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RADIOCHEMICAL DETERMINATION OF SODIUM-24 AND SULFUR-35 IN SEAWATER

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ADMINISTRATIVE INFORMATION

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ABSTRACT

Rapid radiochemical procedures were developed for determining Na^{24} and S^{35} in seawater containing fission product radionuclides. Na^{24} is separated from other radionuclides by scavenging with lanthanum hydroxide; two sodium chloride precipitations with hydrogen chloride gas follow. The disintegration rate is determined by measuring the area of the 1.368 Mev gamma photopeak. The working time required for a single analysis is 1/2 hr; the precision, $\pm$ 1 %; the chemical yield, about 70 %; and the total effective decontamination factor from fission products, $\gg 10^5$.

S^{35} in seawater is separated from other radionuclides through precipitating barium sulfate. This is followed by reducing the sulfate to hydrogen sulfide with hydrogen iodide and by subsequently oxidizing sulfide to sulfate in an alkaline peroxide solution. The resulting sulfate ion is precipitated as barium sulfate for chemical yield determination and counting. The working time required for a single analysis is less than 1 hr; the precision, $\pm$ 5 %; the chemical yield, 70-80 %; and the decontamination factor from fission products, $> 10^7$.

Although the samples tested are salt solutions contaminated with fission products, as in the case of nuclear explosions in the ocean and in salt domes, these methods are applicable to many other types of samples containing fission products and induced activities.

SUMMARY

Problem

The radiological composition of seawater and fallout originating from underwater nuclear devices is mostly a mixture of fission product radionuclides and of radionuclides induced in seawater and weapon debris. Of the radionuclides induced in seawater, Na^{24} is the most abundant from 1 hour to 1 week after detonation and S^{35} is the most abundant for times greater than 1 week. The radiochemical procedures for analyzing contaminated seawater samples for Na^{24} and S^{35} were time-consuming and difficult to perform. The problem was to improve these radiochemical procedures.

Findings

Rapid new radiochemical procedures for Na^{24} and S^{35} in fission product mixtures and in a seawater medium were developed. The working time required for a single analysis is greatly reduced; about 1/2 hour for Na^{24} and 1 hour for S^{35}. The procedures are applicable to salt-containing samples such as would result from nuclear detonations in the ocean and in salt domes, and to other types of contaminated materials.

INTRODUCTION

Nuclear detonation in seawater produces a mixture of radionuclides some of which are formed through neutron capture by those elements found in the water. The composition of the mixture of these induced radionuclides depends upon the time elapsed after the event.

Dyrssen and Nyman[1] calculated the relative activities of the slow-neutron-induced radioelements in seawater. They showed that after the first hour, Na^{24} constitutes nearly all the induced activity throughout the first week, after which almost all the activity is due to S^{35}. Sodium-24 is formed from a (n,γ) reaction on stable Na^{23}, and S^{35} is produced by the (n,p) reaction on stable Cl^{35} and the (n,γ) reaction on stable S^{34}. Approximately 200 times more S^{35} is formed by the (n,p) reaction on Cl^{35} than by the (n,γ) reaction on S^{34}.

Since Na^{24} and S^{35} are the two most abundant radionuclides induced in seawater following a nuclear detonation, it was desirable to develop simpler and more rapid radiochemical procedures for their analyses than those existing.

SODIUM-24

The Na^{24} decay scheme consists essentially of a beta particle of maximum energy of 1.39 Mev, followed by two gammas in cascade at 1.368 and 2.750 Mev.[2] The half-period of Na^{24} is 15.06 hr.[3]

R. J. Prestwood[4] reported a radiochemical separation procedure of Na^{24} from a mixed fission product solution. After an initial iron scavenge on the sample, sodium is precipitated as the sodium magnesium uranyl acetate. The sodium is finally converted to the chloride for counting. The chemical yield is about 50 to 60 %. While excellent decontamination is obtained, this procedure is tedious and time-consuming.

Since Na^{24} has a relatively short half-period, a more rapid method of separation, adaptable to the analysis of numerous samples, is necessary. A procedure employing gamma-ray spectrometry in conjunction with limited chemical separations was devised which provides a considerable saving in time and effort.

SULFUR-35

Sulfur-35 is a pure beta-emitter having a half-period of 87.16 days[5] and a maximum beta energy of 0.1674 Mev.[6]

All of the sulfur in seawater is assumed to be present as the sulfate ion and is usually determined by precipitation as barium sulfate. The procedure and errors involved are adequately discussed in standard works.[7]

Two procedures are known for radiochemically separating S^{35} from mixed fission products. Metcalf[8] described a procedure in which bromine is used to convert sulfide to sulfate, which is then precipitated as benzidine sulfate. Decontamination is effected by repeated extractions of the benzidine sulfate in basic solution with isopropyl ether. This is followed by reprecipitation of benzidine sulfate with benzidine hydrochloride in acid solution. A ferric hydroxide scavenge is made and a final benzidine sulfate precipitation performed for chemical yield determination and counting.

Handley and Reynolds[9] improved Metcalf's procedure by performing three ferric hydroxide scavenges, four benzidine sulfate precipitations, and three isopropyl ether extractions. A decontamination of greater than 10^7 and a chemical yield of 80 % were obtained from a mixed fission product sample. Approximately 3 hr are required to perform 4 determinations.

These procedures are rather slow and unsatisfactory for analyzing numerous S^{35} samples. A more rapid radiochemical procedure was therefore developed.

SEAWATER SAMPLES

In the development of the two radiochemical procedures, seawater was used which was obtained 40 miles off the coast of California. Since seawater contains large concentrations of sodium ion and sulfate ion,

relatively constant at 8.650 and 2.372 g/kg of seawater, these carriers were not added.

