Strontium 90: Estimation of Worldwide Deposition

Abstract. *The relation between the worldwide deposition of strontium-90, as calculated by many investigators over the last decade, and that observed in rainfall in New York City has been relatively constant. On the average, for each millicurie of strontium-90 per square mile deposited in New York City, 0.055 megacurie has been deposited on the earth's total surface. Cumulative deposits of strontium-90 on the earth's surface at various intervals over the last 10 years have been computed from this ratio. From the mean quarterly fraction of the annual strontium-90 fallout in New York City for the last 9 years, the worldwide deposition of this nuclide, equal to 2.48 megacuries, is predicted for 1964.*

Since the inception of nuclear testing, much research has been carried out on the distribution of radioactive debris produced by the testing. In particular, because of the potential biological hazard, the geographical dispersion of strontium-90 has received a great deal of attention.

The computation of the worldwide deposition of this nuclide has been carried out by a number of investigators over the last decade (*1–10*). The number of sampling sites which were used in making these estimates varied from about 20 in the earliest work (*1*), to about 150 in the more recent investigations (*10, 11*). Generally, the methods of making these inventories have involved collating the Sr^{90} analyses of soil samples or precipitation (or both) collected from rather extensive networks throughout the dry land areas of the world. By various methods these data were averaged by latitude bands and weighted for the geographical variability of rainfall, either from mean annual precipitation values at various latitudes or from climatological rainfall maps. In some cases no correction for the rainfall variation was made, and in others the contribution of the so called "dry fallout" was included. Regardless of the method used in making the computation most of the results for a given date are in very good agreement.

The method of rapidly estimating the worldwide deposition of Sr^{90} proposed herein is based upon the Sr^{90} deposition in rainfall from a single site as an indicator of the total fallout on the earth's surface. To test the feasibility of this method and illustrate the procedure, the extensive data from New York City have been used.

Table 1. Yearly strontium-90 fallout and the deposition ratio.

Year	Average worldwide (Mc)	N.Y.C. (*11*) (mc/mi²)	DRWN (Mc per mc/mi²)
1954	0.35	8.	0.044
1955	.60	9.21	.065
1956	.55	11.46	.048
1957	.50	11.53	.043
1958	.85	15.96	.053
1959	1.17	22.50	.052
1960	.36	4.45	.087
1961	.45	6.27	.072
1962	1.27	22.04	.046
1963	2.51	65.5	.038
		Average DRWN	0.055

Table 2. Cumulative worldwide deposition of strontium-90 in megacuries.

Date	Reference							Average value
	(*4*)	(*5*)	(*6*)	(*7*)	(*8*)	(*9*)	(*10*)	
Dec. 1954				0.2			0.5	0.35
Jun. 1955		0.6	0.8					0.70
Dec. 1955				0.9			1.0	0.95
Jun. 1956	0.8	1.1	1.3					1.07
Dec. 1956				1.5			1.5	1.50
Jun. 1957		1.7	1.8					1.75
Dec. 1957				2.1			1.9	2.00
Apr. 1958	2.3							2.30
Jun. 1958		2.5	2.4					2.45
Dec. 1958				2.9			2.8	2.85
Jun. 1959	4.1	4.0	3.8					3.97
Dec. 1959				4.3			3.9	4.10
Jun. 1960			4.1		4.3			4.20
Dec. 1960				4.6			4.3	4.45
Jun. 1961			4.3			4.2		4.25
Dec. 1961				5.0			4.7	4.85
Apr. 1962						4.9		4.90
Dec. 1962						5.8	6.0	5.90

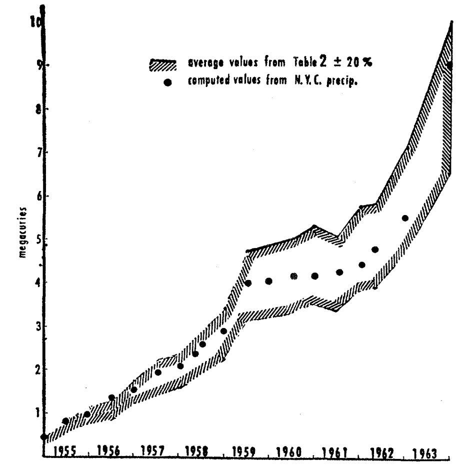

Fig. 1. Cumulative world-wide Sr^{90} deposition from 1955 through 1963. The shaded area represents the average values for each date taken from the studies of many investigators, who used global soil or precipitation results (or both) (Table 2). The dots indicate the deposition on each date computed by multiplying the cumulative New York City fallout (mc per mi²) by the DRWN of 0.055.

