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Global movement of radioactive debris from Chinese atmospheric nuclear tests

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सार — चीन द्वारा वायुमण्डल में किए गए नाभिकीय परीक्षणों से निसृत रेडियोधर्मिता को भूगोलीय स्तर पर गतिशीलता कालोंके आकलन हेतु अनुरेखक के रूप में उपयोग किया गया है। यह पता चला है कि चीन के परीक्षण स्थल लपनोर (40° उ०, 90° पू०) से जापान तक का गतिशीलता काल का आकलन जो वैज्ञानिकों ने निकाला है, तत्संबंधी जापानी आंकड़ों से बहुत मेल खाता है। ऐसा देखा गया है कि सुदूर स्थानों तक मलबे के पहुंचने का गतिशीलता काल तथा जापान में भूतल स्थित स्टेशन पर रेडियोधर्मिता बंटनों का प्रारूप दोनों ही, आरंभिक अवस्थाओं में रेडियोधर्मी बादल के पथ पर निर्भर रहते हैं। दो मामलों में बादलों के पथ के अनुरेखण के लिये अभिकलित उच्च वायुधारा पथ भी इस में प्रस्तुत किये गए हैं।

ABSTRACT. Radioactivity released by the Chinese atmospheric nuclear tests has been used as a tracer to estimate travel times on a global scale. It is found that the travel time estimates to Japan from the Chinese testing site Lop Nor (40 deg. N, 90 deg. E), given by the authors are in good agreement with the Japanese data. The travel times of the debris to distant locations as well as the pattern of radioactivity distributions at ground level stations in Japan are both found to be dependent on the path of the radioactive cloud in the initial stages. The upper airstream trajectories computed in two cases to trace the path of the cloud are also presented.

1. Introduction

Radioactive materials released into the atmosphere during nuclear explosions have been used as tracers, to study the movement of air masses and travel times on the global scale (Rangarajan & Gopalakrishnan 1975, Rangarajan 1981). Travel time of radioactive debris to different locations depend on the prevailing meteorological conditions at the time of detonation of the bomb. The travel time depends also on the height of stabilisation of the radioactive cloud, which, in turn depends on the power and altitude of detonation of the bomb (Peterson 1970). Thus, the radioactive cloud from a low yield surface burst will stabilise in the troposphere, while major portion of the radioactive debris is carried to the stratosphere in the case of a H-bomb with yield in the megaton range. The radioactive debris in the troposphere is usually dispersed by the prevailing westerlies and is preferentially deposited on the ground in the latitude band of the explosion site. The stratospheric debris gets into the troposphere largely through the 'tropopause gaps' during the spring season. Once in the troposphere, the debris reaches the ground level by usual circulation and deposition patterns.

In this paper, a few estimates of the travel times of the radioactive debris from the Chinese testing site at Lop Nor to Japan are presented. These travel time estimates are derived from the dates of first detection of fresh radioactivity from the test by means of swipe samples collected from commercial aircrafts flying from Japan to Bombay. The path of the radioactive cloud has also been deduced from the upper airstream trajectories for two Chinese tests. The observed changes in the course of the radioactive debris is confirmed by the upper airstream trajectories in these cases. The differences in the distribution pattern of the ground level radioactivity at Japanese stations are also attributed to the change of cloud path in the initial stages. This type of study over a number of nuclear tests provides general information on travel times of pollutants around the globe in the latitude band of the source, range of variations possible under special meteorological conditions and extent of diffusion and dispersion of the source, if large scale observation can be carried out on global scale.

2. Sample collection and analysis procedures

Following the announcement of a nuclear test by China, swipe samples were collected from commercial aircrafts reaching Bombay from Tokyo, Japan. These samples were obtained by swiping the deposited dust on the exposed surface of the engine covers of the aircraft. Cotton wool soaked in organic detergents, was used for swiping the exposed surface. For a given type of aircraft, the area of swiping was kept constant to