No suspended matter (inorganic nor organic particles) was visible in the seawater. The concentration of particulate matter[10] in the coastal waters off Massachusetts (depth 70 meters) is 0.4 to 2 mg/l, while that in the ocean water 100 miles beyond the continental shelf is 0.2 mg/l. Also, dissolved organic substances in seawater from the North Atlantic have been estimated to be about 5 to 6 mg/l. Na^{24} and S^{35} are not concentrated by marine organisms.[11] Thus the presence of sodium and sulfur agglomerated in naturally occurring particulate or organic matter was considered negligible. Particulate matter formed from nuclear weapon debris also would contain negligible amounts of Na^{24} and S^{35}.

ANALYSIS OF Na^{24}

The radiochemical procedure developed is summarized as follows: Na^{24} is separated from other radionuclides by scavenging with lanthanum hydroxide; two sodium chloride precipitations with hydrogen chloride gas follow. The disintegration rate of Na^{24} is determined by measuring the area constituting the 1.368-Mev gamma photopeak, which is obtained by scintillation spectrometry with a NaI(Tl) detector and a 256-channel pulse-height analyzer. The gamma-ray spectrometer is calibrated with Na^{24} samples of known specific activity.

PROCEDURE

Analysis

In detail the procedure is as follows: To a hot solution of 25 ml of seawater and 1 ml of lanthanum carrier (10 mg La/ml) in a 50-ml centrifuge tube, add ammonium hydroxide until lanthanum hydroxide precipitates. Centrifuge the solution and filter it through a No. 42 Whatman filter paper into a clean centrifuge tube. Cool the solution in an ice bath. Pass anhydrous hydrogen chloride into the solution by means of the anhydrous hydrogen chloride saturation apparatus (description below). Saturate the solution with the gas under pressure (5 psig) for 3 min after sodium chloride precipitates out. Centrifuge the solution for 30 sec and discard the supernatant solution. Wash the sodium chloride precipitate with 10 ml of hydrochloric acid wash solution (concentrated hydrochloric acid saturated with hydrogen chloride gas) and discard the wash. Dissolve the sodium chloride in 10 ml of distilled water. Again precipitate sodium chloride with anhydrous hydrogen chloride. Wash the precipitate once with 5 ml of the hydrochloric acid wash solution, then filter through a medium-pore sintered glass filter. Wash it twice with 5-ml aliquots of ethyl alcohol saturated with hydrogen chloride gas, and twice with 5-ml aliquots of diethyl ether saturated with hydrogen chloride gas. Spread out the precipitate at the bottom of a preweighed

weighing bottle (standard taper joint No. 29/12), for counting in a previously calibrated gamma-ray spectrometer. After the counting, dry the sodium chloride at 105°C in an oven, and cool in a desiccator. Weigh to determine its chemical yield. If necessary determine the initial amount of sodium in each sample by flame photometry. However, in almost all cases, the amount of sodium in the seawater is a known constant.

Spectrometer Calibration

Place a known aliquot of a Na^{24} solution on a gold-plated VYNS film used for 4-pi beta counting. Dry it under an infra-red lamp and count in a 4-pi gas-flow beta proportional counter to determine the Na^{24} absolute disintegration rate. Pate and Jaffe[12] give a detailed description of the 4-pi beta counting method. Then calibrate the gamma-ray spectrometer with this Na^{24} solution. To obtain a precise measurement of Na^{24} activity, evaluate the data obtained from the 1.368-Mev total absorption peak by the method of Covell.[13] In this method a given fraction of the area of the total absorption peak is determined by analyzing the digital data defining that area of the peak.

256-Channel Gamma Analyzer

The gamma-ray spectrometer used is a USNRDL modified version of the RCL 256-channel pulse-height analyzer, Mark 20, Model 2603 (Manufactured by Radiation Counter Laboratory Inc., Nucleonic Park, Skokie, Illinois). The detector is a 3 in. x 3 in. NaI(Tl) crystal coupled to a 3 in. Dumont, Model 6363 photomultiplier tube, output from which is coupled to a linear amplifier through a cathode-follower preamplifier. The data print out in digital form.

Saturation Apparatus

A 50 ml-centrifuge tube, having a flared top, is fitted with a two-hole rubber stopper. A clamp holds the rubber stopper tightly in the centrifuge tube. One hole holds a gas dispersion tube which is connected to a tank of anhydrous hydrogen chloride. This tube dips below the surface of the solution to be saturated. The other hole holds a glass tube fitted with a glass stopcock. This is connected to a funnel with Tygon tubing. The funnel is inverted and dips 1 mm into water to trap escaping hydrogen chloride gas.

RESULTS AND DISCUSSION

The present procedure for Na^{24} is based on a limited radiochemical separation followed by an assay of a high energy Na^{24} gamma-ray photopeak. This technique gives a very large effective decontamination from other radionuclides. The precision and accuracy of the procedure are determined mainly by the assay of the Na^{24} photopeak. The stability of the gamma-ray spectrometer, the variation of photopeak counts of Na^{24} with specific activity, and the effect of other gamma-emitting radionuclides were determined and are described below.

The precision with which Na^{24} is measured depends much on the stability of the gamma-ray spectrometer. The spectrometer is regularly subjected to quality control procedures in order to maintain a high degree of stability.[13] Experience with the 256-channel analyzer has shown no measurable change in the photopeak counting efficiencies of Co^{60} for over a year. Also, repeated measurements with the same sample have shown that the variation in counting rate is that predicted by counting statistics.

