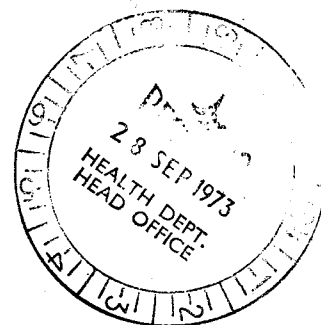




DEPARTMENT OF HEALTH
NEW ZEALAND



ENVIRONMENTAL RADIOACTIVITY
ANNUAL REPORT
1971

compiled by
L. P. Gregory

P
ENV
NATIONAL RADIATION LABORATORY
P. O. BOX 25-099, CHRISTCHURCH
NEW ZEALAND

JUNE 1972

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NOTICE

This report continues the series of annual reports on "Environmental Radioactivity". It presents the results of routine long term measurements of global fallout, particularly in New Zealand, and also includes other surveys of artificial or naturally-occurring environmental radioactivity. It no longer includes detailed results from the special monitoring programmes covering the short term effects of the recent French Nuclear tests in the southern hemisphere. These have been published in a separate report.

The quarterly reports "Environmental Radioactivity in New Zealand" which have been published since 1961 have now been discontinued. At the present levels of radioactive fallout the reporting of these levels on a quarterly basis is unnecessary and unduly emphasises short term fluctuations which are seen in better perspective when viewed over a longer period. The last quarterly to be published was Report No. NRL-F/46 containing the routine results for the third quarter 1971, and also the final results of the special programme monitoring the 1971 French nuclear tests. A report for the fourth quarter will not be published because all routine results for 1971 are given in the present report.

The separate report "Fallout from Nuclear Weapons Tests Conducted by France in the South Pacific from June to August 1971 - and Comparisons with Previous Test Series" was recently published (Report No. NRL-F/47, March 1972). This report presents for the first time under one cover the measurements of short term effects from the 1971 monitoring programme, and makes comparisons with previous programmes. The results of future monitoring programmes covering a particular nuclear test series in the southern hemisphere will be published similarly in a single report at the conclusion of the programme.

UNITS OF RADIOACTIVITY

Ci .. Curie 3.7×10^{10} disintegrations per second
mCi .. millicurie = 10^{-3} Curies
pCi .. picocurie = 10^{-12} Curies .. 2.22 disintegrations per minute

1. Radioactive fallout in rain is expressed as:

- (a) DEPOSITION : millicuries per square kilometre (mCi/km²)
- (b) CONCENTRATION : picocuries per litre (pCi/litre)

$$\text{pCi/litre} = \frac{\text{mCi/km}^2 \times 100}{\text{rainfall in centimetres}}$$

2. The levels of strontium-90 contamination in food and bone are given in "Strontium Units":

picocuries strontium-90 per gram of calcium .. pCi ⁹⁰Sr/g Ca.

Similarly caesium-137 results are given as:

picocuries of caesium-137 per gram of potassium .. pCi ¹³⁷Cs/g K.

NOTE: One litre of whole milk contains approximately: 1.2 g of calcium
1.4 g of potassium

All times given in this report are NEW ZEALAND STANDARD TIME (G.M.T. + 12 hrs).

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TERMS OF REFERENCE AND ACKNOWLEDGEMENT

In September 1957 the New Zealand Department of Health was charged, under a Cabinet directive, with the responsibility for monitoring environmental radioactive contamination in New Zealand and also in any Pacific areas with which New Zealand was associated.

The Department delegated this responsibility to its National Radiation Laboratory at Christchurch where the measurement of radioactive fallout became a natural extension of the work of the Laboratory in the fields of radiation protection - the control of radioactive pollution and the safe use of ionizing radiations in medicine, education, research and industry.

The National Radiation Laboratory therefore undertook responsibility for sample collection, analysis, and interpretation of data on environmental levels of radioactivity. The network of collecting stations shown in Fig. 1 was subsequently established. In addition to the New Zealand sampling, monthly collections of rainwater have also been provided from Fiji and Rarotonga. Within New Zealand, collections were made, and samples were provided, by officers of this and other Government Departments (particularly the staff of the New Zealand Meteorological Service), by pathologists, and by the managers of milk processing plants. Their continued co-operation is gratefully acknowledged as it has made possible the Laboratory's routine monitoring programme.

Because there are no internationally accepted "permissible" levels for radioactive fallout, a set of reference levels has been developed by a panel of senior officers of the National Radiation Laboratory: G.E. ROTH, DIRECTOR: H.J. YEABSLEY, ASSISTANT DIRECTOR: and J.F. McCAHON.

These reference levels are in accord with those adopted by several nations for control of pollution of the environment and their implications are discussed more fully in this report.

The Environmental Radioactivity Section of the Laboratory was responsible for the organisation of the monitoring operations, sample analyses, and reporting and interpretation of results:

| | |
|---------------|--|
| L.P. GREGORY | Officer in Charge, Monitoring Operations, Radiochemistry, Editorial Work. |
| T. BALTAKMENS | Professional Officer, Radiochemistry |
| J.E. DOBBS | Technical Officer, Gamma Spectroscopy |
| R.H. CHAPMAN | Technical Assistant |
| G.K. OSBORNE | Technical Assistant |

The assistance of the mechanical and electronic workshops, the draughting and clerical sections of the Laboratory is gratefully acknowledged.

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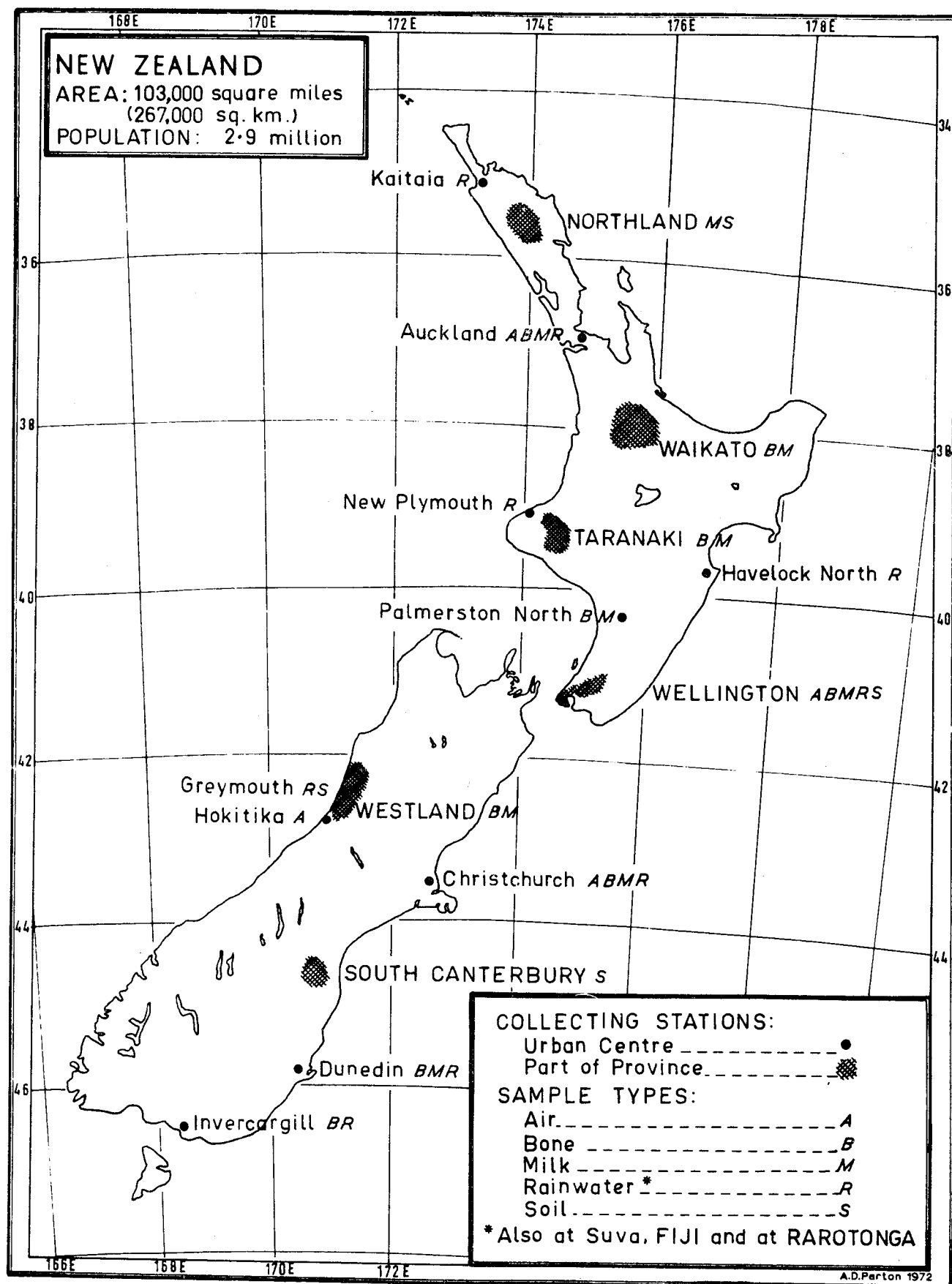


Fig. 1

COLLECTING STATIONS IN NEW ZEALAND

POTENTIAL HEALTH HAZARD AND REFERENCE LEVELS

There are no internationally accepted "permissible levels" for the exposure of people to fallout from nuclear weapons testing. Most of the measurements recorded in this report concern such contamination and it is considered necessary in the public interest to provide some guide by which the significance of the values may be appreciated.

Development of Reference Levels

The simplest procedure is to compare measured values with those which would give the annual "Dose Limits" suggested by the International Commission on Radiological Protection (I.C.R.P.)*. These dose limits were established for individual members of the public so that the risks from controllable radiation sources should be no greater than other risks regularly accepted in every day living. These dose limits are in fact one-tenth of the annual Maximum Permissible Doses for radiation workers. The Commission emphasizes that all controlled radiation exposures should be kept to the minimum practicable and that the risks should be justified in terms of benefits that would not otherwise be received.

The following "Reference Levels" have been derived from these dose limits, making allowance for the risk to children. In no case is a reference level greater than one-third of the concentration which, if maintained indefinitely, would lead to a dose limit. The media and radionuclides listed are those generally accepted as the key items for monitoring fallout contamination, and the units of concentration are those used in the reports of this Laboratory.

Reference Levels:

| | | |
|---------------|--|---------------------|
| In Milk: | Strontium-90 | 270 pCi/g Ca |
| | Caesium-137 | 7,000 pCi/g K |
| | Iodine-131** | 200 pCi/litre |
| In Air: | Mixed fission products between 10 and 80 days old. | 300 pCi/cubic metre |
| In Rainwater: | Mixed fission products between 10 and 80 days old. | 6,000 pCi/litre |

The I.C.R.P. "Dose Limits" specify annual exposures and therefore for those concentrations which can change rapidly with time, such as mixed fission products in air or in rain, or iodine-131 in milk, the average values over the year, rather than transient values, should be compared with the reference levels.

If, during any one year, the average levels do not greatly exceed the reference levels then any resulting increase in risk to the health of an individual would be insignificant, and would not, in itself, justify the disruptions and possible risks associated with remedial actions.

* Recommendations of the International Commission on Radiological Protection: ICRP Publication 9. Pergamon Press, 1966.

** Not a routine measurement (see NRL-F/47 for results of ¹³¹I measurements during the special monitoring programmes).

Comparison of Reference Levels with Natural Radiation Background

It is also necessary to consider the possible hazards from continuing weapons tests. Under these conditions long-lived radioactive debris, accumulating in the environment, and the regular presence of short-lived material, may cause exposure over many years. In this context it is helpful to compare the average (over many years) of the annual doses from fallout with that due to background radiation to which the human race has always been exposed.

The level of background radiation varies markedly from place to place. For reference purposes, however, the "average" annual dose received from the natural environment may be taken as about 120 millirads.

There are a number of areas with large populations where the annual background dose is several times this value. No survey has to date demonstrated that there is a health hazard associated with living in such a region. On the other hand it has not been possible to demonstrate that there is a threshold dose below which no effect on health is produced.

If the reference levels were maintained indefinitely, they would each lead to a dose rate of the same order as that received from average natural background radiation. Thus if a long term average level is expressed as a percentage of a reference level then the resulting risk will be about the same percentage of any risk which may be eventually attributed to radiation from the natural environment.

GENERAL STATEMENT ON THE LABORATORY'S MONITORING RESULTS

During 1971 the average levels of radioactive contamination were small percentages of the reference levels and are evaluated in detail in this report.

The stratospheric fallout of long-lived bomb test material such as strontium-90 reached a maximum in New Zealand in 1964 as a result of the large scale tests by the U.S.S.R. and U.S.A. in 1961 and 1962. Levels then decreased to a minimum in 1968, but have increased slightly since then as a result of the French tests in the South Pacific. The average annual deposition over the past three years has been about one-third of the 1964 maximum.

Levels of strontium-90 and caesium-137 in milk reflect these changes. During the last few years these levels have been very approximately one-half of the maximum levels which were recorded in 1965.

The long term average levels since measurements commenced are also small percentages of the reference levels. It is therefore considered that the levels reported herein do not constitute a public health hazard.

It is convenient to classify radioactive fallout into two types - tropospheric fallout and stratospheric fallout. Tropospheric fallout originates from the injection of fission products into the lower atmosphere (below about 15 kilometres) and is normally associated with nuclear weapons, in the kiloton range, detonated above ground level. The significant characteristics of tropospheric fallout are: the predominance of short-lived radionuclides of relatively high specific radioactivity, resulting in sudden, often dramatic, increases in air radioactivity as the cloud of radioactive particles is carried along by prevailing winds; the dispersion, gravitational settling, and precipitation in rain as the cloud of particles encircle the earth usually at about the same latitude as that of the nuclear test. In a few weeks or months most of the radioactivity has been deposited on the surface and has decayed.

The monitoring of such short term effects from the French Nuclear tests in the South Pacific has been the subject of a recent report (1) published by this Laboratory.

Stratospheric fallout, however, originates from the injection of fission products into the upper atmosphere and largely results from the testing of nuclear weapons in the megaton range. Such devices (hydrogen bombs) detonated at a sufficient height cause most of the radioactivity to be carried into the stratosphere. Fine particles will there drift around the world for months or years before being transferred to the troposphere where they will be subjected to precipitation. Such delayed fallout has two significant aspects: the absence of shorter-lived radionuclides because of radioactive decay; the tendency for the deposition to occur in the mid-latitudes, especially the mid-latitudes of the hemisphere in which the nuclear tests were conducted. Polar and equatorial regions, therefore, will receive less global fallout than countries in the temperate zones such as New Zealand.

The main purpose of the present report is to assess the long term effects due to global fallout. In particular, the levels of a few specific radionuclides such as strontium-90 and caesium-137 are presented. These radionuclides are potentially hazardous to health because they have a long radioactive half-life, and in the case of strontium-90, prolonged retention in human bone. Routine measurements of total beta activity in air and rain are included, and also measurements of the shorter-lived strontium-89 in rain, during periods of nuclear weapons tests. The measurements of some long-lived naturally-occurring radionuclides, such as lead-210 and radium-226, which present a hazard similar to long-lived fallout components, are also included in our routine measurements.

The main criteria for selecting the collecting stations shown in Fig. 1 were:

Routine availability of samples; adequate geographical coverage including rainfall extremes; the proximity of milk producing areas to rain collection sites; and population distribution.

The results of these routine measurements, together with special surveys and monitoring programmes, have been published in a series of quarterly and annual summary reports since June 1961 (2).

Chapter 2: TOTAL BETA ACTIVITY OF AIR FILTER AND RAINWATER COLLECTIONS

1. Fission Products in Air

In the absence of fresh fission products in the atmosphere, the levels of total beta activity in air are usually less than 0.1 pico-curies per cubic metre (typically about 0.03 pCi/m³). Since 1959, however, when measurements first commenced at Christchurch, transient increases in the levels, due to atmospheric nuclear tests, have been observed.

In Fig. 2 the average monthly levels are shown for the four New Zealand stations. The increases caused by the tests, conducted by the United States in the Pacific in 1962, and by the French in the South Pacific since 1966 are apparent. The progressive reduction in the levels after each test series is also apparent. This is particularly noticeable after the 1966 and 1967 French tests in which weapons in the kiloton range only were tested. The relatively rapid rate of decay and removal from the troposphere by deposition is characteristic of such tests. The remaining French test series since 1967, however, have included one or more weapons in the megaton range and the resulting higher altitude of injection causes a delay in the subsequent deposition. This delay is apparent in Fig. 2.

The monthly average levels shown in Fig. 2 have been averaged for each year since 1966, where possible, and are shown in Table 1.

| TABLE 1 | TOTAL BETA ACTIVITY IN AIR - ANNUAL AVERAGES (pCi/m ³) | | | | | |
|--------------|--|------|------|------|-------|------|
| | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 |
| Auckland | 0.14 | 0.08 | 0.12 | 0.12 | 0.16 | 0.21 |
| Wellington | 0.10* | 0.05 | 0.10 | 0.09 | 0.12 | 0.12 |
| Hokitika | | | | | 0.12* | 0.16 |
| Christchurch | 0.11 | 0.06 | 0.07 | 0.07 | 0.10 | 0.15 |
| * Estimate | | | | | | |

The results of measurements on individual air filter samples collected during 1971 are given in TABLE 8 APPENDIX. Filters were changed three times each week except during the special monitoring programme from June to October when they were changed daily at the New Zealand stations. (During this time daily samples were also collected at four Pacific Island stations.) For this period the monthly averages for the New Zealand stations only are given in TABLE 8, the individual results for all stations having been published separately (1).

2. Fission Products in Rain

Increases in the levels of fission products in weekly rainwater samples also occurred concurrently with increases in air radioactivity. The weekly depositions, totalled for each month, are shown in Fig. 3. The peak depositions coinciding with nuclear tests are evident. The difference in levels at Greymouth and Christchurch illustrates clearly the rainfall dependent nature of fallout deposition. Although these two stations are geographically close, and are at approximately the same latitude, they are separated by mountain ranges and represent the extremes in rainfall for the four stations.

