HEALTH AND SAFETY LABORATORY

FALLOUT PROGRAM
QUARTERLY SUMMARY REPORT

(March 1, 1972 through June 1, 1972)

Prepared by

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Environmental Studies Division

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FALLOUT PROGRAM
QUARTERLY SUMMARY REPORT

July 1, 1972

ABSTRACT

This report presents current data from the HASL Fallout Program; the National Radiation Laboratory in New Zealand, the Radiological Physics Division at Argonne National Laboratory, and the EURATOM Joint Nuclear Research Centre at Ispra, Italy. The initial section consists of interpretive reports covering the following topics: meridional transport of strontium⁹⁰, high fallout in the western United States, strontium⁹⁰ and plutonium fallout in Utah, stratospheric inventories to July 1971, and strontium⁹⁰ in 1971 human bone. Subsequent sections include tabulations of radionuclide levels in fallout, surface air, milk, diet, and tapwater. A bibliography of recent publications related to radionuclide studies, is also presented.

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INTRODUCTION

Every three months, the Health and Safety Laboratory issues a report summarizing current information obtained at HASL pertaining to fallout. This report, the latest in the series, contains information that became available during the period from March 1, 1972 to June 1, 1972. The next report is scheduled for publication October 1, 1972. Preceding reports in the series, starting with HASL-42, "Environmental Contamination from Weapons Tests", and continuing through HASL-257, (this report) may be purchased from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia 22151. A complete listing of these Fallout Program Quarterly Summary Reports is given on the title page of this report.

To give a more complete picture of the current fallout situation and to provide a medium for rapid publication of radionuclide and trace element data, these quarterly reports often contain information from other laboratories and programs, some of which are not part of the general AEC program. To assist in developing, as rapidly as possible, provisional interpretations of the data, special interpretive reports and notes prepared by scientists working in the field of fallout are also included from time to time. Many of these scientists are associated in some way with the general AEC program. Information developed outside of HASL is identified as such and is gratefully acknowledged by the Laboratory. In this report, data from the EURATOM Joint Nuclear Research Centre at Ispra, Italy, the Radiological Physics Division at Argonne National Laboratory, and the National Radiation Laboratory in New Zealand are given.

A portion of the radiochemical analyses either have been or are being carried out by commercial laboratories under contract to the HASL Environmental Studies Division. The results of these analyses are reported as part of HASL's regular fallout program. The contractor analytical laboratories which provided data are Nuclear Science and Engineering Corporation, Pittsburgh, Pa.; Isotopes, Inc., Westwood N.J.; Radiochemistry Incorp., Louisville, Ky.; Tracerlab, Div. of LFE, Richmond, Calif. (now Trapelo Div./West); Controls for Radiation, Inc., Cambridge, Mass; Hazleton-Nuclear Science Corp., Palo Alto, Calif. (now Isotopes Palo Alto Laboratories); Food, Chemical and Research Laboratories, Inc., Seattle, Washington; Custom Nuclear Co., Mountainview, Calif.; Ledoux and Company, Teaneck, N. J.; and U. S. Testing Co., Richland, Washington.

This report is divided into four main parts:

1. Interpretive Reports and Notes
2. HASL Fallout Program Data
3. Data from Sources Other than HASL
4. Recent Publications Related to Radionuclide Studies

PART I
INTERPRETIVE REPORTS
and
NOTES

MERIDIONAL TRANSPORT OF Sr^{90} IN THE TROPOSPHERE
par

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ABSTRACT

Data of Sr^{90} concentrations in surface air and in fallout, put in U.S.A.E.C. Health and Safety Laboratory, have been analysed to interpret the dispersion of Sr^{90} in the troposphere during the moratorium 1963-1965. Different processes, such as eddy diffusion, mean meridional motion and stratospheric-tropospheric exchange are examined in relation with this analysis. At low latitudes, of both hemispheres, the distribution of Sr^{90} , for the most part, can be accounted for by a meridional circulation. In the midlatitudes (30-60°N-20-60°S), the direct injection from the stratosphere seems to play a major role in the distribution observed. Some difference in the behaviour of Sr^{90} in the southern hemisphere appears to result from an additional source in the upper troposphere of the southern equatorial zone, due to the interhemispheric exchange. At 70-80° N, in winter, a transfer of Sr^{90} at the ground level from the midaltitudes is suggested.

I. INTRODUCTION

A considerable number of works has been done over the last decade to estimate the burden of radioactivity in the stratosphere for both hemispheres (FEELY et al. 1966 ; TELEGADAS, 1968) and its variations with time (DAVIDSON et al. 1966 ; KREY, 1967 ; ROEDEL, 1967 ; PEIRSON and CAMBRAY, 1967 ; FABIAN et al., 1968 ; NGUYÊN, 1968 ; HOANG et SERVANT, 1969). Nevertheless, the transfer process of nuclear debris from the stratosphere into the troposphere is not well understood. The main factor appears to be the prime importance of the role of jet streams in the process, as shown by STALEY (1960) and DANIELSEN (1967, 1968).

Far less data is available for the troposphere except at ground level, where fallout is recorded all over the world. The circulation pattern has been established for long after observations from U.S. monitoring stations located along the 80th meridian (West) (LOCKHART and BAUS, 1957 ; LOCKHART et al., 1964). The latitudinal profiles of air radioactivity for 1959-1960, following the nuclear test of 1957-1958 clearly suggest that the stratosphere-troposphere exchange takes place at midlatitudes. The maximum intensity, after NEWELL (1961), occurs in the 30-35°N band. This exchange is to be combined with the general circulation pattern of winds along the Earth. The result is :

1) a rapid zonal motion (along a parallel) which is well known ;

2) a slower meridional circulation, which has not been much studied until recently, owing to a lack of wind data at low altitudes (NEWELL, 1961, 1963a). Additional meteorological data for the Hadley cells offer a new possibility for the understanding of this motion (KIDSON et al., 1969 ; NEWELL et al., 1969). They suggest the importance of the altitude exchange at the Equator, and enable to estimate the exchange rate of the whole tropospheric mass from one hemisphere to the other to be equal to 320 days. Moreover, from analyses on atmospheric CO₂ concentrations, JUNGE (1962) has found a time of 400 days for this exchange. Comparable figures were found by NYDAL (1968) after analyses on tropospheric C¹⁴ and later by HOANG et SERVANT (1969) , who utilised the iron-55 fallout distribution in the equatorial regions for the 1963-1965 period. All these studies tend to suggest the importance of the mean meridional motion for the tropospheric transport of trace substances.

