sb^{124} during January of 1964 help explain the observed high fallout rates of these radionuclides during the summer of 1964 (See Figure 7). The relatively low concentrations of Cs^{134} in the stratosphere is in accord with the Cs^{134} to Cs^{137} ratio measurements on biological samples⁽⁷⁾ which have shown a large drop in this ratio since 1961 and indicate that a major injection of Cs^{134} into the atmosphere occurred prior to the past test series.

Stratospheric samples were available which covered latitudes from about 26° to 70° north at longitudes of 97° to 146° west. This covers an area from southern Mexico to northern Alaska. These samples were collected between January 8 and February 18 of 1964. In Figure 10 the ratios of the various radionuclides in these samples to their Cs^{137} content are plotted as a function of latitude. It is interesting that these ratios are essentially constant with changing latitude for all the radionuclides except Y^{88} , Sb^{124} and Zr^{95} . These three radionuclides have short half lives compared with the others and it might be expected that their concentration would decrease with decreasing latitude since the most recent high yield nuclear shots were made at a high latitude. This is generally true for Zr^{95} - Nb^{95} as it does drop off with decreasing latitude. However, both Y^{88} and Sb^{124} show peak concentrations at about 41 and 63 degrees north, and show a definite lack of mixing relative to Cs^{137} .

DEPOSITION AND PROPERTIES OF THE AIR-BORNE RADIONUCLIDES

It has been pointed out that a definite correlation exists between the air concentrations of radionuclides and the seasonal precipitation rate⁽¹³⁾. This correlation appears to exist at our sampling location in Richland, Washington as

shown in Figure 11. Here the monthly precipitation rate shows the typical inverse relationship to the Cs^{137} content of the air. However, the annual precipitation in this area is only about 8 inches and it seems unlikely that local precipitation has a marked effect on air concentrations. Precipitation is not the major mode of fallout deposition during the summer months at our geographical location. Figure 12 shows the fractions of the various air-borne radionuclides which were carried down by rain during the summer of 1964. The total fallout including both dry deposition and rain was collected in plastic lined trays containing about 1/2 inch of water and with a surface area of about 80 ft². In addition, the rain was collected separately in a smaller dry tray which was lined with a new coat of plastic daily to prevent accumulation of dry fallout while waiting for rain. The fractions of various radionuclides which were carried down by rain ranged from 16% for Sb^{124} to 43% for Ru^{106} . The reason for this selectivity of the wash-out process by rain is not clear but it suggests that the various air-borne radionuclides are attached to aerosols of different characteristics.

The water solubility of the fallout radionuclides are of interest in estimating their availability for uptake in the biosphere. The relative solubility of these radionuclides was determined by filtering both the water in which the dry fallout was collected, and rain water samples through a 0.3 μ membrane filter. The fractions of the various radionuclides which were found to be "in solution" by this method are shown in Figure 13. A considerable variation does exist in the solubility of the different radionuclides. The solubilities shown for the rain-carried radionuclides are probably more representative of the actual properties of the fallout since the rain water was collected in a rather short period of time and was then filtered, whereas the dry fallout was collected over a period of several days in the water-filled trays prior to filtration. The rather high solubilities of these radionuclides facilitates studies of their oxidation states. Measurements designed to determine the radionuclide oxidation states and other chemical properties are presently being conducted.

PHYSICAL AND CHEMICAL CHARACTERISTICS OF I^{131} IN FALLOUT

During the past nuclear test series measurements were made to determine both the physical and chemical form of I^{131} in fallout⁽²⁾. The physical form of I^{131} whether gaseous or particulate was determined by filtering air through a filter of 5 μ pore size for particle removal, then passing it through an activated charcoal trap for removal of gaseous I^{131} . The fraction of I^{131} associated with particulate material is compared with the total I^{131} content of the air in Figure 14. The fraction of air-borne I^{131} in the particulate form varied from about 10 to 90%. The peak I^{131} air concentration in October of 1962 was accompanied by a definite peak in the fraction of particulate activity (about 90%) while the peak I^{131} air concentration in November 1962 was accompanied by a minimum of particulate I^{131} (about 12%). Presumably, these extreme differences in the fraction of particulate I^{131} are due to the nature of the nuclear detonations responsible for these peaks in the I^{131} activity. The nature of the gaseous I^{131} in fallout was investigated by placing a two inch thick silver mesh bed (1 mil x 20 mil silver plated copper mesh) in the air sampling head between the filter and the charcoal⁽²⁾. Laboratory experiments had shown that for the flow velocities used this bed was 95 and 99% efficient for removal of I_2 and HI respectively. It was observed that less than 10% of the gaseous I^{131} was held by the silver mesh; therefore, greater than 85 to 90% of the I^{131} is in a form other than I_2 or HI and is presumably present as organic iodides.

