REPORT No.
NRL-F 38

DEPARTMENT OF HEALTH

ANNUAL SUMMARY 1969

ENVIRONMENTAL RADIOACTIVITY

IN NEW ZEALAND

AND

MEASUREMENTS ON SAMPLES FROM FIJI AND RAROTONGA

NATIONAL RADIATION LABORATORY
P.O. BOX 1456, CHRISTCHURCH, NEW ZEALAND

SYMBOLS UNITS AND EQUIVALENTS

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

UNITS OF LENGTH, AREA, VOLUME AND MASS AND THEIR EQUIVALENTS IN THE IMPERIAL SYSTEM

cm_2..	centimetre	0.394 inches
km^2..	square kilometre	0.386 square miles
m^3	cubic metre..	35.31 cubic feet
litre	litre	0.880 quart
g	gram	0.0353 ounce

NOTES

1. Unless otherwise noted, all times given in this report are New Zealand Standard time i.e. G.M.T. + 12 hours.

2. Radioactive fallout in rain is expressed as:

   (a) Deposition - millicuries per square kilometre (mCi/km^2)

   (b) Concentration - picocuries per litre (pCi/litre)

   $$\text{Concentration (pCi/litre)} = \frac{\text{deposition } (mCi/km^2)}{\text{rainfall (cm)}} \times 100$$

   Multiply mCi/km^2 by 2.59 to obtain mCi/sq. mile.

3. The levels of strontium-90 contamination in food and bone are given in "Strontium Units" i.e. picocuries strontium-90 per gram of calcium .....pCi Sr^{90}/g Ca.

   Similarly caesium-137 results are given as picocuries of caesium-137 per gram of potassium.....pCi Cs^{137}/g K.

   One litre of whole milk contains approximately:

   1.2 g of calcium

   1.4 g of potassium.

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POTENTIAL HEALTH HAZARD

The significance of the levels of radioactivity in environmental samples published in this Report may be understood more readily by comparing these levels with the following "permissible levels of radioactivity for the whole population" which have been adopted for use in New Zealand.

These levels have been set as a guide to limit the controlled release of radioactive substances into the environment by licensed users in New Zealand.

They are levels which individually would not require remedial or preventative action and have been chosen to protect the most sensitive age group in the population. It is considered that any risk associated with these levels is exceedingly small and that levels many times as great would involve a hazard which is small compared to commonly accepted risks to life.

"PERMISSIBLE LEVELS OF RADIOACTIVITY FOR THE WHOLE POPULATION"

These levels were derived so as to ensure that the dose to any member of the public arising from the controlled use of radioactive materials does not exceed the Dose Limit recommended by the International Commission on Radiological Protection.

Strontium-90

In Milk:	270 Strontium Units - maintained indefinitely in the milk.
In Bone:	67 Strontium Units

Caesium-137

In Milk:	7,000 pCi/g K - maintained indefinitely in the milk.

Iodine-131

In Milk:	200 pCi/litre - as an average intake over one year.

Total Beta Activity of Mixed Fission Products Between 10 and 80 Days Old

In Air:	300 pCi/m^3 - for continuous breathing.
In Rainwater:	6,000 pCi/litre - for continuous consumption.

GENERAL STATEMENT OF RESULTS ON RADIOACTIVE FALLOUT

In this Report a distinction is made between the levels of radioactivity due to long-lived radionuclides (which have been of major significance in assessing health hazards), and short-lived radionuclides from recent nuclear tests which, although showing increased levels of radioactivity during limited periods, have been of less significance in assessing health hazards.

SHORT LIVED FISSION PRODUCTS - TOTAL BETA ACTIVITY

During 1969 there were no nuclear explosions in the atmosphere of the southern hemisphere. The expected decrease in the levels of fission product activity after the 1968 French tests (which, for the first time, culminated in the explosion of two hydrogen bombs) occurred more slowly than the decrease in levels after the 1966 and 1967 French tests. This delay undoubtedly resulted from the stratospheric injection of hydrogen bomb debris. The subsequent deposition of the debris was thus extended over a longer period.

Levels of total beta activity in air filter and rainwater samples have decreased significantly during 1969, compared with the levels which occurred during the last half of 1968. When averaged over each entire year, however, the levels in air have been about the same in 1968 and in 1969, but levels in rain have been lower in 1969.

LONG LIVED FISSION PRODUCTS - STRONTIUM-90, CAESIUM-137

The deposition on New Zealand of long lived bomb products, such as strontium-90 and caesium-137, from delayed stratospheric fallout, reached a maximum during late 1964 and early 1965. These peak levels resulted mainly from the U.S.S.R. and U.S.A. nuclear tests of 1961 and 1962. Levels then steadily decreased up to the end of 1968. During 1969, however, the country-wide average deposition of strontium-90 increased by about 50% over the 1968 average. This increase has been due to the French nuclear tests in the South Pacific and in particular to the 1968 tests. The deposition in 1969, however, was only one third of the peak deposition in 1964.

The contribution made by the French tests to the total strontium-90 deposition on New Zealand has been estimated for certain periods from measurements of the strontium-89/strontium-90 ratio. The results of this evaluation are given in this Report. The possible interhemispheric transfer of fission debris during the year from the Chinese high yield nuclear test of 27 December 1968 is also discussed in this Report.

During 1969, strontium-90 levels in milk increased about 30%, and caesium-137 levels in milk increased about 22% over the 1968 levels. These increases result from the increase in deposition of long-lived bomb products during the year. The levels in milk in 1969, however, were only about one half of the peak levels in 1965.

In 1965 and 1969 the levels of strontium-90 in milk were 4.3% and 2.5% of the permissible level respectively; and the levels of caesium-137

in milk were about 0.9% and 0.4% of the permissible level respectively. The more important long term assessment of health hazard is given in Table 7 page 23 and on page 24 of this Report.

HEALTH HAZARD

The levels of radioactive fallout measured during 1969 are a small fraction of permissible levels for continuous consumption and do not constitute a health hazard.

GENERAL INFORMATION

In September 1957 the New Zealand Department of Health was charged, under a Cabinet directive, with the responsibility for the monitoring of enviornmental radioactive contamination in New Zealand and the Pacific areas with which it is associated. Subsequently the network of collecting stations shown in Fig. 1 has been established to provide the necessary samples of air, rainwater, soil, milk and human bone. The collections and measurements are being made on a routine basis and the results are published in a series of Quarterly Reports ("Fallout in New Zealand", DXRL-F1 to F9 and NRL-F10 to F18; and "Environmental Radioactivity in New Zealand", NRL-F19 onwards).

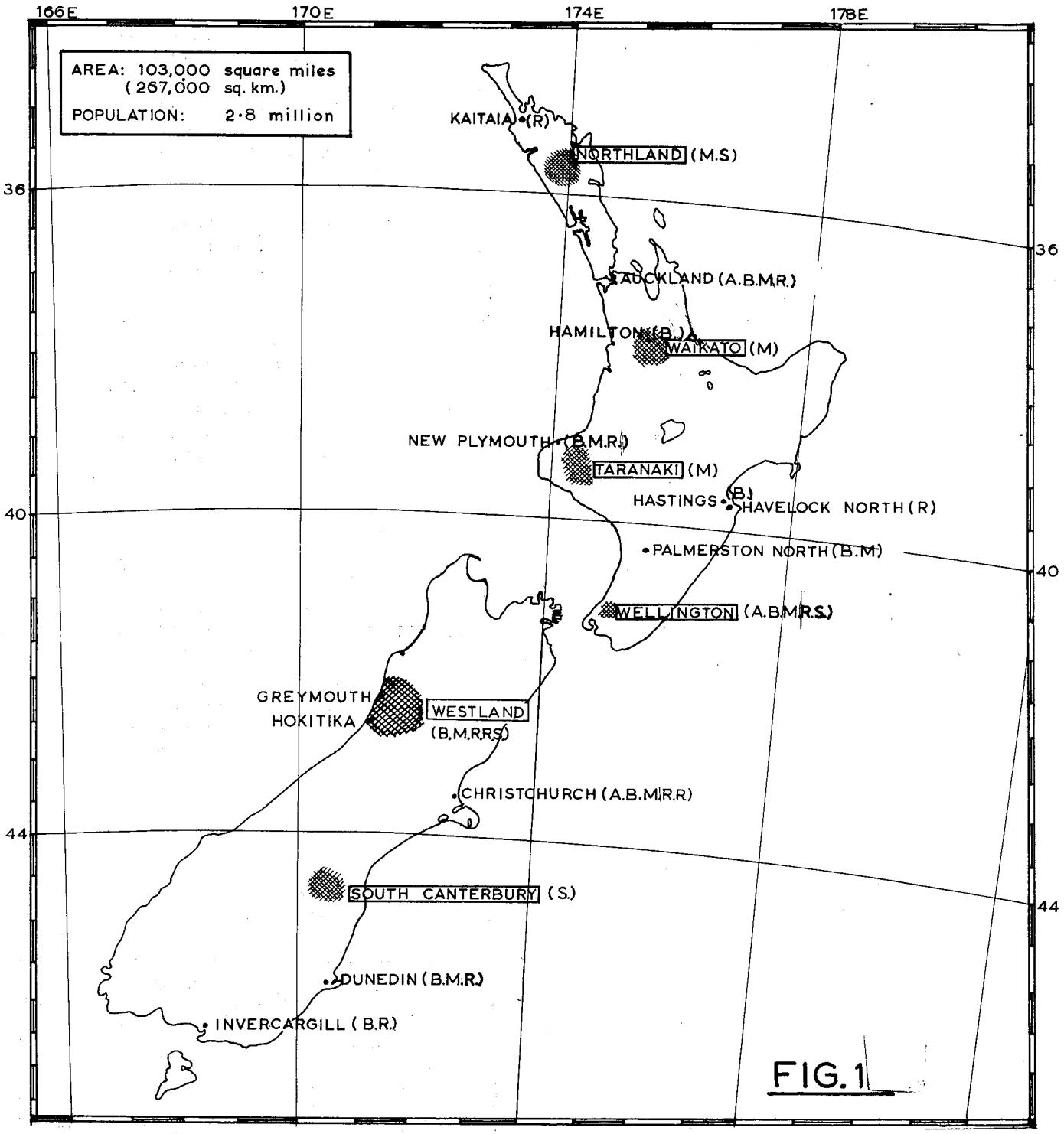
Prior to December 1967 the fourth quarterly results and annual summary were published in a single Report. Since then, however, the Annual Summary Reports have been published separately. Individual results, therefore, are not given in the Annual Summary Reports these having been published in the four preceding quarterly reports each year.

SAMPLE COLLECTION AND EVALUATION

The selection of rainwater collecting stations in New Zealand was based on the requirement that an adequate geographical coverage of the country must be made, taking account of natural features, such as mountain ranges which, particularly in the South Island, account for the extremes in rainfall. Furthermore, proximity of rainwater collecting sites to milk producing areas is desirable, so that comparisons between levels of contamination in rain and milk can be made.

The selection of milk producing areas was based not only on geographical coverage and routine availability of samples but also on population distribution, so that the average result of all stations would be representative of the contamination in the average New Zealand diet.