The absolute disintegration rate of Na^{24} is known through calibration of the spectrometer. The efficiency factor, N'/dpm, vs. the weight of sodium chloride is presented in Fig. 1. N' is the amount of activity from a Na^{24} source counted for 100 seconds which is part of the arbitrarily chosen portion of the total absorption peak extending 10 channels on either side of the maximum activity channel.

Several radionuclides having gamma energies above 1 Mev could interfere with the measurement of the 1.368-Mev gamma ray of Na^{24}. In order to establish these interferences, an estimate is made of the relative activities of the pertinent fission products and induced radionuclides occurring in seawater at 15 hr after irradiation. Table 1 lists the relative activities of the possible interfering induced activities. Column 3 of this table was taken from an article by Senftle and Champion.[14] Here As_λ is defined as the specific initial activity in 1 g of the target material for 1 sec of irradiation with a flux of 10^{12} neutrons/cm^2 sec. Column 4 takes into consideration the relative concentration of the target material in seawater, the relative abundance of the gamma rays having energies above 1 Mev, the decay of each nuclide for a period of 15 hours after fission, and the neutron cross-sections for competing reactions. The number of neutrons emitted per fission from U^{235} undergoing neutron fission is approximately 2.5.[15] One neutron is required for the propagation of one fission reaction. Of the 1.5 neutrons left, two nuclides (H^1 and Cl^{37})[1] absorb approximately 99 %. Thus only a fraction, approximately 6 x 10^{-3}, of all the neutrons

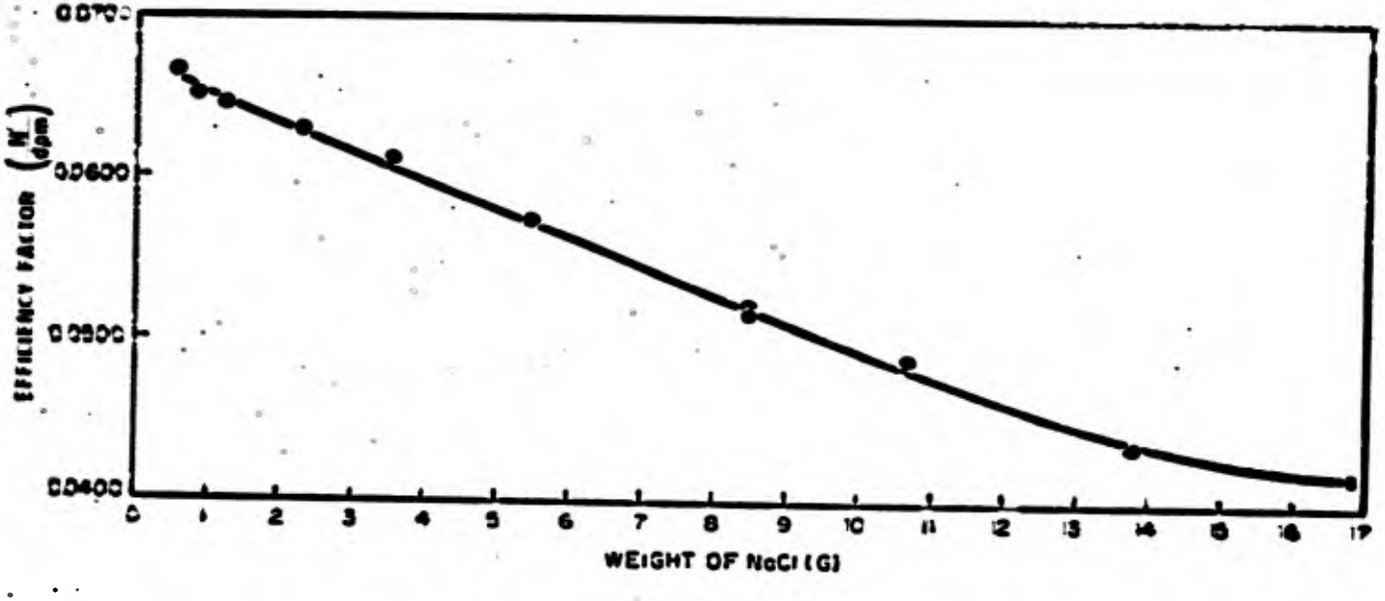

Fig. 1 Efficiency Factor vs. Weight of NaCl

TABLE 1

Relative Activity of Most Abundant Radionuclides Induced by Thermal Neutron Irradiation of Seawater

Induced Radionuclide	$T_{1/2}$	As_{λ}^{a}	Gamma Emission Rate at 15 hr After Irradiation[b] (photons/sec)
Na^{24}	15.06 h	1.8×10^{5}	5.4×10^{2}
Cl^{38}	37.29 m	7×10^{5}	3×10^{-4}
K^{42}	12.44 h	1.5×10^{4}	0.8
Sc^{46}	85 d	1.5×10^{4}	2×10^{-7}
Mn^{56}	2.576 h	1.0×10^{7}	5×10^{-4}
Fe^{59}	45.1 d	4	2×10^{-3}
Co^{60}	5.27 y	8.5×10^{2}	1×10^{-9}
Cu^{64}	12.8 h	4×10^{5}	5×10^{-4}
Ni^{65}	2.564 h	2.1×10^{4}	9×10^{-10}
Zn^{65}	250 d	53	5×10^{-2}
As^{76}	26.1 h	2.4×10^{5}	6×10^{-4}
Br^{82}	35.87 h	6.9×10^{4}	0.6
Ag^{110m}	270 d	2×10^{2}	8×10^{-9}

a. From Reference 14.
b. Normalized to the activity induced by neutrons from 1.32×10^{12} fission events occurring in seawater.