The particulate material collected on membrane filter was chemically fractionated to determine oxidation states of the associated I^{131} . This involved addition of I^- , IO_3^- and IO_4^- carriers, leaching with cold water at pH 12 and chemical fractionation. The experimental results are summarized in Table II and show that about 2/3 of the I^{131} was in the form of I_2 or I^- , 1/3 was present as IO_3^- and little or none was present as IO_4^- .

TABLE II

CHEMICAL FORM OF I^{131} COLLECTED ON MEMBRANE FILTERS

Date	Per Cent of I^{131} Leached from Filters	Fractionation of Leached I^{131}		
		$I_2 + I^-$, Per Cent	IO_3^- , Per Cent	IO_4^- , Per Cent
10/24/62	44	~57	~38	< 5
10/25/62	42	~66	~29	< 5

At the Hanford Atomic Products Operation at Richland, Washington small amounts of I^{131} are released continuously from the exhaust stacks of the chemical separations plants. This source of I^{131} permits a continuation of studies of the physical and chemical behavior of atmospheric radioiodine. Although the I^{131} released from the separations plant stacks is essentially all gaseous, it has been found to be a complex mixture consisting of about half I_2 (and HI) with the remainder consisting of several different organic iodide compounds⁽¹⁴⁾. The chemical species of these organic iodides are presently being investigated.

During a period of above normal I^{131} emission from a separations plant stack, air samples were collected at distances up to 25 mi. to determine if rapid changes occurred as the material moved from its point of release. Sampling was performed from an airplane by pulling air through a membrane filter of pore size 5 microns followed by a charcoal trap. Samples were collected at 200 to 500 ft. by multiple penetrations of the stack plume at distances of 1, 3, 5, 10 and 25 mi. from the source. The fraction in the gaseous state is shown in Table III. It is interesting that very little change in physical form occurs over the distances measured. The total sample activities collected at 25 mi. on 9/4/63 and 10 mi. on 9/3/63 were low and the apparent change in physical form may not be significant. The major change occurs between the stack and the first mile.

TABLE III
PHYSICAL FORM OF I^{131}
AT VARIOUS DISTANCES FROM THE SOURCE

(Sampled from aircraft 9/4/63)

<u>Distance, Mi.</u>	<u>Per Cent Present as a Gas</u>
0	> 99
1	73
3	90
5	92
10	92
25	96 $\pm$ 10% (a)

(9/3/63)

0	> 99
1	82
3	82
5	81
10	58 $\pm$ 20% (a)

(a) Standard deviation of measurements

SHORT-LIVED COSMIC-RAY PRODUCED RADIONUCLIDES

In considering methods of studying atmospheric phenomena including cloud physics, wash out and rain out it becomes apparent that the use of short-lived natural tracers, which are produced by cosmic ray spallation reactions, would be very useful. In investigative studies the natural presence in the atmosphere of cosmic ray produced Cl^{38} (37.3 min) and S^{38} (2.9 hr) was discovered. These radionuclides were found to be present in rain water at concentrations which are readily measurable with the multidimensional analyzer. They are produced by cosmic ray spallation reactions on atmospheric argon. The concentrations of Cl^{38} and S^{38} in 6 rains are recorded in Table IV along with the concentrations of Cl^{39} (55 min) which was measured simultaneously.

An additional spallation produced radionuclide which is present in the atmosphere and can be readily measured in rain water with the multidimensional spectrometer is Na^{24} (15 hr.). Its concentration in three rains is compared with that of Na^{22} level in Table V.

TABLE IV

CONCENTRATIONS OF THE COSMIC RAY PRODUCED RADIONUCLIDES

 Cl^{38} , S^{38} and Cl^{39} in Rain Water^a(dpm liter⁻¹)

Date	Volume, liters	Collection Time, Minutes	Cl^{38}	S^{38}	Cl^{39}
7/29/64	5.10	50	147 ± 15	13 ± 5	200 ± 17
7/30/64	6.64	15	~18	4 ± 2	~10
8/1/64	3.5	50	9 ± 5	b	15 ± 3
8/1/64	1.8	10	31 ± 12	b	28 ± 5
8/12/64	2.2	5	42 ± 13	~7	62 ± 12
8/18/64	10.0	40	55 ± 9	b	53 ± 3

a The plus or minus values are the standard deviations for the measurements.

b Not measured.

