Reprinted from *The Australian Journal of Science*, Vol. 20, No. 5, December, 1957, page 125.

Radioactive Fallout in Australia from Operation 'Mosaic'

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By agreement between the Australian and British Governments, two atomic weapons were tested at the Monte Bello Islands off the north-west coast of Australia in May and June 1956. Both weapons were in the kiloton range and were fired from towers appropriately located on the islands. The first explosion, the smaller of the two, occurred on 16 May and the second and larger one on 19 June 1956. In order to select firing conditions for the tests so that safety was ensured, a complex scientific organization was necessary. In the first place a meteorological network was required not only to provide data to enable appropriate firing conditions to be chosen, but also to indicate probable trends following a firing. Secondly a radiological monitoring service was required to measure the fallout in the immediate vicinity of the test site and also to confirm that the fallout at great distances from the site did conform to prediction. In this paper we shall deal in detail with the meteorological situation and the fallout over Australia since these are of considerable interest.

Simple Phenomenology of Nuclear Explosions

With weapons in the kiloton range the cloud produced by an explosion is roughly in the form of a mushroom which rises to altitudes of between 20,000 feet and 50,000 feet, depending upon the yield and the atmospheric conditions at the time. The radioactive products of the fission reaction and the greater proportion of the radioactive particles which arise from the vaporization by the fireball of unfissioned radioactive material, bomb casing, and ancillary equipment, remain in the cauliflower-like head of the cloud in the form of an exceedingly fine aerosol. It is this high cloud, composed of exceedingly fine particles, that is the source of 'long range' or 'delayed' fallout. This cloud may drift several times around the world in a narrow band of latitude, gradually losing its solid particles by deposition to lower levels where rain may quickly take them to the ground. Sometimes it is possible to show that traces of radioactivity still remain in the remnants of a cloud passing overhead several weeks after an explosion. This can be done by collecting rain at ground level and by using sensitive instruments to prove that the rain contains radioactivity decreasing with time according to the decay law of bomb debris.

In the initial stage of the explosion, violent updraughts are produced and carry into the cloud particles of a wide range of sizes which have acquired radioactivity by intimate contact with the products of fission. As the cloud reaches maximum altitude the relatively large and heavy particles commence to fall back to the ground and are deposited within a few miles of ground zero. The smaller particles within the cloud fall more slowly depending on their size, and their path to earth is determined by wind in the successive layers of the atmosphere through which they fall. It is this type of fallout that gives rise to the area of heavy contamination in the immediate vicinity of the explosion centre and the extension and position of the contaminated area is determined by the wind structure and the height attained by the cloud. This is the 'close in' or 'short range' fallout and it is deposited within a few hours, out to perhaps a hundred miles from ground zero in the general direction of the mean wind. This type of fallout includes a large part of the radioactive products and in these tests meteorological conditions were chosen so that it was deposited into the ocean.

In addition to the two main sources of fallout mentioned above, there is a third source that can lead to light contamination at considerable distances from the explosion centre and away from the path of the high cloud. This arises because small quantities of fine radioactive particles are left behind in the stem of the mushroom cloud. The fallout of this material is affected more strongly by the lower wind

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structure than the heavy particles constituting 'close in' fallout and it is possible for it to be transported many miles from the scene of operations.*

Meteorological Conditions

Character of the Operations

During May and June, the chosen test period, the weather in the vicinity of the Monte Bello Islands is usually characterized by a general south-easterly circulation of air which has been stabilized over the continent up to approximately 6,000 feet. The lower level winds are somewhat variable and markedly affected by the coastal influence, but from 10,000 feet upwards the circulation becomes predominantly westerly. The variability of the atmospheric environment is indicated by movement of the tropopause between 44,000 feet and 59,000 feet, and the freezing level between 10,700 feet and 17,700 feet, while the inversion separating the overlying (dry) maritime air from the modified surface air mass fluctuates between 12,000 feet and 19,000 feet.

From general considerations, it would be apparent that radioactive deposition would occur on the mainland unless each test was conducted during an interval of interruption to the prevailing wind circulations. Operationally, this led to the need for early recognition of the development of a favourable meteorological situation.

The essentials of both precise forecasting and operational economy called for the accurate charting of the wind fields at various heights extending sufficiently westward to give an adequate time lapse in the detection of breaks in the dominant wind patterns up to the tropopause. This purpose was served by a weather ship station about 600 miles to the west of the site, together with a wind-finding station on Christmas Island in the Indian Ocean, and long-range meteorological reconnaissance flights over the Timor Sea. The data secured from these stations was linked to an elaborate meteorological organization (see Figure 1) extending eastwards from Cocos Island and extending from the equator to the coast of the Antarctic Continent. The data from the network were channelled to the Meteorological Group in a special radioteletype communication system handling 20,000 groups per day. In addition, the variations in the local atmospheric structure were measured by a close sequence of radiosonde and radar wind observations up to 60,000 feet, which were continued up to and after the times of firing.

Meteorological Effects

The meteorological data had four direct applications in

(a) predicting the growth and shape of the cloud;

(b) ensuring that the distribution of radioactivity in the vicinity of the firing site would not affect the continued occupation of the test installation;

(c) ensuring that the particulate material would be deposited in the sea;

(d) ensuring that the trajectory of the suspended particulate material over any inhabited areas would be free of any atmospheric processes that might lead to washout by precipitation.

The cloud from a nuclear explosion arises from the high temperature spherical convection cell which is formed at detonation and which, as can be demonstrated experimentally (Batchelor, 1954; Scorer and Ronne, 1956), develops as a rapidly ascending vortex ring entraining air as it rises. The vertical development of the cloud is thus assisted by large temperature lapse rates and the latent heat which would be supplied by the condensation of any appreciable water vapour. The cloud height is related to the stability structure of the environmental atmosphere in the general form $H = \phi\ (Q/\bar{a}\ \bar{\rho})\theta$ where Q represents the heat source, $\bar{a}$ the gradient of potential temperature and $\bar{\rho}$ the gradient of density and ϕ and θ are parameters of diffusion (Sutton. 1950, 1955).

For the first test* the local radiosonde observations taken one hour before the explosion confirmed the forecast that subsidence in a high pressure ridge would extend stable dry air up to 21,000 feet, before meeting the overlying maritime air. The stability structure permitted considerable tolerance in computing the height of the cloud before it could be extended by convectional instability.

For the second test, also, the local radiosonde observations confirmed a structure of stratified layers below 400 mbs (24,490 feet) with no detectable moisture above 850 mbs (4,920 feet) at the top of a surface inversion. Above 400 mbs the air mass was relatively stable up to the tropopause at 124 mbs (about 49,000 feet). During the growth of the second cloud a marked distortion appeared on the stem at the level of a discrete layer of very small temperature lapse shown on the aerological diagram between 500 mbs (18,930 feet) and 410 mbs (23,900 feet) (see Figure 2).

Fallout Patterns

The deposition of the radioactive material from the explosion can be thought of as a settling of particles diffusing under varying scales of turbulence (Meteorology and Atomic

* The very slight activity reported at Marble Bar, Western Australia, and at Cloncurry in Queensland following the second weapon test, could have arisen from this cause. It did not indicate that the radioactive cloud passed over the mainland.

* The synoptic situation on 16 May 1956 placed a warm ridge extending north-eastwards some 300 miles from the Monte Bellos behind a marked trough leading to a large depression in the Australian Bight which was strongly evident at 500 mbs and higher. At the time of firing the local wind structure was associated with a pronounced southerly component at lower levels, which ensured that all dangerous contamination would fall well to seaward.

Energy, 1955) while being displaced by the varying winds they encounter as they fall from their initial position in the cloud. The immediate fallout around the explosion site consists of the strongly radioactive heavier particles with high terminal velocities. Their scatter is related to the degree of gustiness in the local winds.

The lighter particles with progressively lower terminal velocities are carried by the wind up to considerable distances and spread by diffusion at a rate depending upon the degree of stability of the environment. They will be diffused laterally about a centre line coinciding with the direction of the mean wind from the surface up to the top of the cloud, taking into account the variations with time and distance. If the wind direction remains constant with height the contamination contours have a 'key-hole' pattern of width about one-seventh of its length. If, as is the usual case, the wind direction varies with altitude, the contour patterns will be widened and shortened as the displacement of falling particles spreads with their height of origin. This phenomenon of vertical wind shear was to be expected whenever the atmosphere was stratified or built up by overlying air masses. Particles settling from different heights in the cloud will be displaced by the various winds they encounter in each of the strata through which they fall. They will reach the surface at a distance and bearing from ground zero given by the resultant $\Sigma V \frac{h}{v}$, where V is the vector wind, h the depth, and v the settling speed in each stratum they encounter. These displacements can be computed in terms of an 'effective wind' derived for each height.

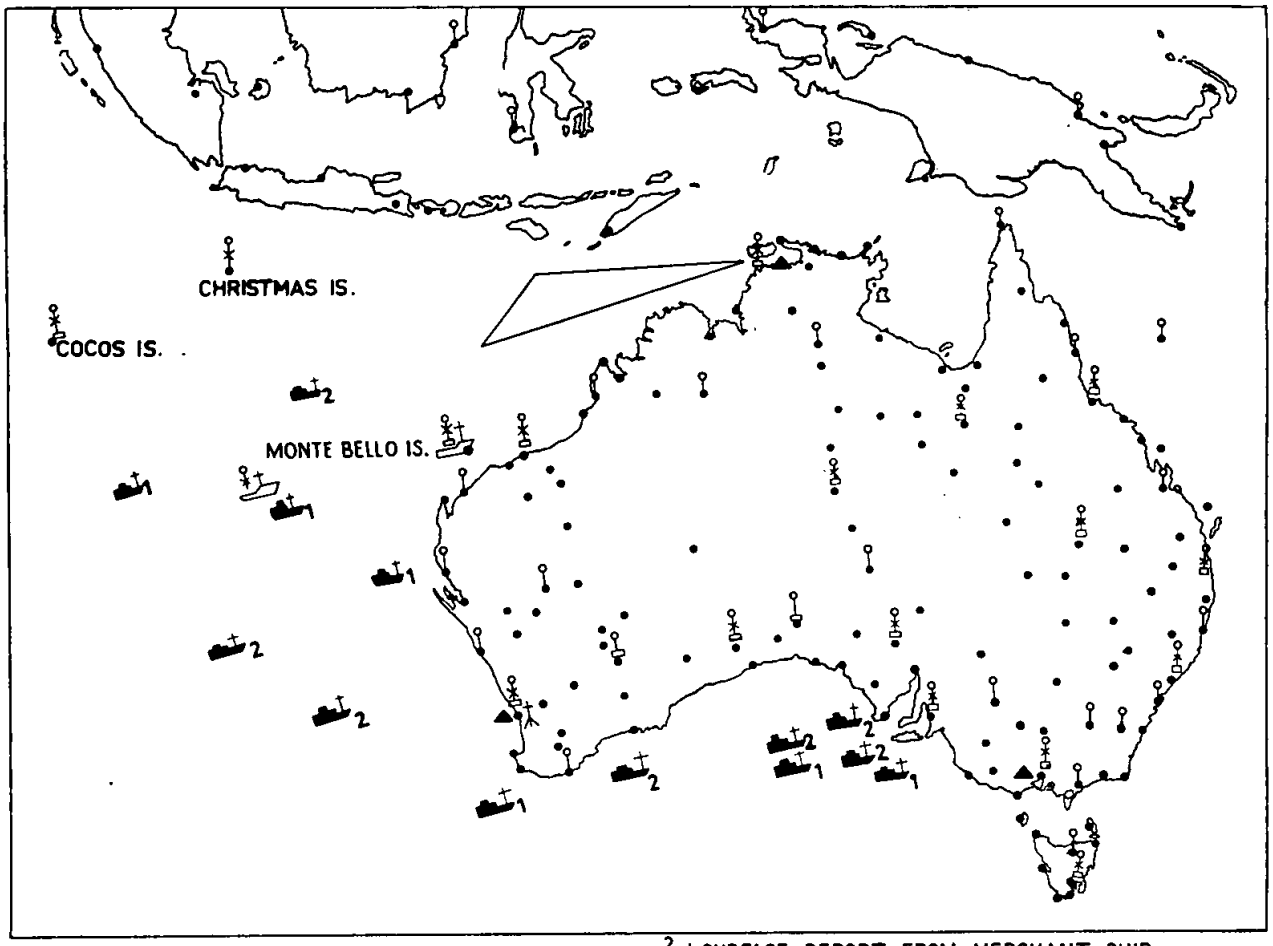

Figure 1
The network of meteorological observatories.

Vertical wind shear at the time of the first test spread the fallout north and north-north-east of the Monte Bellos entirely over the sea. The effect is indicated by the trajectories, computed for particles arriving on the surface of the sea under gravity from 20,000 feet at 20 and 40 hours after firing (Figure 3).

At the second test the wind shear was not so marked and the fallout was spread in a narrow plume lying well off the Australian coast.

The Cloud Trajectories

The finer particles of debris which remain in suspension at the height of the 'mushroom' cloud form a volume of low concentration quickly expanding to hundreds of cubic miles, which is carried by the prevailing wind circulation at that altitude. It is affected by a different order of large-scale turbulence and, as it

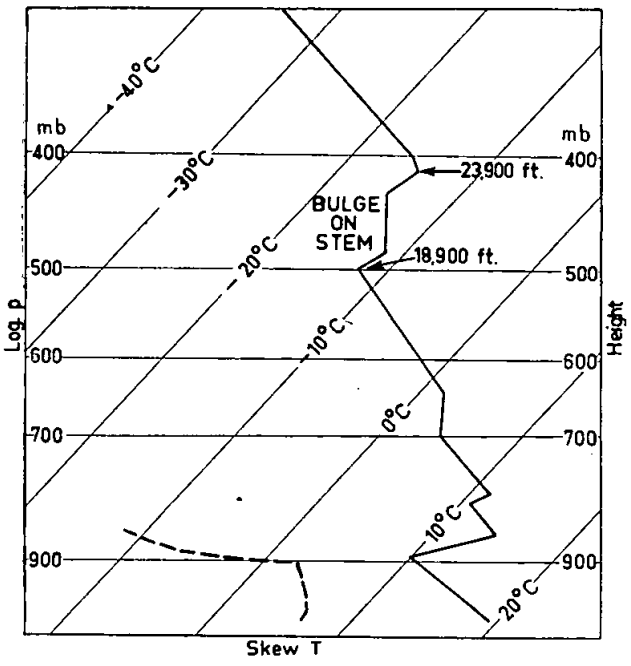

Figure 2

The atmospheric temperature sounding before explosion G2.

travels, it is steadily dispersed over a large area by vertical wind shear and large convectional cells as well as eddy diffusion. The suspended particles may travel around the world several times until they are eventually brought down at great distances and, after long periods, in minute concentrations by eddy transfer or rain.

After the first test the suspended remnants of the 'cloud' moved eastwards along latitude 20°S and were clear of the east coast of the continent within 60 hours (Figure 4). Slight evidence of the passage of the cloud was provided by fallout data at Wyndham, Daly Waters, Cloncurry, Cairns, and Townsville. Later there were indications that it had passed over New Zealand.