released per fission is available for capture by the other components in seawater. Of this, 4.4×10^{-3} is taken by sodium and 2.6×10^{-4} by sulfur. The values in Column 4 of Table 1 were normalized to 1.32×10^{12} fission events to allow direct comparison with calculated fission product activities, given in Table 2. Table 2 lists the fission products having gamma energies above 1 Mev and having relatively high fission yields. Column 3 shows the gamma emission rate of each fission product nuclide at 15 hr post-fission, and takes into consideration the respective mass chain yields.[16] Each value corresponds to the activity from 1.32×10^{12} fission events. This number of fissions corresponds to the fission products obtained by the irradiation, for 1 sec, of 1 g of enriched U^{235} of 93.2 % isotopic abundance, at a thermal neutron flux of 10^{12} neutrons/cm^2 sec. Column 3 of Table 2 is directly comparable to Column 4 of Table 1.

TABLE 2

Relative Activity of Most Abundant High Gamma Energy Fission Products in a Solution Containing 1.32×10^{12} Fissions

Fission Product Nuclide	$T_{1/2}$ (hr)	Gamma Emission Rate at 15 hr After Irradiation (photons/sec)
Sr^{91}	9.7	2×10^{4}
Y^{92}	3.6	4.9×10^{4}
Ag^{112}	3.2	1.1×10^{2}
Te^{131m}	30	1.6×10^{3}
I^{132}	2.4	7.3×10^{2}
I^{133}	22.4	9.2×10^{3}
I^{135}	6.7	2×10^{5}
La^{140}	40	3.7×10^{3}
La^{141}	3.7	1.2×10^{4}

Decontamination tests were made with various radionuclides in the absence of Na^{24}. The decontamination factors of the more abundant radionuclides, given in Table 3, are sufficient for satisfactory removal of the interfering radionuclides. Decontaminations of Y^{92} and Ag^{112} were not tested, because it has been observed that yttrium radioisotopes are effectively removed by a lanthanum hydroxide scavenge, and that silver radioisotopes are separated by formation of the silver chloride complex during the precipitation of sodium chloride in the presence of a high hydrochloric acid concentration.

Excellent recovery by this procedure was obtained from a solution containing 4.06×10^{4} dpm of Na^{24}, fission products of 2.1×10^{10} fissions, and 25 ml of seawater. The results for four aliquots are presented in Table 4. Chemical yields of 70 % were obtained. Gamma-ray spectra of a source containing 4.06×10^{4} dpm of Na^{24}, of fission products (35 hr old) of 2.1×10^{10} fissions, and of a Na^{24} source separated from the above solution, are compared in Figs. 2 and 3. The final sodium chloride precipitate, after separation of the fission products, showed no visible contamination of the Na^{24} gamma-ray photopeak.

TABLE 3

Decontamination Factors of Some Interfering Isotopic Radionuclides

Radionuclides	Decontamination Factor
Sr^{85}	1×10^4
Ba^{133}	1×10^2
La^{140}	6×10^3
Te fission-product isotopes in equilibrium with respective I daughters	6×10^2
I^{131}	1×10^4
Fission Products (2 months old)	3×10^5

TABLE 4

Recovery of Na^{24}

Sample No.	Na^{24} Determined (dpm)
1	4.15×10^4
2	4.02×10^4
3	4.12×10^4
4	4.10×10^4
Average	$4.10 \times 10^4 \pm 1.2$ %

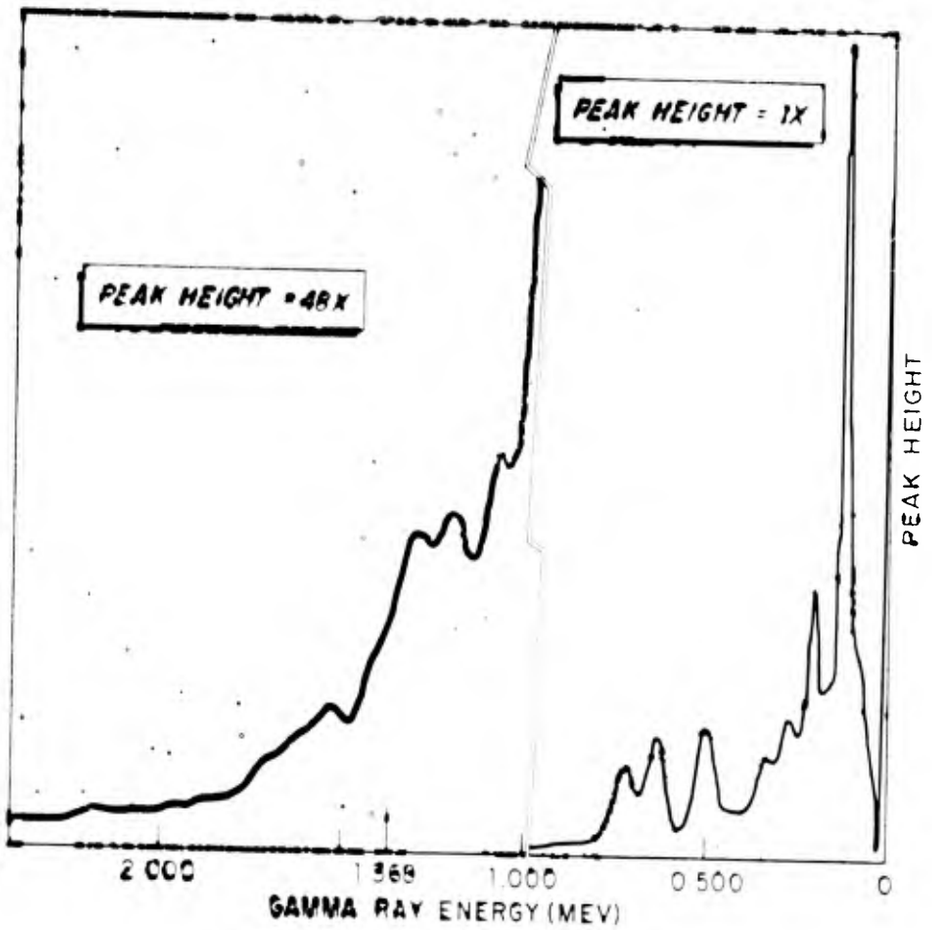

Fig. 2 Combined Gamma Spectrum of a Solution Containing Na^{24} plus Fission Products (35 hr old)

