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STRONTIUM-90 CONCENTRATIONS IN THE HANFORD ENVIRONS

W. B. SILKER

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IN THE HANFORD ENVIRONS

By

W. B. Silker

Analytical Laboratories
Chemical Research and Development Operation

May 20, 1958

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INTRODUCTION

The significance of strontium-90 in the biological food chain, and its relationship to man is well documented.^(1, 2) A great deal of work has been directed toward the problem of world-wide fallout of the debris from nuclear detonations. Relatively little effort, however, has been applied to the investigation of potential sources such as exist in the gaseous effluent from Hanford separations processes. Inclusion of this source is essential for the evaluation of potential exposures of organisms in the environment affected by the Hanford gaseous effluents.

Small amounts of strontium-90 were detected in samples collected in 1955 by filtration of the gaseous effluent from one of the Hanford plutonium separations processes.⁽³⁾ It seemed worthwhile to establish the contribution from this source to the total amount of this isotope in the environs.

OBJECTIVES

The objective of this work was to determine the Hanford contribution of strontium-90 to the environs, in order to evaluate the significance of Hanford processes to the strontium-90 concentrations in biological materials. In addition, data relative to fallout in the Pacific Northwest would also be accumulated.

SUMMARY AND CONCLUSIONS

Analysis of vegetation, soil, and animal bone samples collected from the Hanford reservation yielded average strontium-90 concentrations of 0.35 $\mu\mu\text{c/g}$ of ash, 0.092 $\mu\mu\text{c/g}$ of sample, and 11.2 $\mu\mu\text{c/g}$ of Ca, respectively. No evidence was obtained to indicate significant deposition of strontium-90 from Hanford separations processes to the environs, even in the immediate

vicinity of the source. The results reported revealed that strontium-90 deposition from gaseous process effluents was not measurable above the material which originated from nuclear detonations.

THEORETICAL

If one assumes that significant strontium-90 emission has occurred from the separations process stacks, several generalizations can be made relative to contamination from this source. The strontium-90 concentrations at points near the stacks should be significantly higher than those in locations more distant from the source of contamination; and the highest relative concentrations should be toward the Southeast, in accordance with the measured deposition patterns of iodine-131.

It must be realized that a continuous deposition of strontium-90 from air-borne atomic bomb debris is occurring. The mechanisms of deposition from the atmosphere have been discussed elsewhere. ^(4, 5) One can state that the deposition rate will be nearly constant for a relatively small area. Thus, one may reasonably expect that the area immediately surrounding and including the Hanford Reservation would contain a uniform background concentration of strontium-90 from bomb fallout in addition to the contribution from the separations stacks, which would vary according to the deposition pattern.

Radiostrontium accumulation by plant materials can be either from assimilation by the root system from the environment of the plant, or by direct removal from the atmosphere by such mechanisms as impaction, adsorption and evaporation of precipitation. Transfer of the radiostrontium from vegetation to animal and bird life is then accomplished through the various biological food chains.

EXPERIMENTAL

Three types of samples were analyzed for strontium-90: soil, vegetation, and animal bones. A cursory investigation of soil from the arid region of the Hanford Reservation indicated that about 75 per cent of the radiostrontium was held in the top one-half inch of soil. This surface layer was subsequently sampled for the present study. Vegetation samples were limited, with a few exceptions, to grasses of different varieties. No attempt was made to differentiate the variety or age of the vegetation sample. In general, the samples collected in December were old growth, while new growth material was sampled on subsequent dates. Bones of animals, primarily rabbit femurs, were collected at various locations throughout the Hanford Reservation. Rabbits should be extremely good indicators of localized contamination, as their forage range is limited to approximately one square mile,⁽⁶⁾ and as vegetarians they will tend to furnish an integrated sample of the diet in their immediate environment. A single series of bone samples from water and shore birds of varied dietary habits was analyzed as a preliminary investigation of uptake characteristics of strontium-90 in birdlife.

SAMPLE PRETREATMENT

Samples were pretreated by methods which were similar to those employed by the Chicago Sunshine Group.⁽⁷⁾ Detailed procedures are appended. The available calcium and strontium was leached from soil samples by the ammonium acetate method.⁽⁷⁾ Vegetation samples were reduced by wet ashing with nitric acid. The residual material was baked on a hot plate and then muffled at 600 C for two to four hours. Sample solution was accomplished by digestion in dilute nitric acid. The residual material from the first few samples was fused with sodium carbonate, dissolved, and upon analysis was found to contain no strontium-90. This residue was subsequently discarded. Animal bones were placed directly into a muffle furnace and ashed for two to four hours at 600 C and then dissolved in nitric acid.

CALCIUM ANALYSIS

Whenever possible, the calcium concentration was determined by precipitation of the alkaline earths as oxalates, which were oven-dried at 120 C and weighed. The oxalates were then muffled to the oxide at 800 C and reweighed. When the oxide to oxalate ratio corresponded very nearly to the molecular weights of calcium oxide and calcium oxalate monohydrate, the calcium was taken as 0.715 times the oxide weight. When this ratio was not obtained an aliquot of the acid solution of the oxide was taken for calcium analysis. This method for calcium analysis involved the precipitation of the oxalate from slightly acid solution. The oxalate was dissolved in dilute sulfuric acid and titrated with potassium permanganate.

STRONTIUM SEPARATION

The presence of rare earth fission products which follow yttrium necessitated chemical separation of strontium, which was then reserved to allow buildup of yttrium-90. Strontium was separated by a modification of the method of Glendenin⁽⁸⁾ which employed initial barium and strontium isolation by precipitation as nitrates with fuming nitric acid. Calcium decontamination was made by washing the nitrate precipitate with anhydrous acetone. After an iron hydroxide scavenge, barium was precipitated as the chromate, and strontium was separated as strontium carbonate. The carbonate was weighed for yield determination and reserved for buildup of yttrium-90.