After the second test* the cloud moved north-east over the Timor Sea without approaching the mainland of Australia. Five hours after firing it was found by aircraft more than 200 miles off the coast covering an area of 60 by 40 miles. It continued in a general north-east direction and was again located on this course

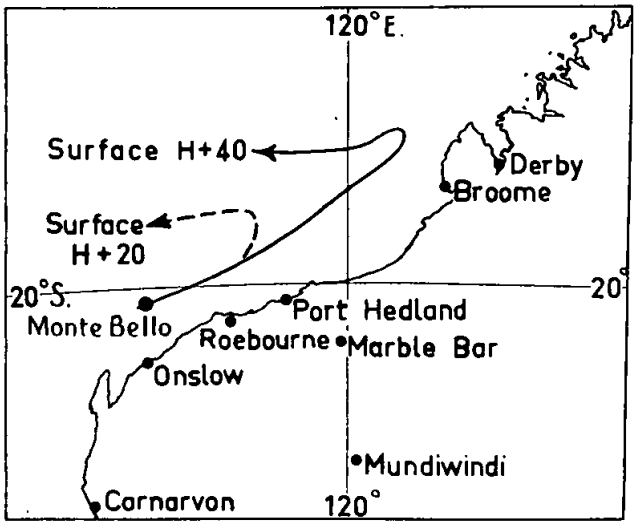

Figure 3

The effect of vertical wind shear for G1 is shown by trajectories computed for particles arriving at the surface of the sea from 20,000 feet at 20 and 40 hours after firing.

seven hours later. In order to check that it had not crossed the coast a box search was made of an area of some 70,000 square miles around Darwin on the afternoon of 20 June, and another coastal search between Broome and Darwin was made on 21 June. The readings showed that no part of the main cloud had approached closer than 200 miles of the mainland.

* The first indication of an interruption to the general wind pattern was seen on 16 June with the detection of a ridge at 300 mbs developing from Shark Bay south-eastwards into the Western Bight. This suggested that a break would follow in the circumpolar wave length of the westerlies which had persisted unusually strongly, thus indicating that an extensive low pressure area controlling the circulation to the south of the Continent would be replaced by a high pressure system.

On the day of firing, an anticyclone over the Australian Bight had a north-westerly pressure gradient over West Australia with a minor trough line off the Coast from North-West Cape to Geraldton. Except for some light rain at Alice Springs, the air mass over the whole of the northern portion of the continent was relatively dry and stable. The 500 mb chart (20,000 feet) featured a marked trough line running NW-SE over Onslow and curving to the east-south-east over South Australia. At this level the wind field streamlines showed a centre of outflow WNW of the Monte Bellos and a family of singular points over the eastern part of West Australia. At 200 mbs (about 40,000 feet) the trough line was further to the west with south-westerly winds off the coast and north-westerlies over the Continent. There was good evidence that the only area subject to rain during the following 24 to 48 hours in the vicinity of the 20,000 feet trajectory would be to the south of latitude 20 in Queensland.

Dispersion of the Stem Material

In addition to the 'close-in' fallout there was some slight fallout on both occasions caused by the dispersion of a small quantity of finely suspended particles from the 'stem' which was trapped in a stable layer somewhat below the base of the cloud.

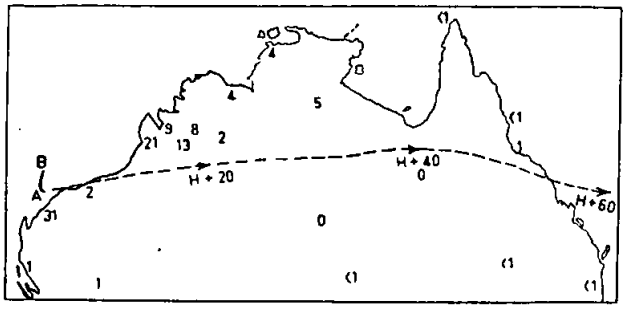

Figure 4

The axis of the 'close-in' fall-out pattern for G1 is indicated by the line AB. The motion of the centre of the high altitude cloud across northern Australia is indicated by the broken line, the time of transit being a little over 50 hours. The cloud expands and dilutes as it ages; its position is indicated at 20, 40 and 60 hours after firing. The numbers included on the diagram are fall-out measurements (refer to Table I) and give the upper limit of whole body gamma-ray dose integrated to 50 years and expressed in millirontgens, which could be received.

At the first test a marked wind shear, which occurred in association with a minor inversion near 10,000 feet, cut off a small amount of the stem material in a local wind circulation from a centre of light outflow near Marble Bar at H + 12 hours. During the following twelve hours, while the centre of outflow moved north-east to Wyndham, the trajectory of these particles at first moved seawards, but later recurved to cross the coast between Onslow and Broome, more than a day after the primary cloud had passed. As a result, small levels of radioactivity were observed at Broome and Onslow (see Table 1).

At the second test, a pronounced stable layer produced a marked bulge on the stem which trapped a small quantity of particulate material and this was spread to the south-east of the Monte Bello Islands (see Figure 5).

The absence of any radioactivity at Carnarvon or Meekatharra confirmed that the area of this type of deposition was quite limited.

The more finely suspended material from this source was quickly spread by a marked divergence in the constant level wind trajectories at 10,000 and 20,000 feet. Within 24 hours it was spread over a width of 600 miles between latitude 22°S and latitude 16°S (see Figure 6). These trajectories curved to the east and south-east and commenced to cross the east coast of the continent during the evening of 21 June. During its course this debris was dispersed in the first 48 hours by vertical shear and extensive meridional scattering without scavenging by precipitation except for the very light and isolated shower near Marble Bar.

TABLE I

Fallout measurements following explosion G1
(S indicates that if any activity was present, it was too small to measure)

Station Number	Location	Activity of daily samples in μc/m² at mid-collection time								Whole body gamma dose to 50 years as a result of fallout from G1 in mr
		16/5	17/5	18/5	19/5	20/5	21/5	22/5	23/5	
1	Adelaide	S	S	S	S	S	S	S	S	0
2	Liveringa	S	1·0	2·7	1·9	0·4	0·03	0·1	0·02	9
3	Woomera	S	S	S	S	S	S	S	S	0
4	Halls Creek	S	S	S	1·0	S	S	0·02	0·01	2
5	Fitzroy Crossing	S	1·1	3·9	0·9	0·04	0·06	0·02	0·04	8
6	Port Moresby	S	S	S	S	S	S	S	S	0
7	Noonkanbah	S	4·5	4·3	1·3	0·1	0·09	0·1	0·02	13
8	Broome	S	21·0	0·5	0·3	0·4	0·2	0·07	0·01	21
9	Kalgoorlie	S	S	S	S	S	S	S	S	0
10	Daly Waters	S	S	0·2	2·5	0·07	0·01	S	S	5
11	Oodnadatta	S	S	S	S	S	0·03	S	S	<1
12	Onslow	S	25·0	4·2	2·0	0·1	0·03	0·05	0·02	31
13	Thursday Island	S	S	S	S	S	0·03	0·01	0·02	<1
14	Wyndham	S	S	2·1	0·7	0·07	0·02	0·05	0·02	4
15	Melbourne	S	S	S	S	S	S	S	S	0
16	Port Hedland	S	1·8	S	0·3	0·04	S	0·02	S	2
17	Meekatharra	S	S	0·3	0·4	0·1	S	S	S	1
18	Geraldton	S	S	S	S	0·01	0·03	S	S	<1
19	Alice Springs	S	S	S	S	S	S	S	S	0
20	Townsville	S	S	S	0·5	0·2	0·03	0·02	0·01	1
21	Sydney	S	S	S	S	S	S	S	S	0
22	Charleville	S	S	S	S	S	S	0·01	0·08	<1
23	Cloncurry	S	S	S	S	S	S	S	S	0
24	Cairns	S	S	S	S	0·2	0·03	0·01	S	<1
25	Brisbane	S	S	S	S	S	S	S	0·02	<1
26	Perth	S	S	S	S	S	S	S	S	0
27	Carnarvon	S	S	S	0·3	0·4	0·01	S	S	1
28	Darwin	S	S	S	1·1	0·6	0·3	0·1	0·02	4
46	Roeburne	Not operating								

On the third day fairly general rain fell in Queensland over an area for which precipitation had been forecast. The radiosonde data showed a convectively unstable air mass below 15,000 feet, indicating sporadic and at times heavy rain which could collect finely suspended radioactive particles which had travelled from the stem.*

The fallout data reported in a later section show that the operational forecasts were conservative in the interest of safety for each test and the measured levels of radioactivity were consistent with the meteorological situation which had been chosen. In particular, levels of fallout which could be harmful were, in each test, deposited over the sea.†

Fallout Measurements in Continental Australia

Although in both tests the close-in fallout occurred entirely within the prohibited area, nevertheless it was expected that there would be some low-level fallout on the Australian mainland. Such fallout would be expected to arise from the small amount of radioactive debris in the upper part of the stem of the cloud. In particular it was to be expected that such activity would have its highest values along the north-west coast of Western Australia, being carried there by low-level winds having westerly and northerly components. The level of such fallout would be expected to fall off as one proceeded to the east and to the south, apart from local enhancement which could occur due to 'rain out'.

With these ideas in view, two types of fall-out measurements were instituted for each explosion. On the nearby coast low-flying aeroplanes equipped with highly sensitive detectors were used in an air search which extended from Onslow to Darwin. This fast aerial survey could be supplemented as necessary by properly equipped teams operating on the ground. In the case of the second explosion, measurements of this type supplemented the high level cloud tracking data and showed conclusively that the high level cloud from this explosion never crossed the Australian coast.

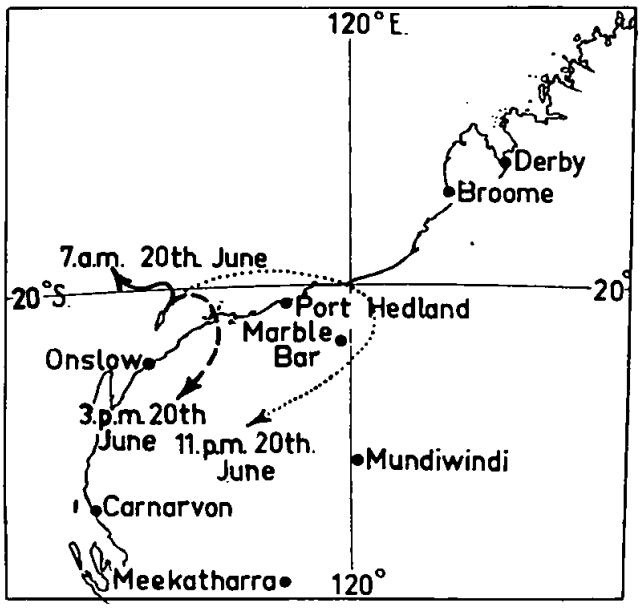

Figure 5
Path of material reaching the ground, at the times shown, from the stem of G2.

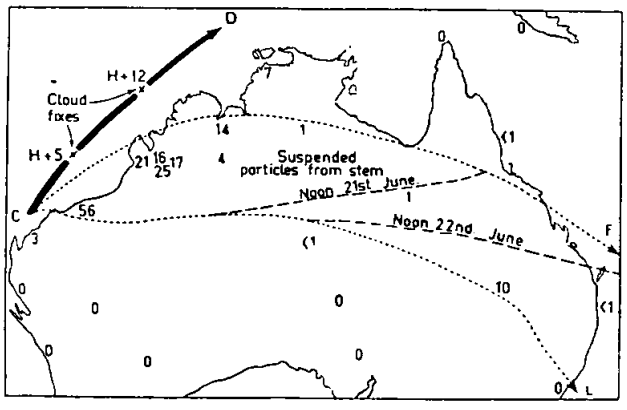

Figure 6
The line CD indicates the trajectory of the high altitude cloud from explosion G2 as it was fixed by aircraft at 5 and 12 hours after firing. Fine material from the stem was dispersed in the area between CF and CE; the broken lines show the approximate times of arrival. The numbers included in the diagram are fall-out measurements (refer to Table II) and give the upper limit of whole body gamma-ray dose integrated to 50 years and expressed in millirontgens.

* Such a process may account for the traces of radioactivity which were reported at Kuridala some 76 hours after firing and by the Japanese collier 'Miyjima Maru' between 21-22°S latitude and 153-154°E longitude also on the afternoon of 22 June. By this time the concentration had fallen so low, as the fallout measurements show, that only minor disturbances could be caused in the natural background radioactivity even with maximum collection by raindrops in isolated localities. After 22 June the rain area contracted eastwards and cleared from Queensland by 25 June.

† Since it was intended to deposit the close-in, high activity fallout into the ocean, it was imperative to ensure that no shipping was present in the area. For this reason an appropriate zone was declared a 'prohibited area' under the Defence Act and the Federal Government issued appropriate instructions to mariners. However, in order to ensure that no ship or fishing vessel strayed into the prohibited area, a continual search was maintained by R.A.A.F. Neptune aircraft, not only over the area itself but over adjoining seas. Movement of coastal shipping was also controlled by the R.A.N. in such a way as to minimize inconvenience and loss of time due to the tests. Crews of coastal trading ships were issued with film badges, the subsequent development of which showed that no sailor or ship had been exposed to any radioactivity as a result of the tests. Partly for security and partly for safety reasons, aircraft in north-western Australia were not allowed to fly within a radius of 250 miles from the firing site. Among other things, this ensured that aircrew and passengers could not be blinded by the brilliant flash of light which occurs at the instant of firing. Measurements of background radioactivity were taken at the main airports along the north-west coast at appropriate times following the explosions, and these airports were opened progressively to traffic when it became certain that no aircraft could be contaminated by passage through a cloud.

In addition to this mobile search a chain of static stations was established along the north-west coast and in addition, further stations were located at strategic points throughout continental Australia as indicated on the map of Figure 7. Two fallout detection methods were employed at each of these stations. In one, suitably placed gummed films were exposed for known times and the activity adhering to them later assessed, while in the other, air was drawn through filter papers for known times and the activity caught in this way was measured. In addition to these measurements, samples of water and mud from a number of reservoirs in Eastern Australia were assessed for radioactivity and a large-scale experiment on the take-up of radioiodine into the thyroids of cattle and sheep was initiated. Each of these will be considered in turn.