The objectives of this paper are :

1) to discuss the role of mean meridional circulation on the dispersion of strontium-90 in the troposphere ;

2) to show the occurrence of interhemispheric exchange ;

3) to assess the influence of the stratospheric injection on the distribution of strontium-90 fallout.

The sources of the data dealing with radioactive fallout and surface air radioactivity are put in U.S.A.E.C. Health and Safety Laboratory (VOLCHOK, 1966; TELEGADAS, 1968 ; VOLCHOK and KLEIMAN, 1969).

II. BEHAVIOUR OF Sr^{90} IN THE TROPOSPHERE

In attempting to interpret the temporal and spatial distribution of Sr^{90} concentrations in surface air and in fallout we examine the different processes which contribute to the behaviour of Sr^{90} in the troposphere, such as mean meridional circulation, eddy diffusion and stratosphere-troposphere exchange. We made the assumption that the activity of Sr^{90} in surface air at each station situated in a band of 10° of latitude wide is representative for the whole band.

II.1 - Northern hemisphere

At high latitudes, in winter, the extension northwards up to 70°N of the indirect cell in the lower layers as pointed out by TUCKER (1959) somewhat contributes to the high value of the Sr^{90} concentrations in surface air (figure 1a). In summer, the extension of the indirect cell disappears and the Sr^{90} concentrations in surface air are lower than those of the midlatitudes.

At midlatitudes, the intensity of the indirect Ferrel circulation computed by several authors ranges from $(22-42) \times 10^6$ tons. s^{-1} (PALMÉN et al., 1963) (VUORELA et al., 1964) (HOLOPAINEN, 1967). These values are of the same order of those connected to the meridional eddy diffusion at the latitude of 40°N $(21-45) \times 10^6$ tons. s^{-1} , (YOUNG and FAIRHALL, 1968). With a mean total mass of tropospheric air in the $40-50^\circ\text{N}$ belt equal to 2.49×10^{14} tons the ensuing flux correspond to a mean tropospheric residence time of a molecule of air and a micronic aerosol, in a latitude band of 10° width, equal to 64 to 137 days. These figures are

much higher than the generally admitted value of 30 days associated with the rainout. It seems therefore that the meridional transport of a micronic aerosol by a circulation and the eddy diffusion is weak. Hence, the shape of the fallout distribution curve of Sr^{90} may be interpreted as a consequence of the direct injection of particulate debris from the stratosphere.

In the tropical zone, the general pattern of the meridional circulation of the Hadley cell is presented by KIDSON et al. (1969) and NEWELL et al. (1969).

In winter, this cell extends across the equator to about 10°S of latitude and the total mass circulation, approximately $170 \times 10^6 \text{ tons.s}^{-1}$, is stronger than in the other seasons, about $(50-100) \times 10^6 \text{ tons.s}^{-1}$. In spring the Hadley cell is located between 0° and 30°N , in summer, the southern Hadley cell spans the equator up to 30°N with a total mass circulation of about $200 \times 10^6 \text{ tons.s}^{-1}$. This general feature associated with the injection of nuclear debris at about 30°N can explain the figures of Sr^{90} concentrations in surface air over the American continent (figure 1b). The strong meridional circulation in winter and the injection in late winter contribute to the simultaneous spring peaks of Sr^{90} concentrations in each band of 10° of latitude. In summer and fall, the weak meridional motion in the latitude belt of $10^\circ\text{N}-30^\circ\text{N}$ results in a steep concentration gradient at a latitude of about 10°N , as noted by NEWELL (1963b). The low concentration in the equatorial region is due to the reduced transfer of air from subtropical latitudes and to the intrusion of air poor in radioactive aerosols, from the southern Hadley cell.

From another point of view, YOUNG and FAIRHALL (1968) have shown with a box model that CO_2^{14} enters the troposphere predominantly at midlatitudes in late spring and its latitudinal dispersion in the troposphere is well accounted for by eddy diffusion.

The main differences with a box model is that the stratosphere-troposphere transfer takes place mostly in the Ferrell cell and the transport process is slow in the Hadley cell ($15-30 \times 10^6$ tons $\cdot s^{-1}$ over the year at 30°). They lead to two difficulties :

- first, the yearly maximum in surface air concentration would be earlier at 30° than at 0° latitude (a delay between 2 to 5 months). The observations (figure 1b) show that it is simultaneous ;

- second, the rainout associated with a residence time of 30 days is so effective that the fallout in the Hadley cell would be negligible in regard to that occurring in the $30-40^\circ$ latitude band, in fact it is two times greater.

A part of the difference could possibly be attributed to the difference of sampling sites. It seems that if the eddy diffusion cannot be ignored in the exchange between the Ferrel and the Hadley cells, a direct injection of Sr^{90} in the Hadley cell at $20-30^\circ$ and an equatorward transport by the meridional circulation are very effective to explain the spread out of the nuclear debris over the equatorial region.

We now attempt to assess the influence of the mean meridional circulation on the stratosphere-troposphere exchange. For this purpose, the variations of the Sr^{90} burden in the lower stratosphere must be examined. TELEGADAS (1968) computed the seasonal stratospheric burden of Sr^{90} for each stratospheric compartment from march 1963 to february 1967. This author pointed out a cyclical behaviour of the lower polar stratospheric burden (between the altitudes of 9 - 15 km, and over the latitudes of $30-90^\circ N$), with a maximum of the amount of Sr^{90} in winter and spring, and a minimum in summer and fall. He suggests an influx of debris from above during fall and winter and a transfer of this debris into the troposphere during spring, the period of maximum deposition. Additional information may be obtained by the estimation of the mass flux of stratospheric air into the troposphere. For the northern hemisphere, the mass flux may be deduced from the ratios of fallout to stratospheric

by DANIELSEN (1968), rather than by mean meridional circulation.