YTTRIUM EXTRACTION

The need for the highest possible sensitivity for yttrium-90 measurement made a carrier separation undesirable because carrier would decrease the effective counting efficiency of the emitted beta particles. Solvent extraction of yttrium-90 from the dissolved strontium salt offered a technique for the carrier-free isolation of yttrium-90, thus eliminating the counting error introduced by self absorption of the yttrium-90 beta particles. Yttrium was extracted from acetate-buffered solutions with thenoyltrifluoroacetone in benzene according to the procedure described by Perkins.⁽⁹⁾ The decay of yttrium-90 from all samples was followed for several half-lives, and with only three exceptions the yttrium-90 was free from contamination.

LOW BACKGROUND COUNTER

The low background counter used in this work consisted of four hemispherical gas flow proportional counters placed in a steel and anticoincidence shield.⁽¹⁰⁾ Backgrounds of 0.6 to 1.2 c/m were obtained with these instruments. Counter geometries were measured with a U. S. B. S. RaDEF standard. Correction factors for backscatter, air and window absorption and spread and rim effect were determined experimentally with yttrium-90 tracer. The counting rates of all samples were measured for a sufficient period of time to insure a statistical counting error of less than three per cent.

The purity of reagents was tested by making complete blank analyses. Initial contamination found on new glassware was removed by treatment with chromic acid and nitric acid. Subsequent to this treatment blanks of less than 0.1 c/m were consistently obtained. Analysis was made of aliquots of a dilution of U. S. B. S. strontium-yttrium-90 spike, Series A. A mean value of 70.40 d/m of yttrium-90 with a standard deviation of 0.84 d/m was obtained, compared to the reference value of 70.37 d/m.

RESULTS AND DISCUSSION

The observed concentrations of strontium-90 in soil, vegetation, and animal bone samples are presented in Tables I, II, and III. For convenience, the results are reported in terms of $\mu\mu\text{c}$ of strontium-90 per gram of sample, calcium and ash, where applicable.

TABLE I

AVAILABLE STRONTIUM-90 IN SOILSA. Hanford Reservation Soils

<u>Sample No.</u>	<u>Location</u>	<u>Date Collected</u>	<u>Sample Size Grams</u>	<u>Available Calcium Grams</u>	<u>$\mu\text{pc Sr}^{90}$ g Sample</u>	<u>$\mu\text{pc Sr}^{90}$ g Calcium</u>
1	Route 4S-4	8-8-56	500	0.457	0.090	98.9
2	Route 4S-12	8-8-56	500	0.377	0.057	75.7
3	Route 4S-20	8-8-56	500	0.420	0.116	138.2
4	Redox					
	Road-2	8-20-56	500	0.472	0.022	23.1
5	Route 11A					
	-12	8-20-56	500	0.756	0.084	55.7
6	Batch Plant	8-20-56	500	0.504	0.185	183.3
7	Wahluke-14	8-21-56	500	0.468	0.032	34.1
8	Wahluke-46	8-21-56	500	0.407	0.032	39.7
9	Pasco-					
	Ringold-12	8-21-56	500	0.518	0.058	56.1
10	Pasco-					
	Ringold-23	8-21-56	500	0.726	0.050	34.6
69	Wahluke-16	4-9-57	500	0.833	0.052	31.1
70	Wahluke-30	4-9-57	500	0.565	0.050	44.0
71	Wahluke-61	4-9-57	500	0.676	0.023	17.0
72	Wahluke-80	4-9-57	500	0.241	0.143	296.6
83	Wahluke-99	4-9-57	500	1.149	0.062	27.1
84	Pasco-					
	Ringold-20	4-9-57	500	1.123	0.140	62.3
85	Pasco-					
	Ringold-25	4-9-57	500	1.359	0.095	35.0
86	Route 3-3	4-10-57	500	0.623	0.117	94.1
87	Goose Egg-11	4-10-57	500	0.337	0.155	230.4
101	Route 2S-2	4-12-57	500	0.298	0.063	105.7
102	Route 10-4	4-12-57	500	0.355	0.072	103.3
103	Route 10-13	4-12-57	500	0.337	0.015	21.5
104	Route 11A-8	4-12-57	500	0.355	0.131	184.3
105	Route 11A					
	-11	4-12-57	500	0.796	0.096	60.3
106	MP Post # 3	4-18-57	500	0.635	0.017	13.1
107	MP Post #14	4-18-57	500	0.690	0.165	119.3
108	MP Post #22	4-18-57	500	1.380	0.068	24.4
109	MP Post #32	4-18-57	298	0.518	0.190	109.4

TABLE I (contd.)