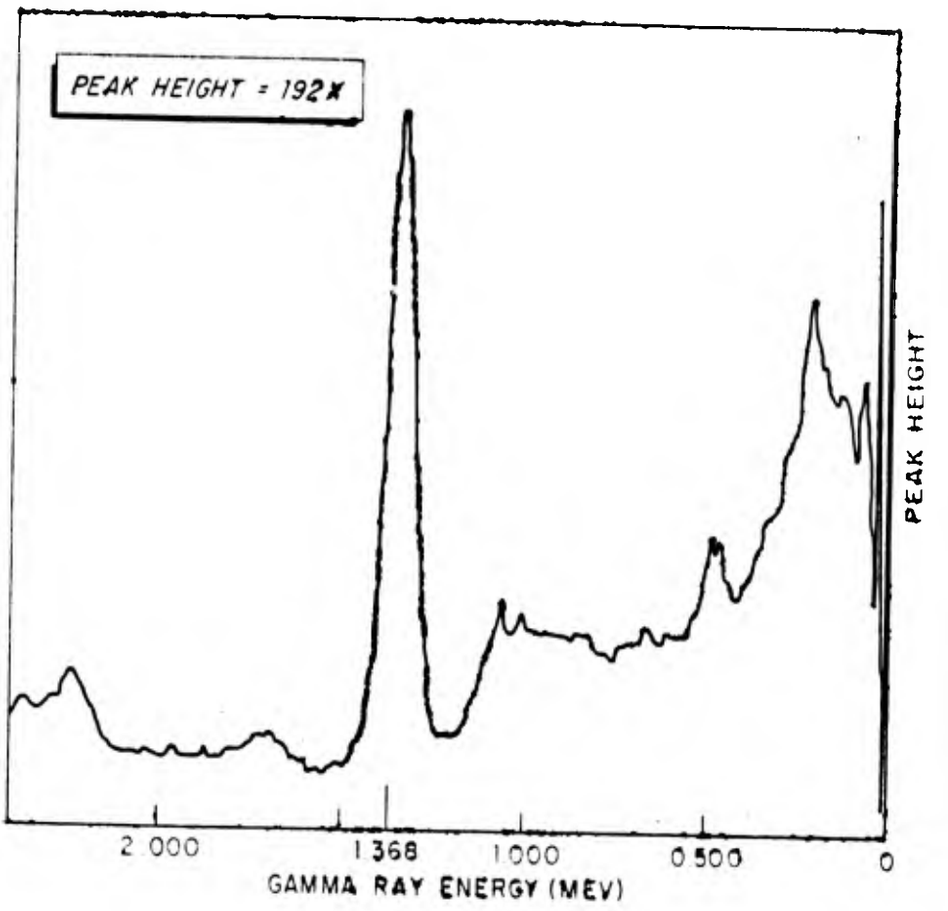

Fig. 3 Gamma Spectrum of Na^{24} separated from a Solution containing Fission Products (35 hr old)

ANALYSIS OF S^{35}

Briefly the procedure developed for analysis of S^{35} is as follows:

The S^{35} is separated from seawater by precipitation of barium sulfate, which is reduced to hydrogen sulfide with hydrogen iodide. The sulfide is subsequently oxidized to sulfate in an alkaline peroxide solution. The resulting sulfate ion is precipitated as barium sulfate for determination of chemical yield and for counting.

PROCEDURE

Analysis

To a 10-ml aliquot of seawater add 0.5 ml of conc. ammonium hydroxide and 5 ml of hydrogen peroxide. Boil. Add distilled water to make up a total volume of 500 ml. Add slowly 1 ml of conc. HCl and 5 ml of 1 M barium chloride solution to precipitate barium sulfate. Filter precipitate through a filter tower containing a filter paper circle, and wash with hot distilled water. If it is necessary to know the amount of sulfate in the seawater sample, at this point filter the barium sulfate quantitatively, wash with water, alcohol, and acetone, dry in an oven, and weigh.

Fig. 4 shows the hydriodic acid reduction apparatus.

