Early radioactive fallout in Israel following the 1961 nuclear weapon tests

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ABSTRACT

Daily samples of airborne and deposited radioactivity were collected in Israel during the months following the 1961 nuclear weapon tests. The age and composition of the fallout was determined by radiochemical and decay analysis. Meteorological analysis of the data shows that except for one case of direct cross-European transport, the favoured path of arrival of the early radioactive fallout into the Levant was by a circumpolar route in the upper troposphere. From December 1961 onwards there is evidence for increasing stratospheric contribution to the collected radioactivity.

Introduction

During the months of September and October 1961, an extensive series of nuclear weapon tests was conducted in the atmosphere over Siberia and within the Arctic circle. The tests followed a period of three years in which no large scale atmospheric nuclear testing had taken place, so that prior to this series the tropospheric fallout levels were very low. Study of the atmospheric circulation pattern of the fallout from this series should therefore be feasible in much more detail than in the past, where different weapon tests in different parts of the world followed each other closely.

In the present paper an attempt is made to relate the fallout collected in Israel to individual events of the test series, in order to utilise the marking of air bodies by nuclear debris in the study of atmospheric circulation. Obviously, observations from a single geographic site cannot be fully interpreted in terms of the global scale picture. The measurements reported below should contribute to a worldwide analysis as more fallout data from different countries become available.

Method of fallout measurements

Daily samples of airborne radioactivity were collected at ground level at Rehovoth (Weizmann Institute) by continuous air filtration through a 2in. membrane filter (type AM–5; Gelman Instrument Corp.) at a fixed rate of 1 cu.ft. per min. The dust collected on the filters was β-counted without further treatment from the third day onwards using a low background counter.

In addition, daily samples of airborne radioactivity were obtained at the site of the Israel Research Reactor (IRR-1) at Nahal Soreq by means of a Victoreen Model 900-2B continuous air monitor on a paper filter (Type Schleicher and Schuell No. 2430). Deposited activity was collected on gummed tape collectors at four sites in Israel. All these samples were ashed and subsequently β-counted according to a technique described previously by Gat and Gilat (1960*a*).

Rainwater samples were β-counted and analysed for their Sr-89 and Sr-90 content by a radiochemical procedure (Gat and Gilat, 1960*b*). Gamma spectra of some of the samples obtained using a 3 in NaI crystal scintillation assembly and 256 channel analyzer will be published elsewhere.

Decay analysis

Some 30 nuclear devices have reportedly been detonated during the two months of September and October, 1961. In order to interpret fallout measurements in terms of air mass