During the period of nulcear testing which started in the Christmas Island area in April 1962, the routine monitoring operations conducted by this Laboratory were extended within New Zealand, and a new network of monitoring and collection stations was established throughout the Pacific area. The extent of these monitoring operations and the results of the measurements have been published in previous issues of the Laboratory's Quarterly Reports. (See particularly DXRL-F5, DXRL-F7, and DXRL-F8).



LOCATION OF COLLECTING STATIONS ESTABLISHED BY THE NATIONAL RADIATION LABORATORY FOR AIR (A), BONE (B), MILK (M), RAINWATER (R), AND SOIL (S), SAMPLES IN NEW ZEALAND Where more than one type of collection is performed (e.g. weekly and monthly rainwater collection) the appropriate symbol is shown twice. Collection areas not confined to a single location but extending over part of a province or district are shown thus ■ NAME

After the conclusion of the 1962 Pacific test series, the monitoring activities of the Laboratory reverted to the established routine pattern. However, during the French series of nuclear tests in the Pacific, which commenced in July 1966, and were continued in 1967 and 1968, the monitoring operations of the Laboratory were again extended. The extent of these operations and the results of the measurements were given in the Annual Summary Reports NRL-F23, NRL-F28 and NRL-F33.

During 1969 there were no nuclear tests conducted in the southern hemisphere and monitoring operations again reverted to the established routine pattern with the exception of strontium-89 measurements which were continued throughout the year.

The following information lists the type and extent of sample collection and measurement undertaken by the Laboratory during 1969. The procedures for radiochemical separations and measurement of radioactivity were described in detail in the Annual Summary for 1966 (NRL-F23) and are only briefly referred to here. The procedures for the measurement of strontium-90 have been modified recently and are being prepared for publication. A copy of these may be obtained from this Laboratory on request.

1. AIR SAMPLING (For Measurement of Total Beta Activity)

Routinely, air filter samples are collected continually at Auckland, Wellington and Christchurch. Sampling involves the collection of particulates in ground level air by drawing the air through 11 cm diameter glass fibre filters using positive displacement pumps. The filters are changed three times weekly. The Auckland and Wellington air samplers pump about $100m^3$ of air each 24 hours and the Christchurch air sampler about $300m^3$ of air each 24 hours. The total beta activity of the entire filter is measured using a 5 inch beta detector. Measurement is made four days after the end of collection to allow for the decay of natural atmospheric radioactivity.

2. RAINWATER

(a) MONTHLY COLLECTION (For Measurement of Strontium-90, Strontium-89 and Lead-210.)

Rainwater is routinely collected by exposing a stainless steel pot of 30 cm diameter and 30 cm height, at ground level, for 1 month at each of the following 11 collecting sites:

Site	Rainfall (during year 1969 in cm)	Site	Rainfall (during year 1969 in cm)
Kaitaia	167	Christchurch	37
Auckland	109	Dunedin	65
New Plymouth	136	Invercargill	109
Havelock North	60		
Wellington	89	Suva, Fiji*	306
Greymouth	200	Rarotonga**	202

* Normally a 3-monthly collection changed to monthly collections from June 1966.

** Monthly collections started June 1966.

The appropriate carriers are added to the collecting pots before despatch to the collecting sites. A supply of distilled water is maintained at the site and is added to the pot when necessary to prevent the contents from evaporating to dryness during dry periods. On arrival at the Laboratory the carriers are separated by ion exchange elution chromatography. Strontium-89 is determined by beta counting and subtracting the contributions from strontium-90 and yttrium-90. Strontium-90 is determined by measurement of its daughter yttrium-90 and lead-210 by measurement of its daughter bismuth-210.

(b) WEEKLY COLLECTION (For Measurement of Total Beta Activity)

Samples of rainwater, collected each week by means of a polythene funnel and bottle collector from Greymouth and Christchurch are processed and measured for total beta activity. The collecting bottles contain carrier solution and the funnels have a diameter of 17.0 cm. The collected rainwater samples are evaporated to dryness and counted in 4.5 inch planchettes using a 5 inch beta detector.

3. MILK

(a) MONTHLY COLLECTION (For Measurement of Strontium-90 and Caesium-137)

Representative milk samples are obtained in New Zealand each month from the following 9 urban centres or provinces:

Northland	Taranaki	Westland*
Auckland	Palmerston North	Christchurch
Waikato	Wellington	Dunedin

* In Westland fresh milk was sampled at Greymouth prior to October 1968 at which time a milk drying plant commenced operations at Hokitika. Since then dried milk has been sampled at Hokitika except for a few months when milk drying operations cease. During these months fresh milk is sampled at Greymouth. The Westland station has been called Greymouth in reports up to October 1968.

Monthly composite samples of milk from each of the sampling areas are also measured for caesium-137 and potassium-40 by gamma spectrometry. Liquid milk samples are dried and powdered before measurement.

Because of the general decrease in strontium-90 levels over the past few years, aliquots of the dried milk samples which were aggregated on a two-monthly basis for each station for ashing and measurement of strontium-90 content, are now aggregated on a three-monthly basis starting at the third quarter 1968.

Strontium carrier is separated from other milk ash constituents with nitric acid followed by ion exchange elution chromatography. Strontium-90 is then measured by the methods already referred to under subsection 2, Rainwater.

4. HUMAN BONE (For Measurement of Strontium-90, Radium-226 and Lead-210)

Post mortem samples of human bone 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.

5. SOIL (For Measurement of Strontium-90)

Soil is sampled annually from the following 4 districts: Northland, Wellington, Greymouth and South Canterbury. Samples were taken at Campbell Island (52.5°S 169.0°E) up to February 1965.

SUMMARY OF ROUTINE MEASUREMENTS AND SPECIAL SURVEYS

A. TOTAL BETA ACTIVITY OF AIR FILTER AND RAINWATER SAMPLES

Over the last decade transient increases in the levels of total beta activity in air filter and rainwater samples have been measured. These increases, which have been of negligible health concern, have resulted from the testing of nuclear weapons in the atmosphere.

Most of the radioactivity produced in nuclear explosions is due to the shorter lived fission products and, therefore, radioactive decay results in a decrease in the levels of radioactivity to near background levels during the months after the nuclear tests. Moreover, the scavenging of the atmosphere by rain further reduces the levels in air filter samples. Fig. 2 illustrates the increases in total beta activity of air and rain resulting from the U.S. tests in the Northern Pacific during April - November 1962 and more recently from the French tests in the Southern Pacific during 3 July - 5 October 1966, 6 June - 2 July 1967 and 8 July - 9 September 1968. The last series culminated in the explosion of two hydrogen bombs. There were no nuclear tests in the southern hemisphere during 1969. The decrease in levels after each test series is also illustrated in Fig. 2 although it is significant to note that the rate of decrease has been slower following the 1968 series. This is attributed to the injection of fission products into the stratosphere by the detonation of the two hydrogen bombs and the subsequent delay in the resulting transfer of fission products to the troposphere where removal by rainfall occurs.

1. Fission Products in Air

In the absence of fresh fission products from nuclear testing in the atmosphere, the levels of total beta activity in air are usually less than 0.1 pCi/m^3 (typically about 0.03 pCi/m^3).

Routine thrice weekly air filter sample changing has been increased to daily air filter sample changing during nuclear test periods. Individual results have been averaged for each month and are shown in Fig. 2. Table 1 summarizes the annual average levels of air radioactivity at the three New Zealand sampling stations for the years 1966 - 1969 inclusive.

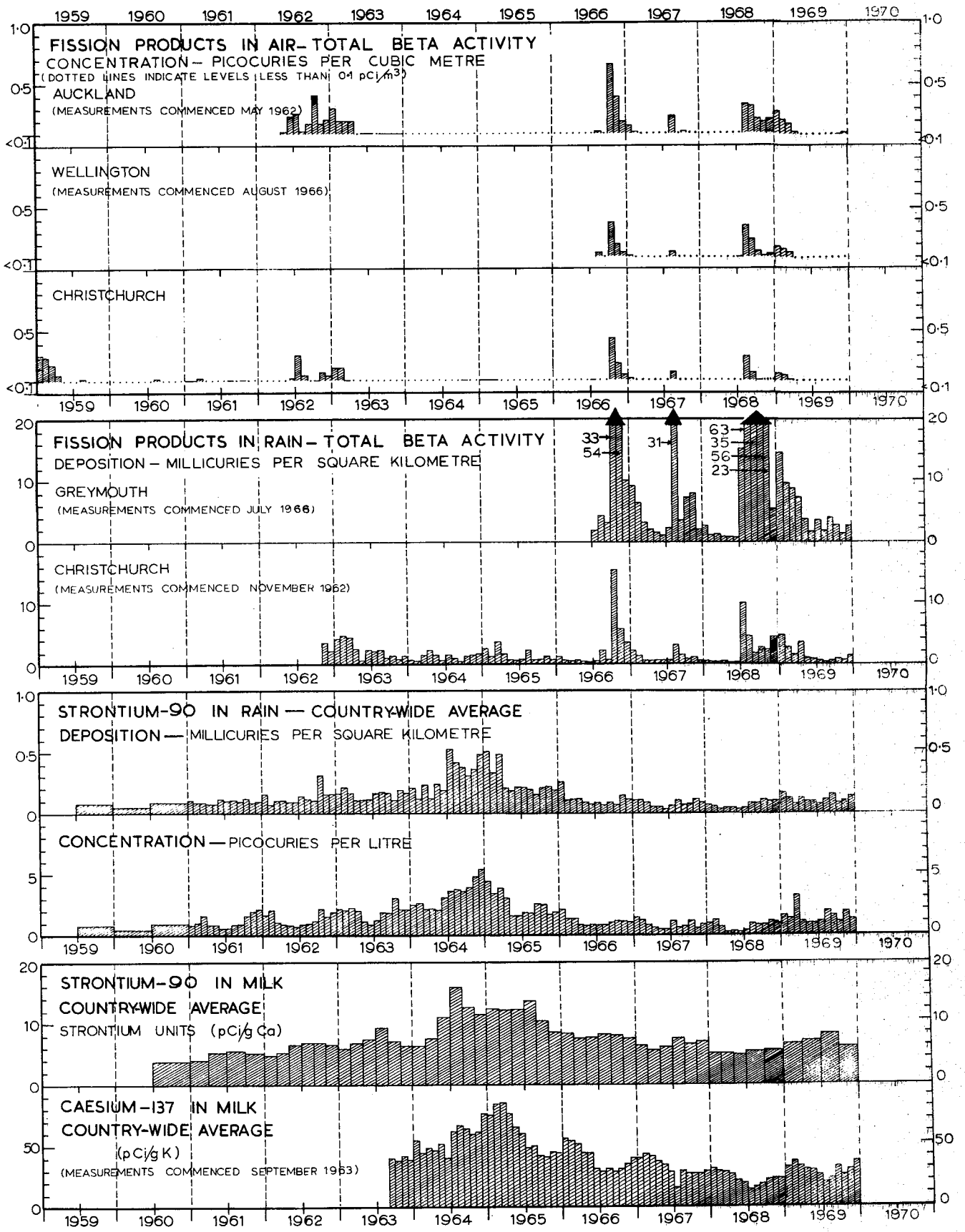


FIG. 2 SUMMARY OF LONG TERM MEASUREMENTS

TABLE 1. TOTAL BETA ACTIVITY IN AIR - pCi/m^3 ANNUAL AVERAGES				
	1966	1967	1968	1969
Auckland	0.14	0.08	0.12	0.12
Wellington	(0.10)*	0.05	0.10	0.09
Christchurch	0.11	0.06	0.07	0.07

* The Wellington station commenced operations in July 1966 at the start of the first seris of French Nuclear Tests in the South Pacific. The average value of air radioactivity for the first half of 1966 has been taken as 0.03 pCi/m^3 which was the average value at Auckland and Christchurch during this period.

