Strontium-90 Fallout from Surface and Underground Nuclear Tests

Abstract. *Deposition of strontium-90 per unit area per unit fission energy from surface blast of the first Chinese atomic bomb was several times heavier than that from an earlier atmospheric test series. The venting of a Russian large-scale underground test also significantly increased deposition of strontium-90 at Niigata, Japan.*

Two unique nuclear test explosions occurred in central Asia within 4 months: the Chinese bomb was detonated at ground level at Lop Nor in the Takla Makan Desert on 16 October 1964, causing a peak of radioactivity in rain at Niigata, Japan, on 18–19 October; and the Russians made an underground test at Semipalatinsk on 15 January 1965, to the venting of which is attributed a surprisingly high level of radioactivity over Japan on 21 January. According to the U.S. Atomic Energy Commission, the fission yield of the Chinese bomb was equivalent to 20 kton of TNT; the Russian bomb equalled between 0.5 and 1.0 Mton of TNT.

These injections of fission products of known origin into the atmosphere provided a useful opportunity for studying the atmospheric behavior of fresh nuclear debris, particularly the deposition of Sr^{90}, generated by surface and underground tests, several thousand kilometers downwind from the test sites. The Sr^{89} activity resulting from the 1961–62 test series had disappeared by decay by the time we started the present work about 2 years after the last of the series. Furthermore, the Sr^{89} activity derived from the Chinese test had decreased to a very low level by early January 1965—to less than 1 percent of activity between 21 and 31 January, which came mainly from the Russian underground test. Consequently a Sr^{89} isotope with a half-life of 50.4 days served as a useful tracer of the Chinese and Russian fresh debris. Large amounts of rain water were collected monthly or bimonthly with an open vessel 1.0 m^2 in area, and samples were analyzed by the ion-exchange procedure (*1*).

Our measurements of Sr^{89} and Sr^{90} activities between 18 October 1964 and 31 March 1965 are summarized in Table 1. The "new" Sr^{90} shown (Table 1) is a Sr^{90} fraction newly deriving from the recent Chinese and Russian tests; its activity was calculated from the measured Sr^{89} activity, its age since formation, and an initial activity ratio $Sr^{89}:Sr^{90}$ (at formation) of 160. It has been shown (*2*) that the fractionated escaping fraction of fresh debris from a small nuclear cratering detonation can have a $Sr^{89}:Sr^{90}$ ratio that varies considerably from 160 for local samples of fallout collected within 7 km of the site. An initial $Sr^{89}:Sr^{90}$ ratio of 160 was, however, believed to be permissible for the purpose of evaluating a new-Sr^{90} fraction from the Sr^{89} data in view of the results of radiochemical analysis of fractionated fallout samples from the Russian test (*3*). The "old" Sr^{90} (Table 1) is a Sr^{90} fraction, resulting mainly from the 1961–62 test series, that had precipitated after prolonged storage in the stratosphere; its activity was calculated by subtracting the new Sr^{90} from the total Sr^{90} measured. All activity values were corrected for radioactive decay to the mean of the collection period.

Table 1. Depositions of Sr^{89} and Sr^{90} per unit area at Niigata between 18 October 1964 and 31 March 1965.

Period	Deposition per unit area (pc/m^2)		
	Sr^{89}	Sr^{90}	
		New	Old
	1964		
18–31 Oct.	4150	28	234
1–30 Nov.	2420	23	501
1–31 Dec.	780	11	587
	1965		
1–15 Jan.	143	2	274
21–31 Jan.	18,500	132	406
1–14 Feb.	1080	9	403
15–28 Feb.	184	2	188
1–15 Mar.	298	4	564
16–31 Mar.	100	2	288