Put the barium sulfate precipitate, filter paper, and 50 ml of concentrated hydriodic acid into a 200 ml 2-necked flask. Reflux this solution until all the barium sulfate dissolves. During this time, apply suction through a 60 ml separatory funnel (H). The hydrogen sulfide gas is absorbed in 75 ml of 1 N sodium hydroxide in a 150 ml flask (D) after passing through a gas dispersion tube (C). After the $BaSO_4$ reduction is complete, apply suction through a 150 ml flask (E). Expel the H_2S gas by adding 20 ml of concentrated hydrochloric acid to the

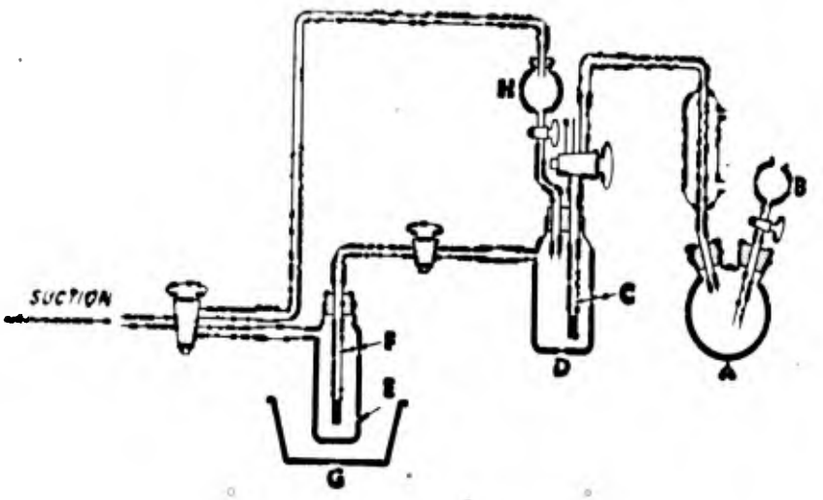

Fig. 4 HI Reduction Apparatus

A. HI reduction flask.

D. Flask containing 1 N NaOH for absorbing H_2S.

E. Flask containing NH_4OH and H_2O_2 for absorbing reformed H_2S.

sodium hydroxide solution in Flask D. Collect, with suction, hydrogen sulfide gas through a gas dispersion tube (F) into Flask E which contains a solution of 25 ml of concentrated ammonium hydroxide and 60 ml of 30 % hydrogen peroxide. An ice bath, G, is necessary to cool the reaction vessel and prevent foaming. Rubber stoppers and tygon tubing are used.

When the oxidation and collection of hydrogen sulfide are completed, transfer the solution from Flask E to a 1-liter flask containing approximately 200 ml of distilled water. Boil to drive off excess ammonia and hydrogen peroxide. (Care is required, as this solution boils vigorously). Add about 0.5 ml of concentrated hydrochloric acid and 5 ml of 1 M barium chloride to precipitate the barium sulfate. After digestion, filter, with the aid of a filter tower, the barium sulfate onto a preweighed No. 42 Whatman filter paper circle. Wash the precipitate twice with hot distilled water, ethyl alcohol, and acetone. Then dry in an oven at 105°C, cool in a desiccator, and weigh. Mount the precipitate on a brass planchet assembly and cover with a thin film of rubber hydrochloride. A rubber O-ring fitted around the brass planchet keeps the precipitate in place. Count the barium sulfate source in a low background beta counter.

Calibration

To facilitate determining the absolute disintegrations per minute of S^{35}, the counter must be calibrated for geometry, self-absorption, and self-scattering. An efficiency factor, the ratio of counts per minute (cpm) to disintegrations per minute (dpm) as a function of the source weight of barium sulfate, can be constructed as follows: Put an equal aliquot of S^{35} of known disintegration rate into each of six 250-ml erlenmyer flasks. (The S^{35} used was calibrated at the National Bureau of Standards and was reported to have been determined with a precision of $\pm$ 3 % by gas counting as sulfur dioxide.) The flasks contain various known amounts of a standardized sulfuric acid carrier. After mixing thoroughly, precipitate barium sulfate, weigh, mount on brass planchet assemblies, and count. Plot the ratio of the net count rate to the absolute disintegration rate corrected for chemical yield against the weight of barium sulfate precipitate (Fig. 5).