II.2 - Interhemisphere exchange in the troposphere

In the Hadley cells, mass flux in seasonal meridional circulation is higher in the southern cell, than in the northern cell by a factor varying between 30 % and 100 %. In the southern, winter and spring (i.e., June-August and September-November), the most intense circulation spreads from 20° S to 10° N and the southwards circulation in the upper branches of the cell is reinforced by eddy processes as noted by NEWELL et al. (1969). Therefore, very effective interhemispheric mass exchange occurs and the influence of the northern hemisphere on the transfer of nuclear debris should be obvious, particularly in the equatorial region (0-10°S). As shown previously the interhemispheric exchange explains some of the variations of the Sr^{90} surface air concentration over the American continent. This influence is also shown by simultaneous seasonal peaks of Sr^{90} fallout (April-June) in both equatorial regions around the world (figure 2). MACHTA et al. (1961) have suggested such an exchange in the upper troposphere from the northern into the southern hemisphere and VOLCHOK (1965) has verified this transfer by analysing the $\text{Sr}^{89}/\text{Sr}^{90}$ ratio from the high elevation CHACALTAYA site (5220 m).

II.3 - Southern hemisphere

South of 10°S, the influence of the northern hemisphere decreases because the fallout peaks appear during the winter and spring seasons of the southern hemisphere and are higher in the 20-30° S band than in the 10-10°S band. This indicates an injection from the southern stratosphere, which is stronger in the former region than in the latter. One may therefore suggest a boundary at about 20°S between the direct and the reversed cells, as shown by meteorological data reported by NEWELL et al. (1969). This boundary is not apparent at ground level over the American continent where Sr^{90} concentrations are nearly equal in both latitude bands. Nevertheless, LAMBERT et al. (1968) have observed over the ocean around the world a narrow zone of about 200 km width located at 22°S, where

concentrations of artificial radioactive aerosols in surface air are very low. These authors suggested that this zone really corresponds to the frontier between the two cells. From the above considerations, the effect of the meridional circulation on the transfer of debris near the ground surface is not clearly marked, as was the case for the northern cell. This is reinforced by the fact that the peak of Sr^{90} concentration in surface air appears on the average one to two months later in the equatorial region than in higher latitudes (figure 1d).

In the midlatitudes, the lack of meteorological data does not enable to construct an adequate model for the mean meridional circulation. However, GILMAN (1965) has deduced, from momentum and mass balance considerations, that the indirect cell has about the same mass circulation as the northern hemispheric cell. From examination of the radioactive data, the following facts are of note :

a) The Sr^{90} concentrations in surface air present a steep gradient with the highest level at $30-40^{\circ}\text{S}$, which does not exist in the northern corresponding region (figure 1c). The action of the mean meridional motion may be reflected by the more or less simultaneous peaks of Sr^{90} concentration in spring and summer (September-February).

b) The Sr^{90} fallout per unit surface is highest in the $30-50^{\circ}\text{S}$ latitudes, whereas in the northern hemisphere the injection is maximum between 40° and 60°N . Another difference is the existence of two periods of maximum deposition, i.e., winter (June-August) and summer (November-January), observed south of 20°S (i.e., between 20° and 60°S) throughout the year.

So in the southern indirect cell, the fallout distribution seems to be mostly governed by the direct stratospheric injection, as in the northern cell. The indirect Ferrel cell seems then extend from 20° to 60°S with a weak mass circulation.

III. CONCLUSION

The general mean meridional circulation as deduced from wind observations could explain to a great extent the latitudinal distribution of Sr^{90} fallout over a great part of the world and surface air concentration over the American continent. This circulation is of great importance in the Hadley cells (30°N - 20°S). Its principal roles are the equatorward transport of nuclear debris from midlatitudes (30°N or 20°S) and the interhemispheric exchange. The fallout figures observed for nuclear debris in the equatorial band cannot be accounted for without the intervention of a meridional circulation. In the midlatitudes (30 - 60°N or 20 - 60°S), the intensities of the mean meridional motion and the meridional eddy diffusion are comparable but seem too weak to be effective in the latitudinal transport of particulate debris. The profiles of the monthly Sr^{90} fallout over the world and surface air concentration over the American continent are best understood by an appropriate stratosphere-troposphere exchange or a "wandering" of the jet-stream with latitude.

The similar pattern, from 1963 to 1965, of the northern hemispheric Sr^{90} fallout in the Hadley cell (0 - 30°N) and in the Ferrel cell (30 - 60°N) shows that the mean monthly injection of nuclear debris from the stratosphere over a year is comparable in both cells. The meridional circulation seems to have no direct influence on the stratosphere-troposphere exchange. This point is reinforced by the fact that in this exchange the mass flux of air is maximum in summer (June-August) when the mean meridional motion is weak. The variations over the year of this exchange seem to be related to tropospheric conditions rather than to stratospheric transport processes.

In the southern hemisphere, the analysis of the meridional distribution of nuclear debris is made difficult by the scarce meteorological data. The most obvious difference of the fallout distribution and concentration in surface air, as compared with that of the northern hemisphere, comes from :

a) an additional source located at the equator in the upper troposphere.

b) a stratospheric source with an intensity modulated by the stratospheric interhemispheric exchange. These two sources cause the strong circulation in the Hadley cell to be less apparent than in the northern hemisphere.

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YOUNG J.A. and A.W. FAIRHALL, Radiocarbon from nuclear weapons tests, J. Geophys. Res., 73, 1185, 1968.

FIGURE 1 : Sr^{90} concentrations in surface air along the 80th W meridian during 1963-1965.

FIGURE 2 : Sr^{90} deposition in the equatorial regions around the world.