Gummed Film Measurements

A network of 29 sampling stations systematically placed throughout Australia as shown in Figure 7 was set up for the purpose of daily collection of radioactive fallout during the 'Mosaic' series of tests. All State capitals except Hobart were included, and the density of stations was slightly greater on the coast of the Australian mainland close to the Monte Bello Islands. Sampling at all stations except Roebourne commenced some time before the first test on 16 June 1956, the earliest being on 1 May 1956. Roebourne only operated for six days commencing on 19 June, the date of the second test. Liveringa, Fitzroy Crossing, and Noonkanbah ceased sampling about the middle of July. The other 25 stations carried out daily

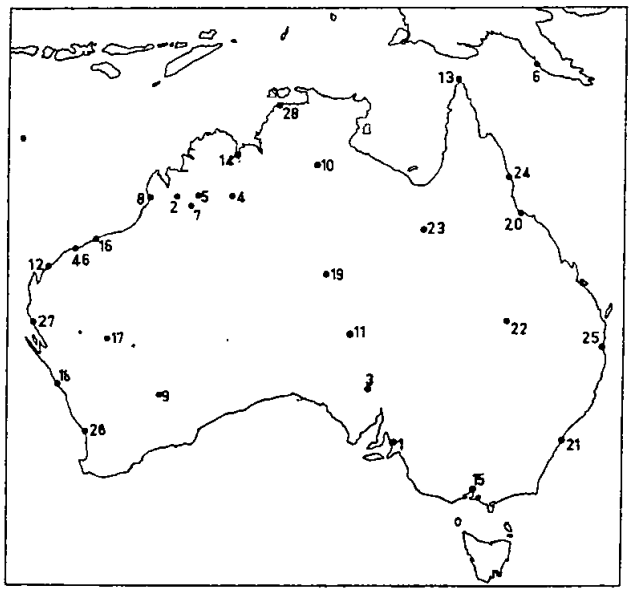

Figure 7
Network of sampling stations. The numbers included on the diagram are the station numbers (refer to Tables I and II).

sampling until the last week in July after which samples were collected for four day periods. The methods of sampling and of counting the samples have already been de-

Table II
Fallout measurements from explosion G2
(S indicates that if any activity was present, it was too small to measure)

Station Number	Location	Activity of daily samples in μc/m² at mid-collection time								Whole body gamma dose to 50 years as a result of fallout from G2 in mr
		19/6	20/6	21/6	22/6	23/6	24/6	25/6	26/6	
1	Adelaide	S	S	S	S	S	S	S	S	0
2	Liveringa	47·0	3·9	0·1	0·2	0·04	S	S	0·02	16
3	Woomera	S	S	S	S	S	S	S	S	0
4	Halls Creek	S	4·5	0·3	0·02	S	S	S	S	4
5	Fitzroy Crossing	S	18·0	0·4	0·2	0·04	S	0·02	S	17
6	Port Moresby	S	S	S	S	S	S	S	S	0
7	Noonkanbah	S	25·0	1·3	0·4	0·1	0·03	0·05	S	25
8	Broome	39·0	12·0	0·2	0·2	0·01	S	S	S	21
9	Kalgoorlie	S	S	S	S	S	S	S	S	0
10	Daly Waters	S	S	0·1	0·5	0·07	S	S	0·02	1
11	Oodnadatta	S	S	S	S	S	S	S	S	0
12	Onslow	S	2·3	0·6	0·02	0·01	0·03	S	S	3
13	Thursday Island	S	S	S	S	S	S	S	S	0
14	Wyndham	S	3·0	7·4	0·7	0·07	S	0·07	0·04	14
15	Melbourne	S	S	S	S	S	S	S	S	0
16	Port Hedland	128·0	17·0	0·3	1·7	0·3	0·09	0·1	S	56
17	Meekatharra	S	S	S	S	S	S	S	S	0
18	Geraldton	S	S	S	S	S	S	S	S	0
19	Alice Springs	S	S	0·2	0·02	S	S	S	S	<1
20	Townsville	S	0·05	0·3	0·05	0·07	0·01	0·02	0·02	1
21	Sydney	S	S	S	S	S	S	S	S	0
22	Charleville	S	S	0·04	5·5	0·07	0·06	S	S	10
23	Cloncurry	S	0·02	0·07	0·5	0·01	S	S	S	1
24	Cairns	S	S	S	S	0·04	S	0·02	0·02	<1
25	Brisbane	S	S	S	0·1	0·04	0·09	S	S	<1
26	Perth	S	S	S	S	S	S	S	S	0
27	Carnarvon	S	S	S	S	S	S	S	S	0
28	Darwin	S	S	S	1·6	1·1	0·5	0·2	0·1	7
46	Roebourne	S	2·6	0·3	0·1	0·01	Not operating			3

scribed in a paper by Dwyer, Keam, Stevens, and Titterton (1957), and will not be repeated here.

Results

The measured activity of each sample has been converted to the actual activity at the mid-collection time by extrapolation using the $t^{-1.25}$ power law. Daily values for the fallout on each of the eight days immediately following the test of 16 June (G1) and also the test of 19 June (G2) are given in Tables I and II. The final column of both Tables gives the whole body gamma dose in milliröntgens received by a person in 50 years after each test as calculated by the method of Hallden and Harley (1956).

Only very small activities were recorded on samples taken after those reported in Tables I and II and by four weeks after each test the fallout was virtually complete, e.g., in the fifth week after G1, only two samples, each containing 0·01 μ c/m^2 of one hour fission products, showed any activity at all and for the same period after G2 only one sample contained any measurable activity.

The data of Tables I and II have been inserted on the maps of Figures 4 and 5 and correlate well with the known meteorological data.

The whole body gamma dose received by a person in the first 50 years as a result of both tests is obtained by summing the last columns in Tables I and II; the values are given in Table III.

In obtaining the daily sample activity values reported in Tables I and II no allowance has been made for the collection efficiency of the gummed film. Brandt (priv. comm.) has obtained a value of 62 per cent. by comparison with high-walled pots, and on his data all activities and gamma doses reported would be multiplied by 1·6.

On the other hand, in the calculation of the whole body gamma dose, no account was taken of the reduction which occurs in practice as a result of weathering of the fission products and the shielding factor which will be provided by the living and occupational habits of man. The reduction factor which should be applied to the gamma doses quoted in Tables I, II and III will vary with location, conditions of housing, and occupation. At a minimum it is estimated that the reduction will be three, but it may be as high as 21 (Stewart, Crooks and Fisher, 1955).

The annual natural background dose to persons in Australia is of the order of 100 mr, but this may vary considerably with changes in latitude, altitude and natural radioactive content of the soil and rocks. In 50 years the average person will receive five röntgens from natural radiation.

Taking into account all factors mentioned above, the whole body gamma dose to a person in the region of highest fallout (Port Hedland) for the first 50 years after this series of tests would be 5 to 30 mr as a result of fallout from both weapons, i.e., between 0·1 and 0·6 per cent. of the natural background dose which would be received in that time. It is interesting to note that the large population centres, Adelaide, Melbourne, Perth and Sydney received no fallout at all, while Brisbane received an integrated dose of considerably less than 0·001 r.

Air Filter Measurements

Air filter measurements give an indication of the levels of airborne radioactivity though they are known to overestimate the inhalation hazard. Experience overseas has shown the lack of a direct correlation between measured air concentrations of fission products and fallout actually appearing on the ground; this has been commented on recently by Blifford, Lockhardt, and Baus (1956). Moreover, because the airpumps used had to operate continuously in remote places without skilled attention and with few spares available, it was expected that samples would not be available for all days throughout the period of measurement. For these reasons, partly technical and partly operational, although it was decided to make air filter measurements at all stations where gummed films were exposed, the data are not so reliable and should not be given as great weight as the gummed film measurements.

In this method an airpump was used to draw air through a filter paper at a rate approximately equal to that at which a human being breathes (about 20 cubic metres of air per

TABLE III

Upper limit of the whole-body γ-dose integrated to 50 years as a result of the combined fallout from G1 and G2.

Sampling Station	Total whole body gamma dose to 50 years as a result of fallout from G1 and G2 in mr
Adelaide	0
Liveringa	25
Woomera	0
Halls Creek	6
Fitzroy Crossing	25
Port Moresby	0
Noonkanbah	38
Broome	42
Kalgoorlie	0
Daly Waters	6
Oodnadatta	<1
Onslow	34
Thursday Island	<1
Wyndham	18
Melbourne	0
Port Hedland	58
Meekatharra	1
Geraldton	<1
Alice Springs	<1
Townsville	1
Sydney	0
Charleville	10
Cloncurry	1
Cairns	<1
Brisbane	<1
Perth	0
Carnavon	1
Darwin	11
Roebourne	3 (G2 only)

TABLE IV

Air activities following explosion G1

Activity of daily air filter samples in mμc/m³ at mid-collection time

(S indicates that if any activity was present, it was too small to measure.)
(N denotes 'not operating'.)

Station Number	Location	16/5	17/5	18/5	19/5	20/5	21/5	22/5	23/5
1	Adelaide	S	S	S	S	S	S	S	S
2	Liveringa	S	0·3	0·7	1·0	0·03	0·09	0·07	S
3	Woomera	S	S	S	S	S	S	S	S
4	Halls Creek	S	S	S	S	S	S	0·02	0·06
5	Fitzroy Crossing	N	N	N	N	S	0·06	0·09	0·01
6	Port Moresby	S	S	S	S	S	S	0·01	S
7	Noonkanbah	S	0·8	0·6	1·0	N	N	N	N
8	Broome	S	8·3	S	0·02	0·04	0·01	0·01	S
9	Kalgoorlie	S	S	N	N	N	N	N	S
10	Daly Waters	S	S	S	0·2	S	S	S	S
11	Oodnadatta	S	S	S	S	S	0·02	S	S
12	Onslow	S	0·7	0·7	0·2	0·01	S	0·1	S
13	Thursday Island	S	S	S	S	0·01	0·01	S	S
14	Wyndham	S	S	1·5	0·5	S	0·01	0·05	0·1
15	Melbourne	S	S	S	S	S	S	S	S
16	Port Hedland	S	S	2·1	0·3	S	0·02	S	S
17	Meekatharra	S	S	S	0·3	0·1	0·03	S	S
18	Geraldton	S	S	S	S	0·01	S	S	S
19	Alice Springs	S	S	S	S	S	S	0·02	S
20	Townsville	S	S	S	0·1	S	S	S	0·01
21	Sydney	S	S	0·02	S	S	S	S	S
22	Charleville	S	S	S	S	S	S	S	0·01
23	Cloncurry	S	S	S	S	S	S	S	0·01
24	Cairns	S	S	S	S	S	0·01	0·01	S
25	Brisbane	N	N	S	S	S	S	S	S
26	Perth	S	S	S	S	S	S	S	S
27	Carnarvon	S	S	0·05	0·4	0·4	S	S	S
28	Darwin	S	S	S	0·2	0·1	0·1	S	S
46	Roeburne	Not operating							

TABLE V

Air activities following explosion G2

Activity of daily air filter samples in mμc/m³ at mid-collection time

(S indicates that if any activity was present, it was too small to measure.)
(N denotes 'not operating'.)

Station Number	Location	19/6	20/6	21/6	22/6	23/6	24/6	25/6	26/6
1	Adelaide	S	S	S	S	S	S	S	S
2	Liveringa	1·7	S	S	S	S	S	S	S
3	Woomera	S	S	S	S	S	S	S	S
4	Halls Creek	S	S	S	S	S	S	0·01	S
5	Fitzroy Crossing	N	5·5	S	S	0·01	0·02	0·01	S
6	Port Moresby	S	S	S	S	S	0·01	S	S
7	Noonkanbah	N	14·0	3·7	0·03	0·03	0·03	S	S
8	Broome	S	0·04	S	0·03	0·03	0·03	0·01	S
9	Kalgoorlie	S	S	S	S	S	0·01	S	S
10	Daly Waters	S	S	S	S	S	0·01	0·01	0·01
11	Oodnadatta	S	S	S	S	S	S	S	S
12	Onslow	S	0·1	0·07	0·01	0·02	0·03	S	S
13	Thursday Island	N	N	N	N	N	N	N	N
14	Wyndham	S	S	2·3	S	0·01	0·3	0·02	0·04
15	Melbourne	S	S	S	S	S	S	S	S
16	Port Hedland	S	2·8	4·5	0·1	0·1	0·03	0·02	0·01
17	Meekatharra	S	S	S	S	0·01	0·01	S	S
18	Geraldton	S	S	S	S	S	S	S	S
19	Alice Springs	S	S	S	0·01	0·03	S	S	S
20	Townsville	S	S	0·03	0·02	0·01	0·01	0·02	0·01
21	Sydney	S	S	S	S	S	S	S	S
22	Charleville	S	S	S	0·1	S	S	S	0·01
23	Cloncurry	S	S	0·06	0·2	S	S	S	0·01
24	Cairns	S	S	S	S	S	0·01	0·02	0·02
25	Brisbane	S	S	S	N	N	N	N	N
26	Perth	S	S	S	S	S	S	S	S
27	Carnarvon	S	S	S	S	S	0·01	S	S
28	Darwin	S	S	S	0·5	S	0·1	0·02	0·06
46	Roebourne	S	0·03	0·07	0·02	0·03	Not operating		

day). Filter papers were changed every twenty-four hours and air-mailed to Melbourne for measurement of any radioactivity which might have been collected. Each sample was counted for 20 minutes at a distance of 1 cm from an end window Geiger counter (type 2B2, 2″ diameter, 2 mg/cm² mica window), the background count of which was approximately 30 c.p.m.

The overall counter efficiency using a Tl^{204} standard calibrated by A.W.R.E. was 13·3 per cent., and this same efficiency was assumed for fission products. The efficiency of the filter paper employed was taken to be 60 per cent. and under the above conditions the standard deviation was approximately 20 d.p.m.; 100 d.p.m. at the time of measurement was considered to be a significant count. All measured activities were extrapolated back to the midpoint of the time of collection. The results are exhibited in Tables IV and V. As was expected, a number of mechanical failures occurred resulting in loss of samples; such instances have been indicated by the letter 'N' in the appropriate place; where the activity was too small to measure, a letter 'S' is used in the table.

Comparison of Tables I and II with Tables IV and V shows that correlation of the results of the two methods is difficult. Not all the results can be used in such a comparison since samples were not collected over the same time intervals. Three stations (Liveringa, Halls Creek and Noonkanbah) could only operate their pumps for a portion of the day since a continuous power supply was not available. A number of others, for staff convenience, changed air samples at 3 p.m. each day and gummed film samples at 6 a.m. (Western Australia) or 9 a.m. (Eastern Australia).

For fallout stations close to the Monte Bello Islands that portion of the fallout collected on the sticky paper generally arrived before the lighter fraction which is sucked into the air-pump. There are some instances of activity being collected in the air samples while nothing significant was observed on the gummed film, and there are roughly the same number where the reverse is the case.

No airborne radioactivity was observed in any of the large population centres (Adelaide, Brisbane, Melbourne, Perth, Sydney). The highest activity in a populated area was observed in Broome. If it is assumed that all the activity there is absorbed by a human being, the inhaled material integrated over a lifetime of 60 years would represent less than 0·04 per cent. of the dose allowable under the recommendations of the International Commission on Radiological Protection. However, this assumption is known to lead to an overestimate because large particulate matter is rejected by the nose while fine particulate matter is inhaled and largely exhaled immediately without retention. These results therefore demonstrate that there was no hazard from airborne radioactive material, even in the near vicinity of the test site.

Measurements of Water and Sludge Samples Collected from Reservoirs

During the period March 1956 to August 1956, water samples both filtered and unfiltered from reservoirs at Mount Isa, Rockhampton, Boyer (Tasmania), Inverell, Wagga, Orange, Mary Vale, Burnie, Darwin, Katherine, Tennants Creek, Canberra, Alice Springs, and Port Moresby were measured for gross radioactivity*. They were treated as follows. Known volumes (1 litre) of the water samples were evaporated to dryness in a sample tray by a continuous drip method and were then counted using a mica window (end window) Geiger counter. The water samples obtained in March and April and early May were used to establish a level of activity due to natural radioactive elements in the water from the various reservoirs. Sampling was continued throughout the trial period and analysis of the results taken up to and including the month of August showed that in no case was there a detectable rise in activity in water samples over the period.

Collection of mud and sludge samples from the same reservoirs commenced early in June 1956. In this case the mud and sludge were evaporated to dryness in a sample tray and a known weight (to give an infinitely thick sample for beta ray counting) was assessed under the same end window counter as that used for the water samples. No examples of activity above the natural radioactive background were observed in these experiments.

Assessment of Radioactive Iodine in the Thyroids of Grazing Animals

Some years ago radioiodine was detected in the thyroid glands of sheep and cattle grazing in the U.S.A. and was shown to be due to fallout (Van Middlesworth, 1954). Subsequent work (Van Middlesworth 1956) indicated that little or none of the iodine burden arises from inhalation—it arises from the ingestion of fallout deposited on the fodder the animals consumed. Any radioiodine collected by an animal is concentrated quickly into the thyroid gland; thus determination of the radioiodine content of animal thyroids makes a highly sensitive fallout detector. The British Agricultural Research Council and Medical Research Council groups pointed out these facts and suggested that such a survey would be of interest during the 'Mosaic' and 'Buffalo' weapon test series. In late 1955 arrangements were made between the British Biological team, the Australian Atomic Weapons Safety Committee, and the Division of Biochemistry and General Nutrition of the C.S.I.R.O. (Adelaide) to make such a survey. The A.W.R.E. provided the necessary equipment for the work and C.S.I.R.O. undertook to obtain the thyroid samples and make the measurements in the

* Some of these samples were obtained through the co-operation and courtesy of Mr. M. J. Martin of Sulphates Limited, and the others through the Department of Works.

Adelaide laboratory. The results will be reported elsewhere (Marston, 1957) and are similar to recent results obtained in the U.S.A. (Comar *et al.*, 1957). They show that the levels of radioiodine activity introduced into the biological cycles by the 'Mosaic' tests (and by the later 'Buffalo' tests) are far below those that are expected to produce any observable effects.