AVAILABLE STRONTIUM-90 IN SOILSB. Off Plant Soils

<u>Location</u>	<u>Date Collected</u>	<u>Sample Size Grams</u>	<u>Available Calcium Grams</u>	<u>$\mu\text{c Sr}^{90}$ g Sample</u>	<u>$\mu\text{c Sr}^{90}$ g Calcium</u>
Benton City, Wash.	8-20-56	500	1.775	0.100	28.2
Wallula, Wash.	4-2-57	500	0.440	0.029	32.5
Dayton, Wash.	4-2-57	500	0.969	0.140	53.6
Colfax, Wash.	4-2-57	500	0.939	0.059	31.2
Lewiston, Idaho	4-2-57	500	1.022	0.106	51.8
Walla Walla, Wash.	4-2-57	500	0.859	0.051	29.6
Pullman, Wash.	4-2-57	500	1.918	0.146	38.1
Spokane, Wash.	4-3-57	500	1.262	0.147	58.4
Reardon, Wash.	4-3-57	500	1.067	0.032	15.2
Davenport, Wash.	4-3-57	440	0.702	0.180	112.6
Lind, Wash.	4-3-57	500	0.737	0.030	20.3
Camas, Wash.	4-23-57	229	0.450	0.197	100.5
Lyle, Wash.	4-23-57	500	0.634	0.076	59.9
Vancouver, Wash.	4-23-57	138	0.389	0.204	72.4
Toppenish, Wash.	4-23-57	394	0.724	0.041	22.1
Goldendale, Wash.	4-23-57	352	0.848	0.059	24.7
Bingen, Wash.	4-23-57	245	0.551	0.222	98.5
Boardman, Ore.	4-24-57	500	0.472	0.116	123.2
Arlington, Ore.	4-24-57	500	0.847	0.058	34.4
Hood River, Ore.	4-24-57	500	0.303	0.147	243.3
Troutdale, Ore.	4-24-57	298	0.254	0.098	115.6

TABLE II
STRONTIUM-90 CONCENTRATIONS IN VEGETATION(a)

Sample No.	Location	Date Collected	Sample Size		Grams Ash	Grams Calcium	$\mu\text{c Sr}$ g Sample	$\mu\text{c Sr}$ g Ash	$\mu\text{c Sr}$ g Calcium
			Oven Dried Grams	Weight Grams					
88	Pasco- Ringold-20	4-9-57	138.0	19.0	0.165	0.07	0.49	56.6	
89	Pasco- Ringold-25	4-9-57	108.5	15.5	0.266	0.18	1.23	71.4	
90	Wahluke-16	4-9-57	51.0	13.5	0.236	0.15	0.57	32.5	
91	Wahluke-30 (Sage)	4-9-57	94.5	8.5	0.429	0.40	4.40	87.2	
92	Wahluke-61	4-9-57	140.0	11.5	0.261	0.05	0.59	25.9	
93	Wahluke-80 (Sage)	4-9-57	145.5	9.0	0.501	0.19	3.02	54.4	
94	Wahluke-99 (Sage)	4-9-57	146.5	10.0	0.366	0.27	3.93	107.4	
95	Goose Egg-11	4-10-57	62.5	11.0	0.249	0.19	1.09	48.1	
96	Route 3-3 (Green cheat grass)	4-10-57	29.0	4.0	0.140	0.60	4.35	124.4	
97	Route 3-3 (Old growth cheat grass)	4-10-57	96.0	12.5	0.367	1.33	10.19	347.2	
98	Route 2S-2	4-12-57	95.0	21.5	0.579	0.36	1.58	58.7	
110	Route 10-13	4-12-57	97.0	28.0	0.451	0.18	0.61	37.8	
111	Route 11A-8	4-12-57	133.0	26.0	0.804	0.30	1.55	50.2	
112	Route 11A-11	4-12-57	119.5	42.5	0.582	0.35	0.98	71.4	
113	MP Post No. 7	4-18-57	57.0	9.0	0.303	0.08	0.51	15.2	
114	MP Post No. 14	4-18-57	99.0	16.0	0.135	0.53	3.31	391.9	
115	MP Post No. 22	4-18-57	63.0	8.5	0.094	0.73	5.40	488.1	

(a) All samples are grasses unless otherwise designated

TABLE II (contd.)
STRONTIUM-90 CONCENTRATIONS IN VEGETATION

Location	Date Collected	Sample Size		Grams Ash	Grams Calcium	$\mu\text{C Sr}^{90}$ g Sample	$\mu\text{C Sr}^{90}$ g Ash	$\frac{\mu\text{C Sr}^{90}}{\text{g Calcium}}$
		Oven Dried Grams	Weight Grams					
B. Offsite Vegetation								
Touchet, Wash.	12-4-56	86.0		15.0	0.316	0.19	1.09	51.9
Wallula, Wash.	12-4-56	196.0		27.0	0.416	0.31	2.28	148.1
Lewiston, Idaho	12-4-56	128.0		10.0	0.283	0.19	2.44	86.4
Pomeroy, Wash.	12-4-56	39.0		7.0	0.143	0.26	1.42	69.7
Pullman, Wash.	12-4-56	126.0		17.0	0.332	0.53	3.96	202.8
Harrington, Wash.	12-5-56	137.5		23.0	0.345	0.31	1.84	123.0
Sprague, Wash.	12-5-56	168.0		12.0	0.244	0.64	9.02	443.4
Spokane, Wash.	12-5-56	110.5		18.5	0.379	0.18	1.06	51.8
Lind, Wash.	12-5-56	140.5		15.5	0.362	0.20	1.82	77.8
Toppenish, Wash.	3-4-57	136.5		19.9	0.386	0.36	2.47	127.1
Toppenish-								
Goldendale Mile 30	3-4-57	156.5		21.6	0.345	0.16	1.15	72.1
Goldendale, Wash.	3-4-57	114.0		19.2	0.266	0.36	2.13	153.3
Lyle, Wash.	3-4-57	95.0		6.9	0.121	0.42	5.77	330.7
Vancouver, Wash.	3-4-57	90.0		10.8	0.162	1.08	9.04	600.7
Camas, Wash.	3-4-57	83.5		7.5	0.350	1.27	14.15	303.3
The Dalles, Ore.	3-5-57	96.0		14.1	0.343	0.96	6.55	269.7
Troutdale, Ore.	3-5-57	87.0		10.3	0.282	0.55	4.61	168.9
Seaside, Ore.	3-5-57	138.0		6.0	0.058	0.24	5.43	561.2
Hood River, Ore.	3-5-57	104.0		18.5	0.576	1.24	6.96	223.5