TABLE V

 Na^{22} AND Na^{24} CONCENTRATIONS IN RAIN WATER(dpm liter⁻¹)^a

Date	Sample Volume (Liters)	Na^{24}	Na^{22}
6/15/64	60	0.70 ± 0.13	0.36 ± 0.03
6/17/64	6.64	2.22 ± 0.25	0.25 ± 0.04
6/18/64	14.32	0.59 ± 0.09	0.19 ± 0.02

a The ± values are the standard deviation.

Measurements during the course of a rain, of radionuclides such as these, would provide useful information for calculating rain-out and wash-out coefficients of the normal atmospheric aerosols.

BIOSPHERIC DISTRIBUTION OF Na²²

Like Cs¹³⁷, Na²² distributes itself through the biosphere and it can be measured in many biological materials by direct counting of the sample ash on the multidimensional analyzer. Measurements of its distribution through the food chain and its calculated concentration in man based on bioassay measurements are present in Table VI. These data point out the usefulness of Na²² as a tracer of weapons testing debris.

TABLE VI

SODIUM-22 IN FOODS, BIOASSAY SAMPLES AND PEOPLE
(d.p.m. per kg)

WESTERN UNITED STATES				ALASKA			
Sample	Location	Date Obtained	Na ²²	Sample	Location	Date Obtained	Na ²²
Elk	Quinault, Wn.	5/64	74.4	Caribou Meat)		7/63	180
Bass	Columbia River	4/64	8.3	Caribou Meat)		7/63	89.1
Milk	Washington	3/64	6.2	Moose Meat)	Near	3/64	58.7
Wheat	Washington	8/63	3.31	Moose Meat)	Kotzebue,	3/64	80.6
Beef)	Local Food	5/64	2.47	Caribou Meat)	Alaska	8/5/61	9.13
Beef)	Store, Washington	3/64	0.52	Caribou Meat)		10/9/61	23.0
Corn	Oregon	4/64	~0.04	Reindeer Meat)		8/63	15.6
Lettuce	California	3/64	0.16	Urine ^c)	Anaktuvuk	1/64	126
Carrots	California	4/64	~0.07	Man (Eskimo) ^b)	Pass, Alaska		3427 ^b
Potatoes	Idaho	4/64	0.68				
Green Beans	Oregon	4/64	~0.20				
Urine Sample ^a	Washington		1.45				
Man ^b	Washington	11/63	39.5 ^b				

a Richland, Washington, composite from several individuals.

b These values are estimated whole body burdens for sodium-22 based on an 11 day biological half-life.

c Composite from 2 Alaskan Eskimos.

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FIGURE 1

Detection System for Multidimensional Gamma Ray Spectrometer

FIGURE 2
Cu⁶⁴ SPECTRA

FIGURE 3
 Co^{60} SPECTRA

FIGURE 4
COMPARISON OF THE BACKGROUND COUNTING RATES OF
A SINGLE CRYSTAL WITH THAT OF THE TWO CRYSTAL
MULTIDIMENSIONAL DETECTOR SYSTEM.

FIGURE 5.

Total Counting Efficiency and Total Coincidence Counting Efficiency of the Detector System

FIGURE 6
AIR CONCENTRATIONS OF RADIONUCLIDES
AT RICHLAND, WASHINGTON DURING
1962-1964

FIGURE 7

COMPARISON OF THE AIR CONCENTRATION OF Y⁸⁸ AND Sb¹²⁴ WITH Cs¹³⁷. Y⁸⁸ AND Sb¹²⁴ ARE CORRECTED TO THE TIME OF PROBABLE INJECTION, NOVEMBER 15 AND DECEMBER 31, 1962 RESPECTIVELY

FIGURE 8

Radionuclide Concentration as a Function of Altitude 11/13/62

FIGURE 9

Ratios of Radionuclide Concentrations in the Stratosphere to that near Ground Level in the Northwest part of the U.S. in January 1964

FIGURE 10

Ratio of the Concentration of Various Air-Borne Radionuclides to that of Cs^{137} as a Function of Latitude. Stratosphere Samples.

FIGURE 11

Comparison of the Air-Borne Cs^{137} Concentration with the Annual Precipitation Curve

FIGURE 12

Fraction of Radionuclide Deposition due to Rain during the Summer of 1964.
(6-11-64 through 9-15-64)

FIGURE 13

Fraction of Radionuclides Found in Solution in the Fallout Trays

FIGURE 14

Physical Form and Abundance of Air-Borne I^{131}