ACKNOWLEDGEMENTS

We wish to thank the many staff members of the meteorological service, without whose co-operation such detailed sampling would have been impossible; Mr. D. J. Stevens and his staff at the Commonwealth X-Ray and Radium Laboratory who assayed the various samples; the U.K. Atomic Energy Authority who, through the A.W.R.E., made equipment available for the fallout network to be established and finally the Director, A.W.R.E., the 'Mosaic' Trials Director and their staff, who spared neither effort nor cost to help the Safety Committee obtain the measurements necessary to establish that conditions imposed to ensure the safety of life and property in Australia were wholly satisfactory and sufficient.

References

BATCHELOR, G. K. (1954): *Q.J.R. Met. Soc.*, 80, 339.

BLIFFORD, I. H. LOCKHART, L. B. and BAUS, R. A.: *Nature*, London, 177, 990.

BRANDT, A. E.: New York Operations Office—Private communication.

COMAR, C. L., TRUM, B. F., KUHN III, U.S.G., WASSERMAN, R. H., NOLD, M. M. and SCHOOLEY, J. C. 1957): *Science*, 126, 16.

DWYER, L. J., KEAM, D., STEVENS, D. J. and TITTERTON, E. W. (1957): *Aust. J. Sci.*, in Press.

HALLDEN, N. A. and HARLEY, J. H. (1956): *Laboratory Report* 56-2, Health and Safety Laboratory, New York Operations Office.

MARSTON, H. R. (1957): In Press.

MIDDLESWORTH, VAN, L. (1954): *Nucleonics*, 12, 56.

MIDDLESWORTH, VAN, L. (1956): *Science*, 123, 982.

SCORER, R. S. and RONNE, C. (1956): *Weather*, 11, 151.

STEWART, N. G., CROOKS, R. N. and FISHER, E. M. (1955): *A.E.R.E.* Report HP/R1701.

SUTTON, O. G. (1955): Note on Entrainment and the Maximum Height of an Atomic Cloud by Lester Machta, *Bull. Am. Met. Soc.*, 31, 217 (1950). *Meteorology and Atomic Energy*, U.S.A.E.C. 1, (July, 1955).

UNITED STATES ATOMIC ENERGY COMMISSION (1955): *Meteorology and Atomic Energy*. U.S.A.E.C. p. 88, 38 (July, 1955).

AUSTRALASIAN MEDICAL PUBLISHING CO. LTD.
SEAMER AND ARUNDEL STS., GLEBE, SYDNEY

Reprinted from *The Australian Journal of Science*, Vol. 21, No. 3, October, 1958, p. 63.

Radioactive Fallout in Australia from Operation Buffalo

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Introduction

Atomic weapon tests were held in Australia at the Monte Bello Islands in 1952 and 1956 and at Emu Field (about 300 miles N.W. of Woomera) in 1953. At the Monte Bello Islands ships were used for accommodation, supplemented by camps ashore; at Emu Field a temporary camp and facilities were built at short notice. By agreement between the U.K. and Australian Governments, a permanent weapon testing site was established in a desert area of south-western South Australia. The village which was built there was named Maralinga (aboriginal for 'thunder') and is located about 25 miles north of Watson on the transcontinental railway line. An airfield capable of dealing with British V-bombers was built as part of the facility, and good laboratory accommodation provided. The firing site is one of the best in the world, being located in a most sparsely populated area; except in the southern sector, the nearest habitations are some 200 miles distant.

The first series of weapon tests to be conducted there occurred during September and October, 1956, and was given the code name Buffalo. In the series four weapons were fired — two from towers, one at ground level, and one was dropped from a Valiant bomber and fused to fire above the surface of the earth.

As on previous occasions, the Australian Atomic Weapons Test Safety Committee was responsible for ensuring that chosen firing conditions could not lead to damage to life or property on the continent, and in this paper we shall give an account of firing conditions and fallout measurements made in continental Australia to ascertain whether radioactivity reaching the ground did conform to the predictions.

A discussion of the phenomenology of nuclear explosions, the type of meteorological network employed and fallout measurement techniques has been given in an earlier paper describing Operation Mosaic (Butement, Dwyer, Eddy, Martin and Titterton, 1957). For the Buffalo operation the fallout network was greatly extended and the number of stations increased from 29 to 86 to give more detailed information.

The detection techniques employed at these stations, however, were the same as those described in the earlier paper, namely, gummed films and air filters. In addition, rain sampling was instituted and, as in the case of the Mosaic experiments, samples of mud and water from a number of reservoirs in eastern Australia were assessed for radioactivity. The large-scale experiment on the take-up of radioiodine into the thyroids of cattle and sheep was continued.

The Meteorological Conditions and Cloud Trajectories

The spring months were chosen as the test period; the weather sequence over southern Australia at that time is characterized by the passage of cold fronts followed by outbreaks of cold air of variable strength and depth. These cold outbreaks interrupt the predominantly overall westerly flow, in which the jet stream may be observed over any given place on about one day in two. In addition to the influence of the jet stream, seasonal characteristics play a big part, as has been shown by an analysis of the upper winds observed each morning at Oodnadatta for three consecutive years: at the 5,000-foot level the vector mean winds for the month of September were 310°/5 knots, 315°/6 knots and 255°/5 knots; at 10,000 feet the values were 255°/11 knots, 245°/8 knots, and 260°/15 knots, and at 20,000 feet 250°/18 knots, 225°/13 knots. and 250°/23 knots. Large values of the standard vector deviation (13 to 25 knots) at each level showed the high variability of the winds in each month.

The degree of atmospheric variation is further indicated by the temperature distribution. At this time of the year on latitude 30°S, the average freezing level is between about 10,000 and 12,000 feet, but the standard deviation of temperature is between about 3° and 4°C at all levels from just above the surface up to the tropopause. The behaviour of the tropopause, too, is complicated by the effects of the jet stream, two tropopauses frequently being found. Statistically, on 10 per cent. of occasions in September and October the first (i.e. lowest) tropopause is encountered at a height of about 28,000 to 29,000 feet or sometimes lower.

It will be obvious from this that statistical analyses alone can provide only limited assistance for the prediction problem, and it was therefore necessary to build up a meteorological organization at Maralinga so that a continuous watch could be maintained and

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early recognition of a favourable firing occasion assured. The variations in the local atmospheric structure at the trials site were measured by a very close sequence of both radar wind and radiosonde observations up to heights of 50,000 feet or more, covering the period both before and after the time of firing.

The first test (Round 1), a tower shot, was held on 27 September 1956. On this occasion the surface synoptic chart showed a ridge of high pressure extending from west to east along the southern coastline, with a cold front extending from near Woomera through Port Augusta to King Island, and ahead of it a well-defined trough of low pressure extending S.E. and S. from the vicinity of Tennant Creek into the north-west corner of N.S.W. In the Tasman Sea a rather deep, slow-moving depression was responsible for the retardation of a high pressure ridge lying just east of the southern Queensland and N.S.W. coast. An analysis of the wind fields at the upper levels showed that there was a minor but quite fast-moving perturbation in the predominant westerly stream. Firing occurred behind this perturbation where the stream had a marked component from the south.

The local radiosonde observations made shortly before firing showed a steep temperature lapse rate up to about 5,000 feet; then a marked stable layer to about 10,000 feet, and above that a lapse rate slightly smaller than the moist adiabatic up to the tropopause (observed at about 32,500 feet). The radiosonde did not detect any moisture in the air above 8,000 feet.

After the explosion a secondary cloud formed between 16,500 and 23,000 feet, and this, together with the main cloud, moved almost due east, between lat. 28°S. and 31°S., at speeds (according to the height) from 20 to 80 knots. The main cloud crossed the coast near Coff's Harbour at about 18 hours, and the secondary cloud at 30 to 36 hours, after firing. Although there was little angular wind shear, and the tracks of both the primary and secondary clouds showed little divergence, the changes with time of the lower level wind fields during the days after firing caused the fine material with a low settling rate to diffuse to the north and the west.

No rain was observed in the area over which the main radioactive cloud moved. However, on the afternoon of 29 September, some wash-out occurred in the Inverell-Brisbane-Lismore area from levels below 20,000 feet.

Round 2, a device of low yield, was fired on the surface on 4 October 1956. The surface synoptic pattern during this period was of marked stability. A ridge of high pressure over the waters to the south of the continent extended from a point about 250 miles south of Cape Leeuwin towards the E.S.E. as far as the southern tip of Tasmania. A rather weak pressure gradient (associated with south to east surface winds) was established over the trials area. A shallow low pressure centre was located over south-eastern N.S.W.

The upper wind patterns showed that at levels above about 10,000 feet there was a persistent and strong westerly flow.

The radiosonde sounding made before firing showed a layer of steep lapse rate up to 4,000 feet, then a layer of very small temperature lapse, and an inversion with the top at about 5,500 feet. Above this the lapse rate was approximately that of the moist adiabatic up to 18,700 feet, except for a small interruption between 10,400 and 12,000 feet. The air was relatively moist up to 20,000 feet apart from a dry layer at about 12,000 feet.

The temperature inversion at the 5,500-foot level was responsible for the formation of a secondary cloud which moved away very slowly over the desert in a general north-westerly direction from the trials site, where after seven hours it was too diffuse to be detected by the tracking aircraft, and, in the next four hours was washed down by heavy rain. In the meantime the primary cloud, which had just penetrated the region of the fast-flowing westerly stream, moved away almost due east to cross the N.S.W. coast some 25 to 30 hours after firing. As in the case of the first test, variations in the low level winds subsequent to firing led to the fine radioactive material drifting to the north as it settled.

No rain was experienced in the areas over which the cloud moved, since by the time it reached the coast the low pressure centre and associated trough in N.S.W. had also moved eastwards to be well out into the Tasman Sea.

On 11 October 1956, Round 3, also a device of low yield, was dropped from an aircraft and detonated above the surface of the desert. Surface synoptic charts showed that a small, rather shallow cell of high pressure 'broke off' from a high pressure ridge extending from Perth to the head of the Bight on the afternoon of 10 October. The rather rapid eastern movement of this centre was accompanied by decreasing strength and directional veering of the lower level wind structure at Maralinga during 11 October. In the upper levels the wind field was much more stable and the directional veering delayed.

The radiosonde ascents made shortly before firing showed a temperature inversion of nearly 8°C just below the 6,000-foot level. Below this inversion the lapse rate was quite steep, while above it was very near the moist adiabatic. There was no recorded moisture above the inversion.

The temperature inversion had weakened a little by firing time, but was still strong enough to trap a small quantity of radioactive material. The major part of the cloud rose to a much greater height. The

primary cloud, which was diffuse, moved east to cross the coast in the Newcastle area about 55 hours after firing.

Veering of the lower level winds following the explosion led to a southerly diffusion of slowly settling material of low activity. Arrival of this material at the surface was detected over South Australia, Victoria and N.S.W. during the period 12 to 16 October, the delay resulting from the light wind regime.

No rain was observed over the south-east areas of the continent throughout the whole of this period.

The final shot of the series, Round 4, a tower burst, was fired shortly after midnight on 22 October. On this occasion the surface

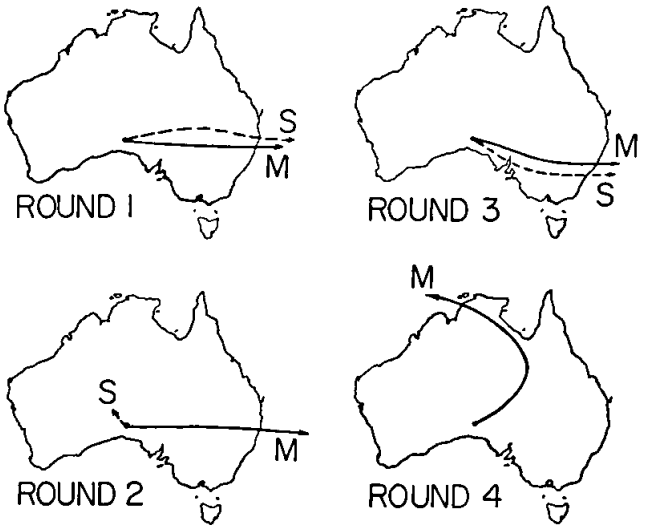

Figure 1

The cloud trajectories are shown for the four explosions. The path of the main cloud (M) is represented by a full line. When a secondary cloud occurred, its path (S) is indicated by a broken line.

chart showed a cold front extending from a shallow low pressure centre in central Western Australia, E.S.E. and S.E. to Adelaide, thence S.E. across central Victoria, passing just east of Tasmania. The southern portion of this cold front was moving rapidly, due to a developing depression centred close to southern Tasmania on the afternoon of 21 October. North of the 35th parallel the front was moving only very slowly. There was a shallow anti-cyclone in the Bight and over the trials area a fairly steep pressure gradient with associated S.W. to S.E. surface wind. Another shallow anti-cyclone was centred just off Brisbane.

On the afternoon of 21 October, at the 5,000-foot level, centres of inflow were located near Ceduna and to the south of Tasmania and a centre of outflow between Kalgoorlie and Forrest. This centre moved east quite rapidly and gave rise to veering winds at the site. At the 10,000-foot level only temporary backing of the wind at the site was experienced as a shallow trough moved east in the stream. At the 15,000-foot level a centre of outdraft had developed in the Marble Bar (W.A.) area, the eastward movement of which led to the gradual veering of winds at the site. The major feature in the upper air, however, was the persistence of a marked trough extending from Arnhem Land across central and south-east Queensland, which later intensified and led to a marked backing of the high level winds.

The upper air sounding showed no marked temperature inversions except for one near the surface, and as a result no secondary radioactive cloud developed. This resulted in the radioactivity being confined almost entirely to the main cloud which moved away to reach the coast just south of Darwin within 24 hours of firing. As the material in the cloud diffused and settled it was spread over a very wide front to the east of the trajectory. Extensive angular wind shear from the tropopause to the surface led to the deposition of material in minute quantities over an arc from Darwin to Newcastle.

No rain fell in the areas over which the cloud moved.

The cloud trajectories for the four explosions are shown in Figure 1.

Fallout Measurements in Continental Australia

In each case the movement of the radioactive cloud was tracked by aircraft until it became too dilute radioactively to be followed with certainty. Fallout measurements within the restricted area of the firing site were made by a variety of automatic recording instruments, mobile surface monitoring units and low-flying aircraft equipped with sensitive detectors.

The network of 86 fallout stations which was employed is shown in Figure 2, and the fallout data from the gummed films is set out in Tables I–V.*

The stations commenced operation on 27 September and continued until 5 November. Tables I–IV record the daily activities for explosions 1 to 4 respectively, the measured activity of each sample being converted to the actual activity at mid-collection time using the $t^{-1.2}$ law known to apply to fission products. The final column of each table gives the whole body γ-dose in milliroentgen associated with each test integrated to 50 years assuming no shielding. Table V gives the cumulative dose for the whole series integrated to 50 years, again assuming no shielding.

The figures, even though they represent the upper limit to the dose which any person might receive, are small. To allow for the effect of shielding afforded by the normal living and occupational habits of man, these

* See Appendix.

exposure figures should be divided by a factor lying between 3 and 21 (Stewart, Crooks and Fisher, 1956). Some recent comparisons of high-walled pot and gummed-film measurements (Keam, Dwyer, Stevens and Titterton, 1958) favour a collection of efficiency of the gummed film close to 100 per cent., differing from the earlier value of 62 per cent. of Eisenbud and Harley (1956); for this reason no efficiency correction has been applied here.