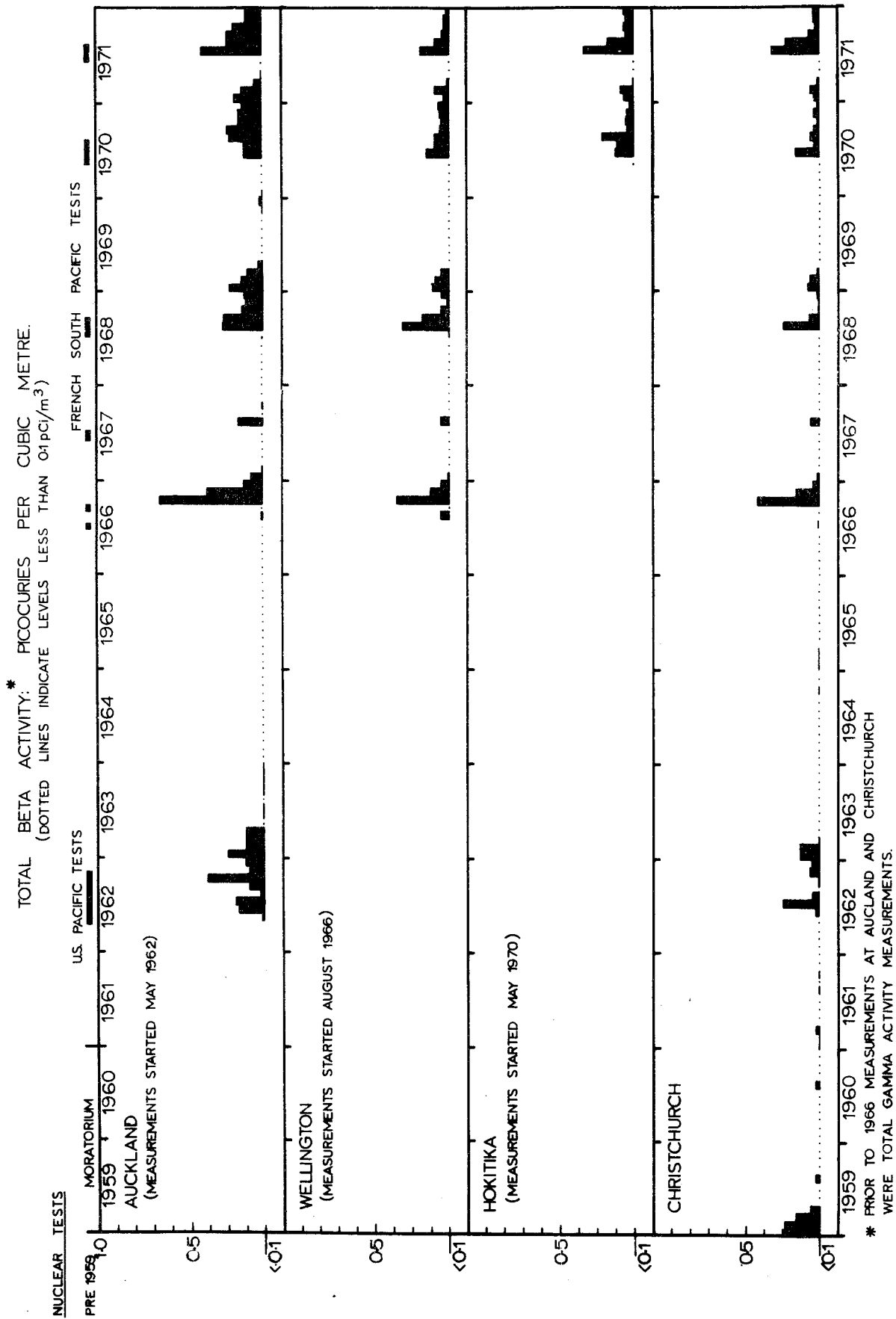


Fig. 2

FISSION PRODUCTS IN AIR - MONTHLY AVERAGES

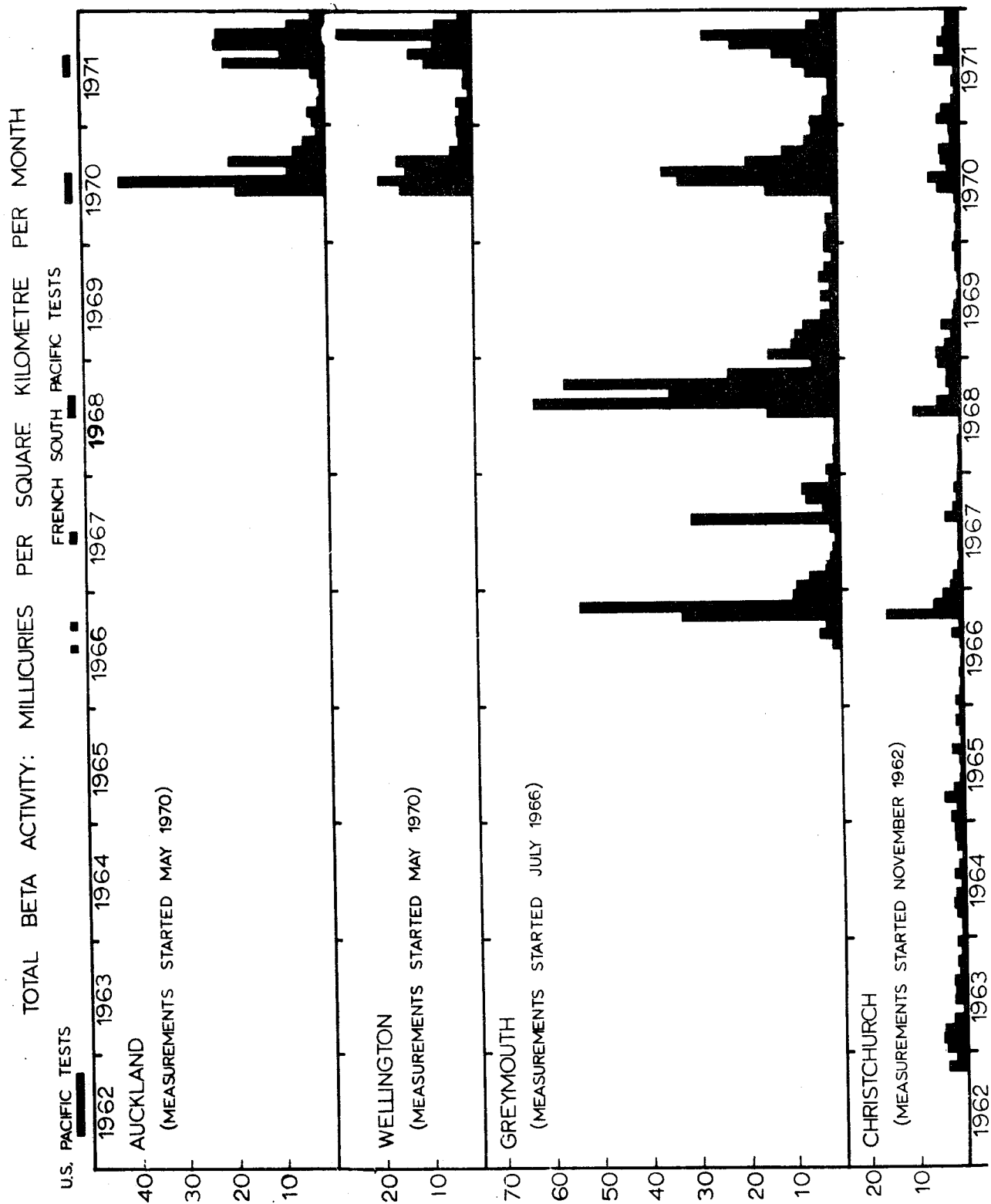


Fig. 3

FISSION PRODUCTS IN RAIN - MONTHLY DEPOSITION

The results for the individual collections during 1971 are given in TABLE 9 APPENDIX. During the special monitoring period, however, monthly totals only are given in this table. The individual results for this period, together with those from nine Pacific Island stations, have already been tabled, and assessed for their associated gamma dose in the separate report (1). Table 9 also gives the average concentration of fission products in rainwater during 1971. This assessment is useful when rainwater is considered to be the sole source of drinking water, because it allows comparison with the reference level which is based on continuous consumption. The average concentration during 1971 was less than 100 pCi/litre at all New Zealand stations.

3. General Statement on Levels of Total Beta Activity in Air and Rainwater

The pattern observed in 1971 was similar to that observed during each of the earlier programmes monitoring French nuclear tests in the Pacific. The levels at the New Zealand stations were small fractions of the Reference Levels.

Chapter 3: SPECIFIC RADIONUCLIDES

1. Introduction

During atmospheric nuclear testing the most potentially hazardous radioactive substances released to the environment are strontium-90 and caesium-137. They are both produced in high yield in nuclear fission and have long radioactive half-lives, 28 years and 30 years respectively. Thus, long after shorter-lived materials have decayed, they both survive and are present in the delayed fallout which occurs after stratospheric injection of fission products. Moreover, the testing of megaton weapons produces a stratospheric reservoir of long-lived fission material, which accounts for most of the global fallout, and for practically all of the strontium-90 and caesium-137 contamination of the environment.

(a) Caesium-137

When deposited in fallout caesium-137 enters plants and the food chain mainly by foliar absorption. Any caesium-137 deposited on the soil tends to become fixed in the soil and is not readily available for uptake through the root systems of plants. The levels of caesium-137 in diet, therefore, tend to reflect the current rate of global fallout rather than the cumulative deposition in the soil. There are, however, certain soil types which do not have this property of fixing caesium to any notable extent. This is particularly true for Taranaki and to a lesser extent for Waikato, Auckland, and Northland. The caesium-137 levels in milk at these places are higher than would be expected on the basis of rainfall and the levels at other New Zealand stations. Caesium-137 entering the human body through food chains does not accumulate in a

specific organ of the body, although it does tend to concentrate to some extent in muscle tissue. The rate of elimination of caesium-137 in the human body is estimated in terms of a few months. It is a gamma as well as a beta emitter and the penetrating nature of the gamma radiations give an external dose to the whole body from deposited fallout, as well as an internal dose from ingested material. The dose to the whole body, including the genetic material, classifies caesium-137 as both a potential somatic and a potential genetic hazard. Caesium is somewhat similar to potassium in its chemical properties and the level of caesium-137 in milk, for example, is often stated in terms of the potassium content of the sample. (e.g. picocuries of ^{137}Cs per gram of potassium). During periods of global fallout the internal dose due to ingested caesium-137 is significantly greater than the external dose due to fallout deposition. The deposition of caesium-137 in rain is not measured directly. However it may be estimated from the strontium-90 deposition because numerous surveys have established that the caesium-137 deposition is approximately one and a half times the strontium-90 deposition.

(b) Strontium-90 and Strontium-89

Strontium on the other hand has chemical properties very similar to calcium. Strontium-90 enters plants by foliar absorption and is also taken up from the soil with calcium by plant roots. The levels in food therefore reflect both the current rate of stratospheric fallout and also the cumulative deposition on the ground. Strontium-90 entering the human body through food chains is deposited along with calcium in human bone where the rate of turnover is very slow and is measured in terms of many years. Strontium-90 is a pure beta emitter and its potential hazard arises from the dose delivered to bone and bone marrow. The risk from strontium-90, therefore, is a somatic one, the genetic risk being insignificant. The levels of strontium-90 in milk and bone are often stated in terms of the calcium content of the sample (e.g. one "Strontium Unit" is one picocurie of ^{90}Sr per gram of calcium). A notable feature of strontium-90 contamination is that the bone of young people, laid down during the time of maximum stratospheric fallout during the last ten to fifteen years, contains a greater concentration of strontium-90 than that of older people whose skeletons were formed prior to large scale nuclear weapons tests.

Another radioisotope of strontium with a much shorter half-life than strontium-90 is strontium-89. This radioisotope has a half-life of 50 days and is present in the environment for several months after nuclear weapons tests. Although considerably less potentially hazardous than strontium-90, mainly because of its shorter half-life, nevertheless the measurement of the ratio of strontium-89 to strontium-90 gives useful information about the proportion of the fresh strontium-90 produced by the current nuclear tests.

The routine monitoring of strontium-90 in global fallout is adequately covered in New Zealand by a continuing measurement of its deposition at selected sites, by occasional measurement of its accumulation in the soil, by its continuing measurement in a selected article of diet from widespread sampling stations, and finally by measurement in human bone which is the critical organ.

(c) Dietary Intake

Milk is the one item of diet which is most appropriate for measurement of strontium-90 and caesium-137 contamination. Both radionuclides enter diet mainly through milk. Surveys have shown that, in countries such as New Zealand where dairy products provide most of the dietary calcium, the level of strontium-90 in milk approximates that of the level in the diet as a whole. Milk is consumed to a greater extent by the younger members of the community and moreover locally produced milk is readily available continuously from nearly all populated areas. It must be emphasised, however, that milk is not one of the more heavily contaminated foods. It is in fact a safer source of dietary calcium because in the transfer of these elements from cow fodder to milk there is a discrimination, against strontium, in favour of calcium. In those countries relying on vegetables to provide the main source of calcium, the ratio of strontium-90 to calcium is generally higher than in milk from the same region.

(d) Naturally-Occurring Radionuclides

The other long-lived radionuclides which are measured routinely are lead-210 and radium-226. These are naturally-occurring and present a similar potential health hazard to the artificial radionuclides. Radium-226 is distributed widely in the earth's crust and produces gaseous radon which diffuses into the atmosphere. One of the radioactive products of this gas is lead-210 which is subsequently deposited as "natural fallout". Lead-210 is measured in the routine monthly rainwater samples which are collected for measurement of strontium-90 fallout deposition. Both radium-226 and lead-210 are long-lived bone-seeking radionuclides, and along with strontium-90 find their way into human bone through food chains. All human bone samples collected for strontium-90 assessment are also evaluated for these naturally-occurring radionuclides.

2. Strontium-90 in Rain

(a) Measurement at nine New Zealand and two Pacific Island Stations

Table 10 APPENDIX lists the monthly values of rainfall, strontium-90 deposition, and strontium-90 concentration in rain for each station during 1971. Fig. 8 APPENDIX shows the individual station values for monthly deposition since monitoring commenced in 1959.

The country-wide average levels of deposition and concentration since mid-1959 are graphed in Fig. 4 for comparison with the country-wide average levels of strontium-90 and caesium-137 in milk.

The highest levels of deposition were reached in New Zealand during late 1964 and early 1965. They were caused by delayed stratospheric fallout from the large scale northern hemisphere U.S.S.R. and Pacific Area U.S.A. nuclear tests in 1961 and 1962, which were conducted before the signing of the Partial Test Ban Treaty. During the three years after the peak deposition, 1966 to 1968, levels fell steadily to a minimum in 1968, even though the French nuclear tests had started in the South Pacific in 1966 and were held during each of these years. The 1968 tests culminated in the detonation of two megaton devices for the first time in these series. After a pause in 1969, the series were resumed

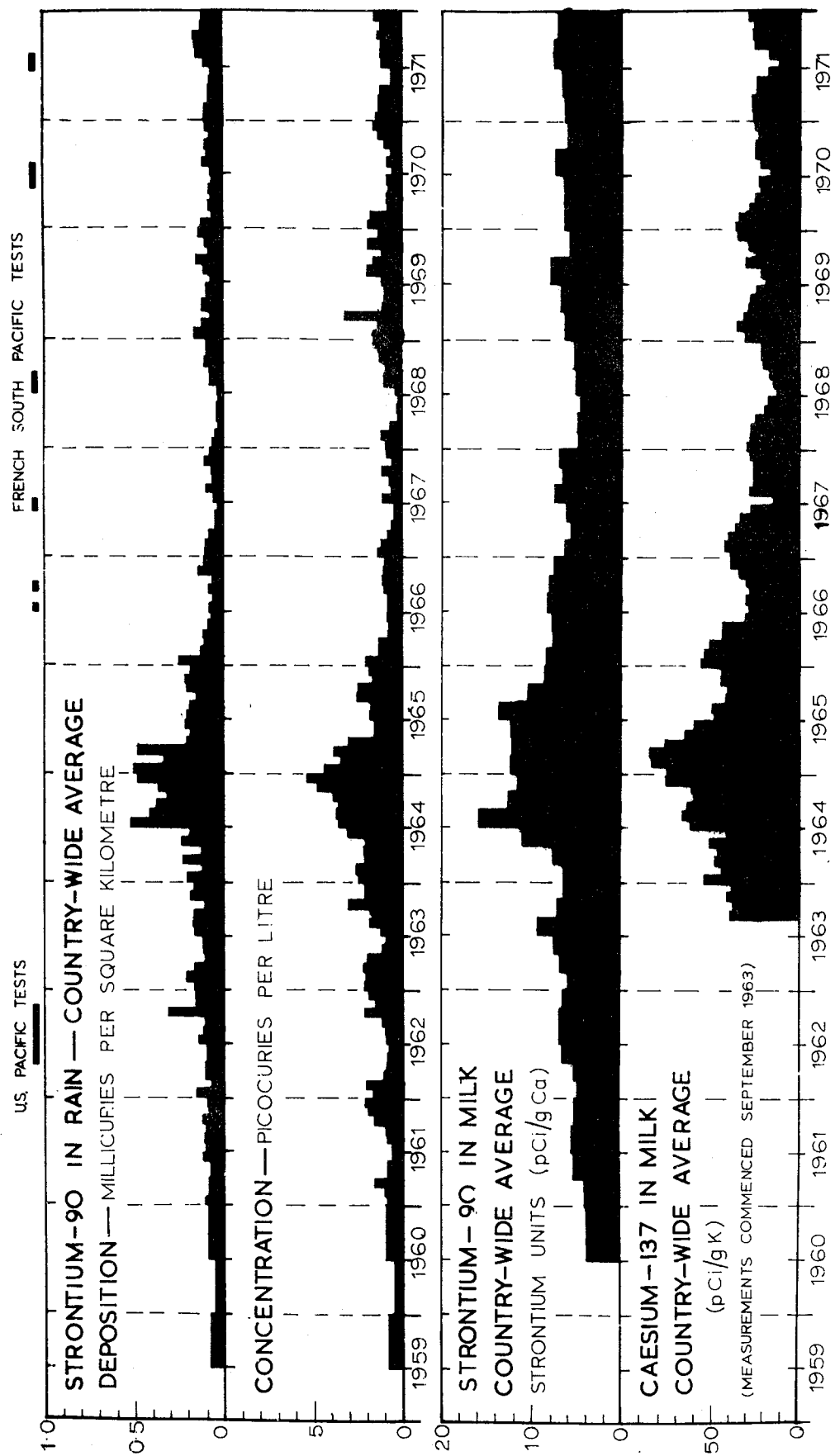


Fig. 4 COUNTRY AVERAGE LEVELS OF LONG-LIVED RADIONUCLIDES IN RAIN AND MILK

in 1970 and 1971 and both of these latter test series also included the detonation of a megaton device. As a result of these atmospheric tests in the South Pacific, levels increased in 1969 and since then have remained at about 50% higher than the minimum level in 1968. These higher levels are, however, only about one third of the peak level in 1964.