TABLE III

STRONTIUM-90 CONCENTRATIONS IN ANIMAL BONES

Sample No.	Sample Location	Sample Type	Date Collected	Grams Ash	Grams Calcium	$\mu\mu\text{c Sr}^{90}$ g Ash	$\mu\mu\text{c Sr}^{90}$ g Calcium
11	Rattlesnake Springs	Rabbit Femur	9-10-56	6.03	2.24	2.34	6.29
12	West of 200W	"	9-10-56	6.33	2.40	5.47	14.43
13	Wahluke NE	"	9-11-56	5.74	2.06	6.41	16.70
14	100 B	"	9-10-56	5.26	2.09	5.10	12.87
15	Prosser Barricade	"	9-11-56	4.52	1.74	4.67	12.10
20	Meteorology Tower	"	9-10-56	6.09	1.74	3.97	13.88
21	East of 200E	"	9-10-56	5.69	1.84	3.89	12.01
22	1 Mile So. of Redox	"	9-10-56	6.54	1.61	2.54	10.29
23	White Bluffs	"	9-10-56	5.57	1.41	3.09	12.18
24	Wahluke East	"	9-11-56	6.36	1.54	2.24	9.27
25	Route 4S, Mile 14	"	9-11-56	4.91	1.53	4.33	13.87
26	Hanford	Mule Deer Femur	9-15-56	10.98	3.40	3.60	11.67
27	100 B	Rabbit Femur	11-5-56	6.32	1.66	5.24	20.00
37	Prosser Barricade	"	11-7-56	4.82	1.82	3.42	9.02
38	Wahluke East	"	11-6-56	5.40	1.99	3.24	8.79
39	Meteorology Tower	"	11-5-56	6.33	2.40	3.83	10.10
40	Route 4S, Mile 14	"	11-7-56	6.57	2.44	3.88	10.46
41	Rattlesnake Springs	"	11-5-56	5.80	2.17	3.22	8.63
42	1 Mile So. of Redox	"	11-5-56	5.52	2.12	2.13	5.56
43	White Bluffs	"	11-5-56	6.52	2.51	2.31	5.99
44	East of 200E	"	11-7-56	6.49	2.48	4.09	10.73
55	West of 200W	"	11-5-56	5.84	2.21	3.37	8.73
56	Wahluke NE	"	11-6-56	5.73	2.12	5.39	14.73

TABLE III (contd.)

STRONTIUM-90 CONCENTRATIONS IN ANIMAL BONES

<u>Sample Location</u>	<u>Sample Type</u>	<u>Date Collected</u>	<u>Grams Ash</u>	<u>Grams Calcium</u>	$\frac{\mu\text{c Sr}^{90}}{\text{g Ash}}$	$\frac{\mu\text{c Sr}^{90}}{\text{g Calcium}}$
	Long Bones					
Upper River	Killdeer	9-24-56	1.30	0.46	2.41	6.84
"	American Merganser	9-24-56	3.84	1.46	0.34	0.88
"	Bairds Sandpiper	9-24-56	0.13	0.05	8.63	21.92
"	Ring Billed Gull	9-24-56	1.78	0.68	0.42	1.09
"	Greater Yellow Legs	9-24-56	1.29	0.47	3.59	9.87
"	Mallard	9-24-56	1.23	0.46	6.76	18.17
"	California Gull	9-24-56	2.28	0.88	0.22	0.54
"	Baldpate	9-24-56	0.70	0.27	1.49	3.85
"	Lesser Common Loon	9-24-56	5.38	2.02	0.73	1.96
Long Beach, Wash.	California Murre	9-5-56	1.30	0.50	0.53	1.39

Several results of the analysis of soil and vegetation samples from locations in Washington and Oregon are included in this report. Although these samples were excluded from the subsequent statistical analysis of strontium-90 contribution from Hanford gaseous effluents, several observations can be made from these samples. In general, the total strontium-90 deposition on Pacific Northwest soils was comparable to that reported for the Chicago area in 1956. The low calcium content of the grasses analyzed in this study resulted in a much higher strontium-90 to calcium ratio than was reported for the Chicago area, but agreement was obtained when the samples were compared on an ashed weight basis. This effect may be partially resolved by the fact that grasses were sampled for this study, while alfalfa was sampled in the Chicago locations. The grasses characteristically metabolize less calcium from the environment than alfalfa, which is a heavy calcium feeder. The soil depth from which these two types of plants derive nutrients is also markedly different; alfalfa has a very deep root system, and grasses have relatively shallow systems. The available strontium-90 is contained in the surface layer of soil, and would be expected to be concentrated in the shallow rooting vegetation. The possibility of filtration and adsorption on the leaf surfaces as a primary concentration mechanism is also suggested.