The highest fallout activity observed was recorded at Lismore as a consequence of the washout discussed earlier, and in Table 1 is shown to lead to a whole body γ-ray dose of

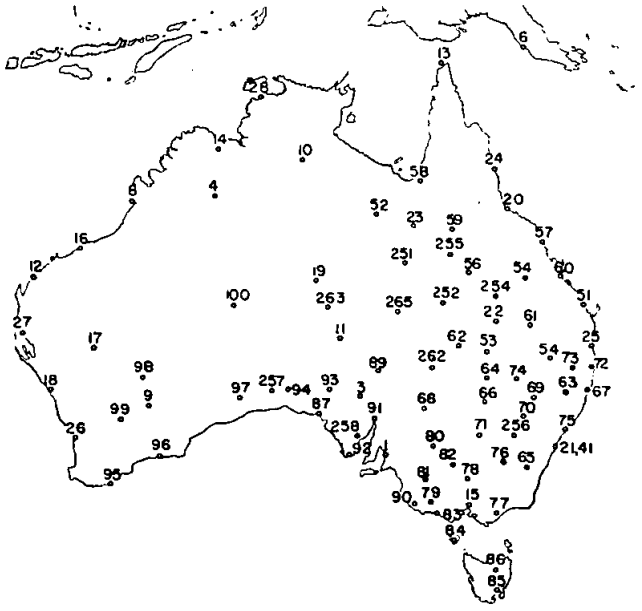

Figure 2

The distribution of the fallout sampling stations over the continent, showing the higher density in the more populous areas down wind from the test site. The location of each station is indicated by its station number (refer to Tables I to IX).

22 mr integrated to 50 years assuming no shielding. The actual integrated whole body dose which could be received by anyone in Lismore as a result of the Buffalo series lies between 1 and 8 mr; this is less than 0·02 to 0·16 per cent. of the background dose received over the period.

At 76 of the fallout stations air pumps were installed to draw air through a filter at approximately the rate at which a human being breathes — 20 cubic metres of air per day. The filters were changed every 24 hours and assayed for radioactivity, the measured activities being extrapolated back to mid-collection time. The results are displayed in Tables VI–IX* and, as was noted in the earlier Mosaic paper, the correlation between the data of Tables I–IV and VI–IX is not good. The figures given represent an overestimate of the inhalation dose which an individual could receive since large particulate matter is rejected by the nose while fine particulate matter, when inhaled, is largely exhaled immediately. Leaving this aside, however, the largest integrated dose occurred at Adelaide, and, taken over a period of 50 years, represents no more than 0·14 per cent. of that allowable under the recommendations of the International Commission on Radiological Protection.

Rain Sampling

Rain collected daily at thirteen meteorological stations between 28 September and 27 October was examined for radioactivity at the Commonwealth X-ray and Radium Laboratories. When rain occurred a sample of 40 ml was counted. Under conditions where the background count corresponded to that of a sample exhibiting an activity of 1 $\mu\mu$c/ml, the minimum activity which could be detected above this background was 0·1 $\mu\mu$c/ml.

The stations were situated at Adelaide, Daly Waters, Oodnadatta, Melbourne, Alice Springs, Townsville, Sydney, Charleville, Cloncurry, Brisbane, Darwin, Rockhampton, Cobar.

More than one point of rain was recorded for the 24-hour collection period on 66 occasions, and, when analysed, 27 of these samples were found to have activities greater than 1 $\mu\mu$c/ml at the time of collection. Most of the activities measured were very small. However, Brisbane, 24 October, and Oodnadatta, 26 October, recorded approximately 200 $\mu\mu$c/ml — much greater than other results. If this rain, which was very light on both occasions, had been collected for drinking water, a calculation assuming the worst possible circumstances — no mixing of this with other water and only this water consumed for a week — indicates that the maximum dose to the whole body integrated to 50 years would be 0·2 rad, and of no consequence. Further, with a normal household water tank, a dilution factor of at least 1000 would usually be incurred, with a corresponding reduction in the dose.

Measurement of Water and Sludge Samples Collected from Reservoirs

During the period August to November 1956, water samples, both filtered and unfiltered, from reservoirs at Mount Isa, Rockhampton, Boyer (Tasmania), Inverell, Wagga, Orange, Mary Vale, Burnie, Darwin, Katherine, Tennants Creek, Canberra, Alice Springs and Port Moresby were measured for gross radioactivity using the methods discussed in the Mosaic paper.* Very small, but detectable, rises in activity occurred in samples from three locations. These rises occurred in samples from

* See Appendix.

* Some of these samples were obtained through the cooperation and courtesy of Mr. M. J. Martin, of Sulphates Limited, and the others through the Department of Works.

Rockhampton in November, from Boyer in October, and from Orange in October and November. In each case the rise in activity detected was so small as to be of no significance from the viewpoint of the health and well-being of humans or livestock or of any industrial application of the water. No examples of activity above the natural background levels were observed at any of the other thirteen sampling points.

Radioiodine Measurements

The affinity of the mammalian thyroid tissue for iodine and its radio-isotopes is well known and has been used widely in clinical applications. In addition, it has proved to be a valuable means of assessing the hazard from the local fallout after nuclear detonations (Comar *et al.*, 1957).

An extensive survey of thyroid glands of grazing sheep and cattle was undertaken by the Division of Biochemistry and General Nutrition of the C.S.I.R.O. (Adelaide) on behalf of the Safety Committee and the Atomic Weapons Research Establishment during these and the preceding weapons tests series. A full discussion of these measurements will be given elsewhere (Marston, 1958).

In addition to this experiment, thyroids of sheep which had grazed within 200 miles of the test site were analysed at Maralinga after each explosion for their radioiodine content.

From the two series of measurements it was hoped to establish levels to which grazing animals were likely to be exposed from this source as a result of the tests.

The largest ^{131}I activity detected from the close-in survey was 56 mμc per gramme of sheep thyroid. In the main survey, Marston's data shows that of the 66 sheep thyroids examined after 27 September 1956, two were found with activities of this magnitude, the others being much less. A comparable number of cattle thyroids were examined and gave similar results.

Maximum permissible levels of ^{131}I for short-term exposure of animals have been given by Scott-Russell, Martin and Whortley (1956), of the British Agricultural Research Council. They calculate that no detectable biological damage would be caused to sheep from the daily ingestion of 26μc of ^{131}I from pasture contaminated with fission products. They assume that grazing on this pasture is limited to the period from the first to the fourteenth day after fission and the activity is referred to the first day. This ingestion would give a *mean* thyroid burden of about 3,000 mμc ^{131}I/gm thyroid for the period, and a total dose to the thyroid of 1,000 rad. For continuous feeding over an entire lifetime the work of Bustad *et al.* (1957) suggests that no biological damage would be observed for sheep having a mean thyroid concentration less than about 600 mμc/gm of thyroid.

It is clear from the measurements, therefore, that the uptake of radioiodine by grazing animals is orders of magnitude below the levels at which any biological effects could be detected and it follows that there is little danger to livestock from this source as a result of these weapon tests.

Acknowledgements

The successful completion of this series of measurements has been largely due to the contribution made by members of the Bureau of Meteorology and the Commonwealth X-Ray and Radium Laboratory in collecting and counting the samples. The authors wish to thank them for their assistance and also the U.K. Atomic Energy Authority who, through A.W.R.E., has made equipment available for the establishment and further extension of the sampling network. Finally, the contribution of the Director, A.W.R.E., and his staff is especially appreciated—every effort was made to furnish the Safety Committee with the information necessary to ensure the safe conduct of the tests and the protection of life and property in Australia.

References

BUSTAD, L. K., GEORGE, L. A., Jr., MARKS, S., WARNER, D. E., BARNES, C. M., HERDE, D. E., and KORNBERG, H. A. (1957): *Rad. Res.*, 6, 380.

BUTEMENT, W. A. S., DWYER, L. J., EDDY, C. E., MARTIN, L. H., and TITTERTON, E. W. (1957): *Aust. J. Sci.*, 20, 39.

COMAR, C. L., TRUM, B. F., KUHN, U. S. G., III, WASSERMAN, R. H., NOLD, M. M., and SCHOOLEY, V. C. (1957): *Science*, 126, 16.

KEAM, D. W., DWYER, L. J., STEVENS, D. J., and TITTERTON, E. W. (1958): (in the press).

MARSTON, H. R. (1958): *Aust. J. Biol. Sci.*, 3, 382.

SCOTT RUSSELL, R., MARTIN, R. P., and WORTELY, G. (1956): An assessment of the hazards resulting from the ingestion of fallout by grazing animals. A.E.R.E. Report ARC/RMC 5.

STEWART, N. G., CROOKS, R. N., and FISHER, E. M. R. (1956): The radiological dose to persons in the U.K. due to debris from nuclear test explosions prior to January, 1956. A.E.R.E. Report HP/R 2017.

APPENDIX

TABLES I-IX

Publication of the results in this appendix was aided by a grant from the Australian Atomic Weapons Test Safety Committee.

TABLE I

Activities from gummed films exposed after Round 1, 27 September 1956

Station and station number	μc/m² at 2100 hours on day of collection[2,3]							Whole body dose[1] from Round 1 (milliroentgens)
	27/9	28/9	29/9	30/9	1/10	2/10	3/10	
1 Adelaide	—	—	—	—	—	—	—	0
3 Woomera	—	—	—	—	—	—	—	0
4 Hall's Creek	—	—	—	0·07	0·03	—	—	<1
6 Pt. Moresby	—	—	—	—	—	—	—	0
8 Broome	—	—	—	—	—	—	—	0
9 Kalgoorlie	—	—	—	—	—	—	—	0
10 Daly Waters	—	—	—	0·03	0·02	0·01	—	<1
11 Oodnadatta	—	—	—	—	—	—	0·02	<1
12 Onslow	—	—	—	—	—	—	—	0
13 Thursday Is.	—	—	—	—	—	—	—	0
14 Wyndham	—	—	—	0·01	0·04	—	—	<1
15 Melbourne	—	—	—	—	—	—	—	0
16 Pt. Hedland	—	—	0·01	—	—	—	—	<1
17 Meekatharra	—	—	—	—	—	—	—	0
18 Geraldton	—	—	—	—	—	—	—	0
19 Alice Springs	—	—	—	—	—	—	—	0
20 Townsville	—	—	—	—	0·07	0·02	—	<1
21 Sydney	—	—	—	—	—	—	—	0
22 Charleville	—	—	0·80	0·01	—	—	—	1
23 Cloncurry	—	—	0·03	—	—	0·01	—	<1
24 Cairns	—	—	—	—	0·01	0·01	—	<1
25 Brisbane	—	—	0·06	0·17	—	—	—	<1
26 Perth	—	—	—	—	—	—	—	0
27 Carnarvon	—	—	—	—	—	—	—	0
28 Darwin	—	—	—	—	0·04	0·01	—	<1
41 Sydney (AEC)	—	—	—	—	—	—	—	0
51 Bundaberg	—	—	—	0·06	—	—	—	<1
52 Camooweal	—	—	0·28	0·03	—	0·01	—	<1
53 Cunnamulla	—	—	0·35	0·02	—	0·01	—	<1
54 Emerald	—	—	—	0·02	—	—	—	<1
55 Goondiwindi	—	0·55	0·57	—	—	0·01	—	1
56 Longreach	—	—	0·10	0·01	0·02	—	—	<1
57 Mackay	—	—	—	0·06	—	0·01	—	<1
58 Normanton	—	—	0·04	0·07	0·02	—	—	<1
59 Richmond	—	—	0·03	0·03	0·04	—	—	<1
60 Rockhampton	—	—	—	0·05	—	—	—	<1
61 Roma	—	—	0·28	0·05	—	—	—	<1
62 Thargomindah	—	2·7	0·81	—	—	0·01	—	3
63 Armidale	—	3·0	1·4	0·01	0·02	0·01	0·01	4
64 Bourke	—	0·54	1·60	0·02	—	—	—	2
65 Canberra	—	—	—	—	—	—	—	0
66 Cobar	—	0·10	0·02	—	—	—	0·01	<1
67 Coffs Harbour	—	—	1·2	0·05	—	—	—	1
68 Broken Hill	—	—	—	—	—	—	—	0
69 Coonabarabran	—	—	0·21	—	—	—	—	<1
70 Dubbo	—	—	0·04	—	—	—	—	<1
71 Hillston	—	—	—	—	—	—	0·02	<1
72 Lismore	—	9·8	14·0	0·12	0·06	0·02	0·01	22
73 Tenterfield	—	1·2	1·6	0·02	—	—	—	3
74 Walgett	—	0·04	0·91	0·09	—	—	—	1
75 Williamtown	—	—	—	—	—	—	—	0
76 Wagga	—	—	—	—	—	—	—	0
77 Sale	—	—	—	—	—	—	—	0
78 Echuca	—	—	—	—	—	—	—	0
79 Hamilton	—	—	—	—	—	—	—	0
80 Mildura	—	—	—	—	—	—	—	0
81 Nhill	—	—	—	—	—	—	—	0
82 Swan Hill	—	—	—	—	—	—	0·01	<1
83 Warrnambool	—	—	—	—	—	—	—	0
84 Currie	—	—	—	—	—	—	—	0
85 Hobart	—	—	—	—	—	—	—	0
86 Western Junction	—	—	—	—	—	—	—	0
87 Ceduna	—	—	—	—	—	0·02	—	<1
88 Leigh Creek	—	1·6	0·07	0·01	—	—	—	1
89 Marree	—	8·2	—	—	—	0·04	0·07	6
90 Mt. Gambier	—	—	—	—	—	—	—	0
91 Pt. Augusta	—	—	—	—	—	—	0·01	<1
92 Pt. Lincoln	—	—	—	—	—	—	—	0
93 Tarcoola	—	—	—	—	0·01	0·02	—	<1
94 Watson	—	—	—	—	—	0·01	—	<1
95 Albany	—	—	—	—	—	—	—	0
96 Esperance	—	—	—	—	—	—	—	0
97 Forrest	—	—	—	—	—	—	—	0
98 Leonora	—	—	—	—	—	—	—	0
99 Southern Cross	—	—	—	—	—	—	—	0
100 Giles	—	0·03	—	—	0·01	—	0·01	<1

[1] These whole body γ doses are integrated to 50 years and take no account of the shielding afforded by the normal living habits of man.

[2] "—" indicates that the sample collected had an activity less than the minimum detectable.

[3] "NS" indicates that a sample was not collected.