High Fallout in the Western United States - An Explanation

by H. L. Volchok, (HASL)

ABSTRACT

Through analysis of the Sr-90 concentrations in precipitation at conterminous U. S. sites, plus Sr-90, Cs-137 and Pu-239 data in surface air, several hypotheses for systematically high fallout in the western U. S. can be rejected. The most plausible explanation, consistent with all of the data, requires a preferential longitude for stratosphere-troposphere exchange at about 110° (west). This is close to the longitude of Salt Lake City, Utah, and with this mechanism, essentially all of the high Sr-90 fallout at that location is reasonably understood.

INTRODUCTION

The impetus for this study comes principally from often observed, odd or unpredictable fallout relationships in the conterminous United States. In particular, we refer to the unexpected high Sr-90 deposits in the Salt Lake City area, and in the central and northern Great Plains states. From soil data at numerous sites in the U. S. the greatest integrated Sr-90 deposit was found consistently to be in the vicinity of Salt Lake City (1,2). Since most fallout at most places is brought to the earth by precipitation, the concentration in rain at Salt Lake City

would have to have been much higher than at other U. S. collection sites, unless some other mechanism of deposition had taken place. Some such alternative mechanisms which have been suggested include:

- (a) local fallout from the Nevada Test Site (NTS),
- (b) resuspended material from the NTS,
- (c) the abundance of salt nuclei in the air (1)
- (d) frequent penetration of thunderstorm clouds into the stratosphere (3)
- (e) frequent "tropopause folding" in this region of the U. S. (4)
- (f) the combination of large desert areas to the west and mountains to the east (5,6).

Local fallout from NTS as a systematic source of excess Sr-90 cannot be considered as a viable explanation since no change was noted after the cessation of atmospheric tests at that site.

On the question of resuspension from NTS, it has been concluded that this mechanism cannot have contributed significant amounts of fallout to the Salt Lake City area since 1959 (7).

A number of experiments have been performed to test the effectiveness of scavenging by salt nuclei (2,8,9), with the

general conclusion that little if any nuclear debris is brought down by this mechanism in excess of that deposited by "normal" means.

The final three listed possibilities, high altitude thunderstorms, tropopause folding and the desert-mountain combination have not been adequately tested using fallout data. In this report, by focusing on the concentrations of Sr-90 in precipitation and surface air, we believe that the latter hypothesis must be discounted in explaining the particular situation as encountered in the western United States.

PRECIPITATION AND CONCENTRATION

The Health and Safety Laboratory (HASL) fallout collection network includes 25 sites in the conterminous United States at the present time. Most of these stations started collections in the late 1950s or early 1960s; the longest running, New York City, began in 1954. The collections consist of "total" Sr-90 fallout on a monthly basis, either in steep-walled stainless steel pots or on cation exchange resin columns. "Total" Sr-90 fallout means that no separation between a dry and wet component is attempted; everything that

falls into the collector and stays is routinely analyzed for Sr-90. In addition the amount of monthly precipitation at or in the vicinity of each site is reported to HASL. The monthly precipitation in cm, Sr-90 deposition in mCi/km² and concentration in pCi/l are published every three months in the HASL Fallout Program, Quarterly Summary Report (10) and these, along with the results from the rest of the world are the basis for global Sr-90 fallout estimates (11) and inventories (12).

It is instructive, before observing the Sr-90 concentration data, to look at the mean annual precipitation for the conterminous United States. Figure 1 is an isopleth representation based upon long time averages at the same 25 fallout collection stations plus about 10 additional ones to fill in sparse areas (13). The stations are shown on the figure as black dots. The patterns of precipitation, on this admittedly very gross scale, are reasonably clear; highest in the extreme northwest and southeast, lowest in the southwest, and a trough of low annual precipitation bisecting the country. This trough of less than 40 cm per year has been shaded in Figure 1.

Figures 2 through 8 are similar contour type maps showing the annual Sr-90 concentration in fallout in the U. S. for the years 1964-1970. The units are picocuries per liter of precipitation (pCi/l). The pattern is extremely repetitious; lowest concentrations on the west and southeast coasts, highest in the west central states. For ease in interpretation and explanation an arbitrary area of "high" concentration has been shaded in these figures.

An obvious question is posed by these data. Are the high concentrations merely a reflection of the precipitation patterns? We think not. There certainly is a general similarity in the regions of low rain and high Sr-90 concentration but a more detailed analysis of the data suggests that other factors must be at least partially responsible for these concentration gradients. For example, consider the stations with highest annual concentration. These are indicated in Figures 2-8 by the small circle in the high areas. Of the seven years studied, Salt Lake City was high for four (1964, 1967, 1968 and 1969) while Helena, Montana was high for three years (1965, 1966 and 1970). Neither Salt Lake City nor Helena are in the region of very lowest precipitation.

Fig.1 mean annual precipitation (cm.)

Fig.2 Sr⁹⁰ conc.(pCi/l) - 1964

Fig.3 Sr⁹⁰ conc.(pCi/l) - 1965

Fig.4 Sr⁹⁰ conc.(pCi/l) - 1966

Fig.5 Sr⁹⁰ conc.(pCi/l) - 1967

Fig.6 Sr⁹⁰ conc.(pCi/l) - 1968

Fig.7 Sr⁹⁰ conc.(pCi/l) - 1969

Fig.8 Sr⁹⁰ conc.(pCi/l) - 1970

Salt Lake City averages about 40 cm per year and Helena about 32. Our lowest precipitation site, El Paso, Texas (22 cm per year average) was never the highest in concentration and often was not even in the high area. Assuming that El Paso is too far south, and perhaps should not reasonably be compared with the more northern sites we considered stations in a fairly confined latitude belt. Table 1 summarizes the mean ratios of Sr-90 concentration and annual precipitation, comparing Salt Lake City (SLC) to three other stations within about 3 degrees of latitude.

TABLE 1

AVERAGE Sr-90 CONCENTRATION AND PRECIPITATION RATIOS

	<u>SLC</u> <u>San Francisco</u>	<u>SLC</u> <u>Medford, Ore.</u>	<u>SLC</u> <u>Denver, Colo.</u>
Concentration Ratio	5.1	3.2	1.5
Precipitation Ratio	0.8	0.9	1.1

From this it seems clear that even within this narrow latitude coverage, and at stations within 20% of the same mean annual precipitation the variability of concentration is much

too large to be attributable simply to the differences in mean rainfall.