2. Fission Products in Rain

Weekly samples of rainwater have been collected since November 1962 at Christchurch and since July 1966 at Greymouth. The weekly values for deposition have been totalled for each month and are shown in Fig. 2. The higher level of deposition of total beta activity at Greymouth is due to the higher rainfall there. The annual rainfall at Greymouth is about 250 cm and at Christchurch about 60 cm, and these two stations have respectively the highest and lowest rainfall of our collecting stations in New Zealand. Table 2 compares the total annual deposition each year.

TABLE 2. TOTAL BETA ACTIVITY IN RAIN - mCi/km^2 ANNUAL DEPOSITION							
	1963	1964	1965	1966	1967	1968	1969
Greymouth				(106)*	77	205	61
Christchurch	28	15	17	32	14	28	18

* July - December 1966 only

B. SPECIFIC RADIONUCLIDES IN RAINWATER, SOIL, MILK, WATER AND HUMAN BONE SAMPLES

1. Strontium-90 in Rain

Country-wide average values for deposition and concentration are shown in Fig. 2 and individual station values for deposition and rainfall are shown in Fig. 3. Strontium-90 deposition on New Zealand reached a maximum during the latter half of 1964 and the first quarter of 1965, mainly from delayed stratospheric fallout from the U.S.S.R. and U.S.A. nuclear tests in 1961 and 1962. Since then levels have steadily decreased up to the end of 1968. During 1969, however, the country-wide average deposition of strontium-90 increased about 50% over the 1968 average deposition. This increase has been due to the recent French nuclear tests in the South Pacific and in particular to the 1968 tests. The deposition in 1969, however, was only one third of the peak deposition in 1964. Table 3 lists the annual deposition at individual stations and the country-wide average deposition since 1960. The annual rainfall listed is the mean over the past 7 years i.e. 1963 - 1969 inclusive.

TABLE 3		ANNUAL DEPOSITION OF STRONTIUM-90 mCi/km^2									
NEW ZEALAND STATIONS	ANNUAL RAINFALL(cm)	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
Kaitaia	142				1.8	4.1	3.1	1.6	1.0	0.9	1.5
Auckland	129	1.2	1.1	1.8	2.0	4.0	2.9	1.3	0.9	0.7	1.3
New Plymouth	150				2.0	5.3	4.2	1.9	1.3	1.0	1.5
Havelock North	71	0.7	0.8	1.0	1.0	1.6	1.7	0.8	0.5	0.6	0.7
Wellington	133	0.8	1.1	1.8	2.0	3.4	3.9	1.6	1.0	0.9	1.1
Greymouth	249	1.5	2.2	2.8	3.7	7.8	5.9	2.2	1.7	1.4	2.2
Christchurch	57	0.5	0.7	0.7	1.2	1.3	1.7	0.7	0.4	0.4	0.7
Dunedin	60				1.0	1.8	2.0	0.7	0.6	0.4	0.7
Invercargill	106	0.5	1.2	1.2	1.7	3.0	2.8	1.1	0.9	0.5	1.2
Country-wide Average		0.9	1.2	1.6	1.8	3.6	3.1	1.3	0.9	0.8	1.2
Suva, Fiji	273		1.0	1.6	2.4	2.5	2.0	1.2	0.8*	1.0	1.3
Rarotonga	240***								(0.9)**	0.7	0.7

* Note correction. (Listed as 0.6 in 1967 and 1968 Annual Summary Reports.)
** Estimate - no sample received for 2 months of 1967.
*** Mean annual rainfall 1967-1969 inclusive.

The annual depositions since 1954 at New York City and at Milford Haven in the United Kingdom are listed in Table 4. The New Zealand country-wide average depositions since 1960 are also listed for comparison. The values for New York City are taken from the Quarterly Summary Report (HASL-224 APP.) of the Health and Safety Laboratory, United States Atomic Energy Commission. The Milford Haven values have been taken from the United Kingdom Atomic Energy Authority's Report "Radioactive Fallout in Air and Rain: Results to the Middle of 1969" (AERE-R6212). After the nuclear tests conducted in the northern hemisphere during 1961 and 1962, strontium-90 fallout reached a maximum in 1963 in the northern hemisphere and in 1964 in the southern hemisphere. Since then levels have fallen until about 1967-1969 during which time they have remained fairly steady except for the New Zealand average deposition which in 1969 increased about 50% over the 1968 average, due to nuclear testing in the southern hemisphere. Table 4 shows that strontium-90 fallout has been about the same at Milford Haven, New York City and New Zealand during 1969. This amounts, in New Zealand, to one third the peak deposition in 1964, while in New York City and Milford Haven the 1963 peaks were about 18 times higher than their present levels.

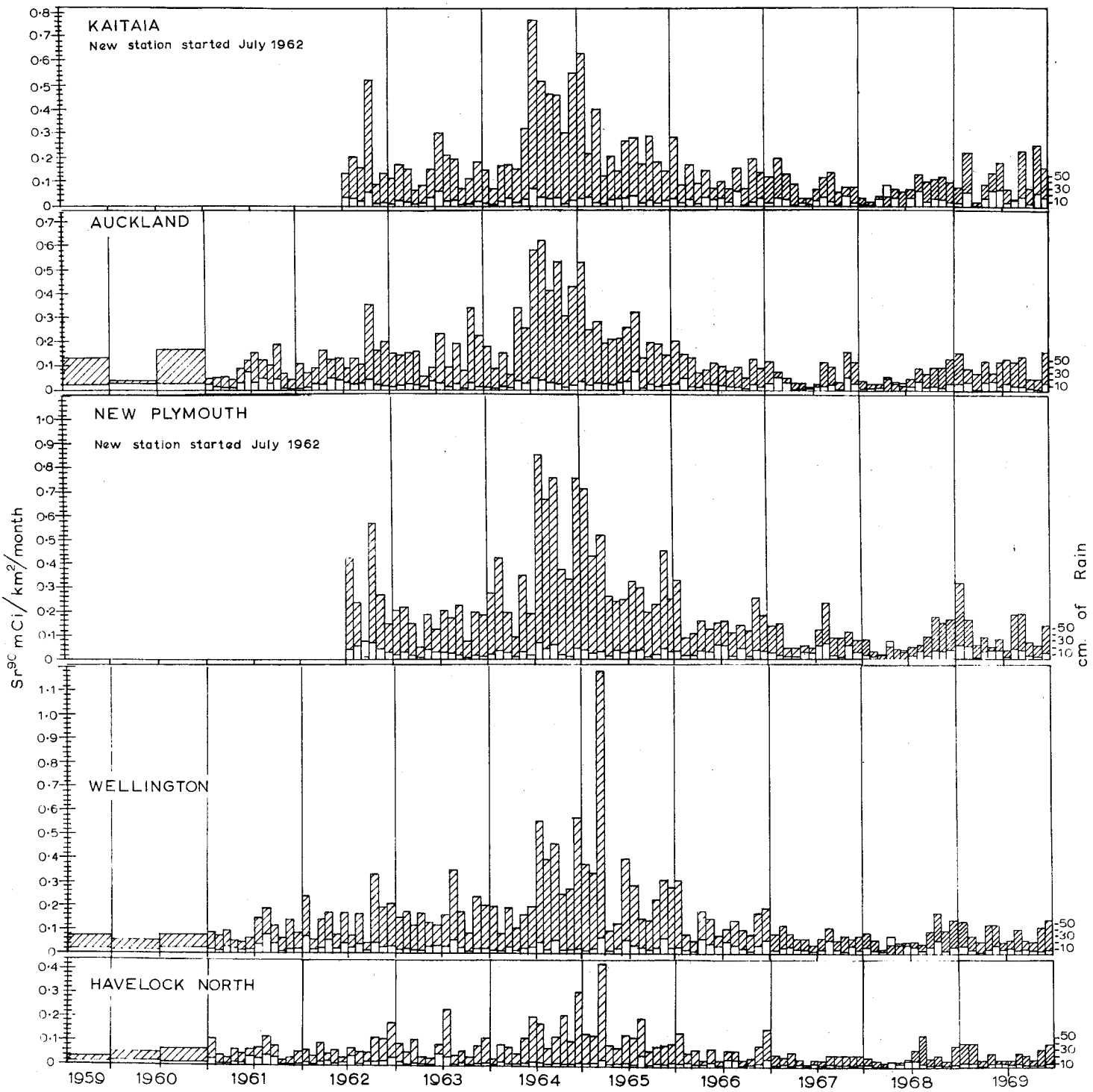


FIG. 3 STRONTIUM 90 IN RAIN

Millicuries Sr per square kilometre per month. Lefthand scale.
Centimetres of rain per month. Righthand scale.