TABLE 2 lists the total annual deposition at individual stations and the New Zealand country-wide average annual deposition for each year since 1960. The depositions at Suva and Rarotonga are also shown in this table, and it is of interest to note that during the last five years the levels at these islands have been generally similar to the New Zealand country-wide average level. It is also of interest to note that during the year of peak deposition of stratospheric fallout in 1964, the level at Suva was significantly lower than the New Zealand average level despite the much higher annual rainfall at Suva. This further illustrates the significant characteristic of stratospheric fallout, previously noted, that the tropics receive less global fallout than the mid-latitudes.

| TABLE 2 ANNUAL DEPOSITION OF STRONTIUM-90 mCi/km ² | | | | | | | | | | | | | |
|--|---------------------------|------|------|------|------|------|------|------|------|------|------|------|------|
| Station | Mean Annual Rainfall (cm) | 1960 | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 |
| <u>NEW ZEALAND</u> | | | | | | | | | | | | | |
| Kaitaia | 144 | | | | 1.8 | 4.1 | 3.1 | 1.6 | 1.0 | 0.9 | 1.5 | 1.0 | 2.0 |
| Auckland | 125 | 1.2 | 1.1 | 1.8 | 2.0 | 4.0 | 2.9 | 1.3 | 0.9 | 0.7 | 1.3 | 0.9 | 1.3 |
| New Plymouth | 154 | | | | 2.0 | 5.3 | 4.2 | 1.9 | 1.3 | 1.0 | 1.5 | 1.2 | 1.9 |
| Havelock Nth | 76 | 0.7 | 0.8 | 1.0 | 1.0 | 1.6 | 1.7 | 0.8 | 0.5 | 0.6 | 0.7 | 0.6 | 1.0 |
| Wellington | 129 | 0.8 | 1.1 | 1.8 | 2.0 | 3.4 | 3.9 | 1.6 | 1.0 | 0.9 | 1.1 | 1.2 | 1.2 |
| Greymouth | 243 | 1.5 | 2.2 | 2.8 | 3.7 | 7.8 | 5.9 | 2.2 | 1.7 | 1.4 | 2.2 | 2.1 | 2.5 |
| Christchurch | 56 | 0.5 | 0.7 | 0.7 | 1.2 | 1.3 | 1.7 | 0.7 | 0.4 | 0.4 | 0.7 | 0.5 | 0.7 |
| Dunedin | 61 | | | | 1.0 | 1.8 | 2.0 | 0.7 | 0.6 | 0.4 | 0.7 | 0.5 | 0.8 |
| Invercargill | 104 | 0.5 | 1.2 | 1.2 | 1.7 | 3.0 | 2.8 | 1.1 | 0.9 | 0.5 | 1.2 | 0.7 | 1.1 |
| Country-wide Average | | 0.9 | 1.2 | 1.6 | 1.8 | 3.6 | 3.1 | 1.3 | 0.9 | 0.8 | 1.2 | 1.0 | 1.4 |
| <u>PACIFIC ISLANDS</u> | | | | | | | | | | | | | |
| Suva, Fiji | 283 | | 1.0 | 1.6 | 2.4 | 2.5 | 2.0 | 1.2 | 0.8 | 1.0 | 1.3 | 0.9 | 1.5* |
| Rarotonga | 221 | | | | | | | | 0.9* | 0.7 | 0.7 | 1.0 | 0.9* |
| The mean annual rainfall is for the years 1963 to 1971 inclusive (at Rarotonga: 1967 to 1971 inclusive) | | | | | | | | | | | | | |
| * Estimate | | | | | | | | | | | | | |

(b) Comparison With Two Northern Hemisphere Stations

Two collection sites in the northern hemisphere where continuing measurements of strontium-90 deposition have been made since about 1954 are Milford Haven in the United Kingdom and New York City. The published results (3) (4) for annual deposition at these collecting stations are compared with the New Zealand country-wide average annual deposition in TABLE 3.

| TABLE 3 | | ANNUAL DEPOSITION OF STRONTIUM-90 | | mCi/km ² |
|---------|------------------------------|-----------------------------------|---------------------|---------------------|
| Year | Northern Hemisphere Stations | | New Zealand Average | |
| | Milford Haven | New York City | | |
| 1954 | 2.0 (up to end of 1954) | 2.8 (Feb.-Dec. incl.) | | |
| 1955 | 2.4 | 3.6 | | |
| 1956 | 2.5 | 4.4 | | |
| 1957 | 2.6 | 4.4 | | |
| 1958 | 5.4 | 6.2 | | |
| 1959 | 5.7 | 8.7 | | |
| 1960 | 1.8 | 1.6 | 0.9 | |
| 1961 | 2.5 | 2.4 | 1.2 | |
| 1962 | 9.3 | 12.3 | 1.6 | |
| 1963 | 20.9 | 23.8 | 1.8 | |
| 1964 | 11.7 | 15.9 | 3.6 | |
| 1965 | 4.8 | 5.5 | 3.1 | |
| 1966 | 3.1 | 2.4 | 1.3 | |
| 1967 | 1.2 | 1.6 | 0.9 | |
| 1968 | 1.2 | 1.3 | 0.8 | |
| 1969 | 0.9 | 1.4 | 1.2 | |
| 1970 | 1.2 | 1.5 | 1.0 | |
| 1971 | 0.7 (to end of June only) | 1.4 | 1.4 | |

It will be seen from this table that the peak depositions from the 1961, 1962 stratospheric injections occurred in 1963 at the northern hemisphere stations and in 1964 in New Zealand. The delay in deposition in the southern hemisphere is explained by the delay in interhemispheric transfer of stratospheric debris. TABLE 3 also shows that the maximum annual deposits at the two northern hemisphere stations were about six times higher than the New Zealand maximum and that levels subsequently fell rapidly and became about the same at all three stations from about 1969. Levels would have fallen below those listed for recent years but for the continuing nuclear weapons tests in the atmosphere, by China in the northern hemisphere, and by France in the southern hemisphere. Such testing has maintained the annual depositions at a relatively steady level during recent years.

3. Strontium-90 Cumulative Deposition

The annual depositions listed in TABLE 3 have been totalled, corrected for radioactive decay, and are presented in Fig. 5 as cumulative deposition.

In addition to the New Zealand country-wide average, the cumulative deposition at the highest rainfall station Greymouth, and at the lowest rainfall station Christchurch, are presented in Fig. 5 to show the range within New Zealand. (The dotted portions of the curves for the New Zealand stations up to mid-1959 are estimates based on some soil measurements undertaken by the U.S. Department of Agriculture at that time.)

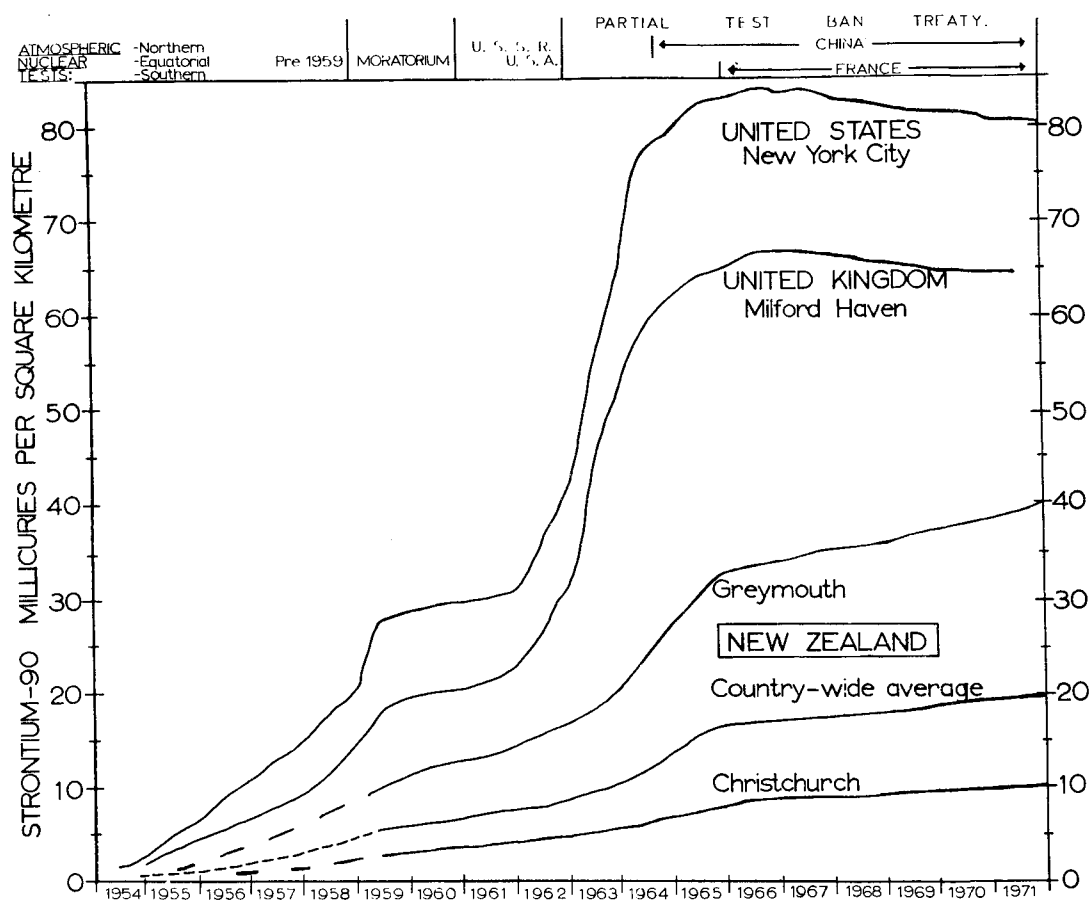


Fig. 5 CUMULATIVE DEPOSITION OF STRONTIUM-90 - COMPARISON

The most significant feature of Fig.5 is the steep rise in the curves for the northern hemisphere stations during the years of maximum fallout rate, and the relatively high cumulative deposition after 1964. The plateaux in these curves represent a sharp drop in the rate of fallout. This is evident at about 1960 after the Test Moratorium of 1959 and 1960, and also after about 1965 following the Partial Test Ban Treaty. The interesting situation was reached after 1966 that the reduction due to radioactive decay of the accumulated strontium-90 was slightly greater than the annual increment from fallout, so that there is a distinct downward trend in each curve.

In New Zealand, however, where the total accumulation is much less, the reduction due to radioactive decay has been less significant. The injection of fresh fission material into the southern hemisphere during the French nuclear tests has caused a rate of fallout somewhat greater than the rate of radioactive decay, thus resulting in the continuing slight upward trend shown in Fig.5.

4. Strontium-90 in Soil

The accumulation of strontium-90 at selected sites in New Zealand has also been evaluated by direct measurement of the strontium-90 in the soil. These measurements have been made at intervals since 1953.

Early measurements were undertaken jointly by the U.S. Department of Agriculture's Soil Survey Laboratory, and the U.S. Atomic Energy Commission's Health and Safety Laboratory (HASL), as part of their world-wide soil sampling programme. They conducted the final sampling for this programme from 1965 to 1967 when the maximum cumulative deposit had been reached in the northern hemisphere (see Fig.5). The results of this programme were published in a series of reports (5).

The New Zealand soil samples collected at the end of 1963 were used for intercomparison of measurements by this Laboratory (NRL) and HASL. Thereafter we took over the measurements of the New Zealand samples during the final stages of the world-wide programme and continued these measurements after the conclusion of that programme.

A special world-wide soil sampling programme was again conducted by HASL from October 1970 to January 1971. The main purpose of this programme was to measure the world-wide deposition of plutonium resulting from a satellite failure and burn-up in April 1964. HASL also measured strontium-90 in these samples, however, and we took duplicates of the New Zealand samples for our own measurements and for further intercomparison.

The results of all these measurements on New Zealand samples is shown in TABLE 4.

| TABLE 4 STRONTIUM-90 IN NEW ZEALAND SOILS mCi/km^2 | | | | | | |
|---|-------------------|------------|----------------|------------|-------|-----------|
| DATE OF SAMPLING | DEPTH OF SAMPLING | LABORATORY | NORTH AUCKLAND | WELLINGTON | | GREYMOUTH |
| | | | | JUDGEFORD | TAITA | |
| End 1953 | 15 cm | HASL | <0.1 | <0.1 | | <0.1 |
| Feb. 1955 | " | HASL | | 0.7 | | |
| Apr. 1956 | " | HASL | 1.5 | 1.3 | | 0.8 |
| Mar. 1958 | " | HASL | 2.5 | 3.7 | | 3.1 |
| Jun. 1959 | " | HASL | 5.5 | 6.1 | | 4.2 |
| End 1960 | 20 cm | HASL | 5.2 | 7.8 | 5.1 | 4.6 |
| End 1963 | " | HASL | 10.2 | 10.5 | 9.0 | 16.7 |
| | | NRL | 9.9 | 10.3 | 8.8 | 16.8 |
| End 1965 | " | NRL | 12.9 | | 12.4 | 23.0 |
| End 1967 | " | NRL | 14.1 | | | 20.8 |
| Jul. 1968 | " | NRL | | | 11.2 | |
| End 1968 | " | NRL | 13.7 | | 11.5 | 19.0 |
| Oct. 1970 | 30 cm | HASL | 16 | | | 24 |
| | | NRL | 16 | | 12 | 24 |

It is evident from TABLE 4 that the results are generally lower than the corresponding results of cumulative deposition calculated from rainwater analyses (Fig.5). It is interesting to note the apparently contradictory situation whereby the accumulation at the end of 1968 was lower than that measured at the end of 1965 or 1967. However, on increasing the depth of soil sampling to 30 cm during the October 1970 soil collection this anomalous situation was largely corrected. The agreement between the values in Fig.5 and TABLE 4 for the low rainfall areas, Christchurch and South Canterbury, is reasonably good. On the other hand, for the high rainfall area Greymouth, direct measurement in soil sampled to a depth of 30 cm gives results only about two-thirds of that expected from rainwater analyses. It is probable that in such places the combined effects of deeper penetration of strontium-90 into the soil, together with a significant run-off of water during heavy rainfalls, may well explain this difference.

The results of the special world-wide 1970 soil measurement programme have been published in a separate report (6). These results indicate that the average level of strontium-90 in New Zealand soils is in reasonable agreement with the average level for other 30°-50° south latitude sites. They also indicate that the average level for the 30°-50° north latitude sites is about 70 mCi/km², about 4 times higher. The New York City measurement was 98 mCi/km², i.e. somewhat higher than that shown in Fig.5.

5. Strontium-89 in Rain

Although the amounts of strontium-89 and strontium-90 produced in nuclear fission are about the same, strontium-89 has, however, a much greater rate of decay, its half-life being only about 50 days. It has therefore a correspondingly much higher initial radioactivity amounting to about 185 times that of the strontium-90 at the time of production in a nuclear explosion. Strontium-89 is therefore very readily detectable during periods of atmospheric nuclear tests. When monitoring strontium-89 in the environment over periods lasting for several months, the decay of the long-lived strontium-90 may be ignored. Therefore the value of the ratio ⁸⁹Sr/⁹⁰Sr from a single nuclear explosion will fall with a half-time of 50 days, i.e. the half-life of the strontium-89.

The monthly deposition of strontium-89 from the French Pacific tests and the ratio ⁸⁹Sr/⁹⁰Sr is listed in TABLE 11 APPENDIX for individual stations during 1971.

In Fig.6 values of the ratio are plotted on a logarithmic scale for individual stations since 1962. The logarithmic scale converts the exponential decay of the ratio to a linear presentation, and the straight lines drawn in Fig.6 represent a 50 day half-life decay. The upper limit of the ratio scale for each station is 185, i.e. the production ratio in a nuclear explosion. If the decay lines in Fig.6 extrapolate back to a ratio of about 185, at the time of a nuclear test, or a brief test series not unduly prolonged, then this indicates that practically all the strontium-90 deposited during that monitoring period is from that test or test series.

The results illustrated in Fig. 6 are therefore interpreted as follows:

- (1) It is generally not possible to draw lines of the correct slope through the plotted points for the early Pacific U.S.A. tests. These tests were prolonged and the production and decay of strontium-89 from the earlier detonations is overlapped by that from subsequent detonations. The net result is an apparent half-time of fall off of the ratio greater than 50 days.
- (2) The French test series, however, have followed a different pattern to the U.S.A. tests and have been relatively brief in duration. In 1966, for instance, the short pause in testing during September is noticeable as two distinct injections of strontium-89 and subsequent declines of the ratio at the correct rate. During the 1966 and 1967 monitoring programmes the lines do not extrapolate back to a ratio of 185 at the time of these tests. The extent of their failure to do so is a measure of the relatively small proportion of the new strontium-90 deposited from these tests, compared with the continuing, but decreasing, stratospheric deposition from the earlier 1961 and 1962 series.

NUCLEAR
TESTS:

U.S. PACIFIC

FRENCH

SOUTH

PACIFIC

RATIO : STRONTIUM-89 TO STRONTIUM-90 (Note Log. Scale)

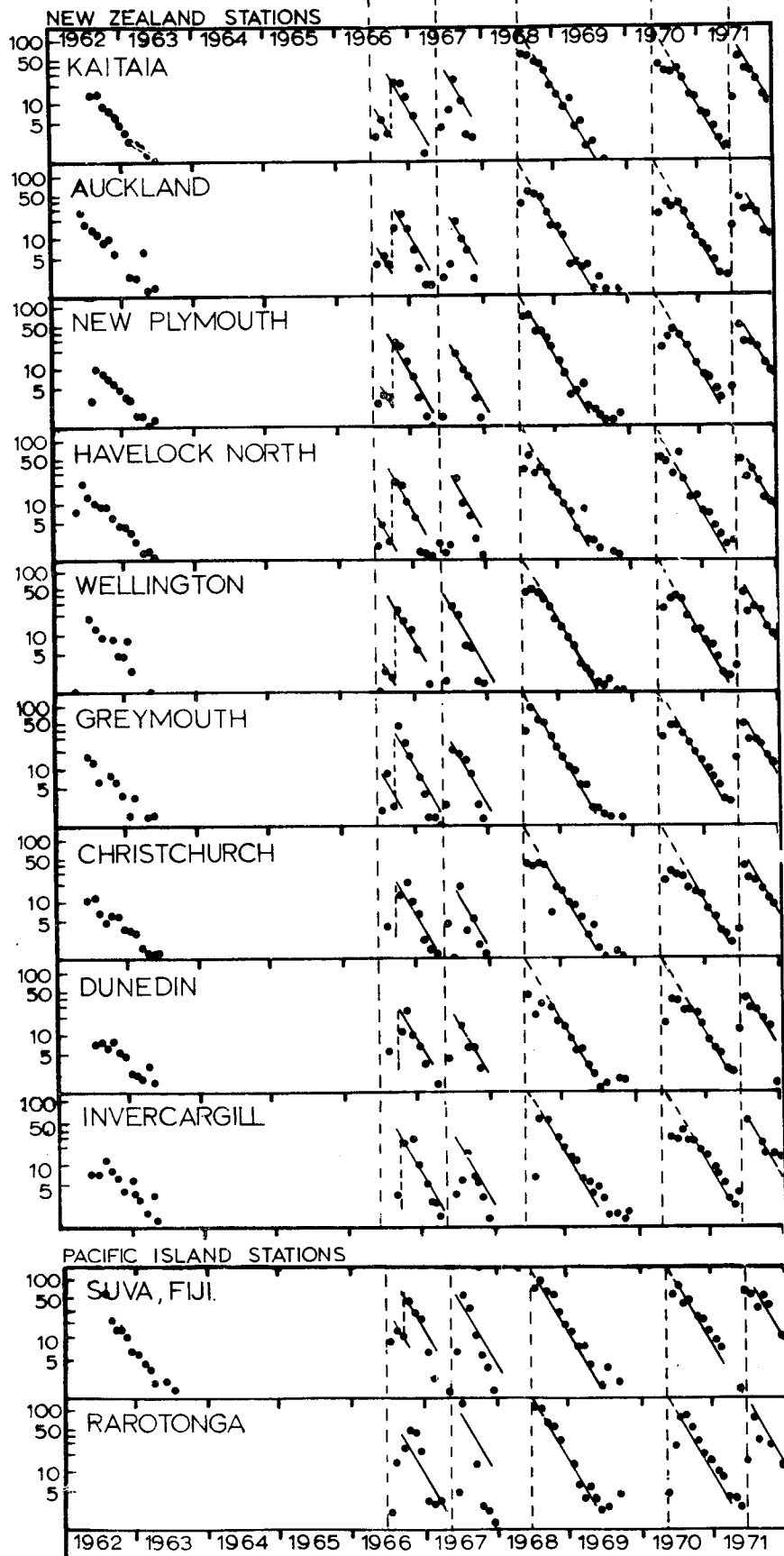


Fig. 6

STRONTIUM-89/STRONTIUM-90 RATIO IN RAINWATER

- (3) During the 1968 and 1970 tests, however, the lines do extrapolate back to a ratio of 185 at the appropriate times for each station without exception. Practically all the strontium-90 deposited during these years, therefore, derived from these tests. The southern hemisphere stratospheric reservoir of strontium-90 from the 1961 and 1962 tests was therefore substantially depleted at this time and did not significantly contribute to the strontium-90 deposited.
- (4) During the 1971 monitoring period the ratio does not extrapolate back to 185 at the time of the 1971 tests. A proportion of the strontium-90 deposited at this time, therefore, derived from earlier tests and these earlier tests would be the French tests of 1968 and 1970 when megaton devices were detonated, rather than the earlier tests of the 1961 and 1962 series from which practically all strontium-90 had already been deposited.
- (5) The distinct tailing off of the ratio towards the end of 1969 at the New Zealand stations, and the slight increase in the ratio at the Pacific Island stations at this time has been attributed to interhemispheric transfer of debris from the high yield Chinese nuclear explosion of 27 December 1968 (7).