The average strontium-90 concentrations in soil and vegetation samples collected on the Hanford Reservation, Eastern Washington and from Arlington, Oregon to the mouth of the Columbia River are presented in Table IV. Uniform average concentrations were observed in the groups of samples from Eastern Washington and the Hanford Reservation. The average annual rainfall for these two areas was approximately the same, and the predicted washout of airborne contamination would be similar for these two areas. The samples collected from the Columbia River valley revealed one and one-half and two and one-half times the strontium-90 concentration in soils and vegetation, respectively, than the other two sampling areas. This increase reflects in part the effect of increased rainfall. The vegetation samples from

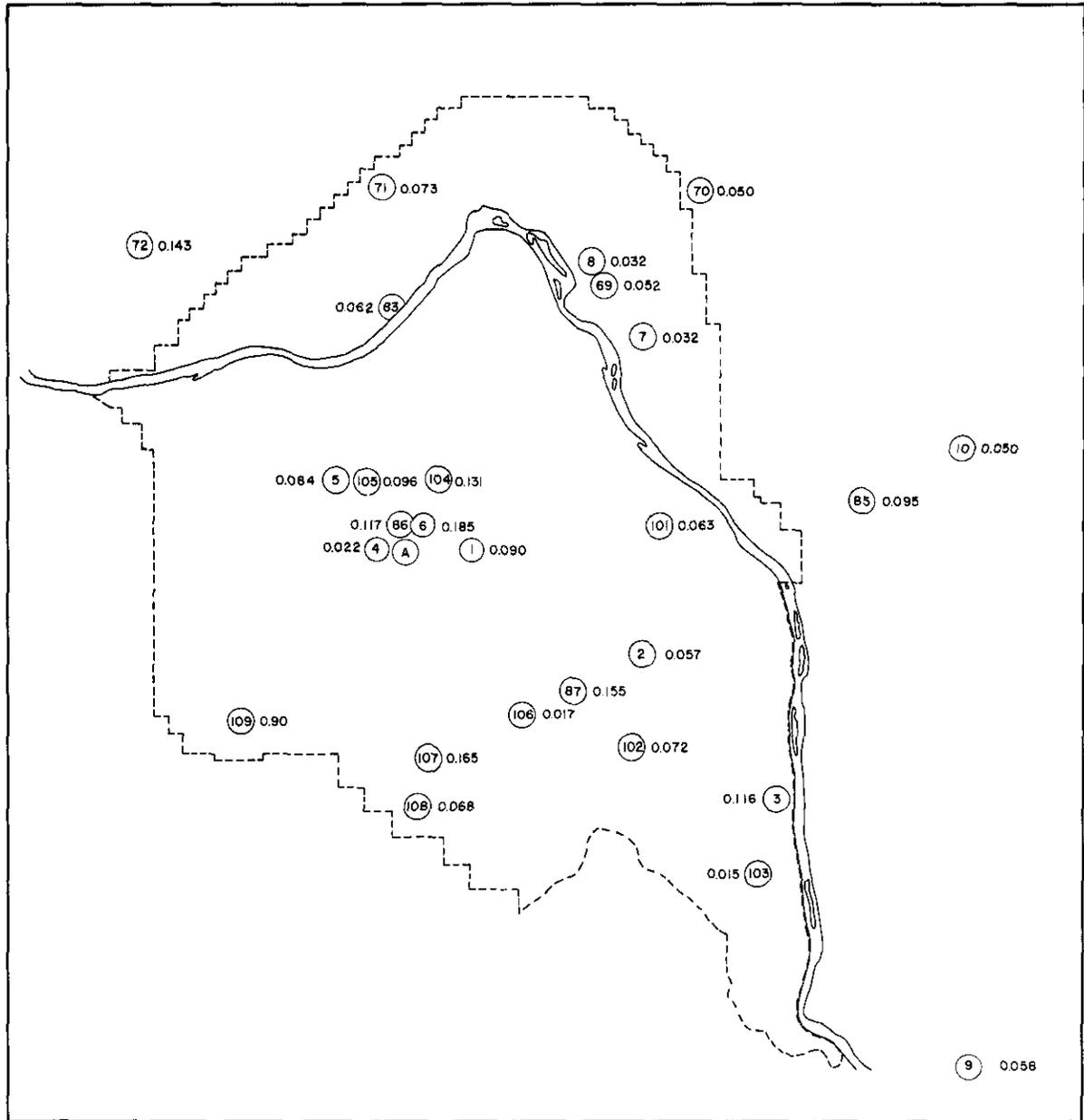
the Columbia River valley were contaminated with fission products whose characteristics indicated that they originated from a fairly recent nuclear detonation and may not offer a true comparison with the other samples.

TABLE IV
CONCENTRATION OF STRONTIUM-90 IN SOIL
AND VEGETATION IN WASHINGTON AND OREGON AREAS

<u>Sampling Group</u>	<u>Averaged Annual Rainfall</u>	<u>Soil</u>			<u>Vegetation</u>		
		<u>$\mu\text{c Sr}^{90}/\text{g sample}$</u>	<u>Max.</u>	<u>Min.</u>	<u>$\mu\text{c Sr}^{90}/\text{g ash}$</u>	<u>Max.</u>	<u>Min.</u>
Hanford Reservation	10	0.092	0.190	0.015	0.35	1.33	0.05
Eastern Washington	15	0.092	0.180	0.029	0.31	0.64	0.18
Columbia River Valley	39	0.143	0.222	0.076	0.82	1.27	0.24