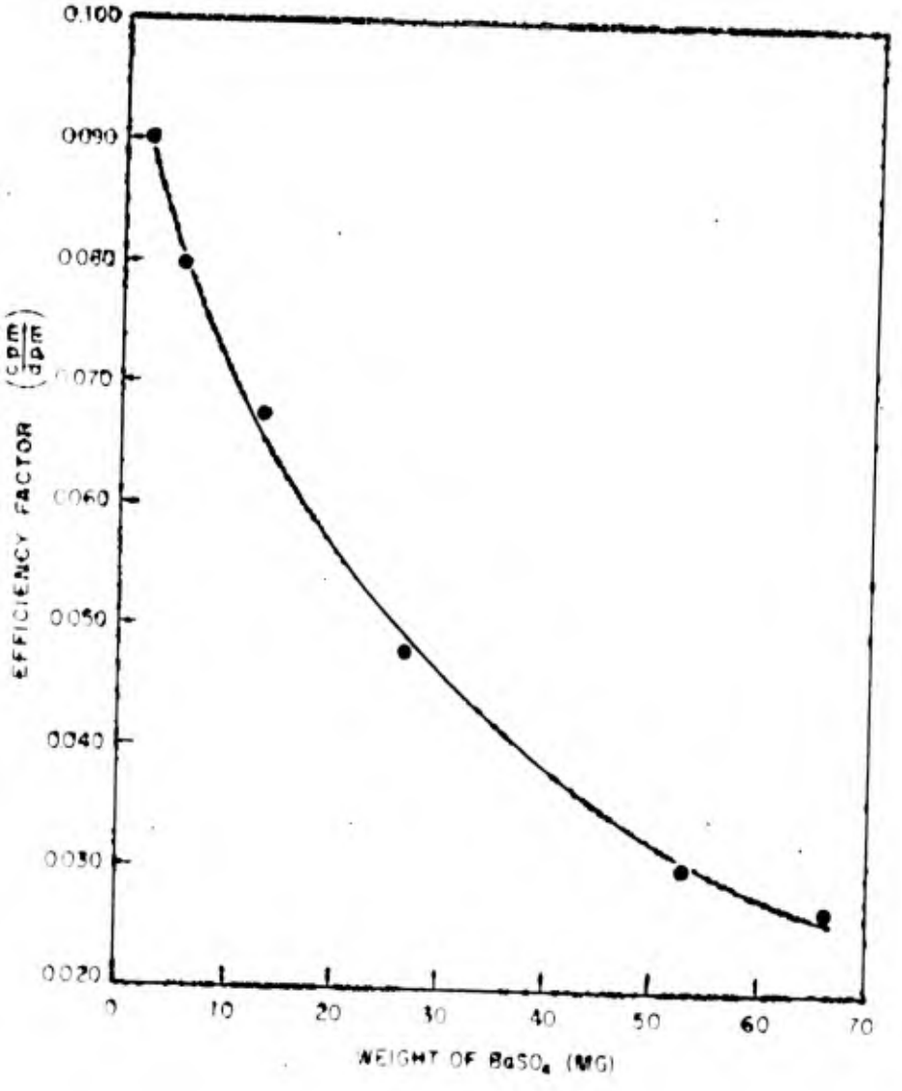

Fig. 5 Efficiency Factor vs. Weight of $BaSO_4$

RESULTS AND DISCUSSION

The purpose of the initial treatment of the sample with hydrogen peroxide is to oxidize any hydrogen sulfide to sulfate ion. This serves to ensure complete exchange between S^{35} and its sulfate carrier.

Bush[17] reported that with concentrated sulfuric acid and excess concentrated hydrogen iodide the reaction product is mainly hydrogen sulfide according to the equation

$$2H^+ + SO_4^= + 8HI \rightarrow H_2S + 4I_2 + 4H_2O$$

However, it is possible to obtain sulfur dioxide if the HI is slightly diluted.

The results of measurements of recovery of known amounts of S^{35} introduced into seawater are presented in Table 5. The usual corrections were applied for chemical yield and counting efficiency corresponding to the weight of barium sulfate precipitate recovered. Each

TABLE 5

Recovery of Sulfur-35 From Seawater

Sample No.	dpm of S^{35} Introduced	dpm of S^{35} Determined
1	8.2×10^2	$8.3 \times 10^2 \pm 5.1\ \%$
2	8.1×10^3	$7.9 \times 10^3 \pm 5.4\ \%$
3	1.62×10^4	$1.47 \times 10^4 \pm 3.1\ \%$

value represents the average of triplicate determinations, and the precision of such determinations was about $\pm$ 5 %. Errors are due mainly to difficulties in obtaining barium sulfate precipitate mounts which were sufficiently reproducible for precise counting of the weak beta-rays of S^{35}. This problem can be partially eliminated by adopting the procedure for assaying S^{35} through gas counting[18] or liquid scintillation counting[19] techniques.

The procedure gives decontamination factors of 10^7 from mixed fission products (Table 6), chemical yields of 70 to 80 %, and a precision of about ± 5 %. This procedure is also adaptable to the simultaneous determination of a large number of samples.

TABLE 6

Decontamination Factors of Various Radionuclides

Radionuclides	Decontamination Factor
Ba^{140}-La^{140}	$>10^7$
Ce^{144}-Pr^{144}	$>10^7$
Cs^{137}	$>10^7$
I^{131}	$>10^7$
Mo^{99}-Tc^{99m}	$>10^6$
Pm^{147}	$>10^7$
Ru^{106}-Rh^{106}	$>10^6$
Sr^{90}-Y^{90}	$>10^6$
Ta^{182}	$>10^6$
Zr^{95}-Nb^{95}	$>10^6$
Mixed Fission Products (18 days old)	$>10^7$

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36	CO, Chemical Corps Training Command
37	Commandant, Chemical Corps Schools (Library)
38	CO, Chemical Research and Development Laboratories
39	Commander, Chemical Corps Nuclear Defense Laboratory
40	CG, Aberdeen Proving Ground
41	CO, Army Medical Research Laboratory
42	Director, Walter Reed Army Medical Center
43	CG, Quartermaster Res. and Eng. Command

44	Quartermaster Food and Container Institute
45	Director, Operations Research Office (Library)
46	Hq., Dugway Proving Ground
47-49	The Surgeon General (MEDNE)
50	CO, Army Signal Res. and Dev. Laboratory
51	CG, Engineer Res. and Dev. Laboratory (Library)
52	Director, Office of Special Weapons Development
53	CG, Ordnance Tank-Automotive Command
54	CO, Ordnance Materials Research Office, Watertown
55	CO, Watertown Arsenal
56	CO, Frankford Arsenal
57	CO, Picatinny Arsenal
58	Jet Propulsion Laboratory
59	Army Ballistic Missile Agency
60	CO, Office of Ordnance Research

AIR FORCE

61	Assistant Chief of Staff, Intelligence (AFCIN-3B)
62-67	Commander, Aeronautical Systems Division (WWAD/ANP)
68	Directorate of Installations (AFOIE-ES)
69	Director, USAF Project RAND
70-71	Commandant, School of Aviation Medicine, Brooks AFB
72	CO, School of Aviation Medicine, Gunter AFB
73	Office of the Surgeon (SUPS.1), Strategic Air Command
74	Office of the Surgeon General
75	Commander, Special Weapons Center, Kirtland AFB
76	Director, Air University Library, Maxwell AFB
77-78	Commander, Technical Training Wing, 3415th TTG
79	Commander, Electronic Systems Division (CRZT)

OTHER DOD ACTIVITIES

80-82	Chief, Defense Atomic Support Agency (Library)
83	Commander, FC/DASA, Sandia Base (FCDV)
84	Commander, FC/DASA, Sandia Base (FCTC5, Library)
85	Commander, FC/DASA, Sandia Base (FCWT)
86-95	Armed Services Technical Information Agency