In summary, it may be said that global fallout from the early tests leading to peak depositions in 1964 had essentially been completed by about 1968 and since then practically all of the strontium-90 deposited at our monitoring stations has derived from the French test series.

6. Strontium-90 in Milk

(a) Routine Measurements at Nine New Zealand Stations

The average levels of strontium-90 in milk for each quarter during 1971 are listed in TABLE 12 APPENDIX for each collecting station. Individual station levels since about 1960 are also shown graphically in Fig.9 APPENDIX.

The country-wide average values since measurements started in New Zealand are shown graphically in Fig.4 together with country-wide average levels of caesium-137 in milk and strontium-90 in rain. This comparison graph clearly indicates the changing levels of these long-lived fallout products in the environment resulting from atmospheric nuclear tests during the last 12 to 13 years.

Levels in New Zealand milk reached their maximum values during 1964 and 1965 when the deposition of strontium-90 in rain was also a maximum. Levels then fell steadily until they reached a minimum in 1968. This decrease, however, has been at a slower rate than the decrease in strontium-90 deposition in rain, because of the accumulating deposit of strontium-90 in soil and the continuing uptake from soil into grass. The rate of decline was halted in 1968 and since then levels have increased slightly due to the French Test series.

TABLE 5 lists the average levels at the individual stations and the country-wide average level for each year since 1962.

| TABLE 5 AVERAGE LEVELS OF STRONTIUM-90 IN MILK - STRONTIUM UNITS | | | | | | | | | | | | |
|--|------|------|------|------|------|------|------|------|------|------|------|----------|
| STATIONS | 1961 | 1962 | 1963 | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | AVERAGE* |
| Northland | 4.5 | 6.3 | 7.5 | 11.2 | 10.6 | 6.5 | 5.1 | 4.1 | 6.3 | 5.2 | 7.3 | 7.0 |
| Auckland | | 5.5 | 5.3 | 9.1 | 9.4 | 6.1 | 5.2 | 3.8 | 6.0 | 5.1 | 5.8 | 6.1 |
| Waikato | 4.1 | 4.9 | 5.6 | 9.5 | 9.8 | 6.3 | 5.0 | 4.1 | 5.4 | 5.2 | 6.0 | 6.2 |
| Taranaki | 7.1 | 9.4 | 9.9 | 17.1 | 16.7 | 12.5 | 10.4 | 8.0 | 9.4 | 9.7 | 10.2 | 11.3 |
| Palmerston Nth | | 4.3 | 4.9 | 7.1 | 8.4 | 4.8 | 3.9 | 3.6 | 5.8 | 3.6 | 5.0 | 5.1 |
| Wellington | | | | | 8.8 | 6.1 | 5.4 | 4.8 | 5.1 | 4.7 | 4.8 | 5.7 |
| Westland | 12.7 | 13.5 | 17.2 | 26.0 | 28.8 | 22.7 | 17.8 | 14.0 | 17.9 | 21.0 | 18.3 | 19.7 |
| Christchurch | 1.6 | 2.1 | 2.7 | 2.6 | 4.3 | 2.4 | 1.9 | 1.6 | 1.7 | 2.2 | 2.0 | 2.4 |
| Dunedin | | 3.0 | 3.7 | 4.1 | 7.4 | 4.0 | 3.1 | 2.4 | 3.0 | 2.5 | 3.0 | 3.6 |
| Country-Wide Average | | 6.1 | 7.1 | 10.8 | 11.6 | 7.9 | 6.4 | 5.2 | 6.7 | 6.6 | 6.9 | 7.5 |
| * Average 1962 - 1971 (for Wellington 1965 - 1971) | | | | | | | | | | | | |

The salient features of TABLE 5 are:

- (1) The expected higher average values in the higher rainfall (West Coast) areas, Greymouth and Taranaki, and the lower average values in dry (East Coast) areas, Christchurch and Dunedin.
- (2) The highest yearly average level recorded was nearly 29 Strontium units at Greymouth during 1965. This was about 7 times higher than the level at Christchurch at that time.
- (3) The progressive decline in average levels during the following years until 1968 when the country-wide average was less than one-half the average during 1965, the year of maximum level.
- (4) The increase since 1968 reaching a country-wide average level of nearly 7 Strontium units in 1971. This is an increase of 33% over the minimum level in 1968, but is still only about 60% of the maximum level in 1965.

(b) Comparison with two Northern Hemisphere Stations

In Fig.7 the country-wide average levels of strontium-90 in New Zealand milk are compared with levels in Canadian (8) and New York City (4) milk.

Levels at the northern hemisphere stations reached maximum values in 1963 and 1964 following fallout from the nuclear tests of 1961 and 1962, whereas the level in New Zealand reached its maximum about one year later in 1964 and 1965, the delay being due to interhemispheric transfer of stratospheric debris. The maximum levels at the northern hemisphere stations were 2 to 3 times higher than the New Zealand maximum. Subsequently levels declined and in recent years levels at the northern hemisphere stations have been only slightly higher than those in New Zealand.

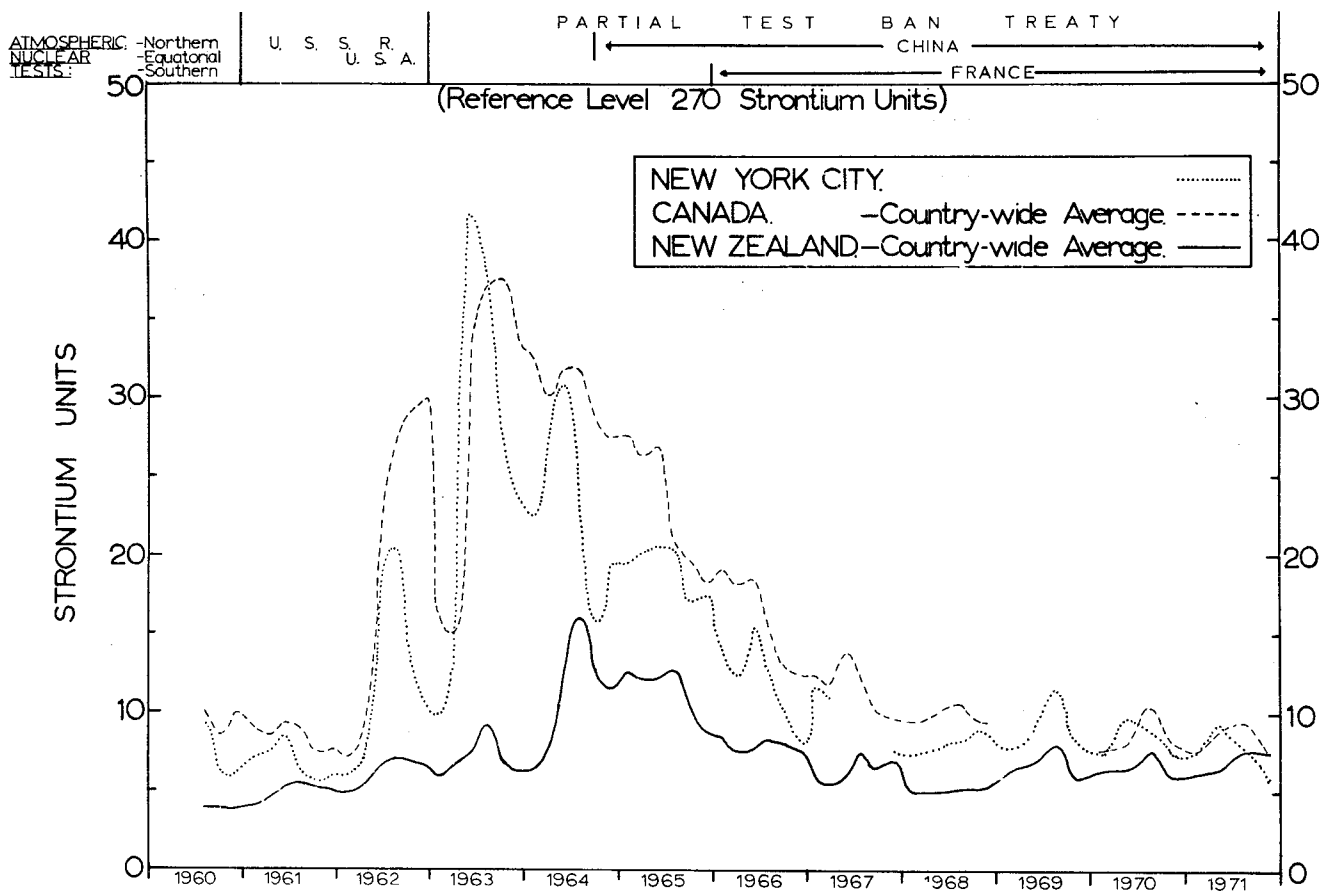


Fig. 7 STRONTIUM-90 LEVELS IN MILK - COMPARISON

(c) Comparison of Measured Levels with the Reference Level

In order to assess any potential health hazard arising from ingestion of strontium-90 in the diet (or in milk, which for practical purposes we may assess in place of diet as a whole), it is essential to consider long-term average levels. The dose to the critical organ, bone, over an extended period, establishes the degree of potential somatic risk. Therefore the levels in diet must also be considered over similarly extended periods.

It is appropriate to attempt a hazard assessment as follows:

Assume that the average levels in New Zealand milk, as measured during the period 1962 to 1971 inclusive, were maintained indefinitely in the average New Zealand diet as a whole. Furthermore consider the discrimination against strontium in its passage from diet to bone (the observed ratio of Strontium Units in bone to Strontium Units in diet is 1 to 4). Under these hypothetical equilibrium conditions the bone levels of New Zealanders would not exceed the levels listed in TABLE 6.

| TABLE 6 STRONTIUM-90 HAZARD ASSESSMENT (1962-1971) | | | |
|--|-----------------|------|----------------------|
| Station | Strontium Units | | % of Reference Level |
| | Milk | Bone | |
| Lowest Level (Christchurch) | 2.4 | 0.6 | 0.9% |
| Highest Level (Westland) | 19.7 | 4.9 | 7.3% |
| Country-Wide Average | 7.5 | 1.9 | 2.8% |

Results of strontium-90 measurements in human bone samples are given in TABLE 14 APPENDIX.

7. Caesium-137 in Milk

(a) Routine Measurements at Nine New Zealand Stations

The levels of caesium-137 in milk for each month during 1971 are listed in TABLE 13 APPENDIX for each collecting station. Individual station levels since mid 1963 are also shown graphically in Fig.10 APPENDIX.

As already noted in the previous section, the country-wide average values since measurements commenced are compared with the levels of strontium-90 in rain and milk in Fig.4. An interesting feature of this comparison is that the average levels of caesium-137 in milk do not show, in any marked fashion, an increase over the past three years.

This is also evident in TABLE 7 which gives the country-wide annual averages since 1964 and also the annual averages at individual stations. The country-wide average level for 1971, for instance, is the same as that for 1968 which was the year of minimum average level, whereas the level of strontium-90 in the same samples of milk was 33% higher in 1971 than in 1968.

| TABLE 7 AVERAGE LEVELS OF CAESIUM-137 IN MILK - pCi/g K | | | | | | | | | |
|---|------|------|------|------|------|------|------|------|---------|
| | 1964 | 1965 | 1966 | 1967 | 1968 | 1969 | 1970 | 1971 | AVERAGE |
| Northland | 49 | 54 | 37 | 26 | 15 | 27 | 22 | 23 | 32 |
| Auckland | 51 | 53 | 33 | 26 | 18 | 26 | 18 | 18 | 30 |
| Waikato | 69 | 84 | 60 | 48 | 36 | 41 | 35 | 36 | 51 |
| Taranaki | 168 | 185 | 141 | 123 | 102 | 101 | 89 | 80 | 124 |
| Palmerston Nth | 19 | 26 | 11 | 7 | 3 | 5 | 6 | 7 | 11 |
| Wellington | 25* | 29 | 18 | 13 | 7 | 9 | 11 | 9 | 15 |
| Westland | 76 | 77 | 43 | 33 | 21 | 38 | 39 | 30 | 45 |
| Christchurch | 7 | 11 | 4 | 3 | 1 | 2 | 4 | 3 | 4 |
| Dunedin | 11 | 18 | 9 | 5 | 3 | 4 | 5 | 5 | 8 |
| Country-Wide Average | 53 | 60 | 39 | 31 | 23 | 28 | 25 | 23 | 36 |
| * Estimate | | | | | | | | | |

This apparent anomaly may be understood on closer inspection of TABLE 7 and Fig.10 APPENDIX where it will be seen that the country-wide average is determined more by the levels at those stations which have a higher milk caesium-137 than would be expected on the basis of rainfall. These higher levels are due to the "soil effect" already noted in Chapter 3, 1.(a). This effect is especially noticeable at Taranaki where the levels are very much higher than those at Greymouth where the rainfall is much greater. The lack of ability of such soils to fix caesium in their upper layers causes higher milk levels during and after periods of high global fallout. Most of the caesium-137 in Taranaki milk has been due to uptake from the soil. It has been steadily decreasing, however, as the caesium-137 penetrates deeper and becomes less available to the plant roots. The net effect is that, in the Taranaki area, the rate of decrease predominates and masks any increase from French test fallout. In Taranaki milk, therefore, there has been a continuing decrease in caesium-137, whereas at most other stations there has been a slight increase during the past few years. This anomalous situation is also evident in TABLE 7 for Waikato and Auckland where the levels in 1971 were the same as those in 1968, the year of minimum level.

(b) Comparison of Measured Levels with the Reference Level

During the period 1964 to 1971 inclusive the country-wide average level was 36 pCi/g K which is about 0.5% of the reference level. At the highest level station, Taranaki, the average level over the same period was 124 pCi/g K, about 1.8% of the reference level, whereas at Christchurch, the lowest level station, the average was 4 pCi/g K, about 0.06% of the reference level.

8. Lead-210 in Rain

During 1965 and 1966 a special survey was conducted to measure the deposition of naturally-occurring lead-210 at four collection sites. The sites were selected from the network of rainwater stations which supply regular monthly samples for strontium-90 determination. The results of this survey showed that lead-210 deposition in 1966 had dropped to one-half of that in the preceding year. Strontium-90 deposition in 1966 had also dropped to less than one-half of that in the preceding year. (This was during the period of decreasing annual Strontium-90 deposition, i.e. from the maximum in 1964, to the minimum in 1968). The possibility that lead-210 had been produced artificially during the 1961 or 1962 large scale atmospheric tests was then considered and investigated further.

Milk ash samples, collected over a period of several years, from five stations were selected from our library of such samples. These were measured for lead-210 to evaluate the changing environmental levels as reflected in milk from different areas. The results confirmed the higher environmental levels during 1965 and also showed some correlation with strontium-90 levels. The results of these surveys were reported in a previous issue of this series of reports (9).

In May 1967 the lead-210 survey was re-started at all rainwater collecting stations and the results for monthly collections to December 1971 are shown in Fig.11 APPENDIX. During this period the country-wide average deposition has ranged from about 0.04 to 0.26 mCi/km²/month with a mean value of the order of about 0.1 mCi/km²/month, which is about the same as that in 1966. The continuing results of this survey

have been published in the previous annual reports of this series since 1967. The deposition of significant amounts of stable lead was also measured at a few airfield stations where piston engined aircraft using leaded petrols were in frequent operation near the collecting area (7).

The significant features of this survey may be summarised as follows:

- (1) Within New Zealand, lead-210 deposition is rainfall dependent in a similar way to strontium-90. High rainfall stations such as Greymouth show elevated values compared to low rainfall areas such as Christchurch.
- (2) At the Pacific Island stations the deposition is significantly greater at Suva, Fiji than at Rarotonga, even when allowance is made for the slightly higher rainfall at Suva. Fiji is considerably closer than Rarotonga to the large land masses of Australia and South East Asia. Moreover, prevailing winds would carry radon, emanating from land surfaces, and also its radioactive daughters including lead-210, towards the east. It seems most probable that lead-210 fallout over the Pacific Area would decrease with increasing distance from these land masses.
- (3) Although the annual deposition of lead-210 in 1965 was significantly greater than it has been since then, and moreover appeared to correlate with strontium-90 levels, there has, however, been no detectable increase in lead-210 during the period of French nuclear tests in the Pacific.
- (4) During the last four years the annual deposition of lead-210 from natural fallout has averaged about 1.3 mCi/km^2 for the New Zealand stations. During the same period the annual deposition of strontium-90 from weapons tests fallout has averaged about 1.1 mCi/km^2 .

9. Strontium-90, Radium-226, and Lead-210 in Human Bone

TABLE 14 APPENDIX lists the levels of artificially produced strontium-90, and naturally-occurring radium-226 and lead-210, in New Zealand human bone samples. These three radionuclides are major bone seekers of potential health hazard, and the levels listed are those present at the time of death. TABLE 14 is subdivided into panels in chronological order. Within each panel the results are listed in order of rainfall area, and within each area in order of age at death.