TABLE 1

Detection of fresh radioactivity from various Chinese atmospheric nuclear tests

Test No.	Test date	Yield (kT)	First detection data: New York-Bombay flight	Tokyo-Bombay flight	Japan ground level data
			Low yield		
2	14 May 1965	20	27 May 1965 (13)	19 May 1965 (4)	16 May 1965 (2)
4	27 Oct 1966	20	N.D.	30 Oct 1966 (3)	3 Nov 1966 (5)
7	24 Dec 1967	15–25	N.D.	30 Dec 1967 (6)	25 Dec 1967 (1)
12	18 Nov 1971	20	N.D.	23 Nov 1971 (5)	20 Nov 1971 (2)
13	7 Jan 1972	20	17 Jan 1972 (10)	N.D.	8 Jan 1972 (1)
18	23 Jan 1976	20	N.D.	28 Jan 1976 (5)	26 Jan 1976 (3)
22	17 Sep 1977	20	28 Sep 1977 (11)	23 Sep 1977 (6) 5 Oct 1977**(18)	21 Sep 1977 (4)
23	15 Mar 1978	20	25 Mar 1978 (10)	18 Mar 1978 (3)	17 Mar 1978 (2)
24	14 Dec 1978	20	N.D.	18 Dec 1978 (4)	N.A.
			Medium yield		
3	9 May 1966	200–500	16 May 1966 (7)	N.D.	11 May 1966 (2)
5	28 Dec 1966	300	3 Jan 1967 (6)	31 Dec 1966 (3)	30 May 1966 (2)
19	26 Sep 1976	20–200	8 Oct 1976 (12)	N.D.	28 Sep 1976 (2)
			High yield (MT)		
6	17 Jun 1967	3	N.D.	20 Jun 1967*(3)	18 Jun 1967 (1)
11	14 Oct 1970	3	22 Oct 1970 (6)	N.D.	15 Oct 1970 (1)
15	27 Jun 1973	2–3	N.D.	30 Jun 1973*(3)	30 Jun 1973 (3)
16	17 Jun 1974	1	1 Jul 1974 (14)	20 Jun 1974 (3) 6 Jul 1974** (19)	19 Jun 1974 (2)
21	17 Nov 1976	3	N.D.	N.D.	19 Nov 1976 (2)

N.D.—Not Detected; *—Low activity ; **—Detected after one revolution around the world

N.A.—Data not available. Nos. in brackets are travel times in days

maintain a proportionality between the radioactivity obtained in the sample to the radioactivity in the atmosphere. These samples were leached using a mixture of 3M hydrochloric acid and 0.1M hydroflouric acid. A known fraction of the leach was evaporated on a perspex planchet of 5 cm diameter. This planchet was used to take the gamma-ray spectrum of the fission product mixtures in the sample. Arrival of fresh radioactivity was characterised by the presence of short-lived fission products such as ^{140}Ba — ^{140}La, ^{131}I, ^{99}Mo etc. The date on which fresh activity from the test is first detected is taken as the day on which the bomb debris has reached the upper atmosphere of Japan. This date can have some uncertainties as discussed later as the aircraft could have intercepted the bomb debris either on its flight to or from Japan which can result in difference of one day. The flight path of the aircraft is such that it is likely to intercept the debris first over Japan or very close to it. Since samples are collected from all the flights coming from Japan, till first active sample is collected, there is break in the collection of the sample only when there was no flight from Japan. In the past number of flights per week has varied from 4 to 7 and whenever there is uncertainty in determining the date of arrival in Japan, it has been taken into account in the discussion of the results. If the sample contained fresh radioactivity from the recent nuclear test under study, radiochemical separation of the sample for specific radionuclides was undertaken to get information about the exploded device. More details of sample collection and analysis procedures as well as of the Chinese nuclear explosions carried out so far have been reported elsewhere (Sadasivan *et al.* 1982, Mishra *et al.* 1980, Vohra *et al.* 1971 and Mishra *et al.* 1974). A similar set of samples are collected from New York-Bombay flights for determining the dates of arrival of the debris over the east coast of U.S.A.

3. Results and discussion

Table 1 gives the dates of first detection of radioactivity over Japan from the various atmospheric nuclear tests carried out by China, since 1965. The travel times (in days) of the fresh debris from these nuclear tests to Japan and the United States of America are given in the parenthesis. For comparison, the time taken for detection at ground level stations in Japan are also given in the same table.

The travel time of radioactive debris to any location on the globe depends on the height at which the cloud stabilises. The cloud height itself is a function of the yield of the bomb and the altitude of detonation (Peterson 1970). Therefore, nuclear tests under discussion are classified into three groups in Table 1, *viz.*, low yield, medium and high yield tests, based on the announced explosion yields. It is observed from Table 1, that the travel times to Japan derived from the aircraft swipe sample data agrees well with the actual Japanese measurements. Maximum differences in the travel time have been observed in the case of the fourth and seventh Chinese tests. The activity was detected earlier by 3 days for the fourth test by the aircraft swipe method, whereas there was a delay of 4 days in the case of the seventh tests. However, the general agreement between the two values (barring the above two cases) suggest that the travel time estimates to Japan derived by this relatively simple method