TABLE I—*Continued*

Activities from gummed films exposed after Round 1, 27 September 1956—*Continued*

Station and station number	μc/m² at 2100 hours on day of collection[2, 3]							Whole body dose[1] from Round 1 (milliroentgens)
	27/9	28/9	29/9	30/9	1/10	2/10	3/10	
251 Boulia	—	—	0·30	—	—	—	—	<1
252 Windorah	—	—	0·85	—	—	—	—	1
254 Tambo	—	—	0·07	0·08	—	—	—	<1
255 Winton	—	—	0·05	—	0·01	—	—	<1
256 Forbes	—	—	—	—	—	—	0·01	<1
257 Cook	—	—	—	—	—	0·02	—	<1
258 Cleve	—	—	—	—	—	0·01	—	<1
262 Tibooburra	3·2	3·6	—	NS	0·06	—	0·01	3
263 Finke	—	—	0·04	—	—	—	—	<1
265 Birdsville	—	0·30	0·07	—	—	—	—	<1

TABLE II

Activities from gummed films exposed after Round II, 4 October 1956

Station and station number	μc/m² at 2100 hours on day of collection[2]							Whole body dose[1] from Round 2 (milliroentgen
	4/10	5/10	6/10	7/10	8/10	9/10	10/10	
1 Adelaide	—	—	—	—	—	—	—	0
3 Woomera	—	—	—	—	—	—	—	0
4 Hall's Creek	—	—	—	—	—	—	—	0
6 Pt. Moresby	—	—	—	—	—	—	—	0
8 Broome	—	—	—	—	—	—	—	0
9 Kalgoorlie	—	—	—	—	—	—	—	0
10 Daly Waters ..	—	—	—	—	—	—	—	0
11 Oodnadatta	0·3	0·10	—	—	—	—	—	<1
12 Onslow	—	—	—	—	—	—	—	0
13 Thursday Is... ..	—	—	—	—	—	—	—	0
14 Wyndham	—	—	—	—	—	—	—	0
15 Melbourne	—	—	—	—	—	—	—	0
16 Pt. Hedland ..	—	—	—	—	—	—	—	0
17 Meekatharra	—	—	—	—	—	—	—	0
18 Geraldton	—	—	—	—	—	—	—	0
19 Alice Springs ..	—	0·09	0·04	—	—	—	—	<1
20 Townsville	—	—	—	—	—	—	—	0
21 Sydney	0·01	—	0·03	—	—	—	—	<1
22 Charleville	—	—	0·03	0·01	—	—	—	<1
23 Cloncurry	—	0·02	0·01	—	—	—	—	<1
24 Cairns	—	—	—	—	—	—	—	0
25 Brisbane	—	—	0·04	—	—	—	—	<1
26 Perth	—	—	—	—	—	—	—	0
27 Carnarvon	—	—	—	—	—	—	—	0
28 Darwin	—	—	—	—	—	—	—	0
41 Sydney (AEC) ..	—	—	0·04	—	—	—	—	<1
51 Bundaberg	—	—	0·01	0·01	—	—	—	<1
52 Camooweal	—	—	0·01	0·01	0·01	—	—	<1
53 Cunnamulla	0·02	0·06	0·02	—	—	—	—	<1
54 Emerald	—	—	—	—	—	—	0·01	<1
55 Goondiwindi	—	0·10	0·20	—	—	—	—	<1
56 Longreach	—	—	0·01	—	—	0·01	0·01	<1
57 Mackay	—	—	—	—	—	—	—	0
58 Normanton	—	—	—	—	—	—	—	0
59 Richmond	—	—	—	—	—	—	0·01	<1
60 Rockhampton ..	—	—	—	—	—	—	—	0
61 Roma	—	—	0·03	—	—	—	—	<1
62 Thargomindah ..	—	—	0·12	0·02	—	—	—	<1
63 Armidale	—	—	0·35	0·01	—	—	0·01	<1
64 Bourke	0·03	0·04	0·12	—	—	0·01	—	<1
65 Canberra	—	—	—	—	—	—	—	0
66 Cobar	—	—	0·06	—	—	—	—	<1
67 Coffs Harbour ..	0·02	0·03	0·05	0·02	—	—	—	<1
68 Broken Hill ..	—	—	—	—	—	0·01	—	<1
69 Coonabarabran ..	—	0·03	0·09	—	—	—	0·01	<1
70 Dubbo	—	—	0·05	—	—	—	—	<1

[1] These whole body γ doses are integrated to 50 years and take no account of the shielding afforded by the normal living habits of man.

[2] "—" indicates that the sample collected had an activity less than the minimum detectable.

[3] "NS" indicates that a sample was not collected.

TABLE II—*Continued*

Activities from gummed films exposed after Round II, 4 October 1956—*Continued*

Station and station number	μc/m² at 2100 hours on day of collection[2]							Whole body dose[1] from Round 2 (milliroentgen)
	4/10	5/10	6/10	7/10	8/10	9/10	10/10	
71 Hillston	—	—	—	—	—	—	—	0
72 Lismore	2·6	0·04	0·01	0·03	0·01	—	0·02	<1
73 Tenterfield	—	—	0·09	0·02	—	—	—	<1
74 Walgett	0·01	0·05	0·13	—	—	0·01	0·01	<1
75 Williamtown	—	—	0·02	—	—	—	—	<1
76 Wagga	—	—	—	—	—	—	—	0
77 Sale	—	—	—	—	—	—	—	0
78 Echuca	—	—	—	—	—	—	—	0
79 Hamilton	—	—	—	—	—	—	—	0
80 Mildura	—	—	—	—	—	—	—	0
81 Nhill	—	—	—	—	—	—	—	0
82 Swan Hill	—	—	—	—	—	—	—	0
83 Warrnambool	—	—	—	—	—	—	—	0
84 Currie	—	—	—	—	—	—	—	0
85 Hobart	—	—	—	—	—	—	—	0
86 Western Junction	—	—	—	—	—	—	—	0
87 Ceduna	—	—	—	—	—	0·08	0·03	<1
88 Leigh Creek	—	—	—	—	—	—	—	0
89 Marree	0·02	0·06	—	—	—	—	—	<1
90 Mt. Gambier	—	—	—	—	—	—	—	0
91 Pt. Augusta	—	—	—	—	—	—	—	0
92 Pt. Lincoln	—	—	—	—	—	—	—	0
93 Tarcoola	—	—	—	—	0·01	—	—	<1
94 Watson	1·5	0·10	—	—	0·02	—	—	<1
95 Albany	—	—	—	—	—	—	—	0
96 Esperance	—	—	—	—	—	—	—	0
97 Forrest	—	—	—	—	—	—	—	0
98 Leonora	—	—	—	—	—	—	—	0
99 Southern Cross	—	—	—	—	—	—	—	0
100 Giles	—	—	—	—	—	—	—	0
251 Boulia	—	—	0·04	—	0·02	0·03	0·01	<1
252 Windorah	—	0·08	0·01	0·01	—	—	—	<1
254 Tambo	0·01	—	0·04	—	—	—	—	<1
255 Winton	—	—	—	—	0·01	—	0·01	<1
256 Forbes	—	—	—	—	—	—	—	0
257 Cook	—	0·07	—	—	—	—	—	<1
258 Cleve	—	—	—	—	—	—	—	0
262 Tibooburra	0·01	0·27	0·47	—	—	0·01	—	1
263 Finke	—	0·11	0·02	—	—	—	—	1
265 Birdsville	—	0·30	0·12	—	—	—	—	<1

TABLE III

Activities from gummed films exposed after Round 3, 11 October 1956

Station and station number	μc/m² at 2100 hours on day of collection[2, 3]										Whole body dose[1] from Round 3 (milliroentgens)
	11/10	12/10	13/10	14/10	15/10	16/10	17/10	18/10	19/10	20/10	21/10	
1 Adelaide	—	0·22	0·09	0·02	0·09	0·01	—	—	—	—	—	<1
3 Woomera	—	0·77	0·09	0·01	0·01	—	—	—	—	—	—	<1
4 Hall's Creek	—	—	—	—	—	—	—	—	—	—	—	0
6 Pt. Moresby	—	—	—	—	—	—	—	—	—	—	—	0
8 Broome	—	—	—	—	—	—	—	—	—	—	—	0
9 Kalgoorlie	—	—	—	—	—	—	—	—	—	—	—	0
10 Daly Waters	—	—	—	—	—	—	—	—	—	—	—	0
11 Oodnadatta	—	—	—	—	—	—	—	—	—	—	—	0
12 Onslow	—	—	—	—	—	—	—	—	—	—	—	0
13 Thursday Is.	—	—	—	—	—	—	—	—	—	—	—	0
14 Wyndham	—	—	—	—	—	—	—	—	—	—	—	0
15 Melbourne	—	—	0·07	0·02	0·04	0·01	—	—	—	—	—	<1
16 Pt. Hedland	—	—	—	—	—	—	—	—	—	—	—	0
17 Meekatharra	—	—	—	—	—	—	—	—	—	—	—	0
18 Geraldton	—	—	—	—	—	—	—	—	—	—	—	0
19 Alice Springs	—	—	—	—	—	—	—	—	—	—	—	0

[1] These whole body γ doses are integrated to 50 years and take no account of the shielding afforded by the normal living habits of man.

[2] " — " indicates that the sample collected had an activity less than the minimum detectable.

[3] " NS " indicates that a sample was not collected.

TABLE III—*Continued*

Activities from gummed films after Round 3, 11th October 1956—*Continued*

Station and station number	μc/m² at 2100 hours on day of collection[2, 3]											Whole body dose[1] from Round 3 (milliroentgens)
	11/10	12/10	13/10	14/10	15/10	16/10	17/10	18/10	19/10	20/10	21/10	
20 Townsville	—	—	—	—	—	—	—	—	—	—	—	0
21 Sydney	—	—	—	—	0·04	—	—	—	—	—	—	<1
22 Charleville	—	—	—	—	—	—	—	—	—	—	—	0
23 Cloncurry	—	—	—	—	—	—	—	—	—	—	—	0
24 Cairns	—	—	—	—	—	—	—	—	—	—	—	0
25 Brisbane	—	—	—	—	—	—	—	—	—	—	—	0
26 Perth	—	—	—	—	—	—	—	—	—	—	—	0
27 Carnarvon	—	—	—	—	—	—	—	—	—	—	—	0
28 Darwin	—	—	—	—	—	—	—	—	—	—	—	0
41 Sydney (AEC)	—	—	—	—	0·04	—	0·01	—	—	—	—	<1
51 Bundaberg	—	—	—	—	—	—	—	—	—	—	—	0
52 Camooweal	—	—	—	—	—	—	—	—	—	—	—	0
53 Cunnamulla	—	—	—	—	—	—	—	—	—	—	—	0
54 Emerald	—	—	—	—	—	—	—	—	—	—	—	0
55 Goondiwindi	—	—	—	—	0·01	—	—	—	—	—	—	<1
56 Longreach	—	—	—	—	—	—	—	—	—	—	—	0
57 Mackay	—	—	—	—	—	—	—	—	—	—	—	0
58 Normanton	—	—	—	—	—	—	—	—	—	—	—	0
59 Richmond	—	—	—	—	—	—	—	—	—	—	—	0
60 Rockhampton	—	—	—	—	—	—	—	—	—	—	—	0
61 Roma	—	—	—	—	0·01	—	—	—	—	—	—	<1
62 Thargomindah	0·03	—	—	—	0·01	—	—	—	—	—	—	<1
63 Armidale	—	—	—	—	0·01	0·01	—	0·01	—	—	—	<1
64 Bourke	—	—	—	0·01	0·02	—	—	—	—	—	—	<1
65 Canberra	—	—	—	0·04	0·08	—	—	—	—	—	—	<1
66 Cobar	—	—	—	0·01	0·01	—	—	—	—	—	—	<1
67 Coffs Harbour	—	—	—	—	0·01	—	—	—	—	—	—	<1
68 Broken Hill	—	—	0·01	—	—	0·01	—	—	—	—	—	<1
69 Coonabarabran	—	—	—	0·01	0·01	—	0·01	—	—	—	—	<1
70 Dubbo	—	—	—	0·03	0·01	—	0·01	—	—	—	—	<1
71 Hillston	—	—	0·01	0·01	—	0·01	0·01	—	—	—	—	<1
72 Lismore	—	—	0·01	—	0·05	—	—	—	0·01	—	—	<1
73 Tenterfield	—	—	—	—	0·01	—	—	—	—	—	—	<1
74 Walgett	—	—	—	—	—	—	—	—	—	—	—	0
75 Williamtown	—	—	—	0·01	0·05	—	0·01	—	—	—	—	<1
76 Wagga	—	—	0·01	0·06	0·01	—	0·01	—	—	—	—	<1
77 Sale	—	—	0·01	—	0·04	—	—	—	—	—	—	<1
78 Echuca	—	—	0·05	0·02	0·03	0·01	—	—	—	—	—	<1
79 Hamilton	—	—	0·01	0·09	0·03	0·04	—	—	—	—	—	<1
80 Mildura	—	—	0·06	0·01	0·01	0·01	—	—	—	—	—	<1
81 Nhill	—	—	0·09	0·06	—	0·03	—	—	—	—	—	<1
82 Swan Hill	NS	NS	0·02	0·01	—	0·02	—	—	—	—	—	<1
83 Warrnambool	—	—	0·04	0·08	0·05	0·03	—	—	NS	—	—	<1
84 Currie	—	—	—	—	0·44	—	—	—	—	—	—	1
85 Hobart	—	—	—	—	0·06	0·01	—	—	—	—	—	<1
86 Western Junction	—	—	—	—	0·04	0·01	—	—	—	—	—	<1
87 Ceduna	0·07	0·05	—	—	—	—	—	—	—	—	—	<1
88 Leigh Creek	—	—	—	0·01	0·02	—	—	—	—	—	—	<1
89 Marree	—	—	—	—	—	—	—	—	—	—	—	0
90 Mt. Gambier	—	—	0·10	0·16	0·02	0·04	—	—	—	—	—	<1
91 Pt. Augusta	—	—	—	0·01	0·01	0·01	—	—	—	—	—	<1
92 Pt. Lincoln	—	—	0·01	0·01	0·05	—	—	—	—	—	—	<1
93 Tarcoola	—	0·08	0·01	0·02	0·02	—	—	—	—	NS	—	<1
94 Watson	15·0	0·10	0·09	0·03	0·01	—	—	—	—	—	—	4
95 Albany	—	—	—	—	—	—	—	—	—	—	—	0
96 Esperance	—	—	—	—	—	—	—	—	—	—	—	0
97 Forrest	—	—	0·07	0·01	—	—	—	—	—	—	—	<1
98 Leonora	—	—	—	—	—	—	—	—	—	—	—	0
99 Southern Cross	—	—	—	—	—	—	—	—	—	—	—	0
100 Giles	—	—	—	—	—	—	—	—	—	—	—	0
251 Boulia	—	—	—	—	—	—	—	—	—	—	—	0
252 Windorah	—	0·03	—	0·03	—	—	—	—	—	—	—	<1
254 Tambo	—	—	—	—	—	—	—	—	—	—	—	0
255 Winton	—	—	—	—	—	—	—	—	—	—	—	0
256 Forbes	—	NS	—	0·01	—	—	0·02	—	NS	—	—	<1
257 Cook	0·11	—	0·02	0·02	—	—	NS	—	—	—	—	<1
258 Cleve	—	0·52	0·03	—	0·12	—	—	—	—	—	—	<1
262 Tibooburra	—	—	0·02	NS	—	—	—	—	—	—	—	0
263 Finke	—	—	—	—	—	—	—	—	—	—	—	0
265 Birdsville	—	—	—	—	—	—	—	—	—	—	—	0

[1] These whole body γ doses are integrated to 50 years and take no account of the shielding afforded by the normal living habits of man.

[2] " — " indicates that the sample collected had an activity less than the minimum detectable.

[3] " NS " indicates that a sample was not collected.