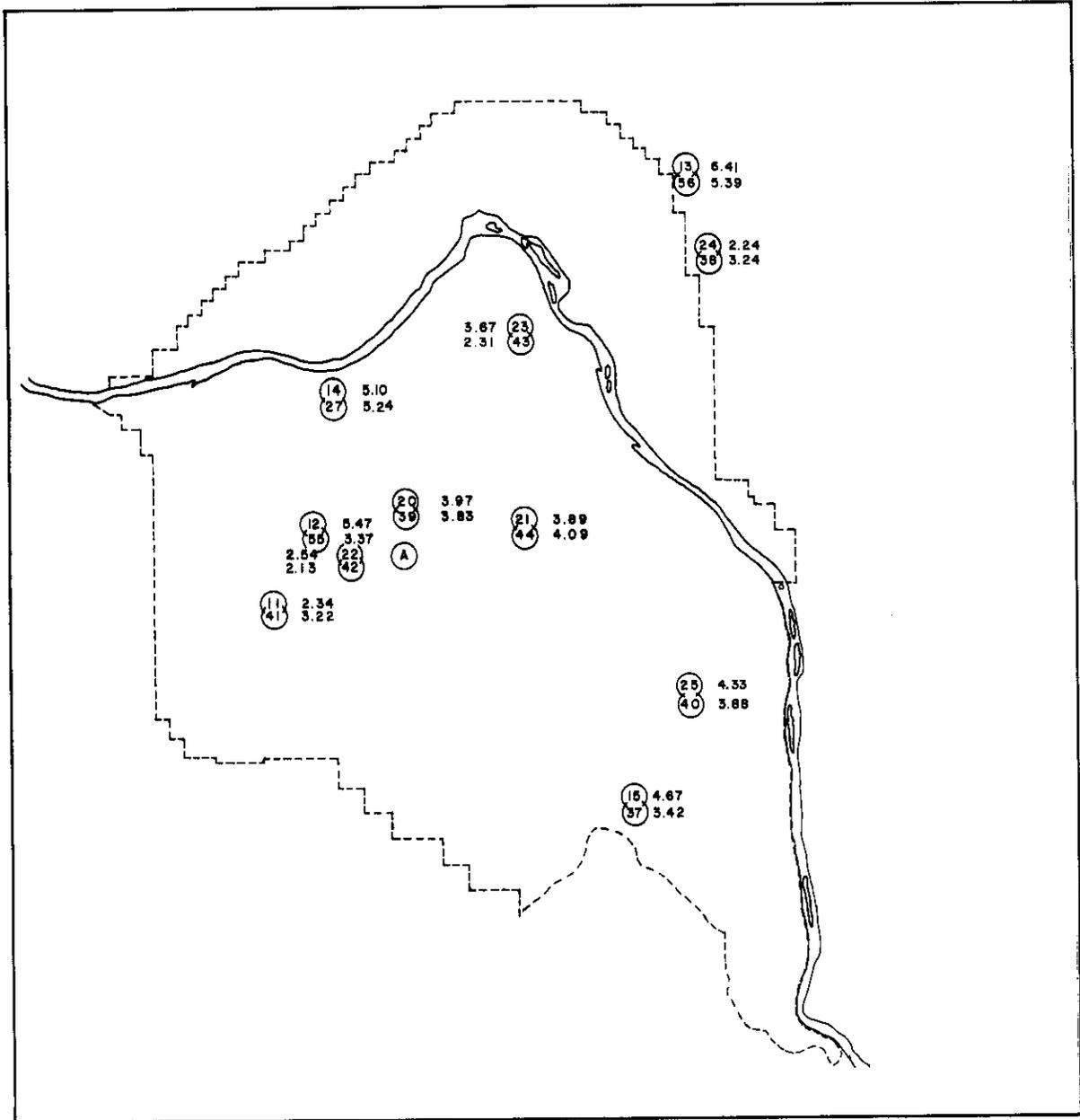
The geographical location of the points sampled from the Hanford Reservation are presented in Figures 1, 2 and 3. From these data, the relative degree of contamination from the separations process stacks was calculated. Statistical analysis of the strontium-90 concentrations in rabbit bones and soil samples revealed no significant correlation with distance in any direction from the separations areas stacks. The higher soil values from locations Route-3-3 and the Batch Plant might be indicative of very localized strontium deposition, although this was not reflected in the animal bones. The deposition of strontium-90 from the separations area stacks might be expected to extend toward the Southeast in accordance with the measured pattern for iodine-131. Correlation of the data from this study with direction, however, yielded a random distribution of concentration with direction from the process stacks.

A comparison of the strontium-90 concentrations in animal bones from different locations in the United States and Great Britain is presented in Table V.