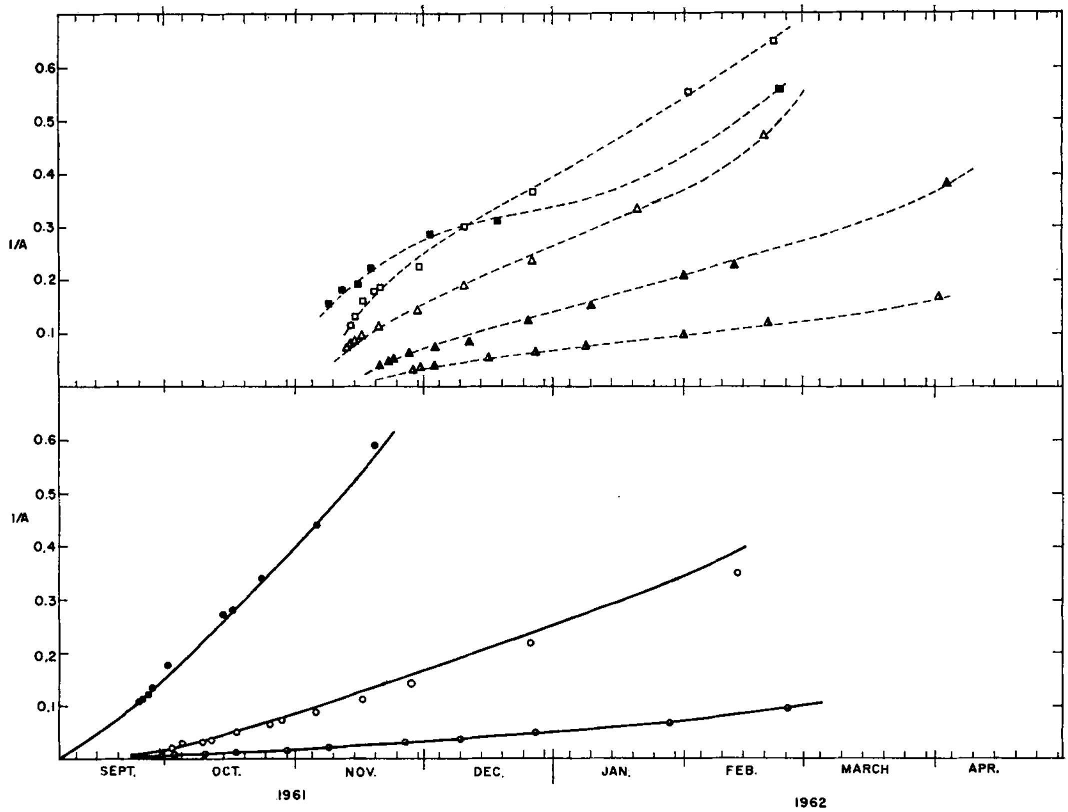

FIG. 1. The decay of representative fallout samples collected at Rehovoth during autumn of 1961, plotted on a reciprocal activity vs. time scale. ●, Sample of Sept. 21, 1961; ◒, Sept. 25, 1961; ○, Sept. 30, 1961. ■, Nov. 5, 1961; △, Nov. 10, 1961; □, Nov. 11, 1961. ▲, Nov. 18, 1961; Δ, Nov. 26, 1961. The solid lines represent the calculated decay curve according to the formula $A_t = A^* t^{-1.2}$.

movements one must know the contribution of individual test explosions to the measured fallout radioactivity. In principle this can be accomplished by determining the relative concentration of fission products of appropriate half life such as Sr-90, Zr-Nb-95, Ru-103, Iodine-131 and Ba-La-140, all of which have reasonably well known fission yields, taking also possible fractionation effects into account.

In the present work an alternative approach, based on an accurate analysis of the decay of the β activity of the fallout samples is used. Whether any sample is made up of debris from one or several bombs and which test was the most recent contributor to the radioactivity can be determined by assuming a decay law for the fission product mixture from any individual weapon test, such as a $t^{-1.2}$ law. A 1/activity vs.time plot was found most convenient for the former determination. FIG. 1 presents such decay plots of several fallout samples; it is seen that only the samples collected up to September 25 decay in a manner consistent with that of a fission product mixture from a single fission event: all later samples seem to be mixed to some extent. In the Sept. 30 sample, this is apparent from the deviation from the theoretical $t^{-1.2}$ decay curve. In later samples, which are less homogeneous, the curvature of the 1/activity plot is inverted during the first months. An upper limit for the time elapsed between sampling and the most recent test (t') may be calculated from the decay data, using the formula