The strontium-90 concentrations range from less than 0.1 to 3.2 Strontium Units (pCi/g Ca). The levels in bone tend to be higher in high rainfall districts where strontium-90 deposition and milk levels are higher. The levels also tend to be higher in young bone formed during the last decade of higher global fallout, as previously noted in Chapter 3, 1.(b). It is of interest to see that in no case does the concentration in bone reach the equilibrium levels calculated from the dietary level for the area as listed in Section 6, TABLE 6 (STRONTIUM-90 HAZARD ASSESSMENT, 1962 - 1971).

The radium-226 levels, however, do not depend on the average rainfall, nor on the age of the subject. With the exception of occupational exposure or accidental ingestion, the levels are expected to reflect the radium content of the local soil and water supplies.

Lead-210 is one of the radioactive daughters of radium-226. Therefore the equilibrium level of radioactivity of lead-210 in a sample would be the same as that of the parent radium-226 in that sample provided that no fractionation or separation of the daughters had occurred. In human bone samples, however, the lead-210 levels are invariably higher than the radium-226 levels, and this is accounted for by the fractionation of the radium chain as follows:

The first product of the disintegration of radium-226 is radon, a gas which can diffuse out of the soil. In its passage out of soil some of the remaining daughters including lead-210 may be deposited in the soil at higher levels nearer plant root systems. Moreover radon that escapes into the atmosphere produces the remaining daughters in the air and these are deposited as "natural fallout". Lead-210 in such fallout becomes readily available to plants by direct foliar absorption, and also by plant root uptake from surface layers of soil. Lead-210 levels, therefore, are higher than radium-226 levels near the surface and this is reflected in higher levels in food chains and in human bone.

Chapter 4: MISCELLANEOUS INFORMATION

1. Plutonium Fallout from a Satellite Failure

In April 1964 a navigational satellite was launched in California containing a "Systems for Nuclear Auxiliary Power" (SNAP) generator. The generator converts heat produced by plutonium-238 decay into electrical energy. The SNAP device was not built for intact re-entry into the atmosphere and when the rocket failed to boost the satellite into orbit, the device burned up releasing plutonium into the upper atmosphere of the southern hemisphere at a height of about 46 kilometres.

Balloon sampling programmes detected the plutonium at about 36 km height four months later, and the dispersion and subsidence was subsequently followed by aircraft sampling programmes. Ground level sampling systems first detected the plutonium in early 1966 and peak depositions occurred in early 1967.

The low rate of deposition and associated technical problems made accurate ground level sampling and measurement difficult. However when deposition was essentially complete the Health and Safety Laboratory of the U.S. Atomic Energy Commission conducted a world wide soil sampling programme at 65 sites (including 3 in New Zealand) to measure the cumulative deposit on the ground. This programme was conducted in October 1970 and the final results were published in March 1972 (6). Strontium-90 was also measured in these samples and duplicates from the New Zealand sites were taken for our own measurements of strontium-90 (see Chapter 3, 4.) Samples were taken to a depth of 30 cm because depth distribution studies confirmed that plutonium had not penetrated below this depth.

During atmospheric nuclear tests any plutonium which is unfissioned is also released into the environment. Such weapons test plutonium had a maximum deposition in the northern hemisphere where it was about five times as much as in the southern hemisphere (a similar situation has also applied to strontium-90 deposition).

The SNAP plutonium because of its unique injection had a different distribution with maximum deposition in the southern hemisphere - about $2\frac{1}{2}$ times that in the northern hemisphere. However the amount of plutonium from weapons tests has been about 20 times the SNAP plutonium, so that the northern hemisphere has had about 4 times the total deposition that has occurred in the southern hemisphere. Even in New Zealand most of the plutonium deposition has derived from weapons tests.

The New Zealand total deposition (weapons test and SNAP plutonium) is estimated at about 3% of the strontium-90 deposition and is much less than 1% the naturally-occurring alpha emitter radium-226 in soil to a depth of 30 cm. The levels are extremely low and orders of magnitude below those considered to be of public health concern.

2. International Intercomparison of Measurements

During 1971 this Laboratory successfully participated in three separate programmes of "International Intercomparison of Measurements of Environmental Radioactivity". The programmes were organised by:

The International Atomic Energy Agency, Vienna, Austria.

The International Reference Centre for Radioactivity, W.H.O., Le Vesinet, France.

The Analytical Quality Service, Environmental Protection Agency, Massachusetts, U.S.A.

Such intercomparison programmes are an important feature of quality control of radiochemical and gamma spectroscopic procedures. A total of 49 determinations, measured at least in duplicate, were made on 14 different samples provided.

The various sample types analysed were: milk, mixed diet, animal blood, animal and human bone, soils, shales, and limestone.

The following radionuclides and elements were measured: strontium-89, strontium-90, barium-140, caesium-137, cobalt-60, ruthenium-106, radium-226, uranium, thorium, calcium, strontium and potassium.

3. List of Previous Environmental Surveys and Measurements

Reports on the routine work of long term significance, and on the extended monitoring programmes during periods of nuclear weapons tests (see NRL-F/47) are published annually. Over the last few years a number of special environmental surveys and measurements have also been undertaken. For completeness and convenience these are listed below:

- (a) Strontium-89 in Milk - New Zealand Stations - 1966 and 1967.
 - (i) Tabled with strontium-90 values (10).
 - (ii) Tabled with strontium-90 and caesium-137 values (11).
 - (iii) Graphical comparison of the country-wide average values of the ratio $^{89}\text{Sr}/^{90}\text{Sr}$ in milk and rain (9).
- (b) Caesium-137, Individual Milk Stations, Taranaki - 1963 to 1968 (12).
- (c) Caesium-137 to Strontium-90 Ratios in Milk - 1963 to 1968 (12).

- (d) (i) Polonium-210 in Leaf Tobacco (13).
- (ii) Polonium-210 in Leaf Tobacco from Four Countries (14).
- (e) Lead-210 in New Zealand Milk (15).
- (f) Radium-226 in Fertilisers (10).
- (g) Caesium-137 in Flour (10).
- (h) Radon-222 in Artesian Water (10) (7).
- (i) Radionuclides in Shell Fish and Seawater (16).
- (j) Radionuclides in Meat Extract (16).

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TABLE 8

TOTAL BETA ACTIVITY OF AIR FILTER SAMPLES : 1971

In Picocuries per Cubic Metre (at time of measurement - four days after collection)

Collection:

From 9.00 a.m. on the date shown to
9.00 a.m. on the following date
(Filters changed routinely three
times each week*)

N.S.

No Sample received.

| AUCKLAND | | | WELLINGTON | | | HOKITIKA | | | CHRISTCHURCH | | |
|----------|--|--------------------|------------|--|--------------------|----------|--|--------------------|--------------|--|--------------------|
| Date | | pCi/m ³ | Date | | pCi/m ³ | Date | | pCi/m ³ | Date | | pCi/m ³ |
| Jan. 1 | | 0.72 | Jan. 1 | | 0.26 | Jan. 1 | | 0.22 | Jan. 1 | | 0.05 |
| " 4 | | 0.03 | " 4 | | 0.12 | " 4 | | 0.07 | " 5 | | 0.13 |
| " 6 | | 0.20 | " 6 | | 0.04 | " 6 | | 0.09 | " 8 | | 0.07 |
| " 8 | | 0.21 | " 8 | | 0.01 | " 8 | | 0.22 | " 11 | | 0.09 |
| " 11 | | 0.32 | " 9 | | 0.15 | " 11 | | 0.18 | " 13 | | 0.18 |
| " 13 | | 0.24 | " 11 | | 0.08 | " 13 | | 0.33 | " 15 | | 0.12 |
| " 15 | | 0.18 | " 13 | | 0.15 | " 15 | | 0.21 | " 18 | | 0.17 |
| " 18 | | 0.15 | " 15 | | 0.11 | " 18 | | 0.21 | " 20 | | 0.11 |
| " 20 | | 0.18 | " 18 | | 0.13 | " 20 | | 0.10 | " 22 | | 0.18 |
| " 22 | | 0.24 | " 20 | | 0.11 | " 22 | | 0.06 | " 25 | | 0.22 |
| " 25 | | 0.26 | " 22 | | 0.16 | " 25 | | 0.12 | " 27 | | 0.08 |
| " 27 | | 0.28 | " 25 | | 0.18 | " 27 | | 0.21 | " 29 | | 0.15 |
| " 29 | | 0.25 | " 27 | | 0.10 | " 29 | | 0.11 | | | |
| " 29 | | | " 29 | | 0.18 | | | | | | |
| Jan. Av. | | 0.25 | Jan. Av. | | 0.13 | Jan. Av. | | 0.16 | Jan. Av. | | 0.13 |
| Feb. 1 | | 0.27 | Feb. 1 | | N.S. | Feb. 1 | | 0.10 | Feb. 1 | | 0.18 |
| " 3 | | 0.27 | " 3 | | 0.39 | " 3 | | 0.12 | " 3 | | 0.11 |
| " 5 | | 0.12 | " 5 | | 0.10 | " 5 | | 0.21 | " 5 | | 0.08 |
| " 8 | | 0.26 | " 8 | | 0.20 | " 8 | | 0.12 | " 8 | | 0.19 |
| " 10 | | 0.32 | " 10 | | 0.15 | " 10 | | 0.39 | " 10 | | 0.14 |
| " 12 | | 0.16 | " 12 | | 0.30 | " 12 | | 0.22 | " 12 | | 0.16 |
| " 15 | | 0.24 | " 15 | | 0.21 | " 15 | | 0.24 | " 15 | | 0.17 |
| " 17 | | 0.12 | " 17 | | 0.10 | " 17 | | 0.07 | " 17 | | 0.17 |
| " 19 | | 0.12 | " 19 | | 0.13 | " 19 | | 0.25 | " 19 | | 0.18 |
| " 22 | | 0.11 | " 22 | | 0.09 | " 22 | | 0.06 | " 22 | | 0.12 |
| " 24 | | 0.35 | " 24 | | 0.11 | " 24 | | 0.20 | " 24 | | 0.17 |
| " 26 | | 0.22 | " 26 | | 0.18 | " 26 | | 0.15 | " 26 | | 0.18 |
| Feb. Av. | | 0.21 | Feb. Av. | | 0.18 | Feb. Av. | | 0.18 | Feb. Av. | | 0.15 |
| Mar. 1 | | 0.25 | Mar. 1 | | 0.22 | Mar. 1 | | 0.15 | Mar. 1 | | 0.19 |
| " 3 | | 0.18 | " 3 | | 0.11 | " 3 | | 0.20 | " 3 | | 0.08 |
| " 5 | | 0.07 | " 5 | | 0.13 | " 5 | | 0.11 | " 5 | | 0.12 |
| " 8 | | 0.23 | " 8 | | 0.14 | " 8 | | 0.16 | " 8 | | 0.14 |
| " 10 | | 0.09 | " 10 | | 0.14 | " 10 | | 0.14 | " 10 | | 0.13 |
| " 12 | | 0.08 | " 12 | | 0.09 | " 12 | | 0.18 | " 12 | | 0.12 |
| " 15 | | 0.16 | " 15 | | 0.08 | " 15 | | 0.08 | " 15 | | 0.06 |
| " 17 | | 0.13 | " 17 | | 0.09 | " 17 | | 0.05 | " 17 | | 0.08 |
| " 19 | | 0.11 | " 19 | | 0.11 | " 19 | | 0.10 | " 19 | | 0.15 |
| " 22 | | 0.15 | " 22 | | 0.10 | " 22 | | 0.14 | " 22 | | 0.13 |
| " 24 | | 0.13 | " 24 | | 0.12 | " 24 | | 0.04 | " 24 | | 0.11 |
| " 26 | | 0.14 | " 26 | | 0.16 | " 26 | | 0.08 | " 26 | | 0.12 |
| " 29 | | 0.12 | " 28 | | 0.07 | " 29 | | 0.06 | " 29 | | 0.06 |
| " 29 | | | " 29 | | 0.03 | | | | | | |
| Mar. Av. | | 0.14 | Mar. Av. | | 0.11 | Mar. Av. | | 0.11 | Mar. Av. | | 0.11 |
| Mar. 31 | | 0.10 | Mar. 31 | | 0.07 | Mar. 31 | | 0.06 | Mar. 31 | | 0.09 |
| Apr. 2 | | 0.18 | Apr. 2 | | 0.08 | Apr. 2 | | 0.11 | Apr. 2 | | 0.12 |
| " 5 | | 0.11 | " 5 | | N.S. | " 5 | | 0.09 | " 5 | | 0.09 |
| " 7 | | 0.16 | " 7 | | 0.06 | " 7 | | 0.19 | " 7 | | 0.09 |
| " 9 | | 0.18 | " 9 | | 0.07 | " 9 | | 0.08 | " 14 | | 0.08 |
| " 11 | | 0.04 | " 12 | | 0.07 | " 12 | | 0.10 | " 16 | | 0.03 |
| " 14 | | 0.06 | " 14 | | 0.06 | " 14 | | 0.02 | " 19 | | 0.03 |
| " 16 | | 0.03 | " 16 | | 0.02 | " 16 | | 0.04 | " 21 | | 0.08 |
| " 19 | | 0.05 | " 19 | | 0.04 | " 19 | | 0.04 | " 23 | | 0.07 |
| " 21 | | 0.16 | " 21 | | 0.10 | " 21 | | 0.12 | " 26 | | 0.07 |
| " 23 | | 0.08 | " 23 | | 0.07 | " 23 | | 0.05 | " 28 | | 0.08 |
| " 26 | | N.S. | " 26 | | 0.07 | " 26 | | 0.06 | | | |
| " 28 | | 0.04 | " 28 | | 0.05 | " 28 | | 0.07 | | | |
| Apr. Av. | | 0.10 | Apr. Av. | | 0.06 | Apr. Av. | | 0.08 | Apr. Av. | | 0.08 |

| AUCKLAND | | | WELLINGTON | | | HOKITIKA | | | CHRISTCHURCH | | |
|----------|--|--------------------|------------|--|--------------------|----------|--|--------------------|--------------|--|--------------------|
| Date | | pCi/m ³ | Date | | pCi/m ³ | Date | | pCi/m ³ | Date | | pCi/m ³ |
| Apr. 30 | | 0.03 | Apr. 30 | | 0.02 | Apr. 30 | | 0.06 | Apr. 30 | | 0.04 |
| May 3 | | 0.05 | May 3 | | <0.01 | May 3 | | 0.03 | May 3 | | 0.02 |
| " 5 | | 0.08 | " 5 | | 0.06 | " 5 | | 0.06 | " 5 | | 0.02 |
| " 7 | | 0.05 | " 7 | | 0.05 | " 7 | | 0.05 | " 7 | | 0.04 |
| " 10 | | 0.06 | " 10 | | 0.06 | " 10 | | 0.06 | " 10 | | 0.06 |
| " 12 | | 0.04 | " 12 | | 0.03 | " 12 | | 0.08 | " 12 | | 0.04 |
| " 14 | | 0.06 | " 14 | | 0.03 | " 14 | | 0.06 | " 14 | | 0.05 |
| " 17 | | 0.06 | " 17 | | 0.04 | " 17 | | 0.11 | " 17 | | 0.04 |
| " 19 | | 0.05 | " 19 | | 0.04 | " 19 | | 0.07 | " 19 | | 0.06 |
| " 21 | | 0.04 | " 21 | | 0.04 | " 21 | | 0.06 | " 21 | | 0.07 |
| " 24 | | 0.02 | " 24 | | 0.02 | " 24 | | 0.08 | " 24 | | 0.05 |
| " 26 | | 0.02 | " 26 | | 0.02 | " 26 | | 0.07 | " 26 | | 0.08 |
| " 28 | | 0.03 | " 28 | | 0.02 | " 28 | | 0.03 | " 28 | | 0.05 |
| May Av. | | 0.05 | May Av. | | 0.03 | May Av. | | 0.06 | May Av. | | 0.05 |

MONTHLY AVERAGES DURING THE SPECIAL MONITORING PROGRAMME*

| | | | | | | | |
|----------|------|----------|------|----------|------|----------|------|
| June Av. | 0.07 | June Av. | 0.03 | June Av. | 0.04 | June Av. | 0.04 |
| July Av. | 0.43 | July Av. | 0.25 | July Av. | 0.38 | July Av. | 0.36 |
| Aug. Av. | 0.29 | Aug. Av. | 0.18 | Aug. Av. | 0.25 | Aug. Av. | 0.28 |
| Sept Av. | 0.29 | Sept Av. | 0.14 | Sept Av. | 0.15 | Sept Av. | 0.16 |
| Oct. Av. | 0.26 | Oct. Av. | 0.13 | Oct. Av. | 0.16 | Oct. Av. | 0.12 |
| Nov. 1 | 0.26 | Nov. 1 | 0.13 | Nov. 1 | 0.25 | Nov. 1 | 0.15 |
| " 3 | 0.35 | " 3 | 0.18 | " 3 | 0.26 | " 3 | 0.17 |
| " 5 | 0.29 | " 5 | 0.17 | " 5 | 0.20 | " 5 | 0.19 |
| " 8 | 0.22 | " 8 | 0.17 | " 8 | 0.21 | " 8 | 0.21 |
| " 10 | 0.20 | " 10 | 0.18 | " 10 | 0.25 | " 11 | 0.26 |
| " 12 | 0.26 | " 12 | 0.14 | " 12 | 0.17 | " 15 | 0.07 |
| " 15 | 0.05 | " 15 | 0.25 | " 15 | 0.06 | " 17 | 0.05 |
| " 17 | 0.15 | " 17 | 0.06 | " 17 | 0.08 | " 19 | N.S. |
| " 19 | 0.14 | " 19 | 0.09 | " 19 | 0.17 | " 23 | 0.05 |
| " 22 | 0.17 | " 22 | 0.07 | " 22 | 0.08 | " 26 | 0.06 |
| " 24 | 0.14 | " 24 | 0.09 | " 24 | 0.09 | " 29 | 0.11 |
| " 26 | 0.09 | " 26 | 0.05 | " 26 | 0.06 | | |
| " 29 | 0.15 | " 29 | 0.13 | " 29 | 0.09 | | |
| Nov. Av. | 0.19 | Nov. Av. | 0.13 | Nov. Av. | 0.15 | Nov. Av. | 0.13 |
| Dec. 1 | 0.18 | Dec. 1 | 0.09 | Dec. 1 | 0.14 | Dec. 1 | 0.11 |
| " 3 | 0.12 | " 3 | 0.08 | " 3 | 0.14 | " 3 | 0.10 |
| " 6 | 0.20 | " 6 | 0.14 | " 6 | 0.20 | " 6 | 0.14 |
| " 8 | 0.12 | " 8 | 0.07 | " 8 | 0.11 | " 8 | 0.05 |
| " 10 | 0.19 | " 10 | 0.15 | " 10 | 0.19 | " 10 | 0.17 |
| " 13 | 0.24 | " 13 | 0.13 | " 13 | 0.13 | " 13 | 0.21 |
| " 15 | 0.16 | " 15 | 0.15 | " 15 | 0.17 | " 15 | 0.23 |
| " 17 | 0.26 | " 17 | 0.16 | " 17 | 0.19 | " 17 | 0.16 |
| " 20 | 0.15 | " 20 | 0.08 | " 20 | 0.08 | " 20 | 0.08 |
| " 22 | 0.20 | " 22 | 0.07 | " 22 | 0.13 | " 22 | 0.08 |
| " 24 | 0.28 | " 24 | 0.15 | " 24 | 0.21 | " 24 | 0.09 |
| " 27 | 0.17 | " 27 | 0.07 | " 27 | 0.16 | " 29 | 0.09 |
| " 29 | 0.17 | " 29 | 0.14 | " 29 | 0.25 | | |
| Dec. Av. | 0.19 | Dec. Av. | 0.11 | Dec. Av. | 0.16 | Dec. Av. | 0.13 |

* During the special monitoring programme, from June to October inclusive, air filter samples were changed daily. For these individual results, including those from four Pacific Island stations, see the separate report on the monitoring of fallout from the French nuclear tests during 1971 (NRL-F/47, March 1972, Table 2). For continuity, the monthly average values for the New Zealand stations during this period are listed again in this table.