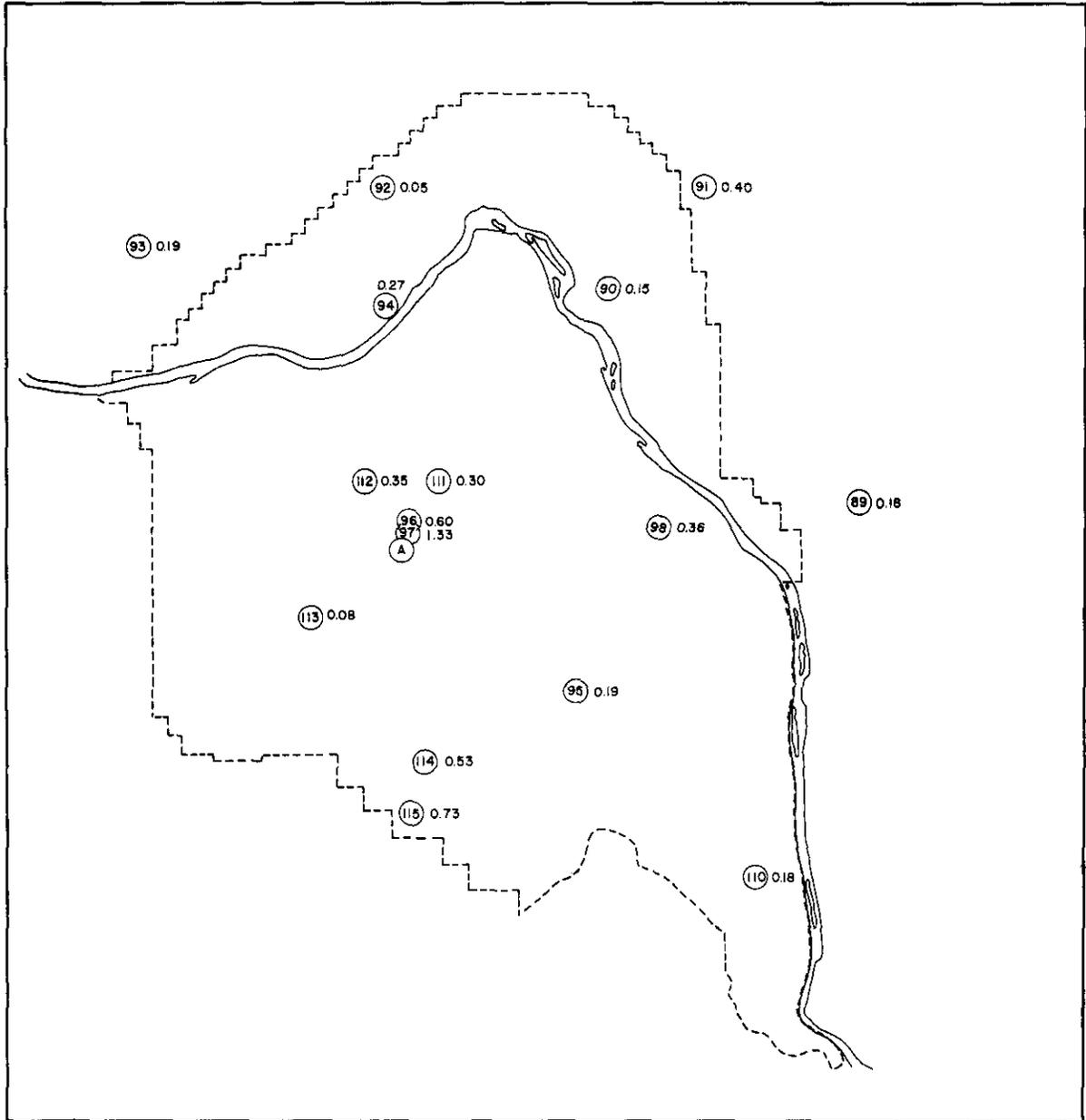
(A) Approximate Center of Separations Areas

FIGURE 1
Available Strontium-90 Concentrations
in Soils of the Hanford Works
in Units of $\mu\mu\text{c Sr-90/g Sample}$



(A) Approximate Center of Separations Areas

FIGURE 2
Strontium-90 Concentrations
in Vegetation of the Hanford Works
in Units of $\mu\mu\text{c Sr-90/g Sample}$



(A) Approximate Center of Separations Areas

FIGURE 3
Strontium-90 Concentrations
in Rabbit Bones on the Hanford Reservation in
Units of $\mu\mu\text{c/g}$ of Bone Ash

TABLE V

COMPARISON OF STRONTIUM-90 CONCENTRATIONS
IN ANIMAL BONES

<u>Sample Location</u>	<u>Sample Type</u>	<u>Sampling Date</u>	<u>Concentration Range</u> $\frac{\mu\text{c Sr}^{90}}{\text{g Calcium}}$	<u>Estimated Available Calcium in Soil</u> g/ft^2
Hanford	Rabbits	1956	7-20 (median 11.2)	2.5
Chicago ⁽¹¹⁾				
Milkshed	Steers	1955	5.5	15
		1955	2.09	21
		1956	0.51	31
Ithaca, ⁽¹¹⁾				
New York	Lamb	1955	4.45-6.98	20
Tiffon, ⁽¹¹⁾				
Georgia	Calf	1955	10.3-12.9	0.76
Petworth, ⁽¹²⁾				
Sussex, Britain	Sheep	1956	15.4-16.6	-----
Boulge, ⁽¹²⁾				
Suffolk, Britain	Sheep	1955	12.7-15	8.6
Norwich, ⁽¹²⁾				
Norfolk, Britain	Sheep	1956	13	14.1

This comparison is subject to errors of unknown magnitude, such as local soil conditions, diet, and age of the animal. The results from local rabbits are in agreement with the other samples, and reflect the higher levels of strontium-90 reported in samples collected from other areas with a deficiency of exchangeable calcium in the soil.

Analysis of bones from shore birds and water birds reflected an interesting trend. The killdeer and Bairds sandpiper, whose diets consist mainly of larvae and insects, showed high concentrations of strontium-90 deposited in the bone as shown in Table III. The mallard and baldpate, vegetarians, reflected strontium-90 concentrations not unlike those observed in rabbits. The piscivores

conversely had low relative concentrations of radiostrontium, apparently reflecting the lesser concentrations of radiostrontium in their diet. Further study of the dietary habits of these birds is suggested.

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APPENDIX I

Preparation of Bone Samples

1. Place a sample of bone, not exceeding thirty grams, in a tared Vycor evaporating dish.
2. Muffle the sample at 600 C for two hours, or until all of the organic material is destroyed.
3. Cool and reweigh the dish and sample, and record the weight of ash.
4. Dissolve the bone ash in 4 N nitric acid, and dilute with water to volume in a suitable volumetric flask.
5. Reserve an aliquot of the sample for calcium determination, and proceed with the strontium determination with the remainder.

APPENDIX II

Preparation of Vegetation Samples

1. Place the vegetation sample in a drying oven at 110C for forty-eight hours.
2. Pass the sample through a Wiley mill.
3. Weigh a 100 g sample and place it in a 2000 ml beaker.
4. Add sufficient 8 N nitric acid to cover the sample, and evaporate to dryness on a hot plate at low heat. Raise the temperature of the hot plate to high heat, and bake the sample.
5. Transfer the sample to a tared 400 ml Vycor evaporating dish and muffle at 400 C for two hours, or until the organic matter is destroyed.
6. Reweigh the dish plus sample, and record the ashed weight.
7. Digest the ash with 200 ml 3 N nitric acid by boiling on a hot plate for five minutes.
8. Cool, centrifuge, and decant the supernatant liquid into a liter beaker.
9. Repeat steps 7-8 and discard the residue.