$$t' = \frac{\Delta t}{(A_3/A_n)^{1/1.2} - 1} - 3,$$

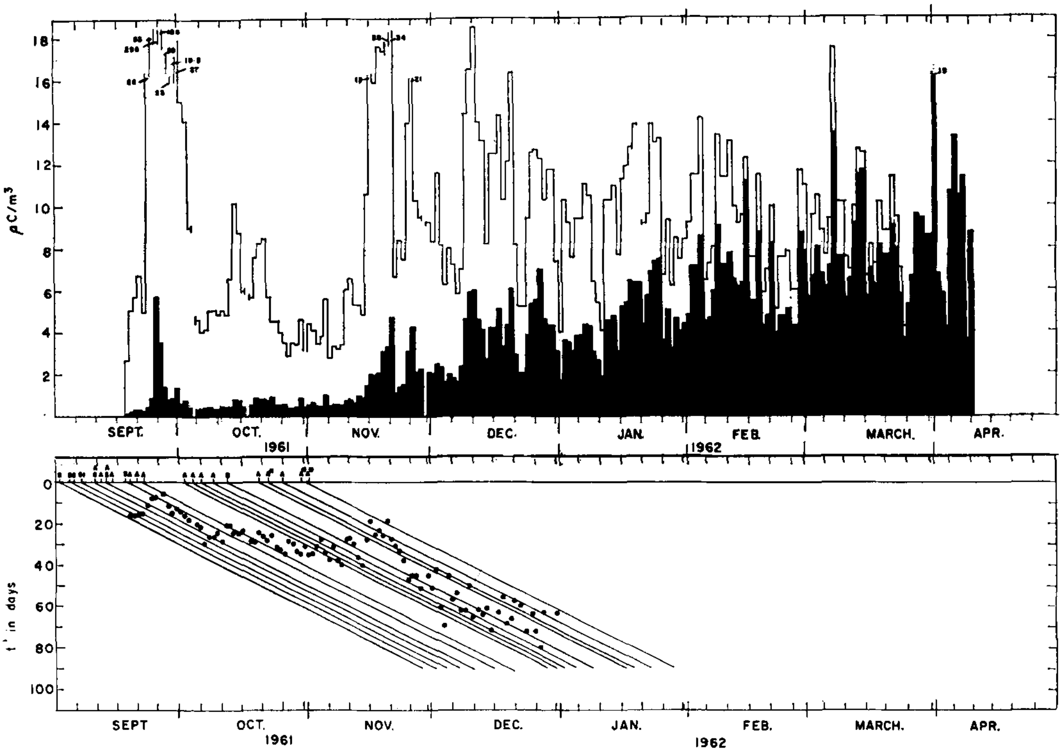

Fig. 2. Airborne radioactivity in Rehovoth surface air. Upper curve: activity of daily samples on third day after sampling. Blackened curve: residual activity of the daily samples in April 1962. Lower curve: computed time interval $-t'-$ between the nuclear test and sampling, based on the decay rate of the fallout samples during the first month after sampling. The announced dates of the nuclear tests are marked on the top of the lower diagram where *S* stands for the Siberian test site, *A* for a test conducted over the Arctic area and *St* a test conducted west of Stalingrad. The larger than 10 MT tests are marked by an asterisk. The straight lines represent the theoretical "ages" of the fallout from these tests.

where A_3 and A_n are the activities on the third and nth day after sampling, respectively, and $\Delta t = n - 3$ is the time interval between counting. Obviously a meaningful t' is obtained if the fallout derives from a single test and decays strictly according to the $t^{-1.2}$ decay law. When the sample is a mixed one the t' obtained by this procedure will be an overestimate, the more so the larger the time interval between counts. This type of analysis is of greatest use in determining the arrival of the first trace of debris from any explosion. The convenience of presenting the "age" in this way is apparent from Fig. 2 in which the values obtained for the daily fallout samples are plotted.

Results of measurements

Fig. 2 shows the daily β activity levels in the surface air at Rehovoth on the third day after sampling as well as the residual activity still present in the samples in April 1962. The extrapolated time origin—t'—of the collected fallout is also plotted for each sample. Straight lines connect the announced explosion dates to these "ages".

The main features of the data are:

(1) No fallout activity was detected in the near surface air during the first 17 days after testing was resumed.

(2) There is a sudden increase of fallout values from Sept. 18 onwards reaching a peak on the 21st. The average age of the material was 15 days. It seems to be quite homogeneous in composition, and probably derives from the test of Sept. 6 near Stalingrad.

(3) High activity levels (up to 300 pC/m³) were recorded from Sept. 23 to Oct. 5. The fallout consisted of very recent fission products,

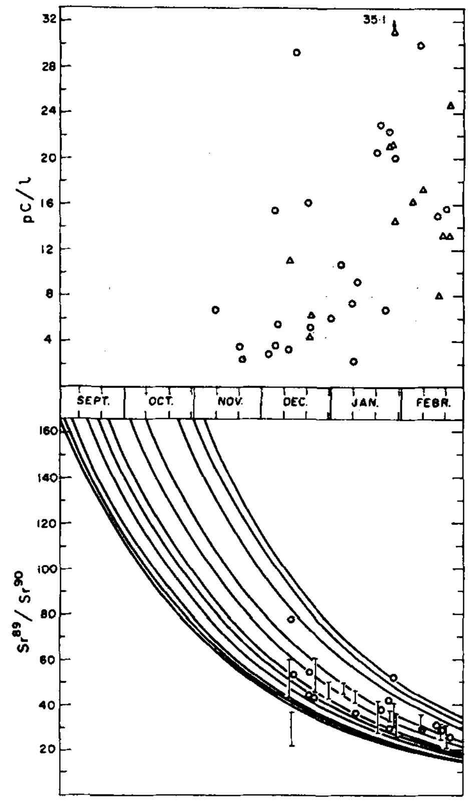

FIG. 3. Strontium-90 content (upper curve) and Sr-89/Sr-90 activity ratio (lower curve) of rain collected in Israel. Solid lines: calculated Sr-89/Sr-90 ratio lines for unmixed fallout samples from every test. Upper curve: △, Rain samples from Tirat Yael, Northern Israel; ○, The first four millimeters of rains of Rehovoth, Central Israel. Lower curve: I, Rehovoth rain, showing probable error of measurement; ○, Tirat Yael rains.

transported into the area in two distinct waves. The material was predominantly from the Arctic megaton test of September 20 or 22. The second wave contained some admixture of fission products from the earlier tests of this series.