SURFACE AIR CONCENTRATION

The HASL Surface Air Sampling Program was initiated in 1963 as an outgrowth of a similar program operated by the U. S. Naval Research Laboratory from 1957 through 1962. The primary objective has been to study the latitudinal and temporal distribution at the earth's surface, of debris from nuclear detonations.

Most of the samplers are grouped roughly along the 80th Meridian (west) extending latitudinally from about 81° North to 90° South. Filter samples are analyzed monthly for a number of radionuclides and stable lead. Details of the sampling, analysis and a compilation of the data are reported quarterly (14).

In 1964, a limited study was carried out in this program, to investigate the effect of longitude on surface air concentrations of nuclear debris (15). To the routine network of stations, six U. S. sites were added, and data from Hong Kong

and 5 United Kingdom points were considered. This study concluded that although seasonal differences in Cs-137 concentrations were evident as a function of longitude, these tended to compensate, and on an annual basis there were no significant longitudinal biases. In the latitude range 35° to 40°N, for example, Table 2 lists the data for six sites in the conterminous U. S. As shown, the standard deviation, of these concentrations from the mean was less than 10%.

TABLE 2

Cs-137 CONCENTRATIONS IN SURFACE AIR, SEPT. 1963 - AUG. 1964

	Longitude (W)	Latitude (N)	Cs-137 (fCi/m ³)
Palo Alto, Cal.	122° 15'	37° 30'	45.
Midwest City, Okla.	97° 30'	35° 25'	54.
Appleton, Wisc.	88° 25'	44° 15'	54.
Chattanooga, Tenn.	85° 20'	35° 03'	59.
Sterling, Va.	77° 28'	38° 58'	50.
New York, N. Y.	73° 50'	40° 40'	<u>54.</u>
		Mean $\pm \sigma$	53. $\pm$ 5.

Unfortunately, Salt Lake City and Helena, Montana were not included in that program. Surface air sampling was initiated at Salt Lake City in 1971, with essentially the same motive; to compare the air concentrations with others at the same longitude. Comparative data are available for plutonium (Pu-239+240 will be referred to as Pu-239) from Denver, Colorado (16) and New York City (14) for the first nine months of 1971. Strontium-90 comparisons for the entire year 1971 can only be made with New York City. These are summarized in Table 3.

TABLE 3
LONGITUDINAL VARIATIONS IN SURFACE AIR CONCENTRATIONS (1971)

	Latitude	Pu-239 (mean Jan-Sept '71) aCi/m ³	Sr-90 (mean 1971) fCi/m ³
Salt Lake City	40° 46'	136	5.0
Denver, Colorado	39° 46'	82	-
New York City	40° 40'	73	3.1

These data, very strongly point up a longitudinal variation not observed in the earlier study of surface air concen-

trations. Undoubtedly, the key element here is the presence of Salt Lake City; comparing Denver and New York alone does not show a strong systematic trend.

DISCUSSION AND CONCLUSION

The foregoing data summaries, serve to shed light on the unexplained fallout highs in the western U. S. The annual concentration maps, Figures 2 through 8, even though based upon a relatively sparse sampling network, clearly reveal the repetitive nature of the effect, both in terms of geographic extent and time. Lack of a strong inverse correlation with mean annual precipitation reduces the probability that the highs merely reflect low rain fall. For the 7 years observed, Salt Lake City was the highest four times and Helena, Montana three. The location of Helena, within the northern Rocky Mountains and not adjacent to any extensive desert area suggests that the hypothesis concerning a buildup of concentration of nuclear debris in an air mass as it moves eastward across a dry area toward a mountain range is not applicable in this situation. Further, the surface air concentrations, as a function of longitude, appear to be quite constant within

a restricted latitude belt, except (in the range of 40°N) for the Salt Lake City area which may be as much as a factor of two higher.

The most likely explanation for all of the observations involves a preferred area of stratospheric-troposphere communication in the western U. S. The longitudes of Salt Lake City and Helena indicate that this area is centered at about 110°W (and probably north of 35°N) and that, as expected, the fallout concentrations drop off rapidly to the west; to the east the high concentrations extend for much longer distances.

The meteorological implications of this explanation are beyond the scope of this report, although numerous explanations for this sort of behavior have been put forth, such as: frequent penetration of the stratosphere by thunderstorms, position of the jet stream, and a preferred region of tropopause folding. With proper meteorological guidance, further experiments could undoubtedly be designed to quantify the geographical extent of this fallout "high" and perhaps further evaluate its relative importance in stratosphere-troposphere exchange.

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E

X Updating Stratospheric Inventories to July 1971

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ABSTRACT

The stratospheric inventories of Sr-90, Zr-95, and Cs-137 are reported to July 1971. The average Cs-137/Sr-90 ratio calculated from the inventories in each hemisphere during 1970 and 1971 (1.45) agrees with the theoretical production ratio of 1.44. Revised calculations indicate that the Chinese test of 10/14/70 and the large French tests of 5/31 and 7/5/71 injected into the stratosphere about 200 and 240 kCi of Sr-90, respectively. Approximately 40 kCi of Sr-90 was injected into the Southern Hemisphere stratosphere probably by the intermediate yield French test of 6/12/71.

This is the fifth in a series of reports (1,2,3,4) which updates the Sr-90, Zr-95 and Cs-137 stratospheric inventories through October 1971. The method of calculating these inventories is a slight modification of the technique which is described in reference (1).

The original method equated the stratospheric burden of a nuclide to its content above 180 mb. In the modification, the stratospheric concentration contours are extrapolated to the actual tropopause heights at the time of collection. These heights are generously provided by Mr. K. Telegadas, Air Resources Laboratory, NOAA. Recalculating all the Project

Airstream inventories since August 1967 by the modified method gave a mean deviation from previously reported results of +3% and +11% for the Northern and Southern Hemispheres, respectively. These differences are not large enough to warrant correcting previously reported inventories.