Table 1 presents the deposition ratios of worldwide and New York City Sr^{90} fallout. The worldwide values were obtained by averaging the various results published by other investigators. The New York City values were reported in the *Health and Safety Laboratory Quarterly* (*11*). The "deposition ratio worldwide to New York," (DRWN) has the units megacuries of worldwide deposition per millicurie per square mile deposited in New York City. Thus, the average yearly ratio of global Sr^{90} deposition to that deposited by rainfall in New York City is 0.055 Mc per mc/mi².

To test the usefulness of this proportionality factor, the values computed from New York City rain were compared with those worldwide integrals already published (Table 2).

Table 3 indicates the accuracy of the empirical method when the DRWN is used. In only 2 of the 19 comparisons in Table 3 does the value from the New York City rain analysis differ from the average integrals by more than 15 percent. The average difference of all the points is 6.8 percent. These differences may be compared with the estimated upper limit of 40 percent as the random uncertainty of the 1959 integral calculation by Alexander *et al.* (*3*). On the more optimistic assumption that the uncertainty for all the

Table 3. Worldwide deposition of strontium-90 computed from New York City rainfall analyses.

Date	Cumulative N.Y.C. (mc/mi^2)	Worldwide deposition (Mc)		
		Cumul. N.Y.C. $\times$ 0.055	Av. from Table 2	Difference (%)
Dec. 1954	8	0.44	0.35	23
Jun. 1955	14.4	0.79	0.70	12
Dec. 1955	16.9	0.93	0.95	2
Jun. 1956	24.9	1.37	1.07	25
Dec. 1956	27.9	1.54	1.50	3
Jun. 1957	35.9	1.97	1.75	12
Dec. 1957	38.6	2.12	2.00	6
Apr. 1958	43.2	2.38	2.30	3
Jun. 1958	47.4	2.61	2.45	6
Dec. 1958	53.4	2.94	2.85	3
Jun. 1959	72.7	4.00	3.97	1
Dec. 1959	74.3	4.08	4.10	1
Jun. 1960	76.5	4.20	4.45	0
Dec. 1960	76.5	4.20	4.45	6
Jun. 1961	78.7	4.33	4.25	2
Dec. 1961	80.8	4.45	4.85	9
Apr. 1962	87.9	4.83	4.90	1
Dec. 1962	100.8	5.54	5.90	6
Dec. 1963	163.8	9.00	8.26*	9
		Average		6.8

* Computed from previous data plus that from (*10*) and (*11*).

worldwide fallout averages of Table 2 is only 20 percent, Fig. 1 was plotted to illustrate the agreement.

To attempt a prediction of the worldwide deposition of Sr^{90} for the entire year of 1964, the fallout of the nuclide in the New York City area must first be estimated. At this time, data for only the first 3 months of 1964 from New York City are available. It has been observed that over the last 9 years, the first quarter of the year has had, on the average, 29 percent of the annual Sr^{90} deposition. Thus, by computation, the total New York City fallout for the first quarter of 1964 is 13 mc/mi^2, and the anticipated 1964 New York City fallout is 45 mc/mi^2.

If this value is adjusted to worldwide deposition by use of the DRWN of 0.055, the predicted global fallout for 1964 would be 2.48 Mc.

The results of this study suggest that deposition of nuclear debris on the earth's surface has been relatively systematic when considered on an annual basis.

Regardless of the actual mechanism of transfer of the particles within the stratosphere and through the tropopause, and in spite of the geographical and spatial heterogeneity of the testing programs from year to year, the relationship of deposited Sr^{90} in the New York City area to that on the entire earth's surface has remained constant. This observation leads to the conclusion that the distribution of debris in the stratosphere does not appreciably affect the ultimate distribution of that material on the ground. Recognizing the well-documented rapid deposition rate of particles in the troposphere, it seems clear that the controlling factor in the final distribution on the earth's surface must be the latitude and longitude at which debris crosses the tropopause. This must be relatively constant to produce the observed results.

Any single fallout collection site could serve as well as New York City as an indicator of worldwide fallout. New York City was chosen for this report because it is the site with the longest continuous documentation of fallout and therefore promises the most accurate average ratio. As an indication of the magnitude of the deposition ratio at other remote locales, Iwo Jima and Adelaide, Australia, were considered. For Iwo Jima a deposition ratio, based upon four years of data (1960–1963), of 0.141 Mc per mc/mi^2 was calculated. Measurements at Adelaide, Australia, (1959–1963) gave a deposition ratio of 0.438.