(4) Fallout material of mixed composition arrived in waves during the period from Oct. 4 to Nov. 14, 1962. It derived from tests conducted in October. The age, based on the initial decay rate, was 20–35 days and activity levels were not very high. Relative activity peaks occurred on October 14 and 20, and again on Nov. 10–12. The latter peak contained material from the 30 MT test shot of October 23.

(5) From Nov. 15–21 an activity peak was recorded, resulting in part from the 50 MT test conducted some 20 days before. The collected fallout contained some debris from previous test shots. A secondary wave of high activity on Nov. 26 as well as the relatively little fallout amounts collected on the ten following days were of mixed origin.

(6) Activity levels from mid-December up to the spring of this year (1962) fluctuated considerably; the age of the fallout corresponded to a predominant contribution from the large tests of the second half of October. The absolute amounts of fission debris (long lived isotopes) rise steadily throughout the period. The long term decay of this material corresponds rather well to the decay law $A_t = A^* t^{-1.25}$. Generally, the air activity levels on rain days were minimal.

The activity levels recorded by the Nahal Soreq air monitor are in qualitative agreement with the results just described. There is, however, a quantitative discrepancy between the two sets of measurements, mainly due to the different efficiencies of the two filtering media, the Rehovoth activity levels being higher by a factor of two.

The results of the deposited activity measurements are difficult to analyze. The timing of the activity peaks and troughs agrees fairly well with those recorded by the air monitors, except of course on rain days. Average "dry fallout" deposition rates increased from about 400 pC/m²·day in October 1961 to 1000 pC/m²·day in mid-winter. The day to day variations are, however, larger than those of the air activity levels. Greatest activity deposition occurred on rain days. A peak deposition of 100 mμC/m²·day was recorded on Nov. 21.

Fig. 3 shows the strontium 90 content of showers collected during this period as well as the ratio of Sr-89 and Sr-90 activities in the same samples. The theoretical Sr-89/Sr-90 ratios at different times following nuclear tests are also plotted. These were calculated assuming fission yields of 2.9 % and 3.5 % respectively for the two nuclides.

The Sr-90 results confirm the increasing amounts of fallout during the second half of winter; the Sr-90 content of the early fallout was smaller by almost one order of magnitude. From the data it is calculated that 7.3 mC/km² of Sr-90 were rain deposited at Rehovoth during the winter of 1961/62. The total Sr-90 deposition, including dry fallout, during the period from the start of the 1961 test series to April 1962 may then be estimated as 9.5 mC/km^2.

The "age" of the fallout samples as determined by the Sr-89/Sr-90 ratios corresponds to an older fission products mixture than was inferred for these samples from a β decay analysis. Since the Strontium-90 deposition during the year prior to this test series was much lower than present levels any contribution of "old" Sr-90 can account for only part of this discrepancy. Possibly the fission yield ratio of the two nuclides under the fissioning conditions of this test series was about 30 % less than the one assumed. In agreement with the previous results the strontium ratio measurements indicate a trend towards more recent origin of the fallout collected later in winter.

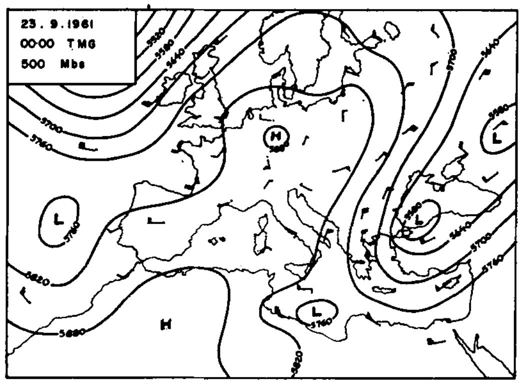

Fig. 4. Synoptic map at the 500 mb layer on Sept. 23, 1961 showing the rapid transport of polar air to the Eastern Mediterranean area.