Sr-90, Zr-95 and Cs-137 Inventories

The stratospheric concentration contours for Sr-90 in February 1971 and for Sr-90, Zr-95 and Cs-137 in May and July 1971 are illustrated in Figures 1 through 7. The inventories at collection time which are computed from these contours and from the contours dating back to August 1970 which were reported earlier (4) are presented in Table 1. There are small changes (<15%) in some of the previously reported August and November 1970 inventories as a result of slight improvements in some of the contours. Figure 8 reflects the hemispheric and total stratospheric burdens of Sr-90 from 1963 to mid 1971.

The stratospheric reaction to the large atmospheric nuclear tests since 1967 is clearly seen in Figure 8 by the typical inventory excursions after such events. In the Northern

Hemisphere the latest documented increase in late 1970 and early 1971 was produced by the 3 MT Chinese detonation on October 14, 1970 (5).

In the Southern Hemisphere, the low yield French tests on June 5 and July 4, 1971 or more likely the intermediate yield test on June 12, 1971 (6) contributed radioactive debris to the lower stratosphere. This contribution can be seen, although not very dramatically, by the increases in the Sr-90 and Cs-137 concentration contours in the low equatorial stratosphere of the Southern Hemisphere between May and July 1971 (Figures 2, 4, 5 and 7). It can also be seen in the slight increase in inventory for Sr-90 and Cs-137 between May and July 1971 as shown in Table 1 and Figure 8. It can be clearly observed in the Zr-95 concentration contours and inventory in Figure 6 and Table 1, respectively.

Cs-137/Sr-90 Inventory Ratio

The Cs-137/Sr-90 ratio of nuclear weapon debris is an important parameter because it serves as a point of comparison among fallout research programs in which only one of these two nuclides is measured. Table 2 gives the ratios in each hemisphere for 1970 and 1971.

One can see from Table 2 that the mean Cs-137/Sr-90 inventory ratio for both hemispheres in 1970 and 1971 and for the total stratosphere since 1970 are all in good agreement with the theoretical production ratio of 1.44 (7).

Nuclear Test Injections

Earlier estimates of the Sr-90 injected into the stratosphere by the French tests of May 31 and July 4, 1970 and by the Chinese test of October 14, 1970 were based upon the Zr-95, Cs-137 and limited Sr-90 inventories of the November 3, 1970 and February 23, 1971 flights (4). More reliable calculations can now be made mainly because the Sr-90 inventory for the February 1971 mission is available.

The Sr-90 inventories in the Northern Hemisphere on 1/15/70, 5/8/70 and 8/17/70 are each corrected to 2/23/71 with a stratospheric half residence time of 10 months (8). The November 1970 mission in the Northern Hemisphere is not included in these calculations because the stratospheric distribution of Chinese debris at that time was localized over northern Europe. Therefore the November samples collected along the western coast of North America were not representative of a homogeneous stratosphere (4).

The resultant average is 101 kCi which is the Sr-90 residing in the stratosphere on 2/23/71 from all tests prior to the Chinese test of 10/14/70. Subtracting 101 kCi from the measured 246 kCi in Table 1 gives 145 kCi of Sr-90 as the amount from the 10/14/70 Chinese test residing in the Northern Hemisphere stratosphere on 2/23/71. Correcting this amount for fallout to shot date gives an injection estimate of 197 kCi Sr-90.

Performing similar calculations with the Zr-95 inventories provides 60 kCi of Zr-95 as the contribution from earlier tests on 2/23/71. Subtracting 60 from 8190 in Table 1, dividing by 226, the production ratio of Zr-95/Sr-90 (7) and correcting for fallout to shot date gives an injection estimate of 199 kCi of Sr-90 which agrees very well with the above Sr-90 inventories. These results are summarized in Table 3. This revised value of about 200 kCi Sr-90 is below the earlier injection estimate of 240 (4) mainly because the Cs-137/Sr-90 ratio of 1.32 which was used to calculate the earlier estimate of Sr-90 is less than the measured 1.59 ratio in the February 1971 mission (see Table 2).

Similar calculations employing the Zr-95 and Sr-90 inventories in the Southern Hemisphere during 1970 can be made for the two large French tests of May 31 and July 4 by assuming a hypothetical single test on 6/15/70. The mission of 8/17/70 is omitted in these calculations because the low inventories for that collection suggest that sufficient stratospheric mixing had not yet occurred since the last test of July 4. The results of these calculations are also presented in Table 3. The revised average of 240 kCi Sr-90 agrees well with the earlier estimate of 250 kCi (4).

If we assume that the fresh fission product debris observed in the Southern Hemisphere during the 7/21/71 mission came from the intermediate yield French test of 6/12/71 and that sufficient stratospheric mixing occurred in the interval between the shot and the mission, Table 3 also shows that about 40 kCi of Sr-90 was injected into the stratosphere by this test.

Table 1

Stratospheric Inventories, kCi

<u>Date</u>	<u>Northern Hemisphere</u>			<u>Southern Hemisphere</u>		
	<u>Sr-90</u>	<u>Zr-95</u>	<u>Cs-137</u>	<u>Sr-90</u>	<u>Zr-95</u>	<u>Cs-137</u>
8/17/70	113	671	172	226	15300	341
11/3/70	154	3520	204	246	8820	376
2/23/71	246	8190	391	163	2310	257
5/25/71	179	1920	249	128	572	170
7/21/71	112	671	168	144	6160	195

Table 2

Cs-137/Sr-90 Stratospheric Inventory Ratios

<u>Date</u>	<u>Northern Hemisphere</u>	<u>Southern Hemisphere</u>
5/8/70	1.35	1.44
8/17/70	1.52	1.51
11/3/70	1.32	1.53
1970 mean	1.40 ± 0.11	1.49 ± 0.05
2/23/71	1.59	1.58
5/25/71	1.39	1.33
7/21/71	1.50	1.35
1971 mean	1.49 ± 0.10	1.42 ± 0.14
Inclusive mean since 5/8/70	1.44 ± 0.11	1.46 ± 0.10
Inclusive mean of total stratosphere since 5/8/70		1.45 ± 0.10

Table 3

Nuclear Test Injections of Sr⁹⁰ (kCi) into
the Stratosphere

<u>Test</u>	<u>Mission</u>	-----Estimates Derived From-----		
		<u>Sr⁹⁰ Analyses</u>	<u>Zr⁹⁵ Analyses</u>	<u>Mean</u>
Chinese Test 10/14/70	2/23/71	197	199	198
French Test 6/15/70*	11/30/70	252	243	
	2/23/71	201	268	241
French Test 6/12/71	7/21/71	47	42	44

*Equivalent date of large tests conducted on 5/31 and 7/4/70.