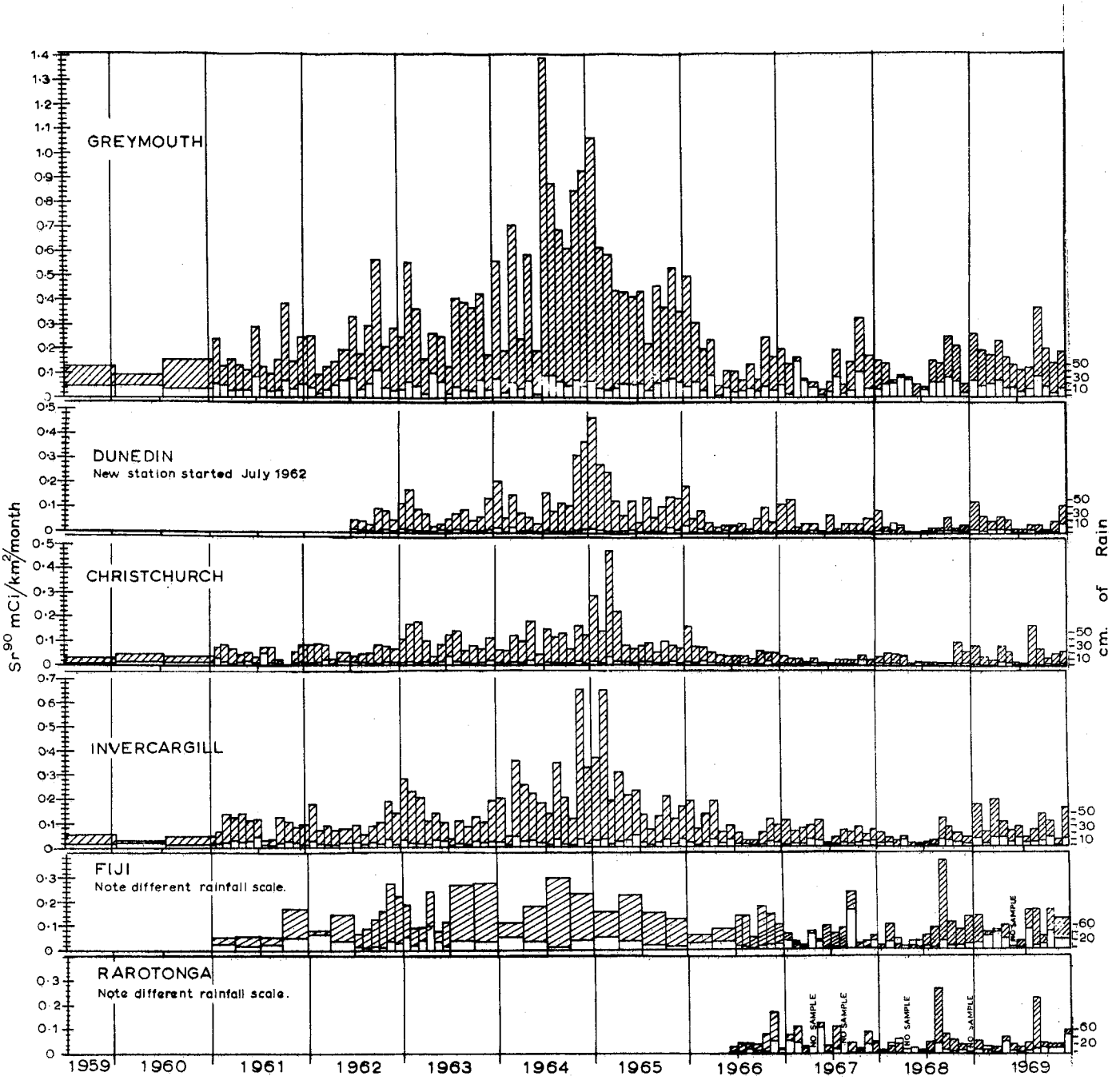


FIG. 3 STRONTIUM 90 IN RAIN

Millicuries Sr^{90} per square kilometre per month. Lefthand scale.
Centimetres of rain per month Righthand scale.

TABLE 4	ANNUAL DEPOSITION OF STRONTIUM-90 mCi/km^2		
YEAR	MILFORD HAVEN	NEW YORK CITY	NEW ZEALAND AVERAGE
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	0.5 (to end of June)	1.3 (to end of Nov.)	1.2

2. Strontium-90 Cumulative Deposition

The annual depositions in Table 4 have been totalled and corrected for radioactive decay and are presented graphically in Fig. 4 as cumulative deposition. The dotted portion of the curve for New Zealand is based on soil measurements undertaken by the U.S. Department of Agriculture on samples from three collecting sites. The part of the curve from July 1959 to July 1962 is derived from our measurements on rain samples from six collecting stations. From July 1962 the average result from our network of nine rainwater collecting stations has been used.

Due to the steadily decreasing levels of fallout since 1963, the situation was eventually reached during 1967 when the reduction of the accumulated strontium-90 by radioactive decay in the northern hemisphere was greater than the annual deposit. The total accumulation at June 1969 was therefore slightly less than that at the beginning of 1967.

In New Zealand, however, where the total accumulation is much less, reduction by radioactive decay has been of less significance. Interhemispheric transfer of strontium-90 and the injection of fresh fission material into the southern hemisphere during the French nuclear tests have resulted in a continuing slight increase in the total accumulation of strontium-90.

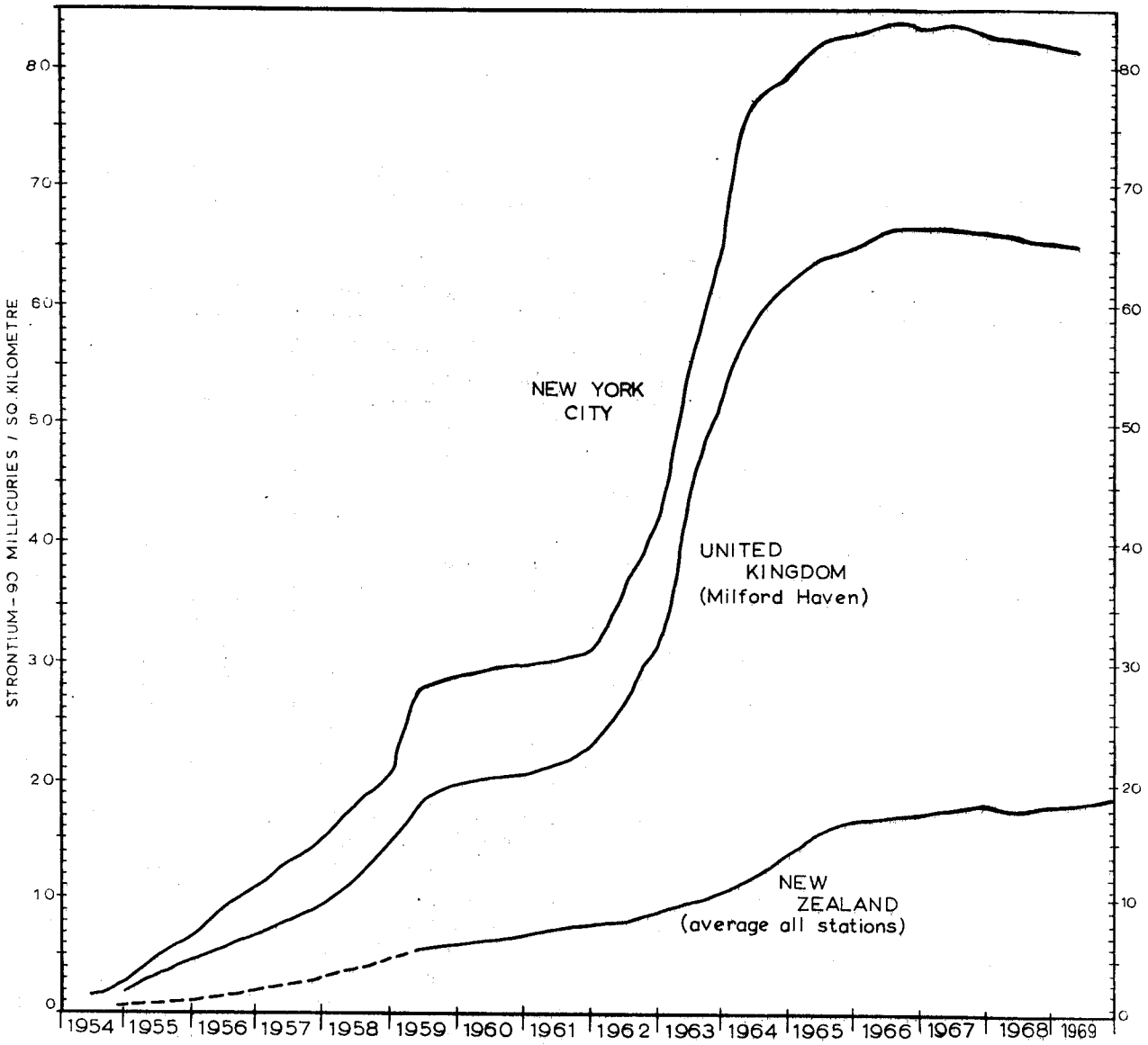


FIG. 4. TOTAL ACCUMULATION OF STRONTIUM-90 FROM RAIN

3. Strontium-90 in Soil

Table 5 lists the results for strontium-90 in New Zealand soils. Measurements were initially undertaken by the Health and Safety Laboratory (HASL) of the U.S. Atomic Energy Commission for the U.S. Department of Agriculture. The 1963/1964 samples were also measured by this Laboratory (NRL) for intercomparison purposes and both sets of results are listed. Since then samples have been measured by this Laboratory.

It is noted that results of soil analyses are generally lower than the corresponding results of cumulative deposition obtained from rainwater analyses. Also the values for the 1968/1969 soil samples listed in Table 5 are lower than those for the corresponding 1965/1966 samples. Soils are sampled to a depth of 8 inches and the possibility

that significant penetration of strontium-90 below 8 inches may have occurred at some sites over the past few year should not be overlooked.

TABLE 5 STRONTIUM-90 IN NEW ZEALAND SOILS - mCi/km^2

SAMPLING DATES	LABORATORY	NORTH AUCKLAND	WELLINGTON JUDEGFORD	TAITA	GREYMOUTH	SOUTH CANTERBURY
Nov. 1953 - Jan. 1954	HASL	<0.1	<0.1			<0.1
Feb. 1955	HASL		0.7			
Apr. - May 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
Dec. 1960 - Jan. 1961	HASL	5.2	7.8	5.1		4.6
Nov. 1963 - Feb. 1964	HASL	10.2	10.5	9.0	16.7	6.3
	NRL	9.9	10.3	8.8	16.8	5.9
Dec. 1965 - Jan. 1966	NRL	12.9		12.4	23.0	9.1
Dec. 1967 - Jan. 1968	NRL	14.1			20.8	8.4
Jul. 1968	NRL			11.2		
Dec. 1968 - Jan. 1969	NRL	13.7		11.5	19.0	8.3

A final world-wide sampling of soil for measuring the distribution and cumulative deposit of strontium-90 was conducted from 1965 to 1967 by the Soil Survey Laboratory, U.S. Department of Agriculture and Health and Safety Laboratory, U.S. Atomic Energy Commission. The results were published in their report "Strontium-90 on the Earth's Surface IV": Report No. TID-24341. The average level of strontium-90 in New Zealand soils, of the order of 14 mCi/km^2 at the end of 1965, is in good agreement with their average soil values for 30° - 50° south latitude. This report also gives an average value of about 70 mCi/km^2 for 30° - 60° north latitude. Maximum depositions have occurred at these latitudes in each hemisphere with minimum depositions at polar and equatorial regions.

4. Strontium-89/Strontium-90 Ratios in Rain

Since July 1966 routine monthly rainwater collections have been measured for the relatively short lived strontium-89 (half-life 50 days) as well as for strontium-90. Values of the ratio strontium 89/ strontium 90 are shown in Fig. 5 for Suva (Fiji), Rarotonga and also for the country-wide average for the New Zealand collecting stations. These measurements were discontinued during the first half of 1968 when levels dropped to below detectable limits. The measurements were reintroduced in July 1968, when the third series of French nuclear tests started, and have been continued until the end of 1969.

The results demonstrate the presence of fresh fission material during and following the French tests of 1966, 1967 and 1968; values of the ratio allow an approximate evaluation of the proportion of the total strontium-90 deposition which is contributed by these tests:

(a) No significant strontium-90 contribution from the 1966 French tests occurred until November 1966 during which month about 20% of the total deposition of strontium-90 on New Zealand is attributed to these tests. In subsequent months the proportion gradually decreased to about 10% during February 1967.

(b) A similar pattern was evident following the 1967 tests. In August 1967 about 20% of the total strontium-90 fallout in New Zealand was due to French tests, the proportion decreasing to about 10% in November 1967.