TABLE 9 TOTAL BETA ACTIVITY OF WEEKLY RAINWATER SAMPLES : 1971

Deposition: mCi/km² (at time of measurement - about four days after collection)

Collection: From date shown to start of next collection.

Rainfall: cm

N.S. No Sample received.

| Collection | AUCKLAND cm mCi/km ² | | WELLINGTON cm mCi/km ² | | GREYMOUTH* cm mCi/km ² | | CHRISTCHURCH cm mCi/km ² | |
|------------|---|------|---|------|---|-----|---|------|
| Jan. 1 | 2.1 | 0.6 | 9.2 | 1.6 | 6.9 | 2.7 | 1.7 | 1.8 |
| " 8 | 3.0 | 0.8 | 0.2 | 0.4 | 0.1 | 0.2 | 0.8 | 0.6 |
| " 15 | <0.1 | 0.2 | 0.5 | 0.3 | 6.2 | 1.3 | 0.1 | 1.1 |
| " 22 | 0.2 | 0.7 | 0.3 | 0.8 | 0.8 | 1.3 | 0.1 | 0.9 |
| January | 5.4 | 2.3 | 10.2 | 3.1 | 14.0 | 5.5 | 2.7 | 4.4 |
| Jan. 29 | 1.3 | 0.2 | TRACE | <0.1 | 7.4 | 0.5 | 0.2 | 1.5 |
| Feb. 5 | 0.4 | 1.6 | TRACE | 0.6 | 0.2 | 0.4 | <0.1 | 0.2 |
| " 12 | 1.2 | 0.4 | <0.1 | 0.8 | 0.3 | 0.8 | 0.3 | 1.1 |
| " 19 | 9.4 | 1.3 | 5.9 | 1.1 | 11.2 | 0.8 | NIL | 0.3 |
| February | 12.3 | 3.5 | 6.0 | 2.6 | 19.1 | 2.5 | 0.5 | 3.1 |
| Feb. 26 | <0.1 | 0.2 | 0.8 | 0.6 | 0.4 | 0.8 | 1.4 | 0.7 |
| Mar. 5 | 3.4 | 0.3 | TRACE | 0.3 | NIL | 0.1 | 0.1 | 0.3 |
| " 12 | 0.9 | 0.4 | 0.3 | 0.4 | 0.2 | 0.5 | TRACE | 0.1 |
| " 19 | 0.7 | 0.3 | 0.6 | 0.3 | 4.5 | 0.7 | 0.5 | <0.1 |
| " 26 | 0.1 | 0.3 | 1.0 | 1.4 | 1.5 | 0.4 | 0.3 | 0.3 |
| March | 5.1 | 1.5 | 2.7 | 3.0 | 6.6 | 2.5 | 2.3 | 1.5 |
| Apr. 2 | 0.2 | 0.1 | 0.1 | <0.1 | 1.0 | 0.4 | 0.1 | 0.3 |
| " 9 | 4.2 | 0.3 | 1.6 | 0.2 | 11.7 | 0.7 | 0.9 | 0.3 |
| " 16 | 4.5 | 0.4 | 0.2 | 0.3 | 2.8 | 0.5 | 0.5 | 0.1 |
| " 23 | 0.4 | <0.1 | TRACE | 0.1 | NIL | 0.1 | NIL | 0.1 |
| April | 9.3 | 0.9 | 1.9 | 0.7 | 15.5 | 1.7 | 1.5 | 0.8 |
| Apr. 30 | 2.7 | 0.3 | 7.4 | 0.5 | 5.1 | 0.6 | 4.1 | 0.4 |
| May 7 | 2.2 | 0.2 | 1.6 | 0.1 | 9.1 | 0.5 | 0.3 | <0.1 |
| " 14 | 1.3 | 0.3 | 4.0 | 0.4 | NIL | 0.2 | 0.8 | 0.4 |
| " 21 | 0.1 | <0.1 | 1.7 | 0.2 | 0.5 | 0.2 | 0.3 | 0.1 |
| " 28 | 4.3 | 0.2 | 5.1 | 0.5 | 7.5 | 0.3 | 6.2 | 0.3 |
| May | 10.6 | 1.1 | 19.8 | 1.7 | 22.2 | 1.8 | 11.7 | 1.3 |

MONTHLY TOTALS DURING THE SPECIAL MONITORING PERIOD **

| | | | | | | | | |
|-----------|------|------|---------|------|------|------|-----|-----|
| June | 6.5 | 3.0 | 8.5 | 1.5 | 23.2 | 6.0 | 3.3 | 0.8 |
| July | 11.2 | 21.0 | 11.8 | 9.6 | 8.3 | 8.8 | 7.8 | 4.9 |
| August | 5.3 | 9.0 | 16.9 | 12.6 | 15.5 | 13.0 | 1.5 | 2.8 |
| September | 16.3 | 23.0 | 11.3 | 7.8 | 33.0 | 21.6 | 3.2 | 4.0 |
| October | 11.3 | 22.2 | 14.8*** | 27.9 | 26.3 | 27.5 | 4.1 | 3.2 |

(continued)

| Collection | AUCKLAND | | WELLINGTON | | GREYMOUTH* | | CHRISTCHURCH | |
|------------|----------|---------------------|------------|---------------------|------------|---------------------|--------------|---------------------|
| | cm | mCi/km ² | cm | mCi/km ² | cm | mCi/km ² | cm | mCi/km ² |
| Oct. 29 | 0.3 | 0.5 | <0.1 | 0.7 | 0.9 | 0.4 | 1.3 | 0.5 |
| Nov. 5 | 1.0 | 1.2 | NIL | 1.4 | <0.1 | 0.1 | TRACE | <0.1 |
| " 12 | 3.2 | 2.0 | 4.7 | 2.2 | 1.6 | 0.3 | 2.6 | 1.1 |
| " 19 | 3.6 | 2.5 | 1.5 | 0.9 | 11.2 | 4.6 | 0.4 | 0.3 |
| " 26 | 5.0 | 1.6 | 8.0 | 2.4 | 1.1 | 0.2 | 1.1 | 0.7 |
| November | 13.1 | 7.8 | 14.2 | 7.6 | 14.9 | 5.6 | 5.4 | 2.6 |
| Dec. 3 | 1.0 | 1.0 | 1.3 | 0.5 | 1.0 | 1.0 | 0.2 | 1.2 |
| " 10 | TRACE | 1.2 | NIL | 0.1 | NIL | 0.1 | NIL | 0.2 |
| " 17 | 0.3 | 0.2 | 0.3 | 0.7 | 4.5 | 0.8 | <0.1 | <0.1 |
| " 24 | 0.6 | 0.4 | 0.3 | 1.0 | 4.6 | 1.0 | 1.3 | 1.1 |
| December | 1.9 | 2.8 | 1.9 | 2.3 | 10.1 | 2.9 | 1.6 | 2.6 |

| | | | | | | | | |
|------------|-------|------|-------|------|-------|------|------|------|
| 1971 TOTAL | 108.3 | 98.1 | 120.0 | 80.4 | 208.7 | 99.4 | 45.6 | 32.0 |
|------------|-------|------|-------|------|-------|------|------|------|

| AVERAGE CONCENTRA- TION | pCi/litre | pCi/litre | pCi/litre | pCi/litre |
|---|-----------|-----------|-----------|-----------|
| DURING 1971 | 91 | 67 | 48 | 70 |
| DURING SPECIAL MONITORING PERIOD | 155 | 94*** | 72 | 79 |

* Collections at Greymouth start one day later than the date listed.

** The monthly totals in this panel are summed from the results of four or five separate weekly collections which, like the other collection periods listed in this table, do not necessarily coincide exactly with each calendar month. The individual results were listed in the separate report on the monitoring of fallout from the French nuclear tests during 1971 (NRL-F/47, March 1972, Table 4).

*** Amended rainfall for weekly collection starting 8 October at Wellington is 1.2 cm. (See Report No. NRL-F/47, page 27). Amended concentration at Wellington during the special monitoring period is 94 pCi/litre. (This correction has no significance in the interpretation of results).

| STRONTIUM-90 IN RAIN : 1971 | | | | | | | | | | | | | | | |
|----------------------------------|---------------|------|------|-------|-------|------|------|------|-------|-------|------|-------|------|-------|-------------------|
| STATION | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | TOTAL | MONTHLY AVERAGE** |
| KAIAIA | Rainfall | 7.0 | 37.3 | 3.9 | 9.1 | 22.1 | 13.7 | 18.6 | 27.8 | 15.5 | 12.2 | 13.6 | 5.9 | 187 | 1.2 |
| | Deposition | 0.06 | 0.20 | 0.06 | 0.11 | 0.07 | 0.06 | 0.29 | 0.35 | 0.28 | 0.21 | 0.21 | 0.12 | 2.02 | |
| | Concentration | 0.9 | 0.5 | 1.6 | 1.2 | 0.3 | 0.4 | 1.6 | 1.3 | 1.8 | 1.7 | 1.5 | 2.1 | | |
| AUCKLAND | Rainfall | 3.6 | 11.5 | 5.1 | 9.3 | 8.7 | 6.7 | 11.1 | 11.3 | 12.8 | 11.4 | 8.5 | 10.5 | 111 | 1.2 |
| | Deposition | 0.06 | 0.08 | 0.03 | 0.06 | 0.04 | 0.05 | 0.15 | 0.17 | 0.23 | 0.15 | 0.17 | 0.15 | 1.34 | |
| | Concentration | 1.5 | 0.7 | 0.6 | 0.6 | 0.5 | 0.8 | 1.4 | 1.5 | 1.8 | 1.3 | 2.0 | 1.4 | | |
| NEW PLYMOUTH | Rainfall | 8.9 | 43.1 | 3.1 | 10.8 | 7.9 | 16.9 | 4.9 | 13.9 | 17.1 | 18.0 | 18.5 | 13.0 | 176 | 1.3 |
| | Deposition | 0.12 | 0.19 | 0.05 | 0.07 | 0.12 | 0.09 | 0.14 | 0.21 | 0.23 | 0.27 | 0.20 | 0.16 | 1.85 | |
| | Concentration | 1.3 | 0.4 | 1.7 | 0.7 | 1.6 | 0.5 | 2.8 | 1.5 | 1.4 | 1.5 | 1.1 | 1.2 | | |
| HAVELOCK NORTH | Rainfall | 9.4 | 5.3 | 4.0 | 11.7 | 18.1 | 2.6 | 12.2 | 10.6 | 9.0 | 17.3 | 6.7 | 5.7 | 113 | 1.1 |
| | Deposition | 0.16 | 0.10 | 0.07 | 0.11 | 0.05 | 0.03 | 0.12 | 0.09 | 0.08 | 0.10 | 0.08 | 0.05 | 1.04 | |
| | Concentration | 1.7 | 1.9 | 1.8 | 1.0 | 0.3 | 1.0 | 1.0 | 0.8 | 0.9 | 0.6 | 1.2 | 0.9 | | |
| WELLINGTON | Rainfall | 8.1 | 4.6 | 6.6 | 2.0 | 10.2 | 8.3 | 11.4 | 15.1 | 9.1 | 17.5 | 7.5 | 4.6 | 105 | 1.2 |
| | Deposition | 0.10 | 0.05 | 0.09 | 0.03 | 0.06 | 0.06 | 0.09 | 0.17 | 0.12 | 0.23 | 0.11 | 0.08 | 1.19 | |
| | Concentration | 1.2 | 1.1 | 1.3 | 1.6 | 0.6 | 0.7 | 0.8 | 1.2 | 1.3 | 1.3 | 1.5 | 1.7 | | |
| GREYMOUTH | Rainfall | 20.6 | 12.6 | 6.1 | 16.6 | 20.5 | 26.6 | 8.3 | 17.9 | 23.8 | 26.7 | 14.6 | 11.2 | 206 | 1.3 |
| | Deposition | 0.21 | 0.12 | 0.15 | 0.15 | 0.16 | 0.13 | 0.08 | 0.31 | 0.37 | 0.44 | 0.17 | 0.20 | 2.49 | |
| | Concentration | 1.0 | 0.9 | 2.4 | 0.9 | 0.8 | 0.5 | 1.0 | 1.7 | 1.6 | 1.6 | 1.1 | 1.8 | | |
| CHRISTCHURCH | Rainfall | 2.7 | 5.3 | 2.2 | 1.5 | 7.3 | 7.5 | 7.9 | 1.7 | 2.8 | 4.0 | 3.0 | 2.3 | 48 | 1.6 |
| | Deposition | 0.11 | 0.09 | 0.04 | 0.02 | 0.05 | 0.03 | 0.07 | 0.02 | 0.03 | 0.09 | 0.03 | 0.07 | 0.65 | |
| | Concentration | 4.0 | 1.6 | 1.6 | 1.6 | 0.6 | 0.4 | 0.9 | 1.4 | 1.1 | 2.2 | 0.9 | 3.1 | | |
| DUNEDIN | Rainfall | 4.9 | 3.3 | 8.2 | 3.0 | 8.6 | 10.7 | 3.0 | 5.5 | 6.7 | 3.1 | 12.7 | 5.2 | 75 | 1.2 |
| | Deposition | 0.07 | 0.05 | 0.11 | 0.06 | 0.04 | 0.04 | 0.02 | 0.04 | 0.07 | 0.06 | 0.14 | 0.10 | 0.80 | |
| | Concentration | 1.4 | 1.6 | 1.3 | 2.0 | 0.5 | 0.4 | 0.7 | 0.8 | 1.1 | 1.8 | 1.1 | 2.0 | | |
| INVERCARGILL | Rainfall | 7.1 | 3.0 | 14.5 | 3.8 | 7.7 | 9.2 | 5.9 | 5.3 | 14.1 | 7.8 | 7.5 | 9.6 | 96 | 1.3 |
| | Deposition | 0.09 | 0.11 | 0.12 | 0.07 | 0.05 | 0.04 | 0.06 | 0.07* | 0.12 | 0.10 | 0.10 | 0.14 | 1.07 | |
| | Concentration | 1.3 | 3.5 | 0.8 | 1.7 | 0.6 | 0.4 | 1.1 | 1.3 | 0.8 | 1.3 | 1.3 | 1.4 | | |
| NEW ZEALAND COUNTRY-WIDE AVERAGE | Rainfall | 8.0 | 14.0 | 6.0 | 7.5 | 12.3 | 11.4 | 9.3 | 12.1 | 12.3 | 13.1 | 10.3 | 7.6 | 124 | 1.3 |
| | Deposition | 0.11 | 0.11 | 0.08 | 0.08 | 0.07 | 0.06 | 0.11 | 0.16 | 0.17 | 0.18 | 0.13 | 0.12 | 1.38 | |
| | Concentration | 1.6 | 1.4 | 1.4 | 1.3 | 0.6 | 0.6 | 1.2 | 1.3 | 1.3 | 1.5 | 1.3 | 1.7 | | |
| SUVA, FIJI | Rainfall | 33.0 | 38.7 | 20.2 | 33.9 | 31.7 | 13.8 | 7.6 | 8.8 | 12.5 | 56.3 | 24.8 | 53.8 | 335 | 0.7 |
| | Deposition | 0.15 | 0.08 | 0.04* | 0.07* | 0.05 | 0.05 | 0.21 | 0.15 | 0.08 | 0.23 | 0.12* | 0.28 | 1.51 | |
| | Concentration | 0.4 | 0.2 | 0.2 * | 0.2 * | 0.2 | 0.3 | 2.7 | 1.7 | 0.6 | 0.4 | 0.5 * | 0.5 | | |
| RAROTONGA | Rainfall | 25.8 | 45.4 | 16.9 | 10.0 | 23.2 | 25.0 | 6.6 | 14.4 | 6.9 | 7.8 | 3.8 | 13.5 | 199 | 0.7 |
| | Deposition | 0.13 | 0.04 | 0.03 | 0.03 | 0.04 | 0.10 | 0.10 | 0.11 | 0.07* | 0.09 | 0.04* | 0.12 | 0.90 | |
| | Concentration | 0.5 | <0.1 | 0.2 | 0.3 | 0.2 | 0.4 | 1.5 | 0.8 | 1.0 | 1.2 | 1.0 * | 0.9 | | |

* No result available. The value given is an estimate.

** The annual average concentration (calculated from the total rainfall and deposition) is slightly lower than the monthly average concentration.