Total deposition of new Sr^{90} per unit area was 0.064 mc/km^2 between 18 October 1964 and 15 January 1965 and 0.149 mc/km^2 between 21 January and 31 March 1965 (Table 1). The earlier deposition evidently resulted from the Chinese test; the latter, from the Russian. Thus even the venting of an underground test, at least if the explosive power is equivalent to 0.5 Mton of TNT, can more than double deposition of Sr^{90} caused by a fission-yield bomb equivalent to 20 kton. The Sr^{90} activity produced by the Chinese bomb was estimated at 2000 c on the basis of the usual assumption that activity produced by such an explosion is 100 c per unit of fission yield that is equivalent to kton of TNT (*4*). At Niigata during the period in question, deposition of Sr^{90} from the Chinese test was estimated at 32 mc/km^2 per megacurie produced; on the other hand, deposition per unit area was 26.5 mc/km^2 between September 1957 and August 1961. When one took into account the decreased rate of deposition between September 1957 and August 1961 (*5*), this 4-year total of deposition was believed to amount to more than 90 percent of an assumed total of deposition to be expected without disturbance by the Russian resumption of nuclear tests on 1 September 1961.

Total Sr^{90} activity injected by the 1957–58 series was assessed at 4.0 Mc (*6*). Deposition of Sr^{90} from the 1957–58 series was evaluated at 6.6 mc/km^2 per megacurie produced. This value may be smaller by less than 10 percent than is reasonable, but it seems sufficiently useful for an estimate of Sr^{90} deposition per unit area in relation to the activity injected by a nuclear explosion. Thus, deposition of Sr^{90} per unit area resulting from the Chinese surface test was about 5 times greater than similar deposition from the 1957–58 atmospheric test series. This fact indicates that nuclear debris resulting from a surface test explosion of low yield is distributed in a narrow latitude band to greater distances downwind from the test site. Thus even low-yield nuclear tests, if frequently conducted at ground level will cause significantly increased Sr^{90} deposition at distances as great as 5000 km downwind from the site.

The percentage contribution from

Table 2. Contribution from new Sr^{90} from the Chinese and Russian tests to total Sr^{90}, and total deposition per unit area at Niigata between 18 October 1964 and 31 March 1965.

Period	Contribution (%)	Total deposition (mc/km^2)
	1964	
18–31 Oct.	10.7	0.262
1–30 Nov.	4.4	.524
1–31 Dec.	1.8	.598
	1965	
1–15 Jan.	0.7	.276
16–31 Jan.	24.6	.538
1–14 Feb.	2.2	.412
15–28 Feb.	1.1	.190
1–15 Mar.	0.7	.568
16–31 Mar.	.7	.290

new Sr^{90} to total Sr^{90} between 18 October 1964 and 31 March 1965 is shown in Table 2, together with the deposition per unit area for total Sr^{90}; contribution (from new to total) for the period 18–31 October 1964 amounted to 11 percent, while a similar contribution of 4.3 percent was derived in the same way from analysis (*7*) of a sample of rain collected at Fayetteville, Arkansas, on 26 October 1964, 10 days after the Chinese explosion. The latter value was less than half the average at Niigata between 18 and 31 October 1964 and was comparable with an average of 4.4 percent at Niigata during November of the same year. The contribution from new Sr^{90} of Chinese origin to total Sr^{90} was estimated at 3.9 percent between 18 October 1964 and 15 January 1965; from new Russian, 7.5 percent between 21 January and 31 March 1965; and from new Chinese and new Russian, 5.8 percent between 18 October 1964 and 31 March 1965.

The Sr^{90} deposition per unit area per unit explosive power of the Russian bomb was 0.30 to 0.15 mc km^{-2} $Mton^{-1}$ between 21 January and 31 March 1965. On the other hand, as the total explosive power of the 1957–58 test series was assessed at 36.3 Mton equivalents (*8*), the Sr^{90} deposition per unit area per unit explosive power for the series was estimated at 0.73 mc km^{-2} $Mton^{-1}$.