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CONCENTRATION OF Sr-90 IN STRATOSPHERIC AIR

(PCI/100SCM)

FEBRUARY 23, 1971

Figure I

CONCENTRATION OF Sr-90 IN STRATOSPHERIC AIR
(PCI/100SCM)

MAY 25, 1971

Figure 2

CONCENTRATION OF Zr-95 IN STRATOSPHERIC AIR

(PCI / 100 SCM)

MAY 25, 1971

Figure 3

CONCENTRATION OF Cs-137 IN STRATOSPHERIC AIR

(PCI/100 SCM)

MAY 25, 1971

Figure 4

CONCENTRATION OF Sr-90 IN STRATOSPHERIC AIR

(PCI/100 SCM)

JULY 21, 1971

Figure 5

CONCENTRATION OF Zr-95 IN STRATOSPHERIC AIR

(PCI/100SCM)

JULY 21, 1971

Figure 6

CONCENTRATION OF Cs -137 IN STRATOSPHERIC AIR

(PCI/100SCM)

JULY 21, 1971

Figure 7

STRATOSPHERIC INVENTORY of Sr-90

Figure 8

B

11 ✓
STRONTIUM-90 IN HUMAN BONE :
- 1971 Results for New York City and San Francisco -

by B. G. Bennett (HASL)

ABSTRACT

Results are presented of determinations of Sr-90 content of 254 specimens of human vertebrae obtained during 1971 in New York City and San Francisco. The average Sr-90 to Ca ratios for adult vertebrae, .80 pCi/g Ca in San Francisco and 1.40 pCi/g Ca in New York represent 7 to 10% decreases from average values of the previous year. Average Sr-90 concentrations in children's bone were somewhat higher than the adult values. An improved bone model has been formulated to describe the variations in Sr-90 content of bone and provide correlation with dietary Sr-90 intake. The two compartment model accounts for both short and long term retention of Sr-90 in bone. Regression analysis of the 11 years of survey data provides values of the relative retention of dietary Sr-90 and the effective bone turnover rate. These parameters of the bone model are constant for adults but age dependent for children. The bone model gives satisfactory description of observed bone Sr-90 levels and allows reliable assessment of the long-term behavior of Sr-90 in man.

Human vertebrae specimens obtained in New York City and San Francisco have been analyzed by HASL for Sr-90 content since 1961⁽¹⁻⁷⁾. The sampling during this 11-year period of varying Sr-90 fallout deposition at these locations provides valuable records of variations in Sr-90 content of bones of children as well as adults. A food sampling program to determine total Sr-90

in the diet of residents of the two cities has also been conducted by HASL during this same time period, so that correlations between Sr-90 intake and bone concentrations can be determined. More accurate description of the long-term behavior of Sr-90 in bone is achieved as the sampling programs continue.

Results for 1971

During 1971, 254 specimens of human vertebrae were analyzed, including 56 from children and 37 from adults obtained in New York City and 91 from children and 70 from adults obtained in San Francisco. A summary of the results of Sr-90 determinations are given in Table 1. The individual analyses are listed in Tables 2 and 3 and are plotted in Figures 1 and 2.

The Sr-90 to Ca ratios for adults are relatively constant, as has previously been observed. The variations about the mean are typical of such survey measurements. The average values and standard deviations for adult vertebrae in 1971 were $1.40 \pm .37$ pCi/gCa in New York and $.80 \pm .35$ pCi/gCa in San Francisco.

The Sr-90 to Ca ratios for children's bone show more variation than the adult values. Generally higher values are

Figure 1 - Sr^{90} in New York Vertebrae - 1971

Figure 2 - Sr^{90} in San Francisco Vertebrae - 1971

obtained for children than adults, but most values are within a factor of $1\frac{1}{2}$ to 2 of the adult values. The highest value measured in New York vertebrae during 1971 was 3.25 pCi/gCa for a $1\frac{1}{2}$ year old child and in San Francisco 2.53 pCi/gCa for a 5 year old child. The approximate average values of Sr-90 concentration have been indicated in Figures 1 and 2.

The higher Sr-90 concentration values in New York bone correspond to greater dietary Sr-90 intake. The Sr-90 to Ca ratios in total diet in New York and San Francisco during 1971 were 12.6 pCi/g Ca and 3.9 pCi/g Ca, respectively (8). The corresponding changes in these ratios in diet from the previous year were a 5% increase in New York and a 7% decrease in San Francisco.

The usual practice in correlating the Sr-90 levels in bone and diet is to refer the skeletal levels during the year n to the dietary Sr-90 intake from mid year of the year n-1 to mid year of the year n. Deaths in the early part of the year are then not compared with diet levels not yet experienced. Table 4 lists the diet results based on consumption estimates specific to the particular urban regions.

Bone Model

An improved bone model has been formulated to correlate the Sr-90 concentrations in diet and bone. The model as it applies to adult vertebrae is described by the equation

$$B_n = cD_n + g \sum_{m=0}^{\infty} D_{n-m} e^{-m\lambda}$$

where

B_n = ^{90}Sr concentration in vertebrae in the year n (pCi)

D_n = ^{90}Sr concentration in diet from mid year in the year $n-1$ to mid year in the year n (pCi)

c = short-term retention of ^{90}Sr in bone

g = long-term " " " " "

$1 - e^{-\lambda}$ = bone turnover rate plus radioactive decay (yr^{-1})

The formula describes a two compartment model, one compartment associated with short-term retention of Sr on bone surfaces and another compartment in which the Sr is more tightly retained in bone. The parameters c and g are independent and not related to the previously used concept of Observed Ratio, since retention can also be associated with processes other than new bone formation. The factors c , g , and λ are constant for adults ($\geq$ age 20 years) but are age dependent for children.