Since all but a negligible portion of the debris injected into the stratosphere originated in the Northern Hemisphere, these conclusions are valid only for such conditions. Unquestionably, a test series carried out in the Southern Hemisphere would result in a surface distribution of debris different from that of past years.

However, from a practical point of view, and barring any Southern Hemisphere injections, this method should prove useful for making predictions for the next several years, whether or not there is further testing.

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References and Notes

1. N. G. Stewart, R. G. D. Osmond, R. N. Crooks, E. M. Fisher, "The worldwide deposition of long-lived fission products from nuclear test explosions," *Atomic Energy Research Establishment, Harwell, Great Britain, Report No. AERE HP/R 2354 (October 1957)*.
2. M. Eisenbud, Statement for the Joint Committee on Atomic Energy, Congress of the United States, 86th Congress, first session, on fallout from nuclear weapons tests (United States Government Printing Office, Washington, May 1959), vol. 1, p. 907; L. T. Alexander, *ibid.* p. 278; K. Telegadas, private communication.
3. L. T. Alexander, R. H. Jordon, R. F. Dever, E. P. Hardy, Jr., G. H. Hamada, L. Machta, R. L. List, "Strontium-90 on the earth's surface," *USAEC, Office of Technical Information Report* (available from the Office of Technical Services, Dept. of Commerce, Washington 25, D.C.), *Report No. TID-6567 (1961)*.
4. J. P. Friend, H. W. Feely, P. W. Krey, J. Spar, A. Walton, "The application of HASP data," *High Altitude Sampling Program, Final report by Isotopes Inc. on Contract DA-29-044-XZ-609 to Defense Atomic Support Agency, Report No. DASA 1300,* vol. 4 (1961).
5. J. L. Kulp and A. R. Schulert, "Strontium-90 in man and his environment," *Final Report No. NYO-9934 by Columbia University to Division of Biology and Medicine, Atomic Energy Commission*, vol. 1 (1962).
6. R. S. Cambray, E. M. R. Fisher, G. S. Spicer, C. G. Wallace, T. J. Webber, "Radioactive fallout in air and rain, results to the middle of 1962," *Atomic Energy Research Establishment, Harwell, Great Britain, Report No. AERE-R 4094 (1962)*.
7. E. P. Hardy, Jr., R. J. List, L. Machta, L. T. Alexander, J. S. Allen, M. W. Meyer, "Strontium-90 on the earth's surface II," *United States Atomic Energy Commission, Office of Technical Information Report* (available from the Office of Technical Services, Dept. of Commerce, Washington 25), *Report No. TID 17090 (1962)*.
8. L. Machta, R. J. List, K. Telegadas, "Inventories of selected long-lived radioisotopes produced during nuclear testing," *Health and Safety Laboratory quarterly summary report, fallout program, United States Atomic Energy Commission, Report No. HASL-142* (available from the Office of Technical Services, Dept. of Commerce, Washington 25, D.C.), Jan. 1964.
9. "Radioactive contamination due to nuclear explosions," *Report of the Scientific Committe on the Effects of Atomic Radiation, United Nations General Assembly, Report No. A/AC.82/R.190 (May 1964)*.
10. W. R. Collins, Jr., "Sr-90 deposition on the earth's surface from 1958 through 1962," *Health and Safety Laboratory quarterly summary report, fallout program, United States Atomic Energy Commission, Report No. HASL-140* (available from the Office of Technical Services, Dept. of Commerce, Washington 25, D.C.) Oct. 1963.
11. E. P. Hardy, Jr., J. Rivera, W. R. Collins, Jr., *ibid., Report No. HASL-144 (April 1964)*.

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Raoult's Law Study of Vanadium Pentafluoride in Uranium Hexafluoride

Abstract. *Binary systems of liquid vanadium pentafluoride dissolved in liquid uranium hexafluoride are nonideal, with negative deviations from Raoult's law in the temperature range 75° to 92°C.*

In order to investigate intermolecular forces between UF_6 and other fluorides, we have studied the solubility of VF_5 in UF_6; hitherto there has been only a limited solubility study of this system by Mears *et al.* (*1*). We measured the total pressures of six binary solutions (through the whole range of mole fractions) of VF_5 dissolved in UF_6 at 75.4°, 82.0°, and 92.7°C. A comparison of these pressures with ideal total pressures calculated from Raoult's law is given in Table 1 and Figs. 1–4; measurements were made by analysis of equilibrium liquid and vapor samples. Comparison shows that