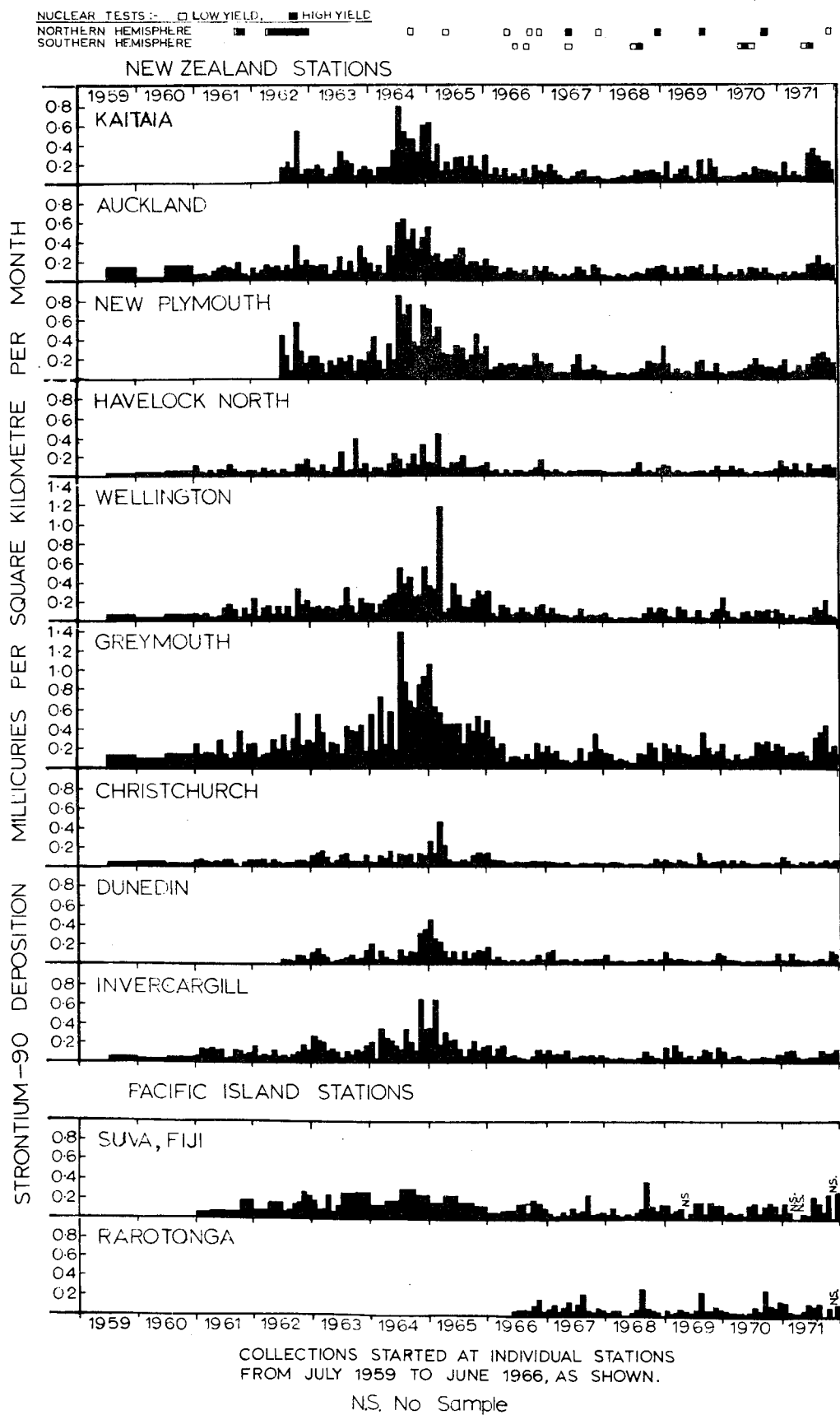


Fig. 8

STRONTIUM-90 IN RAIN - INDIVIDUAL STATIONS

| TABLE 11 STRONTIUM-89 DEPOSITION AND THE RATIO STRONTIUM-89 TO STRONTIUM-90 IN RAIN : 1971 | | | | | | | | | | | | | |
|--|---|-----------|----------|--------------|--------------|------------|-----------|------------|--------------|--------------|-----------|--------------|-----------|
| STATION | | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
| KAITIA | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 0.4 7 | 1.3 6 | 0.3 4 | 0.3 3 | 0.2 2 | 0.7 11 | 16.1 55 | 12.6 36 | 9.6 34 | 5.5 26 | 2.8 13 | 1.3 10 |
| AUCKLAND | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 0.4 8 | 0.5 6 | 0.2 5 | 0.2 3 | 0.1 3 | 1.0 18 | 6.7 45 | 4.9 29 | 7.0 31 | 4.1 28 | 2.1 12 | 1.7 11 |
| NEW PLYMOUTH | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 0.9 8 | 1.3 7 | 0.2 5 | 0.3 4 | <0.1 <1 | 0.4 5 | 6.8 50 | 5.9 28 | 6.4 27 | 6.0 23 | 2.9 13 | 1.4 9 |
| HAVELOCK NORTH | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 1.2 7 | 0.7 7 | 0.3 5 | 0.4 3 | 0.1 2 | <0.1 3 | 6.0 49 | 2.4 27 | 2.7 32 | 2.3 23 | 1.0 12 | 0.5 10 |
| WELLINGTON | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 0.8 8 | 0.4 7 | 0.4 5 | 0.1 3 | 0.2 2 | 0.2 3 | 4.6 49 | 4.0 23 | 3.3 29 | 5.5 24 | 1.5 13 | 0.8 10 |
| GREYMOUTH | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 1.7 8 | 0.7 6 | 0.7 5 | 0.4 3 | 0.4 3 | 1.5 12 | 3.5 42 | 7.0 23 | 8.3 22 | 8.9 20 | 2.1 13 | 1.9 9 |
| CHRISTCHURCH | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 0.8 7 | 0.5 6 | 0.1 4 | <0.1 3 | 0.1 3 | 0.1 4 | 2.7 40 | 0.6 26 | 0.6 21 | 1.5 17 | 0.3 11 | 0.6 9 |
| DUNEDIN | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 0.5 8 | 0.3 6 | 0.5 4 | 0.2 3 | 0.1 3 | 0.5 11 | 0.7 34 | 1.0 24 | 1.6 22 | 0.9 16 | 1.7 12 | 1.2 12 |
| INVERCARGILL | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 0.7 8 | 0.7 7 | 0.5 5 | 0.2 3 | 0.1 2 | 0.1 3 | 3.4 53 | N.S. N.S. | 2.3 20 | 1.5 16 | 1.3 13 | 1.5 11 |
| NEW ZEALAND COUNTRY-WIDE AVERAGE | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 0.8 8 | 0.7 6 | 0.4 4 | 0.2 3 | 0.2 2 | 0.5 8 | 5.6 46 | 4.8 27 | 4.6 26 | 4.0 21 | 1.7 12 | 1.2 10 |
| SUVA, FIJI | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 1.5 10 | 0.6 8 | N.S. N.S. | N.S. N.S. | 0.1 2 | 2.9 63 | 11.7 56 | 4.8 33 | 4.0 52 | 8.6 37 | N.S. N.S. | 3.0 11 |
| PAROTONGA | Deposition mCi $\frac{89\text{Sr}}{90\text{Sr}}/\text{km}^2$ Ratio | 1.2 9 | 0.3 8 | 0.1 4 | 0.1 4 | 0.1 3 | 1.4 14 | 7.4 75 | 3.7 32 | N.S. N.S. | 2.6 29 | N.S. N.S. | 1.4 12 |

N.S. - No result available

| TABLE 12 STRONTIUM-90 IN MILK : 1971 | | | | | |
|--------------------------------------|----------------------------|----------------|---------------|----------------|---------|
| STATIONS | "STRONTIUM UNITS" pCi/g Ca | | | | |
| | First Quarter | Second Quarter | Third Quarter | Fourth Quarter | AVERAGE |
| NORTHLAND | 6.6 | 6.2 | 8.2 | 8.1 | 7.3 |
| AUCKLAND | 5.3 | 3.4 | 7.8 | 6.5 | 5.8 |
| WAIKATO | 5.0 | 5.2 | 8.1 | 5.8 | 6.0 |
| TARANAKI | 9.0 | 8.9 | 12.1 | 10.7 | 10.2 |
| PALMERSTON NORTH | 4.0 | 4.0 | 6.5 | 5.6 | 5.0 |
| WELLINGTON | 4.8 | 4.4 | 5.3 | 4.8 | 4.8 |
| WESTLAND | 16.8 | 19.3 | 17.3 | 19.7 | 18.3 |
| CHRISTCHURCH | 1.7 | 2.6 | 1.8 | 1.9 | 2.0 |
| DUNEDIN | 2.5 | 3.4 | 2.5 | 3.4 | 3.0 |
| COUNTRY-WIDE AVERAGE | 6.2 | 6.4 | 7.7 | 7.4 | 6.9 |

| TABLE 13 CAESIUM-137 IN MILK : 1971 | | | | | | | | | | | | | |
|-------------------------------------|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|---------|
| STATIONS | pCi/g K | | | | | | | | | | | | |
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | AVERAGE |
| NORTHLAND | 19 | 24* | 28 | 24 | 15 | 16 | 11 | 15 | 31 | 26 | 30 | 32 | 23 |
| AUCKLAND | 16 | 18 | 18 | 15 | 13 | 10 | 12 | 18 | 25 | 26 | 22 | 20 | 18 |
| WAIKATO | 36 | 37 | 38 | 37 | 34 | 32* | 30 | 36 | 37 | 40 | 35 | 39 | 36 |
| TARANAKI | 91 | 95 | 83 | 78 | 99 | 57 | 38 | 47 | 88 | 85 | 94 | 106 | 80 |
| PALMERSTON NORTH | 9 | 8 | 9 | 8 | 5 | 2 | 5 | 10 | 7 | 8 | 6 | 7 | 7 |
| WELLINGTON | 10 | 10 | 12 | 9 | 5 | 6 | 4 | 8 | 8 | 11 | 9 | 12 | 9 |
| WESTLAND | 39 | 34 | 41 | 35 | 30 | 32 | 15 | 19 | 26 | 33 | 26 | 35 | 30 |
| CHRISTCHURCH | 6 | 5 | 6 | 5 | 4 | 3 | 2 | 1 | <1 | 3 | 3 | <1 | 3 |
| DUNEDIN | 6* | 9 | 10 | 8 | 7 | 3 | 3 | 2 | 1 | 4 | 4 | 5 | 5 |
| COUNTRY-WIDE AVERAGE | 26 | 27 | 27 | 24 | 24 | 18 | 13 | 17 | 25 | 26 | 25 | 29 | 23 |

* Estimate

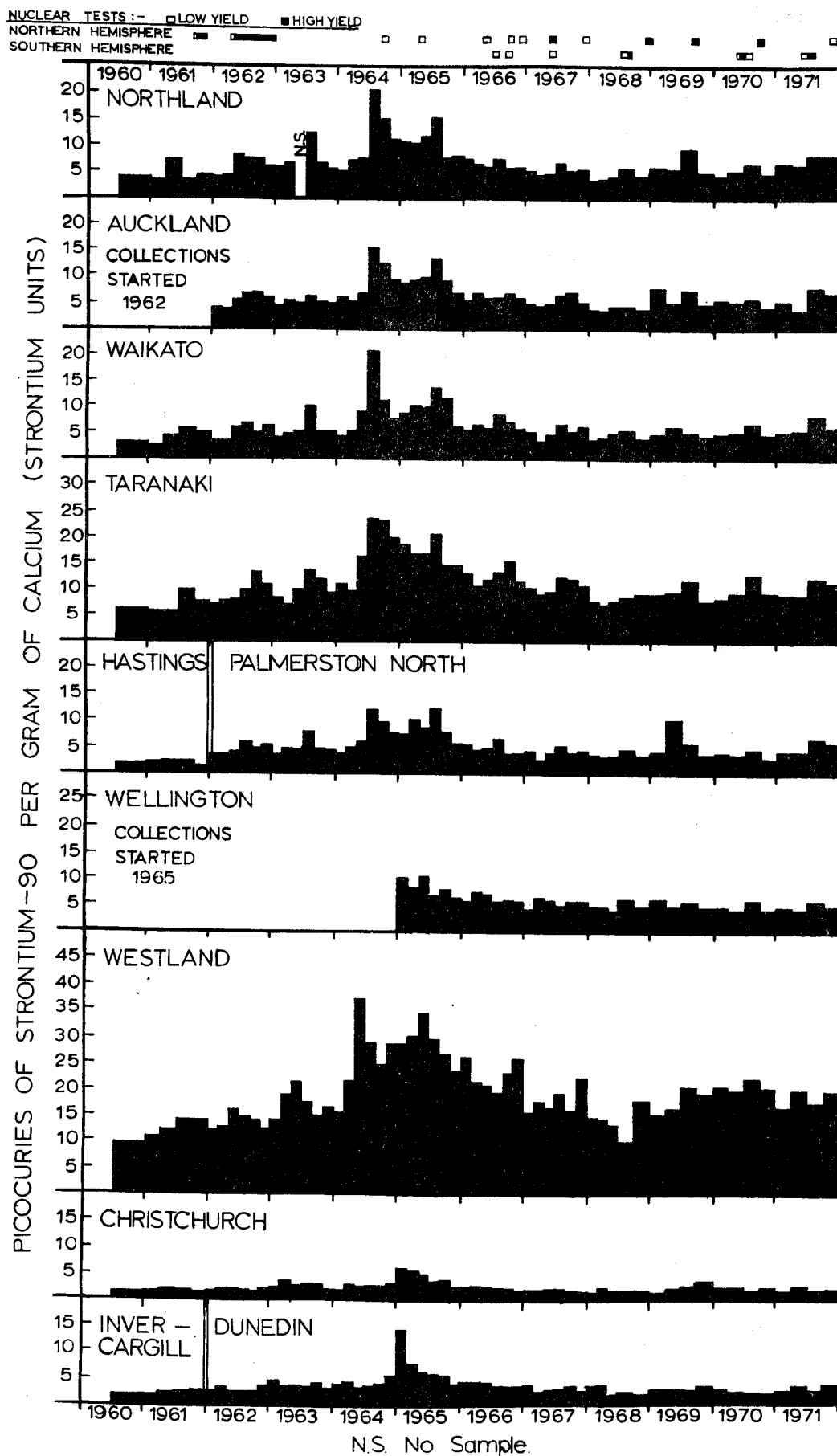


Fig. 9

STRONTIUM-90 IN MILK - INDIVIDUAL STATIONS

COLLECTION STARTED JULY 1963

NUCLEAR TESTS :- □ LOW YIELD ■ HIGH YIELD

NORTHERN HEMISPHERE
SOUTHERN HEMISPHERE

PICOCURIES OF CAESIUM-137 PER GRAM OF POTASSIUM

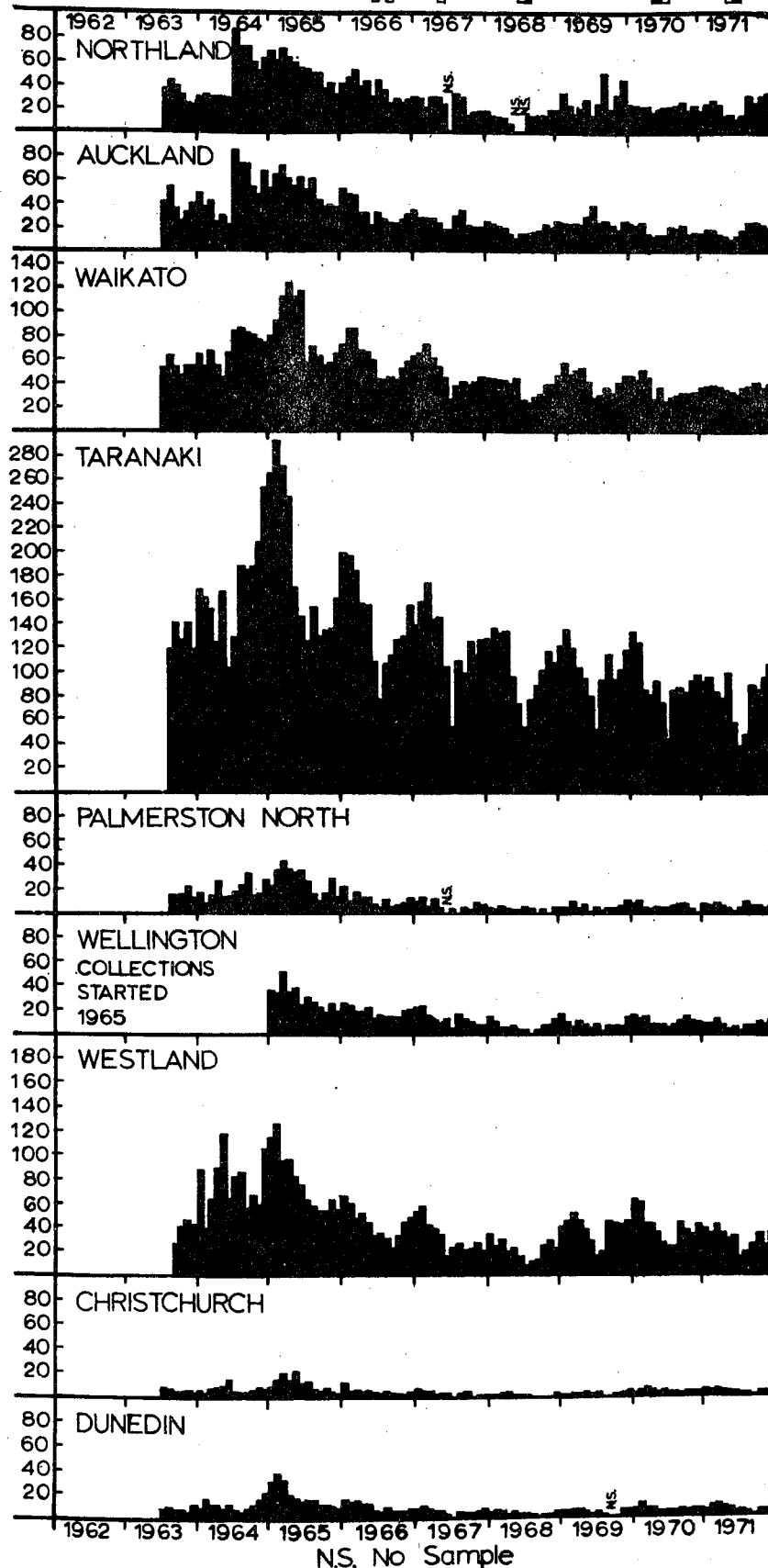
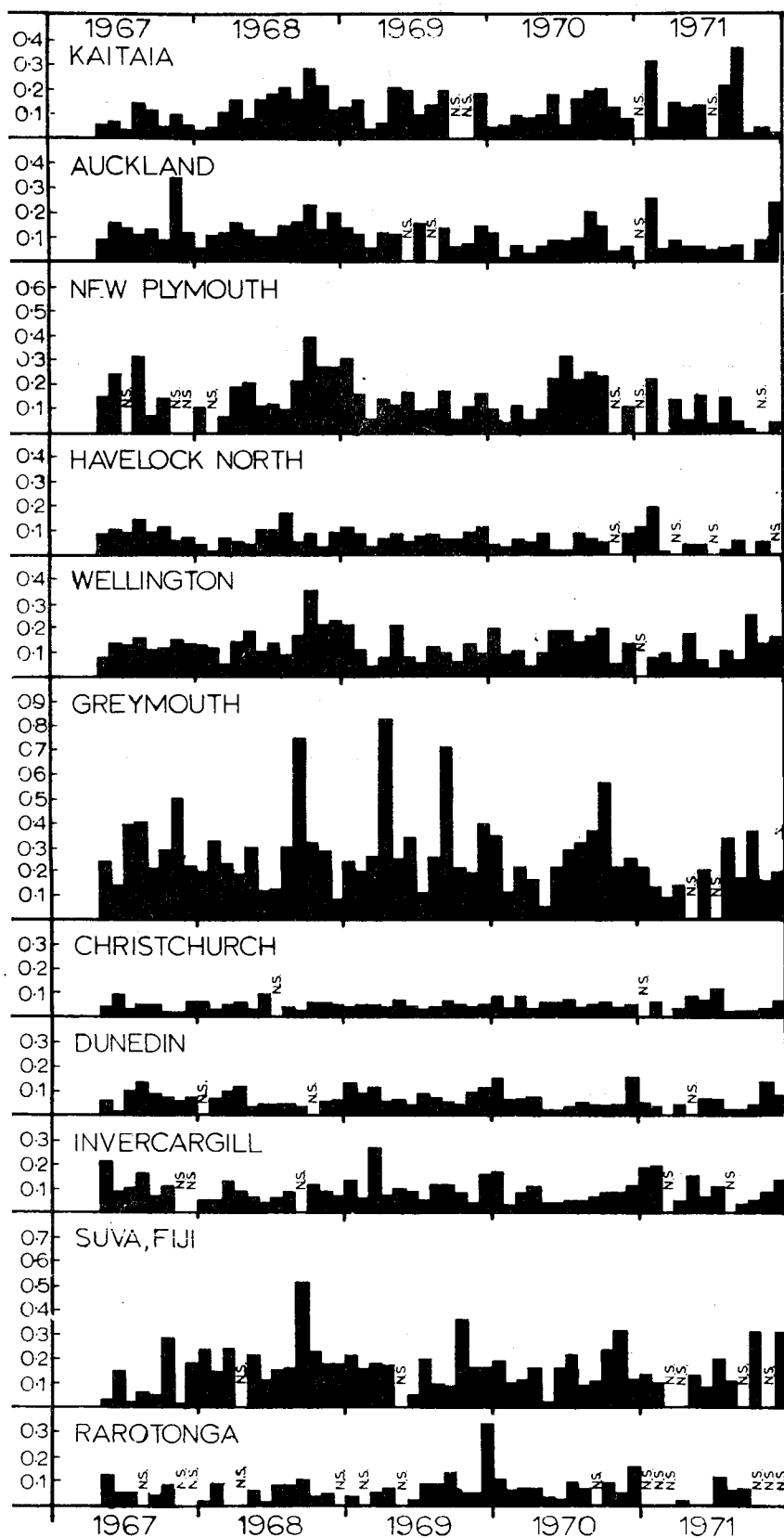


Fig. 10

CAESIUM-137 IN MILK - INDIVIDUAL STATIONS

LEAD-210 DEPOSITION: MILLICURIES PER SQUARE KILOMETRE PER MONTH.