(c) During 1968 and 1969 a significantly higher fraction of the total strontium-90 fallout on New Zealand came from the 1968 French tests and extended over a longer period. About one half of the strontium-90 deposition during the last half of 1968 was due to 1968 test series. This proportion was probably maintained during 1969 although it is more difficult to make an evaluation based on the strontium-89/strontium-90 ratios after this lapse in time. The country-wide average deposition of strontium-90 during 1969 (1.2 mCi/km^2) compared with the deposition during 1968 (0.8 mCi/km^2), however, confirms the greater contribution arising from the 1968 French tests.

Comparing the rate of decrease of the ratio during the three test series, the most striking feature is the much slower rate of decrease after the 1968 tests which, for the first time included stratospheric injection of fission products from the two hydrogen bombs detonated at the close of the 1968 tests.

A detailed analysis of the results shows that the ratio decreased with a half-time of less than 50 days (the half-life of strontium-89) after the 1966 and 1967 tests. This isprobably due to wash-out of troposheric debris produced by the low yield nuclear devices tested, combined with further deposition of strontium-90 from the stratospheric resevoir which has resulted from past (mainly northern hemispheric) testing.

During 1968 and 1969, however, the ratio decreased initially with a half-time of 50 days, and eventually with a half time longer than 50 days. The initial half-time of decrease of 50 days is consistent with a combination of stratospheric and tropospheric fallout from the French tests, whereas the eventual half-time fall off longer than 50 days may be due to interhemispheric transfer of debris from the Chinese high yield nuclear explosion of 27 December 1968. This view is supported by some of the results for the ratio published in the United States Atomic Energy Commission's Health and Safety Laboratory's Quarterly Summary Report for April, 1970 (HASL-224 APPENDIX) for some collecting stations in the Pacific Area slightly north of the Equator, notably Majuro Island ($7^{\circ}5'N$, $171^{\circ}23'E$) and Truk Island ($7^{\circ}28N$, $151^{\circ}51'E$). These stations show elevated values of the ratio during the latter half of 1968 arising from the French tests and also a further elevation of the ratio during the period about March to July 1969 corresponding

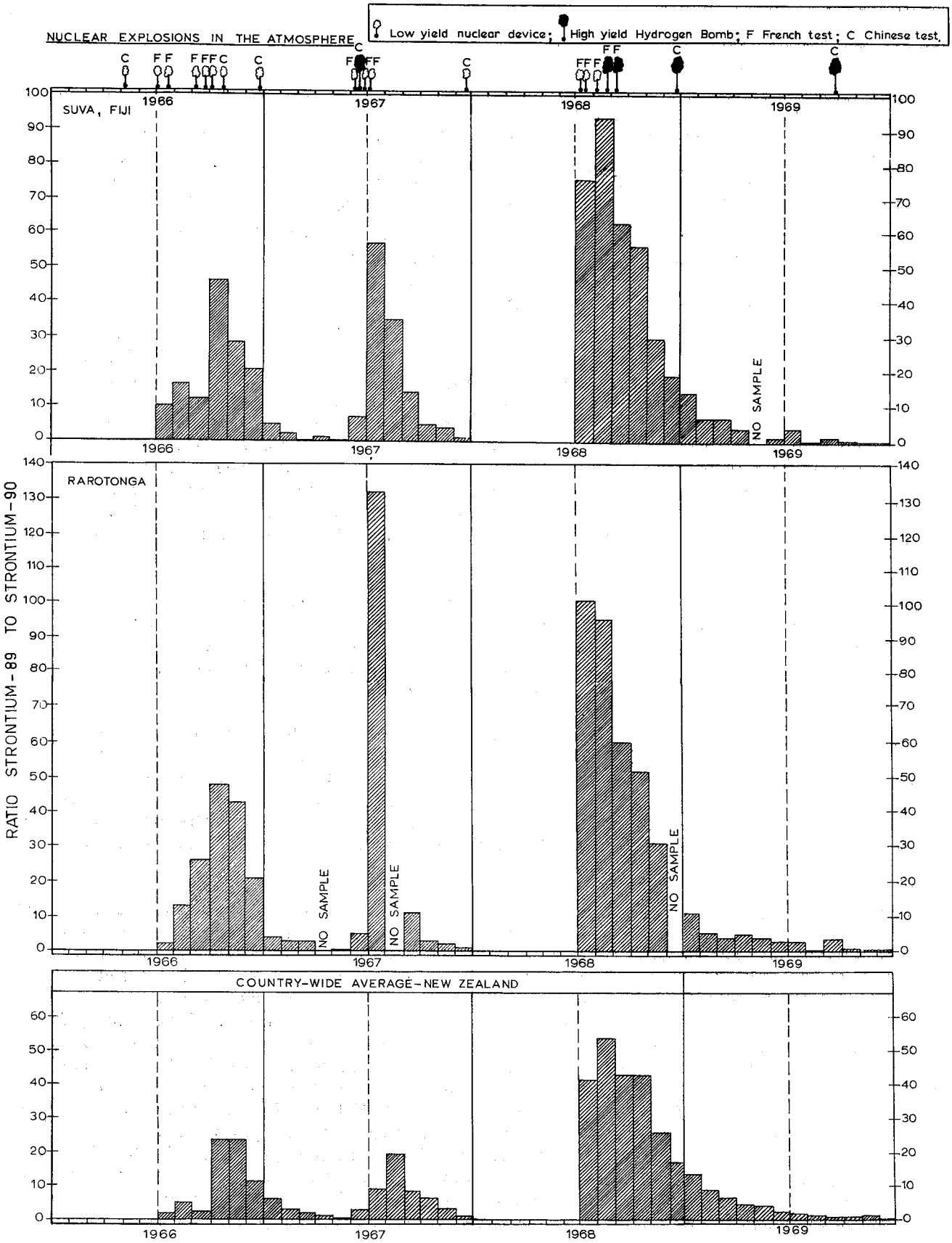


FIG. 5 RATIO STRONTIUM-89 TO STRONTIUM-90 IN RAINWATER SAMPLES

in time with measurements at many northern hemisphere stations where elevated values of the ratio resulted from the Chinese test of December 1968. The measurements of the ratio at several stations in Chile bordering the South Pacific also tend to confirm this view.

5. Strontium-90 in Milk

Country-wide average levels of strontium-90 in milk since about 1960 are shown in Fig. 2 and individual station levels in Fig. 6. The levels in New Zealand milk reached their maximum values during 1964 and 1965 when the deposition in rain was also a maximum. Although these levels have decreased during the years 1966 - 1968 inclusive, the decrease has been at a slower rate than the decrease in strontium-90 deposition because of the accumulating deposit of strontium-90 in soil and the continuing uptake from soil into grass. During 1969 levels increased about 30% over the 1968 levels, corresponding with the increase in deposition during 1969. The levels in 1969, however, were only about half the peak levels in 1965.

During 1969 the country-wide average level was 6.7 Strontium Units, with individual station levels ranging from 1.7 Strontium Units at Christchurch to 17.9 Strontium Units at Westland. Table 6 lists the average levels at individual stations and the country-wide average levels since 1962.

TABLE 6 AVERAGE LEVELS OF STRONTIUM-90 IN MILK - STRONTIUM UNITS

	1961	1962	1963	1964	1965	1966	1967	1968	1969	AVERAGE 1962-1969
Northland	4.5	6.3	7.5	11.2	10.6	6.5	5.1	4.1	6.3	7.2
Auckland		5.5	5.3	9.1	9.4	6.1	5.2	3.8	6.0	6.3
Waikato	4.1	4.9	5.6	9.5	9.8	6.3	5.0	4.1	5.4	6.3
Taranaki	7.1	9.4	9.9	17.1	16.7	12.5	10.4	8.0	9.4	11.7
Palmerston North		4.3	4.9	7.1	8.4	4.8	3.9	3.6	5.8	5.4
Wellington					8.8	6.1	5.4	4.8	5.1	
Westland	12.7	13.5	17.2	26.0	28.8	22.7	17.8	14.0	17.9	19.7
Christchurch	1.6	2.1	2.7	2.6	4.3	2.4	1.9	1.6	1.7	2.4
Dunedin		3.0	3.7	4.1	7.4	4.0	3.1	2.4	3.0	3.8
Country-Wide Average		6.1	7.1	10.8	11.6	7.9	6.4	5.2	6.7	7.8

For health hazard assessment it is more significant to consider average levels over many years. If we postulate that the average levels in milk during the period 1962-1969 are maintained indefinitely in the diet as a whole, and if we accept the observed ratio of strontium-90 in bone to strontium-90 in diet as 1 to 4 then under these steady state conditions levels in the bones of New Zealanders would not exceed the levels listed in Table 7.

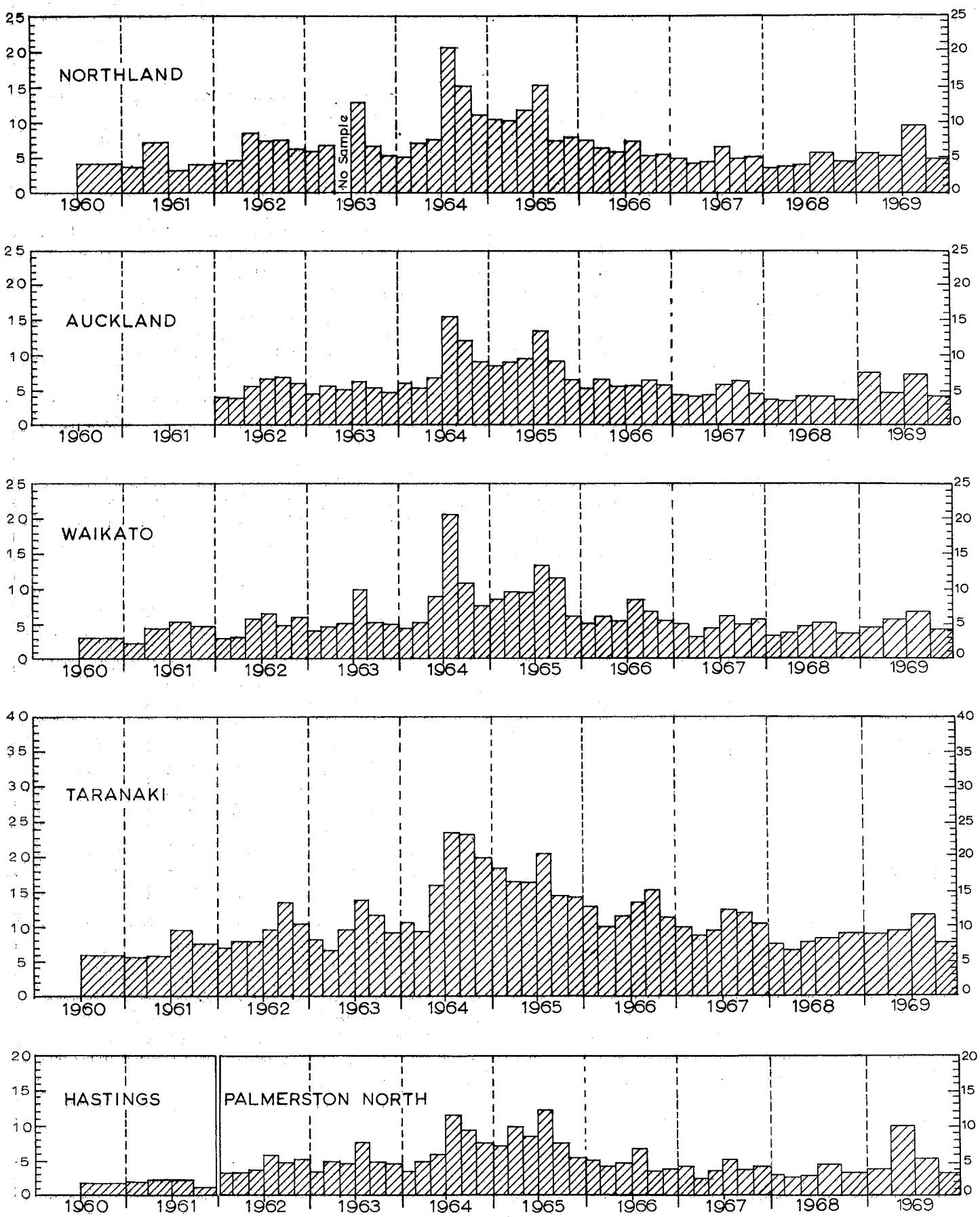


FIG. 6 STRONTIUM 90 IN MILK (Strontium Units=pCi Sr^{90}/g calcium)

