# A Radio-Active Fall-Out Study at Melbourne, Australia

By A. J. DYER and MISS S-A. YEO
Division of Meteorological Physics, Commonwealth Scientific & Industrial Research Organisation, Melbourne, Australia.

(Manuscript received August 31, 1959)

## Abstract

Measurements of the radio-active fall-out occurring in weekly rainfall samples at Melbourne (Aspendale) are presented for the period June 1958 to February 1959. Radio-active decay analyses show the activity to have arisen from nuclear weapons tests carried out near the equator during the period April to September 1958. The results indicate that, despite presumably continuous dispersion, individual radio-active clouds maintain their discreteness and a limited E—W extent even after six or nine months residence in the stratosphere. This property allows a poleward drift speed of order 1 m/sec and zonal circulation velocities ranging from 6 to 17 m/sec to be inferred.

## 1. Introduction

The global fall-out of radio-activity as a result of nuclear weapons tests has been the subject of much enquiry in recent years. The variation of the fall-out pattern as a function of both time and latitude has posed a number of problems for the meteorologist. Several fall-out models have been suggested (LIBBY 1958, MACHTA 1958, MARTELL 1959, STEWART et al 1957) and the difficulty of deciding which may be the correct one is an indication of the limited extent of the present knowledge of the stratospheric circulation.

The investigation to be reported here began chiefly as a contribution to the International Geophysical Year, but the possibility of using radio-activity as a tracer of atmospheric motions was also considered. Measurements of the radio-activity of rain-water were commenced in June 1958, and are still continuing. It is felt that a detailed analysis of the results from June 1958 to February 1959 reveal features of the high-level circulations which bear directly on considerations of the various fall-out models being made by other workers.

## 2. Techniques of Measurement

The most widely used method of measuring the radio-activity of rainwater is to evaporate the sample into a small planchette and determine the total $\beta$-activity using a thin-window counter. This process is extremely time consuming in the evaporation stage and an ion-exchange technique of the type suggested by EDVARSON (1957) seemed more appropriate to our problem.

The ion-exchange resin (Bio-Deminrolit FF)[1] was used in two ways. The normal method, called in the following, "regular", consisted of collecting the rain with plastic-coated funnels and polythene jars and passing it twice through a single column of 10 cc of resin at a flow rate of approximately 1 litre/hr. The resin was then ashed in a silica crucible and the activity determined using an end-window $\beta$-counter (Phillips 18514). Tests indicated that 90 % of the activity was taken up in a *single* passage of the rain-water through the resin.

The alternative method, called "auto", is

[1] Supplied by the Permutit Co. of Australia, Sydney, Australia.

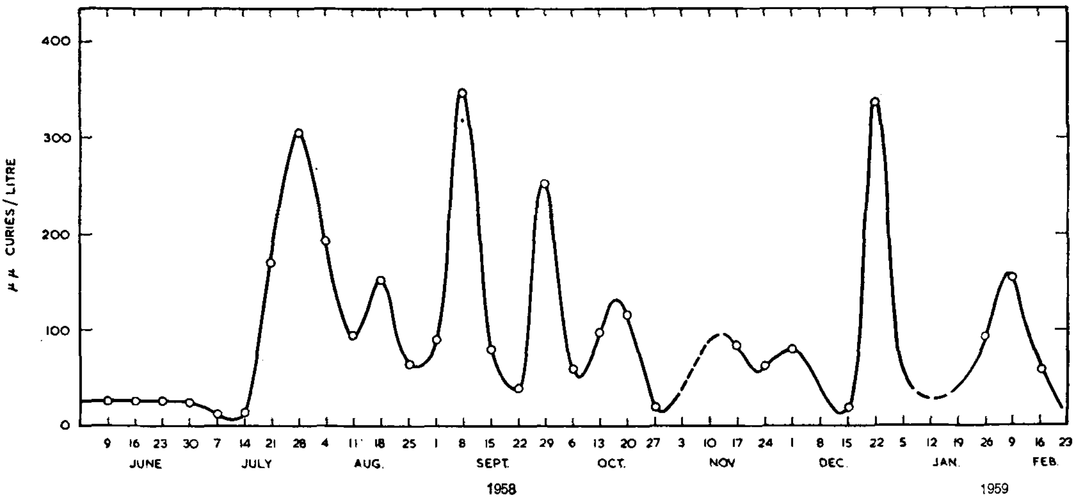

Fig. 1. Radio-activity of weekly samples of rain water.

particularly suited to sampling at a large number of distant field stations in that the rain-water passes through the resin at time of collection. A plastic cartridge containing 10 cc of the resin is fitted in an S-tube between the funnel and the collecting vessel, the S-tube being suitably filled with a measured quantity of distilled water to maintain the resin efficiency.