OCDM

96-97	Office of Civil and Defense Mobilization, Battle Creek

AEC ACTIVITIES AND OTHERS

98	Public Health Service (Cooke)
99	Aerojet General, Azusa
100	Aerojet General, San Ramon
101	Alco Products, Inc.
102	Allis-Chalmers Manufacturing Co., Milwaukee
103	Allis-Chalmers Manufacturing Co., Washington

104	Allison Division -GMC
105	Argonne Cancer Research Hospital
106-115	Argonne National Laboratory
116	Atomic Bomb Casualty Commission
117	AEC Scientific Representative, France
118	AEC Scientific Representative, Japan
119-121	Atomic Energy Commission, Washington
122-125	Atomic Energy of Canada, Limited
126-129	Atomics International
130-131	Babcock and Wilcox Company
132-133	Battelle Memorial Institute
134	Beryllium Corporation
135	Boeing Airplane Co., Seattle
136-139	Brookhaven National Laboratory
140	Brush Beryllium Company
141	Bureau of Mines, Albany
142	Bureau of Mines, Salt Lake City
143	Chicago Operations Office
144	Chicago Patent Group
145	Combustion Engineering, Inc.
146	Combustion Engineering, Inc. (NRD)
147	Committee on the Effects of Atomic Radiation
148-149	Convair Division, Fort Worth
150	Defence Research Member
151	Denver Research Institute
152	Division of Raw Materials, Washington
153	Dow Chemical Company, Rocky Flats
154-156	duPont Company, Aiken
157	duPont Company, Wilmington
158	Edgerton, Germeshausen and Grier, Inc., Goleta
159	Edgerton, Germeshausen and Grier, Inc., Las Vegas
160	General Atomic Division
161-162	General Electric Company (ANPD)
163-166	General Electric Company, Richland
167	General Electric Company, St. Petersburg
168	Glasstone, Samuel
169	Goodyear Aircraft, Akron
170-171	Goodyear Atomic Corporation
172	Grand Junction Operations Office
173	Grumman Aircraft, Bethpage
174	Hawaii Marine Laboratory
175	Hughes Aircraft Company, Culver City
176-177	Iowa State University
178-179	Knolls Atomic Power Laboratory
180-181	Lockheed Aircraft Corporation, Marietta
182-183	Los Alamos Scientific Laboratory (Library)
184	Los Alamos Scientific Laboratory (Sesonske)
185-186	Mallinckrodt Chemical Works
187	Maritime Administration
188	Martin Company

189	Massachusetts Institute of Technology (Hardy)
190	Massachusetts Institute of Technology (Thompson)
191	Monsanto Chemical Company
192	Mound Laboratory
193	NASA Lewis Research Center
194	National Bureau of Standards (Taylor)
195	National Bureau of Standards (Library)
196	National Lead Company, Inc., Winchester
197	National Lead Company of Ohio
198	New Brunswick Area Office
199	New York Operations Office
200	Northern Research and Engineering Corporation
201	Nuclear Development Corporation of America
202	Nuclear Materials and Equipment Corporation
203	Oak Ridge Institute of Nuclear Studies
204	Patent Branch, Washington
205-208	Phillips Petroleum Company
209	Power Reactor Development Company
210-213	Pratt and Whitney Aircraft Division
214	Princeton University (White)
215	Public Health Service, Las Vegas
216	Public Health Service, Montgomery
217	Public Health Service, Savannah
218-219	Public Health Service, Washington
220	Radiation Applications, Inc.
221	Sandia Corporation, Albuquerque
222	Sylvania Electric Products, Inc.
223	Technical Research Group
224-226	Union Carbide Nuclear Company (ORGDP)
227-230	Union Carbide Nuclear Company (ORNL)
231	Union Carbide Nuclear Company (Paducah Plant)
232	U.S. Geological Survey, Denver
233	U.S. Geological Survey, Menlo Park
234	U.S. Geological Survey, Naval Gun Factory
235	U.S. Geological Survey, Washington
236	U.S. Geological Survey, WR Division
237	University of California at Los Angeles
238-239	University of California Lawrence Radiation Lab., Berkeley
240-241	University of California Lawrence Radiation Lab., Livermore
242	University of Puerto Rico
243	University of Rochester (Atomic Energy Project)
244	University of Utah
245	University of Washington (Donaldson)
246-247	Westinghouse Bettis Atomic Power Laboratory
248	Westinghouse Electric Corporation
249	Yankee Atomic Electric Company
250-274	Technical Information Service, Oak Ridge
	USNRDL
275-310	USNRDL, Technical Information Division

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USNRDL-TR-522
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by D. Love and D. Sam 10 July 1961 27 p. tables illus. 19 refs. UNCLASSIFIED

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2. Sulfur isotopes (Radioactive) - Separation.
3. Seawater - Radioactivation analysis.

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S^{35} in seawater is separated from other radionuclides through precipitating barium sulfate. This is followed by reducing the sulfate to hydrogen sulfide with hydrogen iodide and by subsequently oxidizing sulfide to sulfate in an alkaline peroxide solution. The resulting sulfate ion is precipitated as barium sulfate for chemical yield determination and counting. The working time required for a single analysis is less than 1 hr; the precision, ± 5%; the chemical yield, 70-80%; and the decontamination factor from fission products, $>10^7$.

Although the samples tested are salt solutions contaminated with fission products, as in the case of nuclear explosions in the ocean and in salt domes, these methods are applicable to many other types of samples containing fission products and induced activities.

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