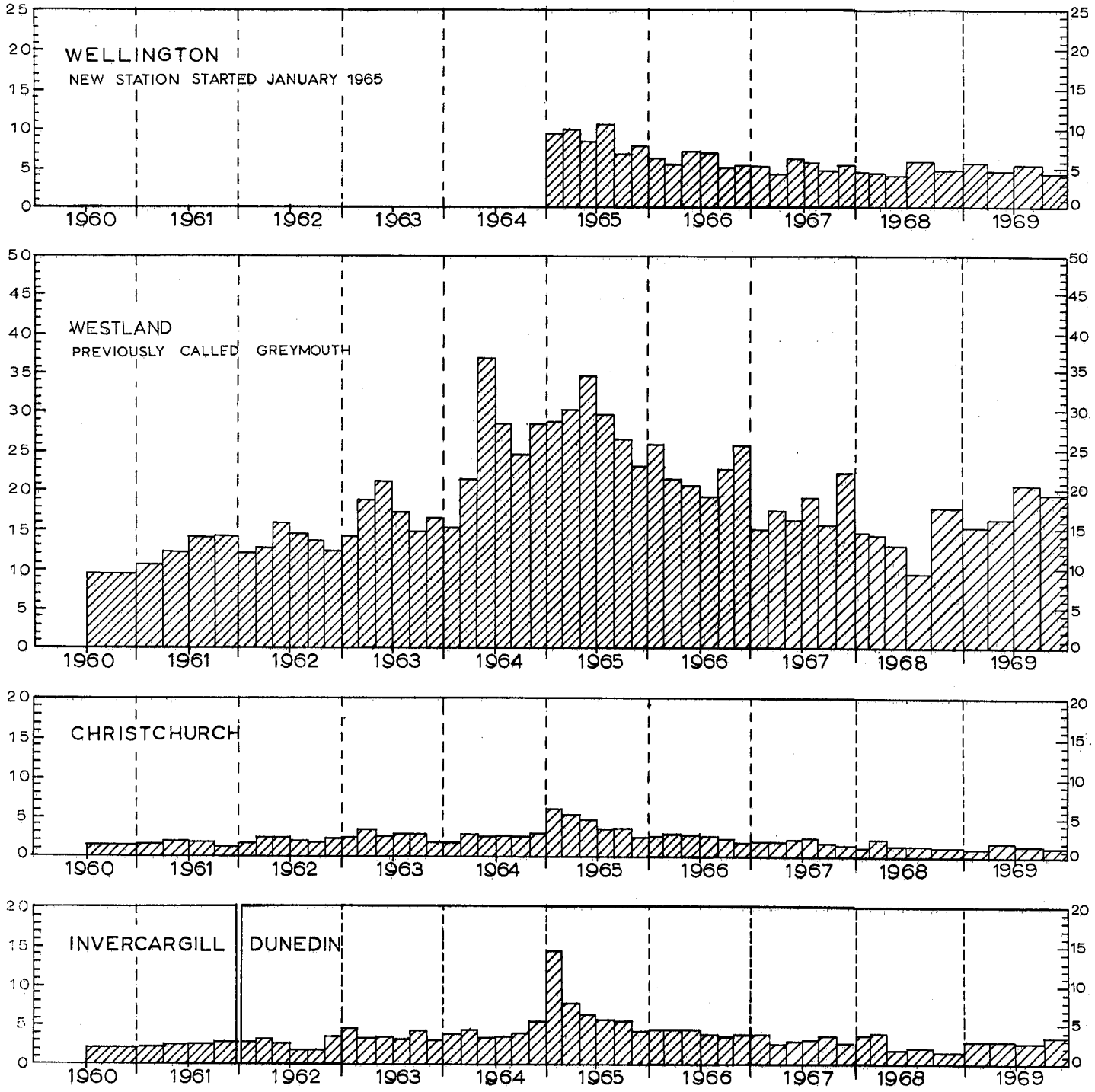


FIG. 6 STRONTIUM 90 IN MILK (Strontium Units = pCi Sr^{90}/g calcium)

TABLE 7	STRONTIUM-90 HAZARD ASSESSMENT (1962-1969)		
STATION	STRONTIUM UNITS MILK	BONE	% OF PERMISSIBLE LEVEL
Lowest Level (Christchurch)	2.4	0.6	0.9%
Highest Level (Westland)	19.7	4.9	7.3%
Country-wide Average	7.8	2.0	3.0%

Results of strontium-90 measurements in human bone samples are given in Table 10.

In Fig. 7 a graphical comparison of the levels of strontium-90 in Canadian, New York City and New Zealand milk is given. The values shown for Canada and New Zealand are the averages of the results for all

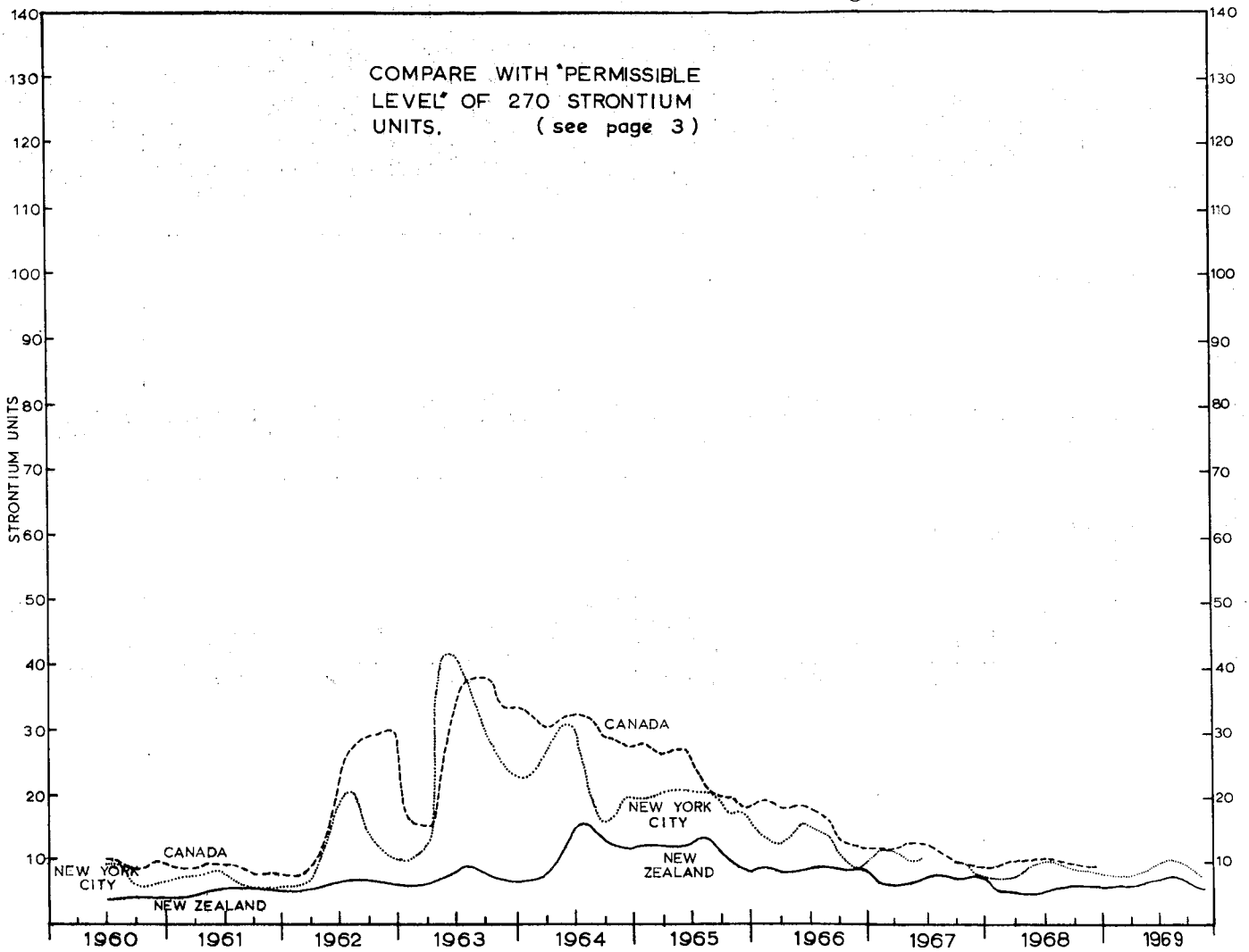


FIG. 7 STRONTIUM-90 LEVELS IN MILK

collecting stations. The Canadian values are taken from the monthly reports "Data from Radiation Protection Programs" of the Radiation Protection Division, Department of National Health and Welfare, Canada. The New York City values are the average of results from samples collected daily from the local milk supply, and are taken from the Fallout Program, Quarterly Summary Reports of the Health and Safety Laboratory, United States Atomic Energy Commission. For purposes of comparison the average level for each two monthly period is plotted for each locality up to June 1968. Thereafter the average level for each three monthly period is plotted.

6. Caesium-137 in Milk

Country-wide average levels of caesium-137 in milk are shown in Fig. 2 and individual station levels in Fig. 8. The levels in New Zealand milk reached their maximum values during the first quarter 1965 and decreased during 1966-1968 inclusive. During 1969 average levels ranged from 2 pCi/g K at Christchurch to 101 pCi/g K at Taranaki. The country-wide average level was 28 pCi/g K an increase of about 22% on the level for the previous year. The 1969 level, however, was still only about one half the peak level in 1965. Table 8 lists the average levels at individual stations and the country-wide average levels since measurements commenced.