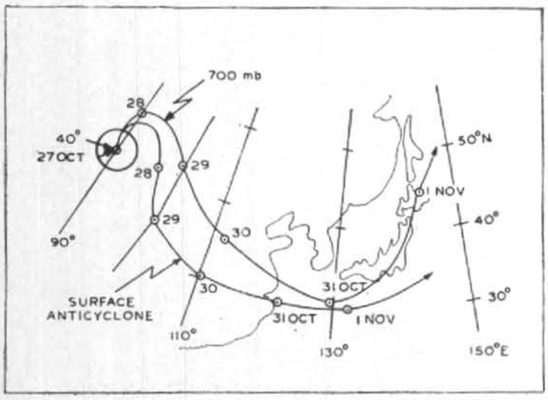


Fig. 1. Upper air stream trajectory after the 4th Chinese nuclear test on 27 Oct 1966

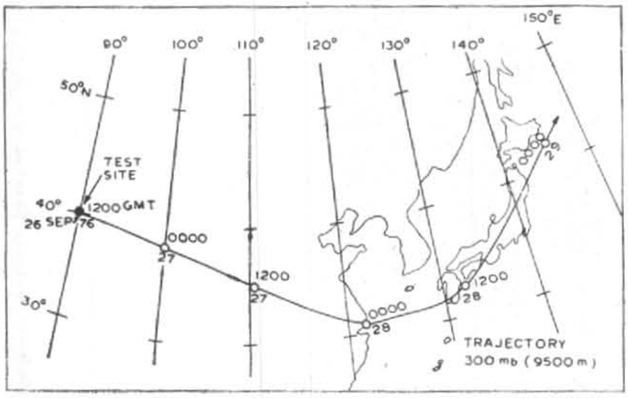
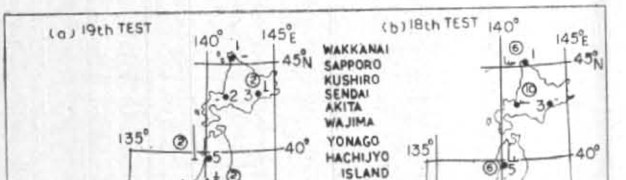


Fig. 2. Chart of airstream in upper atmosphere following Chinese nuclear explosion of 26 Sep. 1976



Figs. 3(a & b). Radioactivity (mCi/km²) at ground level in Japan after the Chinese tests. Arrival time in (days) of debris is indicated within circles. Vertical lines are proportional to activity

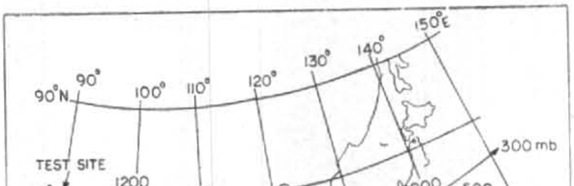


Fig. 4. Chart of air stream in upper atmosphere following Chinese nuclear explosion of 23 January 1976

used by the authors is fairly accurate and reliable in most of the cases.

The first detection of radioactive debris in the Tokyo-Bombay flight depends on the path of the radioactive cloud in the initial stages. The departure of the radioactive cloud from the normal course towards south can result in the early detection of fresh activity by swipe samples as in the case of the 4th Chinese test and towards north can result in delayed/non-detection of fresh activity from Tokyo flights. The path of the radioactive cloud for the 4th Chinese test as given by the airmass trajectory at 700 mb level is given in Fig. 1. The radioactive cloud is passing through 30 deg. N, 110 deg. E on 30 October, where there is a formation of surface anticyclone. Thus, the aircraft leaving Tokyo and flying towards Bombay has intercepted the cloud two days before the arrival of the cloud over Japan, leading to the detection of fresh radioactivity in the aircraft swipe samples. In the case of the seventh Chinese test, the detection of fresh radioactivity in swipe samples was delayed by 4 days, probably due to the fast transit of radioactive cloud over Japan one day after the test, as reported by the Japanese authorities (Japan 1967). The airmass trajectories over Japan, as well as the high altitude flight data shows that the major portion of the radioactive cloud was present above 10 km level (Japan 1967) in a narrow band. It was also noted from the high altitude data that fresh activity was present in small quantities only at 6-7 km level over central Japan, due to which the first increase in activity was observed in the rainwater sample from central Japan. As the spread of the radioactive cloud was small at 10 km level, the aircraft taking off from Tokyo could have missed the debris during the first three days because of its short flight span over Japan. An active sample could, therefore, only be collected from the Tokyo-Bombay flight four days after the test. Thus, it is evident from the above discussion that both the early and late detection of radioactivity in the swipe samples were due to the deviation of the radioactive cloud from the normal path of high altitude westerlies.