Meteorological interpretation of the early fallout

Past analyses (Gat and Tokatly, 1962) have indicated a number of pathways through which fallout activity from the Russian test sites reached the Middle East. Among these were: (*a*) Transport around the pole under conditions of low index circulation with westerly winds in the upper troposphere; (*b*) Direct transport in the lower troposphere from the Siberian (or Arctic) test site under the influence of persistent high pressure systems over Russia; (*c*) Direct tropospheric transport from the Arctic test sites by polar air outbreaks across Europe; (*d*) Delayed stratospheric fallout mainly in the spring following the larger tests. For all megaton tests this latter was the path followed by most of the nuclear debris.

In the present series the most favoured fallout pathway up to Nov. 1961 seems to have been the circumpolar one, except for one case of direct transport according to path (*c*). Later in winter, the results suggest that stratospheric fallout was coming into the area at an over-increasing extent. The seasonal advection of easterly desert air into the Levant (path *b*), which in 1958 was responsible for bringing much fallout to the area, was absent during this autumn. These results will now be discussed in some detail.

During the first half of September, air currents upwards from the 700 mb layer came from the west. Under such conditions the path of arrival of fallout activity is presumably by a circumpolar route. Evidently up to Sept. 17, the cloud paths did not extend southwards enough to affect the area. This seems to be in agreement with the synoptic analysis of Machta *et al.* (1962). Although high pressure cells appeared over the Black Sea area in the very near surface air at the beginning of September these never persisted long enough to maintain a steady southward transport of Siberian air.

The rise of activity levels on the 17th of September and the first activity peak were unaccompanied by any marked synoptic change; southwesterly currents continued to prevail. At about the same time, the US. PHS reported high levels in the United States due to a polar air outbreak over Canada. The decay properties of the peak recorded here indicate that debris from an earlier test is involved, and that there is no obvious connection between the synchronous Israeli and American fallout peaks.

Commencing September 19, for some five days a singular atmospheric pattern developed over Europe (Fig. 4), in which strong currents of polar air masses advanced toward Turkey, west of a line of atmospheric depressions. These transport conditions ceased on the 26th, when the polar air became part of a semistagnant subsiding air mass which remained in the Eastern Mediterranean area till October 5th. From then onwards steady transport of air from the west became dominant. The activity peak during the period Sept. 23–October 5 clearly reflects this meteorological development, the activity levels rising to 300 pC/m^3 (age of

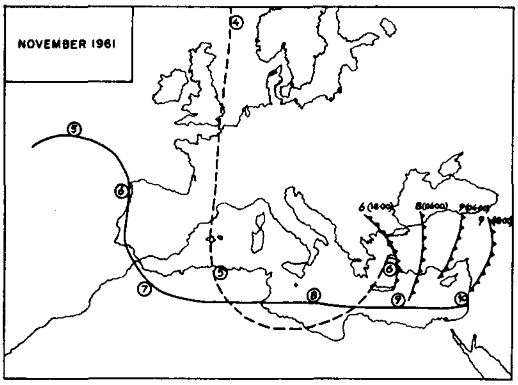

Fig. 5. Back-tracking of the air mass which passed over Israel on Nov. 10, 1961 in the 500 mb layer and the advance of the cold front which passed the area on the sameday.

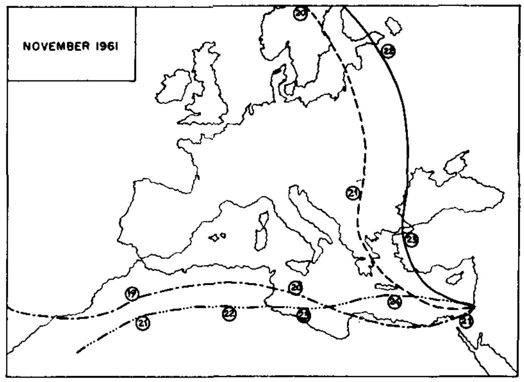

FIG. 7. Back-tracking of upper air (500 mb) which passed over Israel on successive days. —·—, 21.11.61; ———, 22.11.61; ———, 24.11.61; —···—, 25.11.61.

3–4 days). This polar ingression was the only clear case of direct transport from the test sites into the area during the present series. The secondary activity peak of Sept. 30 was probably the result of a local recirculation.

All through the rest of October the Levant was mostly under the influence of westerly winds coming in mainly along the North African shore. On Oct. 14 and again on October 20, cold fronts associated with marked vertical instability passed over this country; they are probably responsible for the relative activity peaks on these dates. It is worth mentioning that the Observatory in Athens reported high fallout levels on October 11 (ANASTASSIADES, 1962). An active depression was centered over Greece at that time, the northeastwards advance of which caused the fallout peak of Oct. 14 in Israel. Generally, the depressions active over Europe at that time affected only more northern latitudes.