TABLE 8 AVERAGE LEVELS OF CAESIUM-137 IN MILK - pCi/g K

	1964	1965	1966	1967	1968	1969	Average 1964-1969
Northland	49	54	37	26	15	27	35
Auckland	51	53	33	26	18	26	35
Waikato	69	84	60	48	36	41	56
Taranaki	168	185	141	123	102	101	137
Palmerston North	19	26	11	7	3	5	12
Wellington	(25)*	29	18	13	7	9	17
Westland	76	77	43	33	21	38	48
Christchurch	7	11	4	3	1	2	5
Dunedin	11	18	9	5	3	4	8
Country-wide Average	53	60	39	31	23	28	39

* estimated for averaging purposes

For health hazard assessment average levels over longer periods are more significant. During the period 1964-1969 inclusive average station levels ranged from 5 pCi/g K at Christchurch (less than 0.1% of the permissible level) to 137 pCi/g K at Taranaki (about 2% of the permissible level). The country- wide average level over the same period was 39 pCi/g K which is about 0.6% of the permissible level for continuous consumption.

7. Caesium-137/Strontium-90 Levels in Milk

The evaluation of the Caesium-137 unit to Strontium-90 unit ratios (pCi Cs^{137}/g K to pCi Sr^{90}/g Ca) for the New Zealand milk network has been continued through 1969 and the pattern of results is similar to

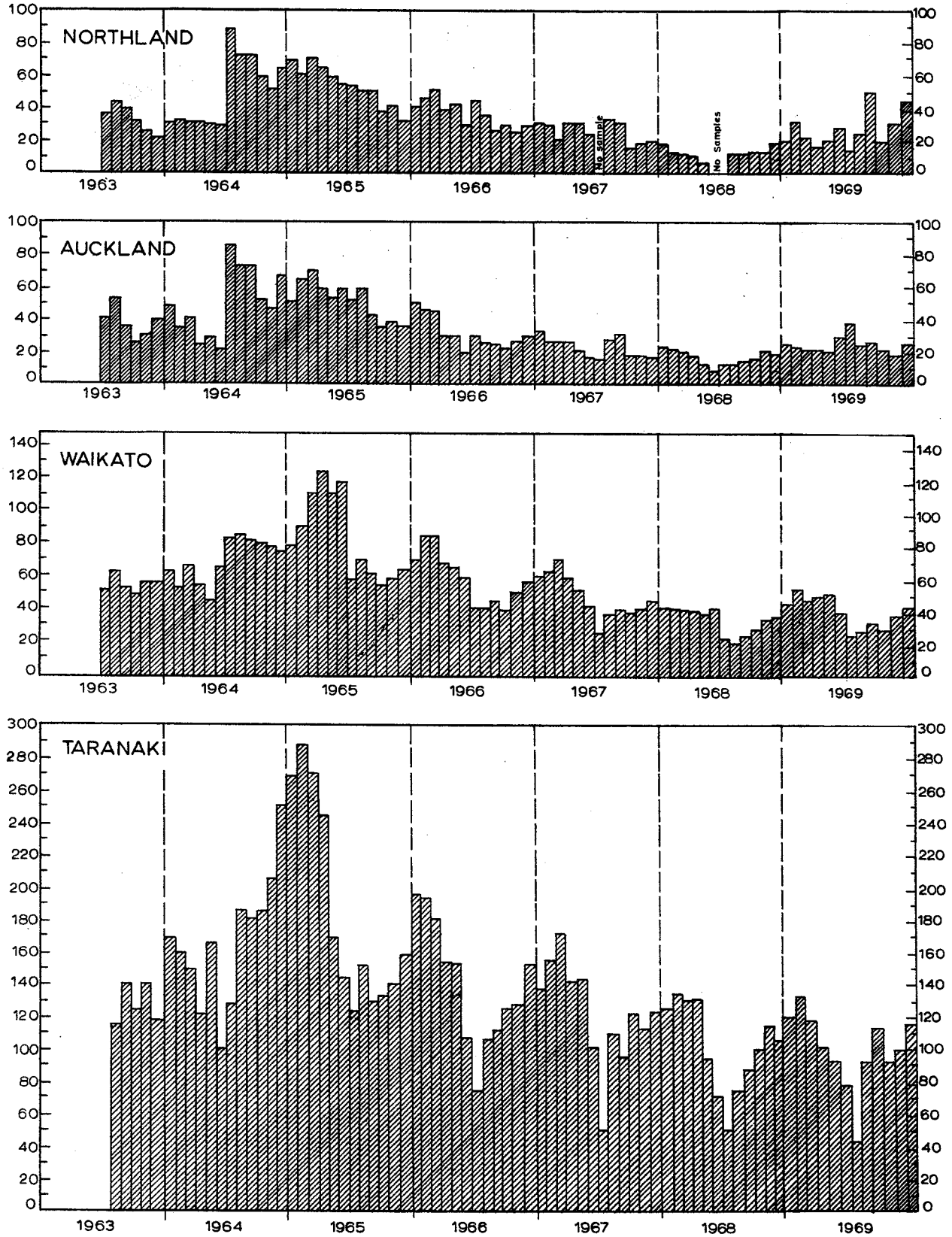


FIG. 8 CAESIUM-137 IN MILK (pCi Cs^{137}/g potassium)

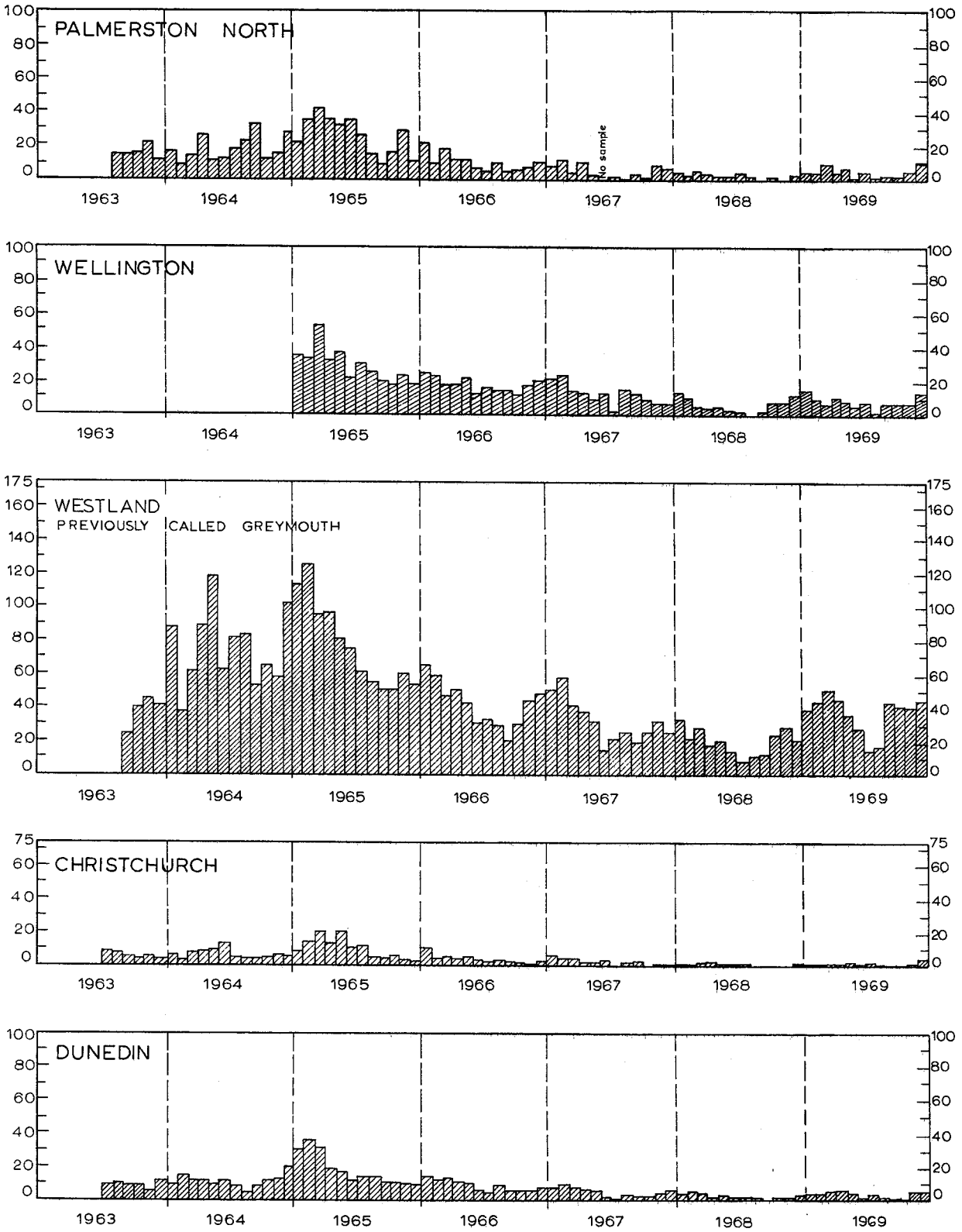


FIG. 8 CAESIUM–137 IN MILK (pCi Cs^{137}/g potassium)

that found in previous years.

Values of the ratio from 1963-1968, including the seasonal variation in the ratio for the two stations of special interest i.e. Taranaki and Waikato, were given in SECTION D, pp38-40 of the Annual Summary Report for 1968, No. NRL - F33.

8. Lead-210 in Rain

Lead-210 is produced in the atmosphere by decay of radon-222 diffusing from land surfaces. The resulting "natural fallout" of lead-210 is of health interest. During 1965 and 1966 a special survey was conducted at four sites selected from the network of rainwater stations which supply regular monthly samples for strontium-90 determination. The results of this survey were published in our Annual Summary 1967, Report No. NRL-F28. The results showed that lead-210 deposition in 1965 had been about twice that in 1966 and the possibility of lead-210 having been formed artificially in one or more of the explosions during the 1961 and 1962 test series was mentioned.

In May 1967 this survey was re-started at all collecting stations and the results for monthly collections up to December 1969 are shown in Fig. 9. During this period the country-wide average deposition of lead-210 has ranged from 0.07-0.26 $mCi/km^2/month$, with a mean value of 0.13 $mCi/km^2/$ month i.e. about the same as in 1966.

During the course of this survey it was noticed that in about one sample in every twelve chemical recoveries of added lead carrier were in excess of 100% i.e. stable lead was also being collected along with the rain sample in these cases. Enquiries were made at the collecting stations, which in most cases were meteorological compounds at airports, and it became evident that the lead deposit derived from piston engined aircraft using leaded petrols. It was not considered desirable or practicable in most cases to change the location of the collecting sites, which have been established for many years for strontium-90 monitoring, in order to overcome this effect. In the case of Rarotonga, however, the collector was removed further from the runway.

All rainwater collections were made for one calendar month in 30 cm diameter pots. The sample containing most lead (25 mg of lead) was collected at Rarotonga. For New Zealand samples giving lead recoveries greater than 100% the stable lead deposited ranged from at least 0.2mg to at least 15 mg per month with a mean value of at least 3.4 mg per month.

The uncertainty about the amount of stable lead deposited will give a low bias to the results up to February 1969. It is estimated that these results should be increased by up to 10% in many cases and perhaps in a few cases by 20% or more.