TABLE IV

Activities from gummed films exposed after Round 4, 22 October 1956

Station and station number	μc/m² at 2100 hours on day of collection[2], [3]														Whole body dose[1] from Round 4 (milliroentgens)
	22/10	23/10	24/10	25/10	26/10	27/10	28/10	29/10	30/10	31/10	1/11	2/11	3/11	4/11	5/11	
1 Adelaide	—	—	—	0·01	—	—	—	—	—	—	—	—	—	—	—	<1
3 Woomera	—	—	—	0·04	—	—	—	—	—	—	—	—	—	—	—	<1
4 Hall's Creek	—	0·14	0·35	0·07	0·05	0·03	0·01	0·01	—	—	—	—	—	—	—	1
6 Pt. Moresby	—	—	—	—	—	—	—	—	0·01	—	—	—	—	—	—	<1
8 Broome	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
9 Kalgoorlie	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
10 Daly Waters	—	—	0·28	0·82	0·03	0·06	0·10	—	—	0·01	—	—	0·01	—	—	2
11 Oodnadatta	0·04	—	—	0·36	0·10	—	—	0·01	—	0·01	0·01	—	—	—	—	1
12 Onslow	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
13 Thursday Is.	—	—	0·10	—	—	—	—	0·01	0·01	—	—	—	—	—	—	<1
14 Wyndham	—	0·12	0·21	0·03	0·09	0·03	—	0·01	—	—	0·01	—	0·01	0·01	0·03	1
15 Melbourne	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
16 Pt. Hedland	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
17 Meekatharra	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
18 Geraldton	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
19 Alice Springs	—	—	0·01	0·18	0·31	0·07	0·01	—	—	—	—	—	—	—	NS	1
20 Townsville	—	—	0·20	0·04	0·05	0·03	0·05	NS	0·02	0·01	0·01	0·03	—	—	—	1
21 Sydney	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
22 Charleville	—	1·80	0·28	0·01	1·56	0·74	0·01	0·04	0·02	—	0·02	—	—	—	NS	8
23 Cloncurry	—	1·13	1·28	0·60	0·15	0·10	0·03	0·02	0·02	—	0·04	0·04	—	—	—	6
24 Cairns	—	0·04	0·25	0·01	—	0·02	0·03	0·03	0·04	—	—	—	—	—	—	1
25 Brisbane	—	0·42	0·21	0·01	0·23	0·10	0·01	0·01	0·03	—	—	—	—	0·01	—	2
26 Perth	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
27 Carnarvon	—	—	—	—	—	—	—	—	0·01	—	—	—	—	—	—	<1
28 Darwin	—	—	—	0·07	0·16	0·13	0·08	0·02	0·01	—	0·01	—	0·01	—	—	1
41 Sydney (AEC)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	0
51 Bundaberg	—	—	0·63	0·05	0·06	1·14	0·08	0·02	0·03	—	—	0·01	0·01	—	NS	4
52 Camooweal	—	1·45	0·92	0·72	NS	0·08	0·07	0·10	0·01	—	0·02	—	—	0·01	—	5
53 Cunnamulla	0·52	0·11	—	0·01	0·32	0·03	—	0·02	0·03	—	0·01	—	—	—	NS	1
54 Emerald	—	0·13	0·25	0·01	0·01	0·29	0·05	—	—	—	0·06	0·04	—	—	NS	2
55 Goondiwindi	—	0·36	0·33	0·01	0·52	0·14	—	0·01	0·02	—	—	—	—	—	—	2
56 Longreach	—	3·25	0·63	0·04	0·11	0·13	0·04	0·03	0·01	—	0·01	0·01	—	—	NS	5
57 Mackay	—	—	0·09	0·08	0·09	0·05	0·06	0·04	0·03	—	—	0·03	0·01	—	—	1
58 Normanton	—	—	0·10	0·09	0·01	—	0·01	0·02	0·03	0·01	0·01	0·01	0·01	—	—	<1
59 Richmond	—	1·23	0·38	0·20	0·10	0·10	0·01	0·01	0·02	—	—	0·04	0·01	—	NS	3
60 Rockhampton	—	0·04	0·35	0·10	0·01	0·36	0·10	0·01	0·04	—	—	0·01	—	—	—	2
61 Roma	—	2·0	0·62	—	1·35	0·72	0·03	0·03	0·06	—	0·02	—	0·01	—	—	8
62 Thargomindah	—	0·33	0·04	0·08	0·22	0·15	—	—	0·04	—	—	0·01	—	—	—	2
63 Armidale	—	2·1	0·14	0·01	0·08	0·03	—	—	0·01	—	—	—	—	—	NS	3
64 Bourke	0·78	—	—	0·18	0·28	—	0·01	0·01	0·02	—	—	—	—	—	NS	2
65 Canberra	0·07	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	<1
66 Cobar	0·29	0·19	—	0·10	0·06	—	—	0·01	0·01	—	—	—	—	—	NS	1
67 Coffs Harbour	—	0·18	0·07	—	0·03	0·02	—	—	—	—	—	—	—	—	—	<1
68 Broken Hill	0·72	—	—	0·08	0·05	0·02	0·01	0·02	—	—	—	0·02	—	—	—	1
69 Coonabarabran	0·34	—	—	0·03	0·05	—	—	—	—	—	—	—	—	—	NS	<1
70 Dubbo	0·10	—	—	0·06	0·04	—	—	0·01	—	—	—	—	—	—	—	<1
71 Hillston	—	—	—	0·05	0·01	—	—	—	—	—	—	—	—	—	NS	<1
72 Lismore	—	0·31	0·38	—	NS	0·15	—	0·01	0·02	—	0·01	NS	—	NS	NS	1
73 Tenterfield	—	0·62	0·16	0·01	0·10	0·18	—	—	0·01	—	—	—	—	—	NS	2
74 Walgett	0·62	0·27	0·01	0·02	0·14	0·03	—	0·01	0·01	—	—	—	0·01	—	NS	1
75 Williamtown	—	0·01	—	—	0·03	—	—	—	0·01	—	—	—	—	—	NS	<1
76 Wagga	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
77 Sale	—	—	—	0·01	—	NS	—	—	—	—	—	—	—	—	—	<1
78 Echuca	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	0
79 Hamilton	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
80 Mildura	—	—	—	0·04	—	—	—	—	—	—	—	—	—	—	—	<1
81 Nhill	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	0
82 Swan Hill	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	0
83 Warrnambool	—	—	—	—	—	—	—	—	—	NS	—	—	—	NS	NS	0
84 Currie	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	NS	0
85 Hobart	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
86 Western Junction	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	0
87 Ceduna	0·01	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	<1
88 Leigh Creek	3·7	0·02	0·03	0·23	0·04	—	—	0·01	—	—	—	—	—	—	NS	2
89 Marree	15·1	—	0·02	0·55	0·02	—	—	0·01	—	0·01	0·01	0·02	—	—	NS	9
90 Mt. Gambier	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
91 Pt. Augusta	—	—	—	0·28	—	—	—	—	—	—	0·01	—	—	—	NS	<1
92 Pt. Lincoln	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	0
93 Tarcoola	—	—	0·05	0·06	—	—	NS	—	—	—	—	—	NS	NS	NS	<1
94 Watson	—	—	0·01	0·02	—	—	—	—	—	—	—	—	—	—	NS	<1
95 Albany	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
96 Esperance	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0
97 Forrest	—	—	—	0·02	—	—	—	—	—	—	—	—	—	—	—	<1
98 Leonora	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	0

[1] These whole body γ doses are integrated to 50 years and take no account of the shielding afforded by the normal living habits of man.

[2] "—" indicates that the sample collected had an activity less than the minimum detectable.

[3] "NS" indicates that a sample was not collected.

TABLE IV—*Continued*

Activities from gummed films exposed after Round 4, 22 October 1956—*Continued*

Station and station number	μc/m² at 2100 hours on day of collection[2,3]														Whole body dose[1] from Round 4 (milliroentgens)
	22/10	23/10	24/10	25/10	26/10	27/10	28/10	29/10	30/10	31/10	1/11	2/11	3/11	4/11	5/11	
99 Southern Cross	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	0
100 Giles	—	0·13	0·08	0·05	0·03	0·01	0·01	—	—	NS	0·03	—	—	—	0·01	<1
251 Boulia	0·50	0·31	0·29	0·14	0·30	0·09	—	0·02	—	—	0·03	—	—	—	NS	2
252 Windorah	—	0·73	0·01	0·05	0·43	0·33	—	0·04	0·01	—	0·01	—	—	—	—	3
254 Tambo	—	1·74	0·32	—	0·28	0·36	0·01	0·01	0·04	—	0·02	—	—	—	NS	4
255 Winton	—	1·06	0·80	0·12	0·15	0·15	0·03	0·02	0·01	—	0·04	0·01	—	—	—	4
256 Forbes	—	—	—	0·07	0·03	—	—	—	—	—	—	—	—	—	NS	<1
257 Cook	—	—	—	0·01	—	—	—	—	—	—	—	—	—	NS	NS	<1
258 Cleve	—	—	—	0·03	—	—	—	—	—	—	—	—	—	—	—	<1
262 Tibooburra	8·7	0·17	—	0·25	0·01	—	NS	—	—	—	—	—	—	NS	NS	5
263 Finke	—	—	—	0·33	0·06	0·01	—	—	—	—	0·01	—	—	—	NS	1
265 Birdsville	13·0	0·43	—	1·10	0·57	0·26	0·01	0·05	0·01	—	0·01	—	—	NS	NS	11

TABLE V

Total whole body dose as a result of fallout from the Buffalo Series, estimated using gummed films

Station and station number	Whole body Dose[1] (milliroentgens)
1 Adelaide	<1
3 Woomera	1
4 Hall's Creek	1
6 Pt. Moresby	<1
8 Broome	0
9 Kalgoorlie	0
10 Daly Waters	3
11 Oodnadatta	1
12 Onslow	0
13 Thursday Island	<1
14 Wyndham	1
15 Melbourne	<1
16 Pt. Hedland	<1
17 Meekatharra	0
18 Geraldton	0
19 Alice Springs	1
20 Townsville	1
21 Sydney	<1
22 Charleville	9
23 Cloncurry	6
24 Cairns	1
25 Brisbane	2
26 Perth	0
27 Carnarvon	<1
28 Darwin	1
41 Sydney (AEC)	<1
51 Bundaberg	4
52 Camooweal	5
53 Cunnamulla	1
54 Emerald	2
55 Goondiwindi	4
56 Longreach	5
57 Mackay	1
58 Normanton	1
59 Richmond	3
60 Rockhampton	2
61 Roma	9
62 Thargomindah	4
63 Armidale	7
64 Bourke	4
65 Canberra	<1
66 Cobar	1
67 Coffs Harbour	2

TABLE V—*Continued*

Total whole body dose as a result of fallout from the Buffalo Series, estimated using gummed films—*Continued*

Station and station number	Whole body Dose[1] (milliroentgens)
68 Broken Hill	1
69 Coonabarabran	1
70 Dubbo	<1
71 Hillston	<1
72 Lismore	24
73 Tenterfield	4
74 Walgett	3
75 Williamtown	<1
76 Wagga	<1
77 Sale	<1
78 Echuca	<1
79 Hamilton	<1
80 Mildura	<1
81 Nhill	<1
82 Swan Hill	<1
83 Warrnambool	<1
84 Currie	1
85 Hobart	<1
86 Western Junction	<1
87 Ceduna	<1
88 Leigh Creek	4
89 Marree	15
90 Mt. Gambier	<1
91 Pt. Augusta	<1
92 Pt. Lincoln	<1
93 Tarcoola	<1
94 Watson	5
95 Albany	0
96 Esperance	0
97 Forrest	<1
98 Leonora	0
99 Southern Cross	0
100 Giles	1
251 Boulia	3
252 Windorah	4
254 Tambo	4
255 Winten	4
256 Forbes	<1
257 Cook	<1
258 Cleve	<1
262 Tibooburra	9
263 Finke	2
265 Birdsville	12

[1] These whole body γ doses are integrated to 50 years and take no account of the shielding afforded by the normal living habits of man.

[2] " — " indicates that the sample collected had an activity less than the minimum detectable.

[3] " NS " indicates that a sample was not collected.

TABLE VI

Activities from air pump filters after Round 1, 27 September 1956

Station and station number	μμc/m³ at 2100 hours on day of collection[1, 2]						
	27/9	28/9	29/9	30/9	1/10	2/10	3/10
1 Adelaide	—	—	—	—	—	—	—
3 Woomera	—	—	—	—	—	—	—
4 Hall's Creek	—	—	—	—	NS	—	—
6 Pt. Moresby	—	—	—	—	—	—	—
8 Broome	—	—	—	20	—	—	—
9 Kalgoorlie	—	—	—	—	—	—	—
10 Daly Waters	NS	NS	NS	420	70	70	30
11 Oodnadatta	—	90	—	10	—	—	20
12 Onslow	—	—	—	—	—	—	—
13 Thursday Is.	—	—	—	—	—	—	20
14 Wyndham	—	—	20	200	3000	50	50
15 Melbourne	—	—	—	—	—	—	—
16 Pt. Hedland	—	—	—	—	—	—	—
17 Meekatharra	—	—	—	—	10	—	—
18 Geraldton	—	—	—	—	—	—	—
19 Alice Springs	—	—	30	—	—	—	—
20 Townsville	—	—	—	—	260	70	40
21 Sydney	—	—	—	—	—	—	—
22 Charleville	—	—	360	—	—	—	10
23 Cloncurry	—	—	50	20	40	130	60
24 Cairns	—	—	—	—	20	120	50
25 Brisbane	—	—	50	140	10	—	—
26 Perth	—	—	—	—	—	—	—
27 Carnarvon	—	—	—	—	—	—	—
28 Darwin				No samples			
41 Sydney (AEC)	—	—	—	—	—	—	—
51 Bundaberg	—	—	—	540	40	—	—
52 Camooweal	—	—	710	40	10	90	60
53 Cunnamulla	—	—	1400	30	10	10	10
54 Emerald	—	—	—	620	20	10	20
55 Goondiwindi	—	—	—	50	—	—	—
56 Longreach	—	—	40	10	NS	20	NS
57 Mackay	—	—	—	—	70	100	90
58 Normanton	—	—	90	400	300	40	50
59 Richmond	—	—	90	90	370	150	60
60 Rockhampton	—	—	—	600	10	50	20
61 Roma	NS	10	570	40	10	40	—
62 Thargomindah	—	90	NS	50	—	NS	—
63 Armidale	—	2200	1700	—	10	10	10
64 Bourke	—	1200	90	10	—	—	—
65 Canberra	—	—	—	—	—	—	—
66 Cobar	—	—	80	—	—	—	—
67 Coffs Harbour	—	—	380	10	—	—	—
68 Broken Hill	—	90	—	—	—	—	—
69 Coonabarabran	—	—	160	10	10	—	—
70 Dubbo	—	70	10	30	—	—	NS
71 Hillston	—	—	—	—	—	—	—
72 Lismore	—	2900	440	50	60	—	10
73 Tenterfield	—	—	300	10	10	—	—
74 Walgett	—	—	400	140	—	70	—
75 Williamtown	—	—	110	—	—	—	—
76 Wagga	—	—	—	—	—	—	—
77 Sale	—	—	—	—	NS	—	—
78 Echuca	—	—	—	—	—	—	—
79 Hamilton	—	—	—	—	—	—	—
80 Mildura	—	—	—	—	—	—	—
81 Nhill	—	—	—	—	—	—	—
82 Swan Hill	—	—	—	—	—	—	—
83 Warrnambool	—	—	—	—	—	—	—
84 Currie	—	—	—	—	—	—	—
85 Hobart	—	—	—	—	—	—	—
86 Western Junction	—	—	—	—	—	—	—
87 Ceduna	—	—	—	—	—	—	—
88 Leigh Creek	—	500	—	—	—	—	—
89 Marree	—	850	—	—	—	—	20
90 Mt. Gambier	—	—	—	—	10	—	—
91 Pt. Augusta	—	—	—	—	—	—	—
92 Pt. Lincoln	—	—	—	—	—	—	—
93 Tarcoola	—	—	—	—	10	—	—
94 Watson	—	—	—	—	—	10	—
95 Albany	—	—	—	—	—	—	—
96 Esperance	—	—	—	—	—	—	—
97 Forrest	—	—	—	—	—	—	—
98 Leonora	—	—	—	—	10	—	—
99 Southern Cross	—	—	—	—	—	—	—
100 Giles	—	—	—	—	10	10	10

[1] "—" indicates that the sample collected had an activity less than the minimum detectable.
[2] "N" indicates that a sample was not collected.