The equipment was calibrated by using standard solutions of potassium carbonate. A rain-sampling period of one week was used, except for the first case (June 1958) in which a monthly sample was taken.

For the few weeks when no rain occurred the "regular" collector was washed out with one litre of distilled water and this was then treated in the usual way. Before each sampling period the collecting funnels and jars were thoroughly washed with distilled water.

### 3. Estimation of Explosion Dates

An estimate of the date of origin of the fission sample can be made by using the decay law $I_t = I_0\ t^{-1.3}$ of HUNTER and BALLOU (1951), in which the activity $I_t$ at time $t$ after the explosion is related to the activity $I_0$ at $t = 1$ (In our case $t$ is measured in weeks). Using this expression one can write $I_{2t} = 0.41\ I_t$, and the unknown ($t$) can thus be estimated by determining the time for the activity of a sample to decay to 0.41 times its initial observed value.

If the decay of a sample is plotted on a log-log scale of activity versus time, linear interpolation can be used to determine $t$ by the above method even if the time origin of the graph is only approximately correct. In a few cases a non-linear plot was obtained, and the estimated explosion dates for these are therefore somewhat uncertain.

It is well known that the exponent in the decay law assumes slightly different values for different types of nuclear explosions, and the dangers of using a constant value of 1.3 are well recognised. Apart from this point, which will be discussed later, the error in estimating $t$ is thought to be about 6 %.

### 4. Results

The results obtained are listed in Table 1 and presented in Figure 1.

Two things of interest are immediately obvious from Table 1. Firstly, the good agreement of the "auto" and "regular" techniques in estimating the explosion date is encouraging. Secondly, it is evident that the estimated explosion date varies considerably from week to week.

Series of United States and United Kingdom test explosions were conducted in equatorial regions from April to September 1958. If the debris from such series of explosions were distributed quickly throughout the whole atmosphere so that a homogeneous mixture was created it would most likely follow a decay law appropriate to a mean of the explosion

**Table 1. Radio-active rain measurements at Melbourne, Australia.**

| Date of Collection | Amount Rain mm | $\mu\mu$ curies/litre | mc/Km$^2$ | Estimated explosion dates | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Regular | Auto | Series | | | | | | |
| June 1958 | 21 | 23.6 | 0.49 | — | | | | | | | | |
| 7. 7.58 | 22 | 7.3 | 0.16 | — | | | | | | | | |
| 14. 7.58 | 38 | 12.2 | 0.47 | — | | | | | | | | |
| 21. 7.58 | 21 | 164 | 3.52 | May 25 | | A | | | | | | |
| 28. 7.58 | 07 | 295 | 2.10 | July 3 | | | B | | | | | |
| 4. 8.58 | 10 | 193 | 1.99 | June 26 | | | B | | | | | |
| 11. 8.58 | 15 | 92 | 1.41 | June 3 | | A | | | | | | |
| 18. 8.58 | 32 | 147 | 4.70 | June 10 | June 11 | | | C | | | | |
| 25. 8.58 | 28 | 63 | 2.70 | June 24 | June 22 | | B | | | | | |
| 1. 9.58 | 09 | 86 | 0.74 | June 28 | June 17 | | B | | | | | |
| 8. 9.58 | 04 | 334 | 1.25 | June 16 | — | | | C | | | | |
| 15. 9.58 | 14 | 78 | 1.05 | May 19 | — | A | | | | | | |
| 22. 9.58 | 42 | 41 | 1.71 | May 25 | May 25 | A | | | | | | |
| 29. 9.58 | 07 | 246 | 1.68 | May 29 | — | A | | | | | | |
| 6.10.58 | 19 | 56 | 1.07 | July 2 | — | | B | | | | | |
| 13.10.58 | 23 | 96 | 2.15 | July 13 | Aug. 4 | | | | D | | | |
| 20.10.58 | 13 | 111 | 1.48 | Aug. 14 | — | | | | | E | | |
| 27.10.58 | 32 | 19.4 | 0.62 | July 15 | July 25 | | | | D | | | |
| 3.11.58 | | — | — | No measurement | | | | | | | | |
| 10.11.58 | 25 | — | — | No measurement | | | | | | | | |
| 17.11.58 | | 80 | 2.03 | Aug. 12 | Aug. 11 | | | | | E | | |
| 24.11.58 | 20 | 60 | 1.18 | June 25 | July 27 | | B | | | | | |
| 1.12.59 | 20 | 76 | 1.49 | Aug. 31 | — | | | | | | F | |
| 8.12.58 | 00 | No rain | 0.44 | Sept. 8 | Aug. 25 | | | | | | F | |
| 15.12.58 | 39 | 17.3 | 0.67 | June 23 | — | | B | | | | | |
| 22.12.58 | 02 | 325 | 0.49 | Sept. 4 | — | | | | | | F | |
| 29.12.58 | 00 | — | — | No measurement | | | | | | | | |
| 5. 1.59 | | No rain | 0.59 | Sept. 11 | — | | | | | | F | |
| 12. 1.59 | 01 | No rain | 0.18 | July 27 | — | | | | | | | G |
| 19. 1.59 | 00 | No rain | 0.33 | June 11 | — | | | C | | | | |
| 26. 1.59 | | — | — | No measurement | | | | | | | | |
| 2. 2.59 | 06 | 89 | 0.58 | July 27 | — | | | | | | | G |
| 9. 2.59 | 04 | 152 | 0.57 | July 30 | — | | | | | | | G |
| 16. 2.59 | 19 | 56 | 1.05 | Aug. 4 | — | | | | | | | G |
| 23. 2.59 | 00 | No rain | 0.28 | Sept. 16 | — | | | | | | F | |