This finding suggests that the Russian blast caused heavy deposition of Sr^{90} per unit area per unit explosive power, deposition of the same order as that from the 1957–58 atmospheric series, in Niigata, more than 5000 km from Semipalatinsk. Table 2 further shows that the contribution decreased with time and became constant at 0.7 percent; this fact may imply that atmospheric mixing of new Sr^{90} from the Chinese and the Russian tests with old Sr^{90} from the 1961–62 test series was almost complete by early January and early March 1965, respectively.

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Geomagnetic Polarity Epochs: A New Polarity Event and the Age of the Brunhes-Matuyama Boundary

Abstract. *Recent paleomagnetic-radiometric data from six rhyolite domes in the Valles Caldera, New Mexico, indicate that the last change in polarity of the earth's magnetic field from reversed to normal (the Brunhes-Matuyama boundary) occurred at about 0.7 million years ago. A previously undiscovered geomagnetic polarity event, herein named the "Jaramillo normal event," occurred about 0.9 million years ago.*

Earlier quantitative investigations of the geomagnetic polarity epoch time scale have placed the last change in the polarity of the earth's magnetic field (from the Matuyama reversed epoch to the Brunhes normal epoch) at 1.0 million years ago (*1, 2*). In a recent publication (*3*) we pointed out that the revision of the age of the normally magnetized Bishop Tuff (Pleistocene), of California, from 1.0 to 0.7 million years made the age of the Brunhes-Matuyama boundary less certain. Over 15 reversely magnetized volcanic rocks with potassium-argon ages in the range between 1.5 and 1.0 million years clearly define the boundary as being younger than 1.0 million years. Between 1.0 and 0.7 million years, however, the only datum was that from the Bishop Tuff, and thus the revision of its age raised the possibility that the boundary might be as young as 0.7 million years.

We have now completed paleomagnetic measurements and potassium-argon age determinations of 19 Pleistocene volcanic units from the Valles Caldera, Sandoval County, New Mexico. Six of these units, all rhyolite domes that were emplaced in the caldera after the extrusion of the Bandelier Tuff (*4*), have potassium-argon ages between 0.7 and 1.0 million years (Table 1), and are therefore important for defining the age of the Brunhes-Matuyama boundary. The ages are based on replicate potassium and argon determinations, and the paleomagnetic data were obtained from multiple samples. Sampling and measurement techniques are essentially the same as those described previously (*2, 5*). Ages were measured on sanidine, except for unit 3X194, for which obsidian was used, and were calculated with $\lambda_\epsilon = 0.585 \times 10^{-10}$ yr^{-1}, $\lambda_\beta = 4.72 \times 10^{-10}$ yr^{-1}, $K^{40}/K = 1.19 \times 10^{-4}$ mole/mole. The atmospheric corrections ranged from 20 to 58 percent for the five younger units and from 76 to 77 percent for 3X194. The standard deviation of the calculated ages is 6 percent for 3X194 and 4 percent for the other units. This calculated standard deviation is based on the results of replication studies (*6*) and on the effect on precision of the atmospheric argon correction as calculated from the formula given by Lipson (*7*).

The discovery of both normal and reverse remanent magnetizations (as well as an intermediate direction) in these rocks is not surprising because they were formed near the time of the last polarity transition. Finding the normal and intermediate directions bracketed between reversed directions was, however, not anticipated and suggests three possibilities: (i) The precision of the potassium-argon age measurements is not sufficiently high to distinguish between the ages of the units, that is, 4D057 and 3X187 are really younger than the other domes; (ii) One or more of the domes may have self-reversed remanent magnetization (*8*); or (iii) There may be a short polarity event near the Brunhes-Matuyama boundary.

There is no stratigraphic evidence concerning the relative ages of the first five domes listed in the table, although all are known to be younger than 3X194. Four other domes in the Valles Caldera that are normally magnetized and are stratigraphically younger than any of the domes discussed here give ages between 0.43 and 0.54 million years. Thus, the ages in Table 1 are not inconsistent with the known stratigraphy. These relations, and the fact that at least two of the calculated ages would have to be in error by more than four times their standard deviations, lead us to reject the first hypothesis.

To investigate the possibility of self-