APPENDIX III

Extraction of Exchangeable Calcium and Strontium in Soils

1. Crush the air-dry sample and pass the sample through a 2 mm sieve.
2. Place 500 g of the prepared sample in a four liter beaker and add sufficient neutral normal ammonium acetate to cover.
3. Stir well and let stand overnight.
4. Filter the sample through two thicknesses of coarse filter paper, and leach the sample with ammonium acetate until a total of two liters of leachate is obtained.
5. Transfer the leachate to a four liter beaker and evaporate to dryness.
6. Bake the residue until dehydration of the salt is complete.
7. Loosen as much of the dry residue as possible with a spatula and transfer to an evaporating dish.
8. Place the evaporating dish in a muffle at about 150 C, heat to 600 C, and hold this temperature for about one hour.
9. To the small amount of residue remaining in the beaker, add 200 ml of water, and 10 ml of 30% hydrogen peroxide.
10. Cover and boil for 15-20 minutes.
11. Combine the ashed residue and peroxide treated residue.
12. Add small portions of hydrochloric acid with stirring until all of the carbonates are decomposed; add 10-15 ml in excess.
13. Heat the solution to about 90 C and add 1:1 ammonium hydroxide with stirring until a faint odor of ammonia persists.
14. Boil for 2-3 minutes to coagulate the precipitate and filter through coarse filter paper.
15. Wash the filter with 200 ml of a hot 2% ammonium chloride solution.

16. To the combined filtrate and wash, add 20 drops of methyl red indicator and acidify with hydrochloric acid; add 10-15 ml in excess.
17. Heat to 90 C and add 25 grams of oxalic acid.
18. Continue heating for 2-3 minutes and slowly add 1:1 ammonium hydroxide until the solution turns a light yellow.
19. Digest at 90-95 C for 1-2 hours.
20. Collect the oxalate precipitate in a Gooch crucible.
21. Determine calcium and strontium in the oxalate precipitate.

APPENDIX IVStrontium Separation

1. Place the acid extract in a beaker of suitable size, and add 40 mg of strontium carrier and 10 mg of barium carrier.
2. Neutralize the sample with 12 N sodium hydroxide.
3. Heat to boiling.
4. Add 40 ml of saturated sodium carbonate with stirring.
5. Allow the sample to cool for thirty minutes.
6. Centrifuge.
7. Discard the supernatant liquid.
8. Dissolve the carbonate precipitate in a minimum of concentrated nitric acid.
9. Add fuming nitric acid until precipitation starts.
10. Cool for one minute with running tap water and centrifuge.
11. Suspend the well drained precipitate in 20 ml of anhydrous acetone. Cool for one minute with running tap water and centrifuge.
12. Dissolve the precipitate in 6 ml of water and add 18 ml of fuming nitric acid. Cool for one or two minutes with running tap water. Centrifuge and discard the supernatant liquid.
13. Dissolve the precipitate in 10 ml of water, add 2-3 mg of iron carrier and precipitate iron hydroxide by addition of 6 N ammonium hydroxide.
14. Centrifuge and decant the supernatant liquid into a clean centrifuge tube.
15. Neutralize the solution to the phenolphthalein end point with 6 N nitric acid, add 1 ml of 6 N acetic acid and 2 ml of 6 N ammonium acetate. Heat the solution nearly to boiling and add 1 ml of 1.5 N sodium chromate drop by drop with stirring. Continue stirring for about one minute and centrifuge.

16. Decant the supernatant liquid into a clean centrifuge tube, and add 5 ml of saturated sodium carbonate with stirring. Centrifuge and discard the supernatant liquid.
17. Wash the precipitate twice with water and once with ethanol.
18. Transfer the precipitate to a tared one inch counting dish with ethanol.
19. Dry under an infra-red heat lamp, weigh and reserve for build-up of yttrium-90.

APPENDIX V

Yttrium-90 Extraction Procedure

1. To a 60 ml separatory funnel, add 10 ml of TTA solution (10 g thenoyl-trifluoroacetone in 100 ml of benzene), 5 ml of 0.5 N nitric acid, and shake mechanically for five minutes. Discard the aqueous phase.
2. Dissolve the strontium precipitate in 5 ml of 0.5 N nitric acid and transfer the solution to the separatory funnel.
3. Add 10 ml of buffer solution (0.5 M sodium acetate, 0.1 M acetic acid) and extract for 10 minutes. ~~Discard~~ the aqueous phase. *Discard*
4. Extract five minutes each with two 10 ml portions of 0.1 M sodium acetate-0.1 M acetic acid.
5. Back extract the yttrium-90 into 10 ml of 0.1 N nitric acid. *(8 ml)*
6. Evaporate the aqueous phase to dryness on a one inch stainless steel counting dish and measure the yttrium-90 disintegration rate.

10 ml of 0.5 N nitric acid, shake for 5 min. to 10 min. with a small amount of benzene. Transfer the solution to the separatory funnel. Add 10 ml of buffer solution (0.5 M sodium acetate, 0.1 M acetic acid) and extract for 10 minutes. Discard the aqueous phase. Extract five minutes each with two 10 ml portions of 0.1 M sodium acetate-0.1 M acetic acid. Back extract the yttrium-90 into 10 ml of 0.1 N nitric acid. Evaporate the aqueous phase to dryness on a one inch stainless steel counting dish and measure the yttrium-90 disintegration rate.

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