Strontium 90 in rain due to nuclear tests at higher latitudes

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ABSTRACT

In The Netherlands concentrations of strontium 90 in rain during 1959, 1962 and 1963 originating from Soviet nuclear tests in the fall of 1958, 1961 and 1962, respectively, were approximately proportional to that part of the fission yield which corresponds to debris introduced into the lower stratosphere.

Introduction

During the periods October 1958, September–October 1961, and August–December 1962 radioactive debris was injected into the northern polar stratosphere as a result of nuclear weapons tests conducted by the Soviet Union at Novaya Zemlya. In the present communication the concentration of strontium-90 in rain at Rijswijk, Z.H. (52° N, 4° E) originating from each of these test series will be related to data on the release of fission energy published recently (Federal Radiation Council, 1963; MARTELL & DREVINSKY, 1960).

Fall-out from the October 1958 series

The contribution of Sr^{90} from the October 1958 series to fall-out of this nuclide in 1959 has been calculated previously (BLEICHRODT, BLOK & VAN ABKOUDE, 1961) assuming for debris from these tests a radioactivity ratio of Sr^{89} and Sr^{90} of 180 on October 15, 1958. The Sr^{89}/Sr^{90} ratio for material from earlier explosions was supposed to be 60 on the same date. However, recent measurements by HALLDEN *et al.*, (1961) suggest that in debris from megaton weapons the Sr^{89}/Sr^{90} ratio at the time of explosion is 147 instead of 180. Using this value the fraction of Sr^{90} from the autumn tests is found to exceed 100 % for several months during 1959, the highest value being 110 % for April. This may mean that a ratio of 147 on October 15, 1958, does not adequately characterize debris from these Soviet detonations. The best estimate of the concentration of Sr^{90} originating from the Soviet tests is probably obtained by assuming its contribution to be 100 % in April 1959, which corresponds to a Sr^{89}/Sr^{90} ratio of 161 on October 15, 1958. Average concentrations of Sr^{90} for bimonthly periods derived by means of this ratio are given in Table 1 in picocurie per liter of rain per megaton of fission energy. A fission energy of 12.5–15 megatons (MARTELL & DREVINSKY, 1960) was taken for the Soviet series in the autumn of 1958.

Nearly all debris from these tests was injected into the lower levels of the polar stratosphere (FRIEND *et al.*, 1961) and was deposited on the earth's surface during 1959 (BLEICHRODT, BLOK & VAN ABKOUDE, 1961).

Fall-out from the 1961 tests

After a moratorium of 34 months atmospheric testing of megaton weapons was resumed in September 1961. During the first eight months of 1962 Sr^{90} fall-out consisted mainly of debris from Soviet tests in September and October 1961. This could be concluded from the Sr^{89}/Sr^{90} ratio and follows also from a comparison of concentrations of Sr^{90} in rainwater during 1960,

TABLE 1. *Concentrations of strontium-90 in rain at Rijswijk, Z.H., due to the injection of radioactivity into the lower stratosphere.*

Picocuries per liter per megaton of fission energy.

Period	1959	1962	1963	Average
Jan.–Febr.	0.32–0.38[a]	0.41–0.46	0.21–0.36	0.36
March–April	0.94–1.14	0.46–0.62	0.45–0.78	0.73
May–June	1.17–1.41	0.89–1.08	0.67–1.16	1.06
July–August	0.31–0.38	0.53–0.63	0.42–0.73	0.50
Average: Jan.–August[b]	0.62–0.74	0.55–0.65	0.48–0.83	0.65

[a] Values for 15 and 12.5 megaton of fission energy, respectively.
[b] Total strontium-90 deposition (pc/m²) divided by the product of total rainfall (litre/m²) and fission yield (megatons).

1961 and 1962. An estimate of the fraction of 1961 debris acquired from nuclide ratios suffers from the same uncertainties as mentioned above in connection with the calculations for 1959. Therefore it is impossible to assess this fraction with high accuracy. The higher value given in Table 1 has been obtained by assuming all Sr^{90} to originate from the 1961 detonations, the lower by taking the difference of the concentrations of 1962 and 1961, as it is to be expected that the amount of old debris during 1962 did not exceed the values of 1961 (see also WALTON *et al.*, 1963). It is seen that the contribution of the Soviet 1961 tests is known with an accuracy of about 10 %.

The amount of fission energy corresponding to debris placed in the lower stratosphere ("the first few tens of thousands of feet above the tropopause") is estimated at 17 megatons for the 1961 tests. Multimegaton weapons injected another 8 megaton equivalents of fission products into the upper stratosphere (Federal Radiation Council, 1963). To compute the data of Table 1 it has been assumed that during the period January–August 1962 only the 17 megaton equivalents in the lower stratosphere gave rise to fall-out of Sr^{90}. This seems justified in the light of results of rhodium-102 measurements by KALKSTEIN (1963).