dates and with an exponent approximately equal to 1.3. Using an incorrect exponent, the *estimated* explosion dates would progress slowly from week to week. This picture would only emerge from the present data if the correct exponent varied erratically from week to week. This in itself implies a degree of inhomogeneity inconsistent with the hypothesis of a uniform distribution in the atmosphere.

What appears to be a more plausible explanation of the variability of the present results is that the use of the $t^{-1.3}$ law is substantially correct and that samples from different test explosions are obtained in consecutive weeks. If this view is adopted for the time being, the estimated explosion dates can be used to "tag" the passage of a particular atomic cloud. This has been done in Table 1 in which the re-occurrence of the same (or nearly the same) date is recognised as being due to a sample from the same test explosion (Series A, B etc.). The mean explosion date for each series can then be compared (Table 2) with the dates of known nuclear tests obtained from press reports.

Other United Kingdom tests during this period were low yield explosions on August 22 and September 23, and a megaton explosion on April 28. The United States also conducted tests on May 11—12 and July 5. No information of the yield of any of the U.S.A. tests is available, although from micro-barograph records here it is believed that large explosions took place on June 28 and July 12.

It is of interest to analyse the arrival time and circulation times of each of the atomic clouds (Table 3).

**Table 2. Comparison of estimated and known explosion dates.**

| Series | Mean estimated Explosion Dates | Actual Explosion Dates | |
|---|---|---|---|
| A | May 26 | May 25 | U.S.A. Test Eniwetok |
| B | June 28 | June 27 | U.S.A. Test Eniwetok |
| | | June 27 | U.S.A. Test Bikini |
| | | June 28 | U.S.A. Test Eniwetok |
| | | July 2 | U.S.A. Test Bikini |
| C | June 12 | June 10 | U.S.A. Test Bikini |
| | | June 14 | U.S.A. Test Bikini |
| D | July 14 | July 11 | U.S.A. Test Bikini |
| E | Aug. 13 | Aug. 12 | U.S.A. Test Johnston Island (Missile) |
| F | Sept. 6 | Sept. 2 | U. K. Test Christmas Island, High Yield |
| | | Sept. 9 | U. K. Test Christmas Island, High Yield |
| G | July 30 | July 26 | U.S.A. Test Eniwetok |
| | | Aug. 1 | U.S.A. Test Johnston Island (Missile) |

**Table 3. Analysis of arrival and circulation times.**

| Series | Arrival time (weeks) | 1st Circulation time (weeks) | 2nd Circulation time (weeks) | 3rd Circulation time (weeks) |
|---|---|---|---|---|
| A | 7.5 | 3 | 5, 6, 7 | — |
| B | 3, 4 | 3, 4 | 5 | 7, 10 |
| C | 9 | 3 | (19) | — |
| D | 13 | 2 | — | — |
| E | 9 | 4 | — | — |
| F | 11.5 | 3 | 7 | — |
| G | 19 | 3, 4, 5 | — | — |
| Mean times | 10.6<br>Corrected 9.0 | 3.1 | 6.0 | 8.5 |
| | Mean meridional drift | Mean zonal circulation | | |
| | 0.9 m/sec corrected to 1.1 m/sec. | 17 m/sec | 10 m/sec | 6 m/sec |

The various values obtained are grouped closely about their mean values. A mean drift velocity and mean zonal circulations can be calculated from the mean arrival time and mean circulation times respectively (Table 3). As the first arrival of a cloud at this latitude is unlikely to occur precisely at the longitude of Melbourne, the arrival time will be overestimated on the average by approximately half the zonal circulation time. An appropriate correction is made in Table 3.