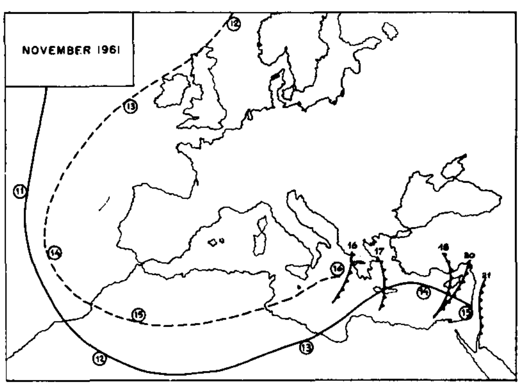

Fig. 6. Back-tracking of the air masses associated with the fallout peak of Nov. 15–21, 1961. The daily position at noon is computed for air moving in the 500 mb layer, and for surface air advancing with a cold front.

Prior to the first arrival of fallout from each of the two large test shots of the present series (on Nov. 10–12 and Nov. 15–21 respectively) very prominent and persistent depressions over Southwestern Europe had steered air from the Northern Atlantic into the Mediterranean area. In both cases these air masses then advanced eastwards with slow moving cold fronts. Fig. 5 summarizes this development which brought material from the test of October 22 into Greece on November 6 (ANASTISSIADES, 1962), and to Israel four days later. The postulated trajectory at the 500 mb layer is computed according to the method of HINZPETER *et al.* (1959). Fig. 6 shows the air trajectories prior to the arrival of debris from the superbomb of Oct. 30. It is apparent that the first trace arrival on November 15 as well as the air feeding the advancing cold front had followed almost identical paths around Europe.

A rapidly changing pressure pattern over Europe in the second part of the month resulted in the arrival in this region of air from different origins on successive days. This seems to be the cause for the trough in the fallout curve of Nov. 22–24, the secondary peak of Nov. 26 (which was very prominent in Greece three days before) and the sharp decline of radioactivity levels immediately afterwards. The computed upper air trajectories are plotted on Fig. 7. If one or two days for mixing to the ground from the upper air levels is allowed, one can again associate peak fallout values with air masses with a cross-zonal transport history and activity troughs with a zonal air circulation. Evidently throughout the autumn, the cross zonal transport conditions in the upper European troposphere were of great importance in determining the fallout levels in the Eastern Mediterranean area. However, by November all of the northern hemisphere seems to have been contaminated to some extent with the result that, irrespective of meteorological conditions, the activity levels never dropped below 3 pC/m³.

Instead of the expected gradual decline of activity levels during winter a marked increase from mid-December onwards occurred. A meteorological discussion will be forthcoming later. It is worthwhile to mention, however, that backtracking of many of the air masses associated with high fallout levels during this period shows them to have taken part only in a high index circulation. Early stratospheric fallout was probably the main reason for these increasing activity levels. An alternative explanation, namely, that the fallout was due to a gradual southward spread of contaminated air from the polar troposphere, cannot be entirely ruled out until activity measurements from stations situated in more northern locations are published. It seems, however, rather unlikely in view of the known short atmospheric residence times of tropospheric fallout.

Conclusion

The pattern of fallout transport into the Middle East following the 1961 test series was quite regular. Except for one case of direct fast advection, the route taken was such that at least two weeks elapsed between any test and the arrival of the related fallout activity. Because of its low age the activity levels were rather high during the months of September, October and November. However, the quantity of fission debris involved was generally small, indicating that the early fallout resulted from only a minor fraction of the fission debris. This was no longer the case later in winter, when increasing fallout levels have caused a total strontium-90 deposition far in excess of the one predicted by Machta *et al.* (1962) for this area. No sudden marked spring rise in activity levels has been found although the gradual increase of activity levels during the winter months has continued into spring.

The fallout encountered so far in the 1961 series differs in one respect from the fallout resulting from the 1958 October tests and for that matter from the first French test in the Sahara, in that the radioactivity seems to be more uniformly distributed between different sized dust particles and that fewer "hot spots" are encountered. Although autoradiograms of present fallout samples indicate some lumping in the activity distribution this is never very marked. As a result the relative responses of the various monitoring systems do not differ as much as in previous years and the different measurements are generally mutually consistent. An interesting conclusion which must be drawn is that the rise in activity levels during winter is not due to any gravitational settling of "heavy" particles but must be attributed to some other meteorological phenomenon.

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