Beginning March 1969, the effect of stable lead deposition was minimized by increasing the amount of lead carrier used and by altering the procedures so that the daughter nuclide Bismuth-210 is separated for measurement.

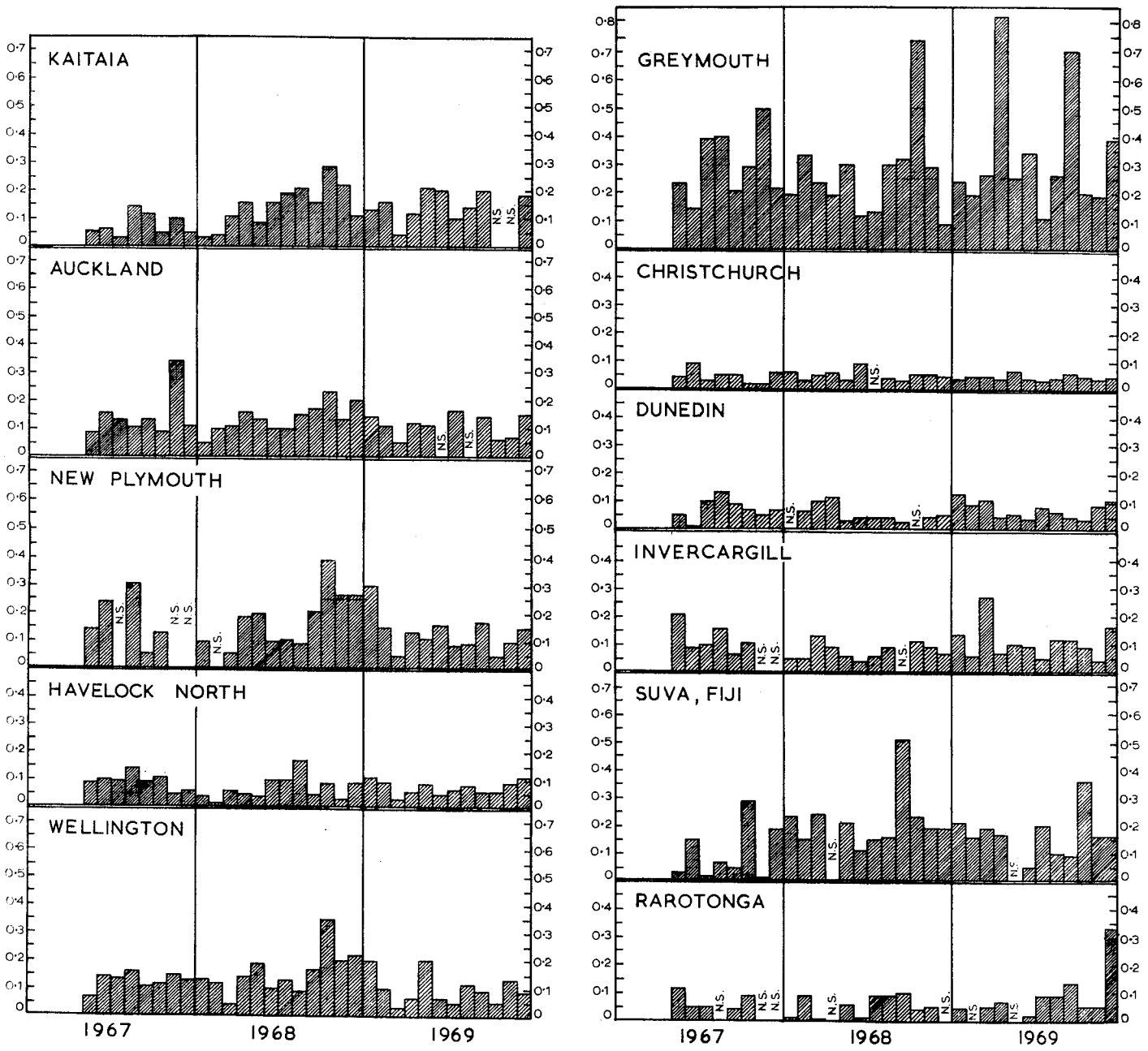


FIG. 9 LEAD-210 IN RAIN mCi/km²/month

N.S.- NO SAMPLE

9. Radon-222 in Artesian Waters

Radon-222 is a radioactive but chemically inert gas which is produced from radium naturally present in underground rock and sediments. The radon dissolves in underground waters and (unlike the parent radium-226 and the remaining members of this radioactive series i.e. polonium, lead and bismuth radionuclides) the radon is not removed to any significant extent from the water by natural chemical or physical processes such as precipitation or filtration. Radon is therefore commonly present in relatively high concentrations in water issuing from underground wells.

During May 1969, the radon concentration was measured in artesian water from 22 Christchurch wells. These wells ranged in depth from 104 feet to 513 feet. The measurements were made by rapid radiochemical separation and beta counting of the 20 minute half-life daughter bismuth-214 which had been allowed to attain equilibrium with the radon in the samples. The beta activity of the bismuth daughter was measured using the 5 inch detector of a Beckman Wide-Beta II low background counter. The first measurements for each bismuth source were made within 20 minutes after separation from the water sample, and measurements continued for several half-lives of each bismuth-214 source. The counter was calibrated using identical procedures on standard radium-226 solutions which had been suitably stored until radioactive equilibrium had been established. Nearly all measurements were made in duplicate, and good agreement was obtained for each sample pair.

Table 9 lists the results of this survey.

As shown in Table 9, the radon concentration ranged from 330 to 1,140 picocuries per litre dpending on the locality of the well. Where more than one well was available for measurement at the same locality, the tendency was for higher radon concentrations from the deeper wells. Several samples of high pressure tap water at this Laboratory were also measured during the course of this survey and the levels remained fairly constant at about 800 pCi/litre. In conjunction with this survey, lead-210 was also measured in Laboratory high pressure water. As was anticipated, the concentration of lead-210 was very low - approximately 0.02 pCi/litre or less, which was at about the limit of detection of the measurement procedure.

The levels of radon in Christchurch artesian waters are fairly typical of those published in other countries for underground waters, although at certain spas, levels several hundred times greater have been reported in the literature. There is no internationally accepted "Permissible Level" for radon in drinking water, although the figure of 2,000 picocuries per litre has been suggested. However, there are many places in the world where the population for generations has been consuming water with radon concentrations many times higher. Christchurch waters, however, average less than half this suggested "Permissible Level".

TABLE 9	THE RADON CONTENT OF CHRISTCHURCH WELLS	
Well No.	Depth (Feet)	Radon (Picocuries/Litre)
A No. 1	506	760
No. 3	110	500
B No. 1	448	830
No. 2	104	600
C No. 1	437	800
D No. 1	134	750
E No. 4	133	550
F No. 2	394	870
No. 3	104	Approx. 700
G No. 3	475	810
H No. 2	439	780
I No. 4	423	930
J No. 5	468	1140
K No. 1 + No. 2	464, 465	790
L No. 4	467	850
M No. 1 + No. 2	156, 224	1110
N No. 1	419	920
O No. 1	469	770
P No. 1 + No. 2	513, 380	700
Q No. 2	158	330
R No. 1	340	670
No. 2	106	Approx. 550

NOTE: The results for F No. 3 and R No. 2 wells are approximate. These wells contained water enriched in CO_2 which interfered to some extent with the measurements.

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

Table 10 summarizes all the results of measurements of long lived artificial and natural radionuclides that have been made on New Zealand ashed human bone samples. Previously published results (see especially Report No. NRL-F33) gave the radionuclide levels at the time of measurement. The results listed in Table 10, however, have been adjusted for radioactive decay of the various radionuclides where this has been significant and now refer to the radionuclide levels at the time of death.

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

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

TABLE 10 RADIONUCLIDES IN HUMAN BONE

Sample No.	Rainfall Area	Date of Death	Age at Death	Bone	RADIONUCLIDE LEVELS		
					ARTIFICIAL	NATURAL	
					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	"	4/64	SB	L	0.6	-	-
26				R	0.9	-	-
26				V	0.8	-	-
26				S	0.7	-	-
24	"	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

Continued on Page 32

TABLE 10 (continued)

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
46	Low	7/66	7y	F	1.9	0.009	0.036
42	"	6/66	16y 6m	F	1.0	0.074	0.098
43	"	6/66	19y	F	0.5	0.010	0.057
49	**	9/66	18y	F	0.5	0.023	0.085
52	Medium	8/66	3y	F	2.1	0.036	0.046
41	"	6/66	3y 6m	F	2.4	0.020	0.069
44	"	6/66	7y	F	2.0	0.006	0.048
47	"	7/66	7y	F	2.3	0.013	0.037
53	"	8/66	9y	F	1.3	0.022	0.054
51	"	8/66	14y	F	1.1	0.024	0.038
87	"	12/66	14y 7m	F	1.0		
78	"	12/66	15y	F	1.8		
50	"	10/66	16y	F	0.9	0.030	0.067
38	"	6/66	17y	F	1.0	0.021	0.047
45	"	6/66	20y	F	0.9	0.010	0.046
48	"	8/66	22y	F	0.6	0.010	0.042
40	"	6/66	24y	F	0.5	0.012	0.073
54	"	8/66	25y	F	0.4	0.019	0.042
39	"	6/66	31y	F	0.5	0.016	0.093
37	High	5/66	17y	F	1.0	0.014	0.058

Age at death: y year, m month, SB stillborn.

Bone: F femur, H humerus, L long bones, V vertebrae, R rib, S skull.

* Occupationally exposed to luminizing materials.

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

ACKNOWLEDGEMENT

Work Done on Collection of Samples

The assistance of the Director of the New Zealand Meteorological Service (Dr J. F. Gabites) and of his staff of observers has made it possible to:

1. Obtain air filter samples at Wellington from the air sampler installed by this Laboratory;
2. Obtain weekly rainwater samples at 2 collecting stations;
3. Obtain monthly rainwater samples at 2 Pacific Islands and at 9 collecting stations in New Zealand.

Officers of the New Zealand Department of Health obtained air filter samples at Auckland from the air sampler installed by this Laboratory.

Samples of artesian water were obtained through the assistance of the Christchurch City Council Waterworks Engineer and his staff.

Other types of samples are obtained through the assistance of the Soil Bureau, Geological Survey, and Fruit Research Orchard of the Department of Scientific and Industrial Research, from pathologists, and from a number of privately operated milk processing plants.

Work Done Within the Laboratory

All measurements of gross radioactivity and specific radionuclides were made in the low level environmental section of this Laboratory:

(a) All arrangements for sample collection, radiochemical procedures, and measurements of alpha and beta radioactivity are under the control of Mr L. P. Gregory, Principal Radiation Officer, who is also responsible for the editorial work in the preparation of this series of reports. Professional assistance is given by Mr T. Baltakmens, and technical assistance by Mr R. H. Chapman.

(b) Gamma ray spectroscopy is under the control of Mr H. J. Yeabsley, Deputy Director. The measurements are made by Mr J. E. Dobbs, Technical Officer.

Maps and graphs for this report have been drawn by Mrs S. Godfrey.

G.E.ROTH
DIRECTOR