## 5. Discussion

A tentative explanation of the above results can be advanced in the following terms. The observed fact that fission debris arrived at ground level at latitude 38° S for a period of several months after a series of test explosions clearly implies a stratospheric circulation from equator to middle latitudes if one accepts the well established residence time of one month for radio-active particles within the troposphere. The radio-active cloud produced by an atomic bomb appears to migrate (or disperse) polewards from the equator with a limited amount of spreading in an east-west direction. The latitude dependance of $Sr^{90}$ deposition observed by several authors, STEWART et al (1957), MARTELL (1959) would favour the idea of migration rather than dispersion. The greatest amount of east-west spreading observed was that of Series A and Series G which were detected for three consecutive weeks at a period of four to seven months after the date of explosion. This indicates an east-west spread of about half the global circumference at this latitude.

MINTZ (1954) has presented data on mean zonal winds as a function of height, latitude and season. The value of 15 m/sec for the first observed circulation of the earth by the cloud suggests from Mintz's data a height of approximately 100 mb. (16 km). Values of 7.5 m/sec and 5 m/sec for the subsequent circulations imply that even greater heights are involved. Heights of 400 mb (7 km) to 700 mb (3 km) would also give the correct zonal velocities but these lie well within the troposphere and can presumably be ignored.

WEXLER (1957) in an examination of the Krakatoa dust cloud movement finds evidence for a mean meridional drift at 19 km height of 1.6 m/sec at 10° N decreasing to 0.6 m/sec at 40° N. Similar values are reported in another context by PRIESTLEY and TROUP (1954) for the region between the latitudes 30° and 35°. The value of 1.1 m/sec found in the present investigation for a mean meridional drift between equatorial regions and 38° S seems therefore to be consistent with the above notion of stratospheric circulation.

A number of models of global fall-out have been suggested; LIBBY (1958) proposes that stratospheric debris is distributed uniformly over both hemispheres with a stratospheric residence time of 5—10 years, and attributes the observed latitude dependence and increase in spring fall-out to rainfall variations and the testing of sub-megaton weapons in middle latitudes. STEWART et al (1957) find their results in agreement with the zonal circulation model proposed by BREWER (1949) and DOBSON (1956) in which air rising into the stratosphere at the equator descends into the troposphere in middle and polar latitudes. A recent discussion by MARTELL (1959) attributes the increase in spring fallout to Russian tests in the immediately preceding autumn together with a short stratospheric residence time in middle latitudes.

The present results strongly suggest the existence of a poleward drift in the lower stratosphere, and indicate that even after a period of six to nine months the debris from a test explosion is not distributed uniformly throughout the stratosphere. During this period some of the radio-activity appears at the ground in middle latitudes, but there is no indication of the mechanism by which the radio-activity reaches the troposphere.

A plausible view would be that the stratospheric residence time depends on the size of the bomb and to some extent the height at which it was exploded.

An examination of fall-out data for other parts of the world in the same terms would be of obvious value. A sampling period of one week appears to be particularly suited to this type of study.

## 6. Acknowledgements

Many thanks are due to Miss Y. Mullins who assisted in the design of the experiment and carried out a number of the measurements and computations. Mr. G. Grauze collected and processed the samples.

## REFERENCES

BREWER, A. W., 1949: Evidence for a world circulation provided by the measurements of helium and water vapour distribution in the stratosphere. *Q. J. Roy. Met. Soc.* **75**, pp. 351—363.

DOBSON, G. M. B., 1956: Origin and distribution of polyatomic molecules in the atmosphere. *Proc. Roy. Soc. London* A **236**, pp. 187—192.

EDVARSON, KAY, 1957: A method for monthly collection of radio-active fall-out. Appendix to a report for U. N. Scientific Committee on the effects of atomic fall-out.

HUNTER, H. F., and BALLOU, N. E., 1951: Fission product decay rates. *Nucleonics* **9**, pp. C 2—7.

LIBBY, W. F., 1958: Isotopes in meteorology. *Bull. Amer. Met. Soc.* **39**, pp. 65—68.

MACHTA, L., 1958: Discussion of meteorological factors and fall-out distribution. *U.S.A.E.C. HASL*-**42**, pp. 310—338.

MARTELL, E. A., 1959: Atmospheric aspects of Sr. 90 fall-out: *Science* **129**, pp. 1197—1206.

MINTZ, Y., 1954: The observed zonal circulation of the atmosphere. *Bull Amer. Met Soc.* **35**, pp. 208—213.

PRIESTLEY, C. H. B., and TROUP, A. J., 1954: Physical interactions between tropical and temperature latitudes. *C.S.I.R.O. Aust. Div. Met. Phys. Tech.* Pap. No. 1.

STEWART, N. G., OSMOND, R. G. D., CROOKS, R. N., and FISHER, MISS E. M., 1957: The world-wide deposition of long-lived fission products from nuclear test explosions. *A.E.R.E. Publ. No. AERE* HP/R 2354.

WEXLER, H., 1951: Spread of the Krakatoa volcanic dust as related to high level circulation. *Bull Amer. Met. Soc.* **32**, pp. 48—51.