Debris from the United States tests which started on April 28, 1962 (10 megaton equivalents in the lower, 1 in the upper stratosphere (Federal Radiation Council, 1963)) was detected at Rijswijk during July and August. Moreover radioactivity from the Soviet 1962 series arrived in August. No corrections have been applied for Sr^{90} from these sources because its contribution to the total Sr^{90} deposition, as calculated from Sr^{89}/Sr^{90} ratios, was at most 3 % in July and 9 % in August.

Fall-out from the U.S.S.R. tests in 1962

An estimated amount of 30 megaton equivalents of fission products were introduced into the lower and 30 megaton equivalents into the upper stratosphere by the Soviet tests of 1962 (Federal Radiation Council, 1963). It is assumed again that for the concentration of Sr^{90} in rain during the first eight months of 1963 only the portion injected into the lower stratosphere is of importance.

The fraction of Sr^{90} during 1963 originating from the Soviet 1962 explosions is not easy to assess by means of fission product ratios because 4 sources (Soviet 1961 and 1962, U.S. 1962, and old material) contributed to Sr^{90} fall-out. Moreover the series of detonations at Novaya Zemlya extended from the beginning of August to the end of December which renders it difficult to determine an average explosion date without too large a possible error. However, an upper limit for the contribution of the various sources to Sr^{90} fall-out during 1963 may be estimated in the following way.

The concentration of Sr^{90} in rain during the period January–August 1963 due to explosions performed prior to September 1961 will probably be smaller than that during the corresponding period in 1961 (see also WALTON *et al.*, 1963). This means that in 1963 at least 90 % of the Sr^{90} originates from explosions during 1961 and 1962.

According to other authors (quoted by WALTON *et al.*, 1963) about 10 megaton equivalents of Sr^{90} from the Soviet detonations in 1961, i.e. $\frac{1}{3}$ of the amount injected by the Soviet 1962 explosions, resided in the lower stratosphere (below 70,000 ft) of the northern hemisphere after the spring of 1962. Probably the contribution of this debris to fall-out in 1963 was even less than $\frac{1}{3}$ of that from the Soviet 1962 series because part of it moved southwards to tropical regions (MACHTA & TELEGADAS, 1963) where little exchange occurs between stratosphere and troposphere.

The concentration of Sr^{90} from the U.S. tests in 1962 may be estimated from fall-out data and fission yields for the U.S. and Soviet explosions in 1958. Sr^{90} fall-out during January–August 1959 originating from the equatorial stratosphere contributed 18 % to the total, as calculated with the Sr^{89}/Sr^{90} ratios on October 15, 1958, used above. Part of the equatorial debris originated from the U.S. Hardtack tests in the summer of 1958 (MARTELL & DREVINSKY, 1960; BLEICHRODT, BLOK & VAN ABKOUDE, 1961), which injected 4 megaton equivalents (MARTELL & DREVINSKY, 1960) of fission products, i.e. $\frac{1}{4}$ to $\frac{1}{3}$ of the fission energy released by the Soviet series in October 1958, into the tropical stratosphere. The ratio of the fission energy release of the U.S. and Soviet explosions in 1962 was $\frac{1}{4}$, so that in fall-out during 1963 less than 22 % of the amount contributed by the Soviet 1962 series is expected to originate from the U.S. 1962 detonations. This fraction will probably also be an overestimation because the Hardtack tests were conducted at 11° N (Bikini and Eniwetok) and the U.S. 1962 series mainly at 2° N (Christmas Island).

From the above considerations it follows that a lower value for the fraction of Sr^{90} from the Soviet 1962 tests in fall-out during 1963 is 58 %. In Table 1 the concentration of Sr^{90} from the last Soviet series is given for a fission energy release of 30 megatons in the lower stratosphere and a contribution of these tests to fall-out of 58 and 100 % respectively. The average value of 79 % probably will be accurate within 20 %.

Conclusions

In view of the many variables involved the agreement of the data for 1959, 1962 and 1963 is better than expected. It may be concluded that at least as far as Western Europe is concerned the concentration of Sr^{90} in rainwater following megaton tests in Arctic regions as have been carried out by the U.S.S.R. in the autumn of a number of years, can be predicted rather accurately as a function of time if data on the release of fission energy are available.

Previously (BLEICHRODT, BLOK & DEKKER, 1961) it was shown that the gross radioactivity in air during the spring of 1956 and 1959, corrected for decay in order to obtain a quantity proportional to Sr^{90} activity, also suggests a reproducible relation between Sr^{90} fall-out and fission yield in agreement with the data in Table 1. This would mean that this relation is not limited to explosions at polar latitudes because the Soviet tests in 1955 were conducted at 52° N (MARTELL & DREVINSKY, 1960). It should be mentioned however that considerations of fission product ratios (MACHTA, 1961; MARTELL & DREVINSKY, 1961) did not yield a clear picture in this case because of uncertainties in the assumptions to be made.

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