N.S. No Sample or No Results Available.

Fig. 11

LEAD-210 IN RAIN - INDIVIDUAL STATIONS

TABLE 14

RADIONUCLIDES IN HUMAN BONE

Rainfall Area:

The areas within New Zealand from which samples have been obtained are classified according to mean annual rainfall:

Low: up to 100cm per year
 Medium: 100 to 150cm per year
 High: over 150cm per year

Age at Death:

y year, m month, SB stillborn.

Bone Type:

F femur, H humerus, L longbones,
 V vertebrae, R rib, S Skull.

| Sample Data | | | | | Radionuclide Levels*** | | |
|-------------|---------------|---------------|--------------|-------|------------------------|----------------------|--------------------|
| | | | | | Artificial | Naturally-Occurring | |
| Sample No. | Rainfall Area | Date of Death | Age at Death | Bone | Strontium-90 pCi/g Ca | Radium-226 pCi/g ash | Lead-210 pCi/g ash |
| 3 | Low | 7/61 | 5m | F,V,R | 0.9 | 0.016 | 0.047 |
| 4 | " | 7/61 | 9y | F,V | 0.6 | 0.011 | 0.053 |
| 7* | " | 9/61 | 23y | F,V | 0.7 | 0.214 | 0.355 |
| 1 | " | 6/61 | 53y | F | <0.1 | 0.026 | 0.101 |
| 2 | " | 7/61 | 60y | F | <0.1 | 0.011 | 0.099 |
| 33 | " | 9/61 | 78y | H | 0.2 | 0.012 | 0.054 |
| 34 | " | 9/61 | 79y | H | 0.1 | 0.013 | 0.040 |
| 29 | " | 2/61 | 83y | H | 0.1 | 0.017 | 0.050 |
| 5 | High | 9/61 | 68y | F | 0.2 | 0.012 | 0.080 |
| 31 | " | 11/61 | 68y | H | 0.3 | 0.010 | 0.074 |
| 8 | " | 10/61 | 80y | F | <0.1 | 0.040 | 0.106 |
| 6 | " | 9/61 | 85y | F | <0.1 | 0.010 | 0.111 |
| 10 | Low | 5/62 | 7y | F | 0.5 | 0.020 | 0.094 |
| 36 | " | 1/62 | 56y | H | 0.3 | 0.009 | 0.118 |
| 32 | Medium | 2/62 | 53y | H | 0.3 | 0.046 | 0.193 |
| 30 | " | 2/62 | 67y | H | 0.2 | - | - |
| 19 | High | 12/62 | 9m | F | 3.2 | 0.036 | 0.079 |
| 11 | " | 11/62 | 1y | F | 2.1 | - | - |
| 12 | " | 11/62 | 2y 6m | F | 1.2 | 0.020 | 0.060 |
| 23 | " | 12/62 | 8y | F | 1.6 | 0.026 | 0.078 |
| 9 | " | 5/62 | 16y | F | 1.4 | 0.017 | 0.150 |
| 15 | " | 11/62 | 16y | F | 0.6 | 0.013 | 0.057 |
| 14 | " | 11/62 | 19y | V,R | 0.9 | 0.013 | 0.190 |
| 13 | " | 11/62 | 72y | V | 0.9 | 0.021 | 0.173 |
| 16 | Low | 11/63 | 4y | F | 2.3) | 0.009 | 0.094 |
| 16 | " | " | " | V | 2.5) | | |
| 35 | Medium | 6/63 | 84y | H | 0.3 | 0.041 | 0.077 |
| 17 | High | 8/63 | 1y 3m | F | 2.1 | 0.026 | 0.096 |
| 27 | " | 12/63 | 3y 9m | L | 2.2 | 0.012 | 0.085 |
| 18 | " | 8/63 | 5y | F | 1.3 | 0.010 | 0.076 |
| 22 | " | 7/63 | 5y 6m | F | 1.4 | 0.008 | 0.050 |
| 21 | " | 1/63 | 7y | F | 0.9 | 0.026 | 0.151 |
| 20 | " | 2/63 | 19y | F | 1.4 | 0.023 | 0.072 |
| 25 | Low | 4/64 | SB | L | 1.0 | - | - |
| 25 | " | " | " | R | 1.0 | - | - |
| 25 | " | " | " | V | 0.9 | - | - |
| 26 | Low | 4/64 | SB | L | 0.6 | - | - |
| 26 | " | " | " | R | 0.9 | - | - |
| 26 | " | " | " | V | 0.8 | - | - |
| 26 | " | " | " | S | 0.7 | - | - |
| 24 | Low | 4/64 | 6y | F | 1.2) | 0.021 | 0.069 |
| 24 | " | " | " | V | 1.0) | | |
| 28 | High | 2/64 | 6y | L | 1.4 | 0.008 | 0.058 |
| 74 | Low | 11/66 | 3y | F | 3.0 | 0.014 | - |
| 46 | " | 7/66 | 7y | F | 1.9 | 0.009 | 0.036 |
| 42 | " | 6/66 | 16y 6m | F | 1.0 | 0.074 | 0.098 |

(continued)

| Sample Data | | | | | Radionuclide Levels | | |
|-------------|---------------|---------------|--------------|------|-----------------------|----------------------|--------------------|
| | | | | | Artificial | Naturally-Occurring | |
| Sample No. | Rainfall Area | Date of Death | Age at Death | Bone | Strontium-90 pCi/g Ca | Radium-226 pCi/g ash | Lead-210 pCi/g ash |
| 43 | " | 6/66 | 19y | F | 0.5 | 0.010 | 0.057 |
| 49** | - | 9/66 | 18y | F | 0.5 | 0.023 | 0.085 |
| 58 | Low | 7/66 | 20y | F | 0.9 | 0.017 | 0.090 |
| 71 | " | 11/66 | 21y | F | 0.5 | 0.037 | |
| 68 | Low | 8/66 | 23y | F | 0.4 | 0.010 | 0.109 |
| 79 | Medium | 12/66 | 2y 6m | F | 1.5 | 0.011 | |
| 52 | " | 8/66 | 3y | F | 2.1 | 0.036 | 0.046 |
| 72 | " | 11/66 | 3y | F | 1.5 | 0.013 | |
| 86 | " | 12/66 | 3y | F | 2.4 | 0.030 | |
| 41 | " | 6/66 | 3y 6m | F | 2.4 | 0.020 | 0.069 |
| 83 | " | 11/66 | 5y | F | 1.5 | 0.016 | |
| 44 | " | 6/66 | 7y | F | 2.0 | 0.006 | 0.048 |
| 47 | " | 7/66 | 7y | F | 2.3 | 0.013 | 0.037 |
| 56 | " | 8/66 | 7y | F | 1.5 | 0.010 | 0.076 |
| 80 | " | 12/66 | 7y 9m | F | 2.1 | 0.021 | |
| 62 | " | 8/66 | 8y | F | 1.4 | 0.016 | |
| 81 | " | 11/66 | 8y 8m | F | 1.4 | 0.030 | |
| 61 | " | 8/66 | 9y | F | 1.4 | 0.014 | 0.100 |
| 53 | " | 8/66 | 9y | F | 1.3 | 0.022 | 0.054 |
| 65 | " | 9/66 | 9y | F | 1.3 | 0.142 | 0.292 |
| 76 | " | 11/66 | 9y | F | 1.0 | 0.020 | |
| 84 | " | 12/66 | 10y 7m | F | 1.2 | 0.029 | |
| 73 | " | 11/66 | 12y | F | 1.2 | 0.016 | |
| 59 | " | 9/66 | 13y | F | 1.2 | 0.017 | 0.119 |
| 60 | " | 8/66 | 14y | F, V | 1.2 | 0.013 | 0.087 |
| 51 | " | 8/66 | 14y | F | 1.1 | 0.024 | 0.038 |
| 87 | " | 12/66 | 14y 7m | F | 1.0 | 0.012 | 0.043 |
| 63 | " | 8/66 | 15y | F | 1.1 | 0.010 | 0.075 |
| 78 | " | 12/66 | 15y | F | 1.8 | 0.031 | 0.042 |
| 55 | " | 8/66 | 16y | F | 1.7 | 0.016 | 0.063 |
| 50 | " | 10/66 | 16y | F | 0.9 | 0.030 | 0.067 |
| 75 | " | 11/66 | 16y | F | 0.9 | 0.014 | |
| 77 | " | 12/66 | 16y | F | 1.0 | 0.010 | |
| 38 | " | 6/66 | 17y | F | 1.0 | 0.021 | 0.047 |
| 82 | " | 11/66 | 17y | F | 1.1 | 0.033 | |
| 70 | " | 10/66 | 18y | F | 1.0 | 0.038 | |
| 64 | " | 7/66 | 19y | F | 0.9 | 0.018 | 0.102 |
| 45 | " | 6/66 | 20y | F | 0.9 | 0.010 | 0.046 |
| 57 | " | 7/66 | 22y | F | 0.6 | 0.011 | 0.071 |
| 48 | " | 8/66 | 22y | F | 0.6 | 0.010 | 0.042 |
| 69 | " | 10/66 | 22y | F | 0.8 | 0.013 | 0.097 |
| 40 | " | 6/66 | 24y | F | 0.5 | 0.012 | 0.073 |
| 54 | " | 8/66 | 25y | F | 0.4 | 0.019 | 0.042 |
| 85 | " | 12/66 | 27y | F | 0.2 | 0.012 | |
| 39 | " | 6/66 | 31y | F | 0.5 | 0.016 | 0.093 |
| 67 | High | 8/66 | 14y | F | 2.4 | 0.017 | 0.115 |
| 37 | " | 5/66 | 17y | F | 1.0 | 0.014 | 0.058 |
| 66 | " | 8/66 | 17y | F | 1.4 | 0.016 | 0.092 |
| 89 | Low | 1/67 | 18y | F | 1.0 | 0.023 | |
| 91 | High | 7/67 | 3y | F | 2.6 | 0.008 | |
| 92 | " | 12/67 | 15y | F | 1.4 | 0.014 | |
| 90 | " | 6/67 | 18y | F | 1.9 | 0.026 | |
| 93 | High | 4/68 | 5y | F | 1.7 | 0.022 | 0.031 |
| 94 | " | 8/68 | 15y 6m | F | 1.6 | 0.026 | |
| 96 | Medium | 4/71 | 15y 10m | V | 1.1 | 0.011 | |
| 97 | " | 4/71 | 18y | - | 1.0 | 0.041 | |
| 95 | " | 4/71 | 76y | V | 1.1 | 0.024 | |

* Occupationally exposed to luminizing materials.

** Resident in New Zealand a very short time - most of life spent in Australia.

*** To convert approximately pCi/g Ca into pCi/g ash multiply by 0.39.

TECHNICAL INFORMATION ON COLLECTION AND MEASUREMENT

1. Air Filter Sampling (For Measurement of Total Beta Activity)

The samplers are portable, motor-driven, positive displacement pumps operating at 230 volts 50 cycle A.C. They collect particulates in ground level air by drawing the air through 11 cm diameter glass fibre filters (Whatman GF/A). About 100 cubic metres of air are sampled each day and the filters are changed three times each week during routine monitoring operations. The samplers are calibrated using gas meters before despatch to the monitoring stations. At the Laboratory at Christchurch, however, a permanently installed sampler, having several times the pumping capacity of the portable samplers, is used.

The air filters are mailed to the Laboratory and the total beta activity of the entire filter is measured using the five inch diameter detector of a Beckman Wide Beta II Automatic Planchette Counting System. Measurement is made four days after collection to allow for the decay of natural atmospheric radioactivity. The sensitivity of the measurement is of the order of 0.01 pCi/m³. The counter is calibrated using a KCl standard prepared and measured under similar geometry.

2. Weekly Rainwater Sampling (For Measurement of Total Beta Activity)

Samples are collected by means of a polyethylene funnel, 17.0 cm diameter, fitted into the neck of a polyethylene collection bottle containing carrier solution. The sample is despatched to the laboratory in its collection bottle, where it is transferred quantitatively, using acid washes, to a beaker for evaporation to a sufficiently small volume. The sample is then transferred quantitatively to an 11.5 cm diameter stainless steel planchette and evaporated to dryness. The total beta activity is then measured using the 5 inch detector of the Beckman Counting System (as for air filter measurement). The counter is calibrated using a KCl standard prepared and measured under similar geometry. The measured total beta activity, and funnel collection area, are the basic data from which the deposition (mCi/km²) is calculated. The concentration of fission products in the rainwater is then calculated from the deposition and rainfall during the collection period.

3. Monthly Rainwater Sampling (For Measurement of Strontium-90, Strontium-89 and Lead-210)

Rainwater is collected by exposing a stainless steel pot of 30 cm diameter and 30 cm height at ground level during each calendar month. The pots contain strontium and lead carrier solutions. Distilled water is kept at the site and is added to the pot during dry spells to prevent evaporation to dryness.

At the Pacific Island stations, and at the North Island New Zealand stations, the collected rainwater is concentrated at the collecting station by passing the rainwater through a column of cation exchange resin. The resin is then mailed to the Laboratory. At the South Island New Zealand stations the collection pots and contents are despatched in transport boxes, and the concentration is done at the Laboratory.

The added carriers together with the collected radionuclides, are

eluted from the resin and redissolved. Radiochemical separation is then achieved by ion exchange elution chromatography. The radio-nuclides are evaluated by beta counting in low background counters: Strontium-89 is determined by beta counting the separated strontium source without delay. Corrections are made for the contribution from strontium-90, and also when significant, from yttrium-90; Strontium-90 and lead-210 are determined, after a suitable period for daughter ingrowth, by beta counting yttrium-90 (after separation from the strontium source), and by beta counting bismuth-210 (in the lead source). Counters are individually calibrated for each radionuclide using standard sources in similar geometry to sample sources. The standard sources are prepared using the appropriate carriers and standard solutions of the radionuclides. These procedures have been published in detail in one of the Laboratory's technical reports (17).

4. Milk Sampling (For Measurement of Strontium-90, Caesium-137, Calcium and Potassium)

Composite milk samples are obtained from each collecting station each month. Dried milk samples are obtained whenever possible. Liquid milk is dried and powdered before measurement.

Caesium-137 and naturally occurring potassium-40 are measured directly on the dried samples by gamma spectrometry. After these measurements have been made the samples are aggregated on a quarterly basis for each station and are then ashed for strontium-90 evaluation.

Strontium carrier is separated from milk ash solutions by precipitation from nitric acid followed by fractional elution. Strontium-90 is then determined, after a suitable ingrowth period, by measurement of its daughter yttrium-90. Calcium is determined gravimetrically as the oxalate from an aliquot of the milk ash (17).

5. Human Bone Sampling (For Measurement of Strontium-90, Radium-226, and Lead-210)

Post Mortem samples are obtained whenever possible. Samples have been collected at Auckland, Hamilton, Hastings, Napier, New Plymouth, Palmerston North, Wellington, Nelson, Greymouth, Christchurch, Dunedin, Invercargill, and from some provincial areas.

The samples are ashed, dissolved, and carriers are added. Separation of carriers and associated radioactivities is achieved by precipitation in nitric acid followed by sequential, fractional elution. Strontium-90 is evaluated as for milk ash samples. Radium-226 is coprecipitated on barium sulphate and determined by alpha scintillation counting. Lead-210 is determined by deposition of its daughter polonium-210 on silver foil after a suitable ingrowth period. The polonium activity is then measured by alpha scintillation counting (18).

6. Soil Sampling (For Measurement of Strontium-90)

Soil is sampled annually from the four collecting sites indicated in Fig.1. Samples were also taken at Campbell Island (52.5°S 169.0°E) up to February 1965. The radiochemical procedures used are given in the Laboratory's technical report (17).

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- (3) "Radioactive Fallout in Air and Rain, Results to the middle of 1971". United Kingdom Atomic Energy Authority, AERE-R6923
- (4) "Fallout Program, Quarterly Summary Report, April 1, 1972". Health and Safety Laboratory, United States Atomic Energy Commission, HASL-249 APPENDIX.
- (5) "Strontium-90 on the Earth's Surface". United States Atomic Energy Commission, (1959 Results, TID-6567); (1960-1961 Results, TID-17090); (1961-1967 Results, TID-24341).
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- (16) "Environmental Radioactivity in New Zealand". Annual Summary, 1970, Report No. NRL-F/43.

- (17) "The Determination of Radiostrontium in Rainwater, Soil, Milk, and Bone". L.P. Gregory, National Radiation Laboratory Report No. NRL-RM/3, 1970.
- (18) Accepted for publication in "Analytical Chemistry" (see Reference 17, page 34, for an outline of the procedures).

* This Laboratory was formerly known as "The Dominion X-Ray and Radium Laboratory".

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