Among the three medium yield tests, third, fifth and nineteenth test listed in Table 1, only the fifth test could be detected by swipe sample from Tokyo-Bombay flight. In the case of the third Chinese test, the height of stabilisation of the cloud was beyond 9 km as is evident from the high altitude data (Japan 1967) and air mass trajectory. The cloud passed over central Japan and the increase in radioactivity reported at ground level is only 1/10th of the levels observed after the first and second Chinese tests. It may be for this reason that the aircrafts leaving Tokyo did not intercept the cloud in the course of their flight path. The nineteenth Chinese test activity also was not detected in the aircraft swipe samples from the Tokyo-Bombay flights. This is due to the northward diversion of the radioactive cloud as a result of which the commercial aircraft leaving Tokyo could not intercept the debris and hence no active sample was collected. The airmass trajectory obtained by authors from the meteorological data following the nineteenth test is shown in Fig. 2. This trajectory showing a northward diversion of the cloud agrees very well with the airmass trajectory given by Japanese agency (Japan 1967).

In the case of the high yield nuclear explosions (yield in megaton range) the cloud entered the stratosphere and hence escaped detection as it happened in the case of the 21st Chinese test. The high altitude sampling studies over Japan after this 3 megaton test showed the presence of only very small amounts of fresh radioactivity even at 11 km height over northern Japan (Japan 1977). The activity from the eleventh Chinese test was also not detected in swipe samples from Tokyo-Bombay flights, as the cloud stabilised beyond 10 km level. However, in this case an active sample was obtained from the New York-Bombay flight after six days, unlike in the case of twenty first test. A possible explanation for this could be that after the high yield explosion, a small portion of the cloud remained in the troposphere which was intercepted by the aircrafts giving a low activity sample as noted in the case of the sixth and fifteenth tests. For these tests, no active sample could be obtained from the New York-Bombay flights.

The travel time of radioactive debris to different locations is very much dependent on the path of the cloud in its initial stages. It has been observed that the activity from Chinese tests is detected earlier than usual in UK and later than usual in Hong Kong if there is a northward diversion of the cloud. Thus, fresh activity was detected in U.K. in 7 and 8 days respectively from the nineteenth and third Chinese nuclear tests, as against the normal detection time of 10-15 days. Similarly, the first detection of fresh activity at Hong Kong was between 15-22 days and 14-21 days for the above tests (Rangarajan 1981) compared to the usual detection time of 3-14 days for most of the other tests. The poleward diversion of the radioactive cloud for the nineteenth test (Fig. 2) is also well reflected in the detection of fresh radioactivity at ground level in Japan, which is shown in Fig. 3(a). The radioactivity increases recorded at the ground stations along the cloud path are considerably higher than the activity increase observed at the southern stations such as Hachijio island. This pattern is in contrast to the activity distribution at the ground level stations in Japan after the eighteenth Chinese test, when the cloud followed the path of the westerlies. The radioactivity levels and travel time to the different sampling stations in Japan after eighteenth test are shown in Fig. 3(b) and the upper air stream trajectory in Fig. 4. It is evident from these figures that the northern stations which are away from the cloud path show less increase compared to the southern stations. After the twenty first Chinese test, fresh activity was detected only in Japan (2 days), Central Europe (8-15 days) and Sweden (8 days) in the first round of the cloud. The first detection of activity in U.K. is after 40-47 days for this test which may be due to very slow diffusion of the cloud from the lower stratosphere to the ground level.

The time taken by the radioactive cloud to travel round the globe could also be estimated from the second peak in activity at the same place. Following the sixteenth and twenty second Chinese tests, sampling was continued till activity was detected from the second round of the radioactive cloud. Such second detection dates are also given in Table 1. The time interval between the first and second arrivals can be taken as the travel time of the radioactive debris around the globe. The travel times thus obtained are 16 days and 12 days, respectively, for the two tests. These values are in agreement with values reported by other investigators (Rangarajan 1981).

4. Conclusions

(1) Travel times of radioactive debris in the initial stages can be derived fairly accurately using this simple method of sampling.

(2) The radioactivity levels at ground level stations immediately after the nuclear test is a definite indication of the cloud path as seen in the few cases described in the text.

(3) Travel times around the globe can easily be obtained by the method used and described in this paper using radioactivity as tracer.

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