TABLE VII

Activities from air pump filters after Round 2, 4 October 1956

Station and station number	μμc/m³ at 2100 hours on day of collection[1, 2]						
	4/10	5/10	6/10	7/10	8/10	9/10	10/10
1 Adelaide	—	—	—	—	—	—	—
3 Woomera	—	—	—	—	—	—	—
4 Hall's Creek	—	—	—	—	10	—	NS
6 Pt. Moresby	—	—	—	—	—	—	—
8 Broome	—	—	—	—	—	—	—
9 Kalgoorlie	—	—	NS	NS	NS	NS	NS
10 Daly Waters	30	100	30	40	50	10	10
11 Oodnadatta	—	30	—	—	10	—	—
12 Onslow	—	—	—	—	—	—	—
13 Thursday Is.	20	—	—	—	—	—	20
14 Wyndham	20	No further samples					
15 Melbourne	—	—	—	—	—	—	—
16 Pt. Hedland	—	—	—	—	—	—	20
17 Meekatharra	—	—	—	—	—	—	—
18 Geraldton	—	—	—	—	—	—	—
19 Alice Springs	—	60	150	20	40	10	—
20 Townsville	10	—	—	30	100	30	10
21 Sydney	—	—	10	—	—	—	—
22 Charleville	10	—	600	50	—	10	—
23 Cloncurry	50	120	350	230	20	30	10
24 Cairns	30	10	—	—	80	80	20
25 Brisbane	10	—	50	80	—	—	—
26 Perth	—	—	—	—	—	—	NS
27 Carnarvon	—	—	—	—	—	—	—
28 Darwin	No Samples						
41 Sydney (AEC)	—	—	—	—	—	—	—
51 Bundaberg	20	—	—	70	—	—	—
52 Camooweal	40	20	250	220	20	20	40
53 Cunnamulla	—	60	520	10	—	—	—
54 Emerald	20	20	20	120	10	—	—
55 Goondiwindi	10	—	350	30	—	—	—
56 Longreach	20	20	90	130	—	10	—
57 Mackay	20	10	10	30	90	10	—
58 Normanton	50	210	80	80	90	30	40
59 Richmond	40	30	180	230	40	30	20
60 Rockhampton	20	—	—	100	10	—	—
61 Roma	20	—	380	100	—	—	10
62 Thargomindah	—	—	420	170	—	—	10
63 Armidale	—	—	150	—	—	—	—
64 Bourke	20	—	80	10	—	—	—
65 Canberra	—	—	—	—	—	—	—
66 Cobar	—	—	60	—	—	—	—
67 Coffs Harbour	—	—	20	20	—	—	—
68 Broken Hill	—	—	—	—	10	—	—
69 Coonabarabran	—	—	40	—	—	—	—
70 Dubbo	—	—	20	—	—	—	—
71 Hillston	—	—	—	—	—	—	—
72 Lismore	90	20	20	50	—	—	—
73 Tenterfield	—	—	80	40	—	—	—
74 Walgett	—	—	350	—	—	—	—
75 Williamtown	—	10	—	—	10	—	—
76 Wagga	—	—	—	—	—	—	—
77 Sale	—	—	—	NS	—	—	—
78 Echuca	—	—	—	—	—	—	—
79 Hamilton	NS	—	—	—	—	—	—
80 Mildura	—	—	—	—	—	—	—
81 Nhill	—	—	—	—	—	—	—
82 Swan Hill	—	—	—	—	—	—	—
83 Warrnambool	—	—	—	—	—	—	—
84 Currie	—	—	—	—	—	—	—
85 Hobart	—	—	—	—	—	—	—
86 Western Junction	—	—	—	—	—	—	—
87 Ceduna	—	—	—	—	—	—	—
88 Leigh Creek	—	—	—	—	—	—	—
89 Marree	—	50	—	—	—	10	—
90 Mt. Gambier	—	—	—	—	—	—	—
91 Pt. Augusta	—	—	—	—	—	—	—
92 Pt. Lincoln	—	—	—	—	—	—	—
93 Tarcoola	—	—	—	—	—	—	—
94 Watson	230	—	—	—	—	—	—
95 Albany	—	—	—	—	—	—	NS
96 Esperance	—	—	—	—	—	—	—
97 Forrest	—	—	—	—	—	—	—
98 Leonora	—	—	—	—	—	—	—
99 Southern Cross	—	—	—	—	—	—	—
100 Giles	10	550	—	60	50	—	—

[1] "—" indicates that the sample collected had an activity less than the minimum detectable.
[2] "NS" indicates that a sample was not collected.

TABLE VIII

Activities from air pump filters after Round 3, 11 October 1956

Station and station number	μμc/m³ at 2100 hours on day of collection[1, 2]										
	11/10	12/10	13/10	14/10	15/10	16/10	17/10	18/10	19/10	20/10	21/10
1 Adelaide	—	14000	4000	250	330	20	—	—	—	—	—
3 Woomera	NS	6000	20	10	20	30	—	—	—	—	—
4 Hall's Creek	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
6 Pt. Moresby	—	—	—	—	—	—	—	—	—	—	—
8 Broome	—	—	—	—	—	—	10	10	—	—	—
9 Kalgoorlie	NS	NS	—	—	20	—	—	—	—	—	—
10 Daly Waters	10	10	20	20	10	10	10	10	—	—	—
11 Oodnadatta	—	—	—	30	60	20	—	—	—	—	—
12 Onslow	—	—	—	—	—	—	—	—	—	—	—
13 Thursday Is.	10	10	—	—	10	10	—	—	—	—	—
14 Wyndham	No samples										
15 Melbourne	10	NS	300	40	—	20	—	—	—	—	—
16 Pt. Hedland	—	—	20	—	—	—	10	10	—	—	—
17 Meekatharra	—	—	—	—	—	—	—	—	—	—	—
18 Geraldton	—	—	—	—	—	—	—	—	—	—	—
19 Alice Springs	—	10	—	20	20	60	—	—	—	—	—
20 Townsville	—	—	—	—	10	—	—	—	—	—	—
21 Sydney	—	—	—	240	150	10	20	—	—	—	—
22 Charleville	—	—	—	—	10	—	20	—	—	—	—
23 Cloncurry	—	40	20	10	20	10	10	—	—	—	—
24 Cairns	—	20	10	10	10	10	—	—	—	—	—
25 Brisbane	—	—	20	10	—	—	10	10	—	—	—
26 Perth	NS	NS	NS	NS	—	—	—	—	—	—	—
27 Carnarvon	—	—	—	—	—	—	—	—	—	—	—
28 Darwin	No samples										
41 Sydney (AEC)	—	—	—	350	200	10	10	—	—	—	—
51 Bundaberg	—	—	10	—	—	—	10	—	—	—	—
52 Camooweal	—	—	—	10	20	20	10	—	—	—	NS
53 Cunnamulla	40	—	—	—	10	20	30	—	—	—	—
54 Emerald	—	—	10	10	10	10	10	10	—	—	—
55 Goondiwindi	—	—	—	—	10	10	20	10	—	—	10
56 Longreach	—	—	10	10	10	20	20	—	—	—	—
57 Mackay	—	—	—	10	10	—	—	—	—	—	—
58 Normanton	—	10	10	NS	10	—	—	—	—	—	—
59 Richmond	10	10	20	10	10	10	—	—	—	—	—
60 Rockhampton	—	—	—	—	10	—	—	10	—	—	—
61 Roma	—	—	—	10	—	10	10	—	—	—	—
62 Thargomindah	—	—	—	—	—	10	40	20	—	—	—
63 Armidale	—	—	170	370	10	—	20	—	—	—	—
64 Bourke	—	—	—	—	10	70	30	—	—	NS	NS
65 Canberra	—	—	380	1400	130	20	40	—	—	—	—
66 Cobar	—	—	—	—	—	80	30	—	—	—	—
67 Coffs Harbour	—	—	—	200	60	10	10	—	—	—	—
68 Broken Hill	—	—	1100	10	50	160	—	—	—	—	—
69 Coonarabran	—	—	—	900	—	20	40	—	—	—	—
70 Dubbo	—	—	—	2300	—	—	NS	NS	NS	NS	NS
71 Hillston	—	—	1800	320	—	80	70	—	—	—	—
72 Lismore	—	30	—	10	90	10	10	10	—	10	20
73 Tenterfield	—	—	—	10	—	—	10	—	—	—	—
74 Walgett	—	—	10	10	—	30	50	—	—	—	—
75 Williamtown	—	—	—	210	140	10	30	—	—	—	—
76 Wagga	—	—	230	2500	110	30	20	—	—	—	—
77 Sale	40	—	440	70	30	20	—	—	—	—	—
78 Echuca	—	—	950	2600	120	60	70	—	—	—	—
79 Hamilton	—	—	1500	630	120	40	—	—	—	—	—
80 Mildura	—	—	2800	70	100	70	—	—	—	—	—
81 Nhill	—	—	6400	440	30	50	—	—	—	—	—
82 Swan Hill	—	—	1900	1500	30	60	—	—	—	—	—
83 Warrnambool	—	—	1100	240	340	40	—	—	—	—	—
84 Currie	—	—	—	10	40	20	—	—	—	—	—
85 Hobart	—	—	—	—	10	10	—	—	—	—	—
86 Western Junction	—	—	—	—	30	30	—	—	—	—	—
87 Ceduna	—	9500	30	120	190	—	—	—	—	—	—
88 Leigh Creek	500	—	—	10	50	140	—	—	—	—	—
89 Marree	250	—	—	20	30	50	—	—	—	—	—
90 Mt. Gambier	—	20	1300	600	140	30	—	—	—	—	—
91 Pt. Augusta	—	260	10	10	130	20	—	—	—	—	—
92 Pt. Lincoln	—	200	2100	10	—	—	—	—	—	—	—
93 Tarcoola	—	—	—	—	40	—	—	—	—	—	—
94 Watson	3200	90	130	140	10	20	—	—	—	—	—
95 Albany	—	—	—	—	—	—	—	—	—	—	—
96 Esperance	—	—	—	—	—	—	—	—	—	—	—
97 Forrest	220	40	350	20	—	—	—	—	—	—	—
98 Leonora	—	—	—	—	—	—	—	—	—	—	—
99 Southern Cross	—	—	—	10	—	—	—	—	—	—	—
100 Giles	—	—	10	20	20	—	—	NS	NS	NS	NS

[1] "—" indicates that the sample collected had an activity less than the minimum detectable.

[2] "NS" indicates that a sample was not collected.

TABLE IX

Activities from air pump filters after Round 4, fired 22 October 1956

Station and station number	μμc/m³ at 2100 hours on day of collection[1,2]														
	22/10	23/10	24/10	25/10	26/10	27/10	28/10	29/10	30/10	31/10	1/11	2/11	3/11	4/11	5/11
1 Adelaide	—	—	—	—	—	—	10	—	—	—	—	—	—	—	—
3 Woomera	—	—	—	—	—	—	—	—	—	10	—	—	—	—	—
4 Hall's Creek	—	190	—	—	—	—	30	—	—	—	—	—	—	—	20
6 Pt. Moresby	—	—	—	—	—	—	—	—	10	10	—	—	10	—	—
8 Broome ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9 Kalgoorlie	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
10 Daly Waters	—	—	160	650	40	10	20	20	10	—	—	—	—	—	—
11 Oodnadatta	290	—	—	10	—	—	—	—	—	—	—	—	—	—	—
12 Onslow ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13 Thursday Is. ..	—	—	—	—	—	—	—	70	30	10	40	10	10	10	—
14 Wyndham	No samples														
15 Melbourne	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
16 Pt. Hedland ..	20	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17 Meekatharra..	40	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18 Geraldton	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19 Alice Springs	—	10	10	40	50	—	—	20	—	—	10	—	—	—	—
20 Townsville	—	—	150	20	10	10	60	NS	10	10	10	10	—	—	—
21 Sydney ..	—	—	—	—	—	—	—	—	—	—	—	—	10	—	—
22 Charleville	—	200	80	—	330	80	20	10	20	—	10	NS	NS	NS	NS
23 Cloncurry	—	60	530	300	70	110	30	30	10	10	30	30	10	—	—
24 Cairns ..	—	—	320	20	—	10	—	20	10	10	10	20	20	20	—
25 Brisbane	—	50	20	10	40	30	—	—	—	—	—	—	—	—	—
26 Perth ..	10	—	—	—	—	—	—	—	—	—	—	—	—	—	—
27 Carnarvon	—	—	—	—	10	—	—	—	—	—	—	—	—	NS	NS
28 Darwin ..	No samples														
41 Sydney (AEC)..	—	—	—	—	—	—	—	—	—	—	—	NS	NS	NS	NS
51 Bundaberg	—	—	30	200	70	20	10	10	10	—	—	10	—	—	NS
52 Camooweal	—	330	700	970	NS	100	20	20	10	10	20	10	—	—	—
53 Cunnamulla	—	300	20	—	No further samples										
54 Emerald..	—	60	30	90	40	200	10	21	10	—	—	10	—	—	NS
55 Goondiwindi ..	—	170	10	—	40	20	10	10	—	—	—	—	—	—	—
56 Longreach	—	550	20	50	280	100	—	10	—	10	—	10	—	—	NS
57 Mackay ..	—	—	120	140	—	50	20	10	20	—	10	—	—	—	—
58 Normanton	—	—	60	90	40	—	10	40	60	40	140	40	10	10	—
59 Richmond	—	1200	650	320	1000	330	50	20	30	20	40	70	—	—	NS
60 Rockhampton	20	10	160	220	40	20	—	20	10	—	—	10	—	—	—
61 Roma ..	—	350	30	—	—	90	40	20	10	10	—	—	—	—	—
62 Thargomindah	20	60	70	10	—	NS	—	—	—	—	—	—	—	—	—
63 Armidale	—	80	20	20	20	—	—	—	—	—	—	—	—	—	NS
64 Bourke ..	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	—	—	—	—	NS
65 Canberra	10	—	—	—	—	—	—	—	—	—	—	—	—	—	NS
66 Cobar ..	120	—	—	10	10	—	—	—	—	—	—	—	—	—	NS
67 Coffs Harbour	—	280	—	—	10	—	—	—	—	—	—	—	—	—	—
68 Broken Hill	10	—	—	60	40	10	10	30	—	—	10	—	—	—	—
69 Coonabarabran ..	—	—	—	40	—	—	—	—	—	—	—	—	—	NS	NS
70 Dubbo ..	NS	NS	NS	NS	—	—	—	10	—	—	—	—	—	—	—
71 Hillston ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS
72 Lismore ..	—	20	—	—	NS	—	—	—	—	—	—	NS	—	NS	NS
73 Tenterfield	—	80	—	—	10	10	—	—	—	—	—	—	—	—	NS
74 Walgett ..	20	40	—	—	—	10	10	20	—	—	—	—	—	—	NS
75 Williamtown ..	—	10	—	—	40	—	—	—	—	—	—	—	—	—	NS
76 Wagga	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
77 Sale ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
78 Echuca ..	—	—	—	—	—	—	10	—	—	—	—	—	—	—	NS
79 Hamilton	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
80 Mildura ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
81 Nhill ..	—	—	—	—	—	—	10	—	—	—	—	—	—	—	NS
82 Swan Hill	—	—	—	—	—	—	10	—	—	—	—	—	—	NS	NS
83 Warrnambool ..	—	—	—	—	—	—	—	—	—	—	—	—	—	NS	NS
84 Currie ..	—	—	—	—	—	—	NS	NS	NS	NS	—	—	—	NS	NS
85 Hobart ..	NS	NS	NS	NS	NS	NS	NS	NS	—	—	—	—	—	—	—
86 Western Junction	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS
87 Ceduna ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS
88 Leigh Creek	1500	—	—	10	—	—	—	—	—	10	—	—	—	—	NS

[1] "—" indicates that the sample collected had an activity less than the minimum detectable.

[2] "NS" indicates that a sample was not collected.

TABLE IX—*Continued*

Activities from air pump filters after Round 4, fired 22 October 1956—*Continued*

Station and station number	μμc/m³ at 2100 hours on day of collection[1, 2]														
	22/10	23/10	24/10	25/10	26/10	27/10	28/10	29/10	30/10	31/10	1/11	2/11	3/11	4/11	5/11
89 Marree ..	900	2500	—	10	—	—	10	—	—	—	10	—	—	—	NS
90 Mt. Gambier ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
91 Pt. Augusta	—	—	—	30	—	—	—	—	NS	—	—	—	—	—	NS
92 Pt. Lincoln	—	—	—	—	—	—	10	—	—	—	—	—	—	—	NS
93 Tarcoola	—	—	—	—	—	—	NS	—	—	—	—	—	NS	NS	NS
94 Watson	—	—	—	—	—	—	—	—	—	—	—	—	—	—	NS
95 Albany ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
96 Esperance	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
97 Forrest ..	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
98 Leonora	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
99 Southern Cross	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	—	—	—	—	NS
100 Giles ..	No samples														

[1] " — " indicates that the sample collected had an activity less than the minimum detectable.
[2] " NS " indicates that a sample was not collected.

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