Variations of the above bone model were investigated, such as the inclusion of an exponential in the short-term retention term. The best fit in this form, however, was with a very high order exponential, indicating essentially complete turnover of the short-term component during the course of a year.

The above formula for the bone model maintains a desired simplicity and yet gives adequate description of the year-to-year changes in Sr-90 content of bone. The values obtained for the model parameters allow reasonable interpretation.

⁹⁰Sr in Adult Vertebrae

The observed Sr-90 concentrations in adult vertebrae are shown in Figure 3. Additional approximate values for the earliest years of contamination (1954-59) in New York from the data of Kulp and Schulert(9) have also been included. The adult data include only samples from individuals age 20 years or older in 1954, thus representing adult metabolism for the entire contamination period.

A definite decreasing trend in the observed values is apparent since 1965, corresponding to decreases in dietary Sr-90 intake. The relatively large standard deviations about the

Figure 3. ^{90}Sr in adult vertebrae - observations (points with standard deviations) and bone model predictions (solid lines)

average values preclude extremely accurate determination of the actual decreases and thus the bone turnover rates, however these are becoming more firmly established as additional years of data accumulate during periods of decreasing Sr-90 levels in diet.

From regression analysis of the measured New York adult diet and vertebrae values through 1970 in the above bone model, one infers a turnover rate of 13% per year for adult vertebrae. This value also fits the 1971 result within the standard deviation, but based on least squares criteria from the average observed values, a turnover rate of 18% per year is more appropriate for the data through 1971. This latter value also gives the best fit to the San Francisco data through 1971. These best fits to the observed data using the bone model are shown in Figure 3. The values of the bone model parameters are included in Table 5.

The model shows peak Sr-90 concentrations in adult vertebrae in 1965, in agreement with observations. Subsequent decreases are achieved with a turnover rate which is reasonable, in view of the remodeling and diffusion processes occurring in bone.

The bone model appears to be quite responsive to Sr-90 levels in diet and gives very satisfactory fits to the observed Sr-90 levels in vertebrae.

⁹⁰Sr in Children's Bone

The Sr-90 concentration in children's bone can be determined by the formula

$$B_{i,n} = (c_i + g_i) D_{i,n} + [B_{i-1,n-1} - c_{i-1} D_{i-1,n-1}] e^{-\lambda_i}$$

The bone model parameters are defined as before. The subscript i indicates the age dependence.

For the newborn, the Sr-90 concentration can be related empirically to the mother's diet. The Sr-90 to Ca ratio in bone of newborn varies from .1 to .2 times the Sr-90 to Ca ratio in diet of the mother during the year prior to the birth. An average of about .16 is obtained from the survey data.

From the regression results for children, one infers that a one compartment, single exponential model ($c_i = 0$) applies to children under age 8 years. The one compartment formulation of the above model closely corresponds to the previously used Rivera bone model⁽¹⁾. The undifferentiated nature of bone of young children

and the relatively high turnover rates justify the one compartment treatment.

The turnover rates and relative retention as a function of age are shown in Figures 4 and 5 and are listed in Table 5. The turnover rates reflect bone growth activity and are highest for the youngest children. Nearly 100% per year turnover rate is indicated for the 0 - 1 year age range. A relatively high turnover rate, about 40%, is maintained through the pre-teenage years. The values then decrease to the adult value.

The relative retention of Sr-90 in bone, shown in Figure 5, is the fractional retention of the dietary Sr-90 intake ($c_i + g_i$) per gram of skeletal calcium. The highest efficiency for Sr-90 retention is obtained for the youngest children. Increased efficiency associated with increased growth is also indicated for children in the early teenage years.

The magnitude of the relative retention was determined by assuming that vertebrae is representative of entire skeletal behavior. This assumption becomes less satisfactory for older children and adults. Initial estimates of body burden will be

Figure 4. Turnover rates for vertebrae inferred from the two component bone model.

Figure 5. Retention of ^{90}Sr per gram skeletal Ca. The upper histogram is the total relative retention, c_i is the short-term component and g_i the long-term component.

high and estimates at later times will be low, assuming less initial retention and slower turnover rates for compact bone. Integral results should be more representative for the entire skeleton, such as the cumulative dose results following a period of Sr-90 intake of one year or more.

Several such analyses involving application of the bone model, including the dose to age 70 following a short period of intake for an NCRP study and the dose commitment from Sr-90 due to nuclear weapons testing for the United Nations Scientific Committee on the Effects of Atomic Radiation, have already been performed.

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TABLE 1

STRONTIUM-90 TO CALCIUM RATIOS IN HUMAN VERTEBRAE
SUMMARY OF 1971 DATA

Age range at death	New York		San Francisco	
	No. of Specimens	pCi ⁹⁰ Sr/qCa	No. of Specimens	pCi ⁹⁰ Sr/qCa
0-1 mo			56	0.68
0-4 mo			9	0.72
1-2 mo	4	1.90		
2-3 mo			3	1.28
2-4 mo	4	2.41		
5-13 mo			2	1.65
1-2 yr	1	3.25	3	1.81
2-3 yr	2	1.74	1	1.16
3-4 yr	2	2.65	3	1.47
4-5 yr	3	2.00	3	1.43
5-6 yr	2	2.28	2	1.74
6-7 yr	1	2.30	1	0.61
7-8 yr			1	1.62
8-9 yr	1	2.52		
9-10 yr	1	1.99	2	0.53
10-11 yr			1	0.69
11-12 yr	1	2.01	1	0.81
13-14 yr	3	2.42		
14-15 yr	3	2.13	1	1.46
15-16 yr	2	2.30		
16-17 yr	4	2.43		
17-18 yr	7	1.89		
18-19 yr	11	1.90	2	0.94
19-20 yr	5	1.71		
20-30 yr	11	1.63	3	1.22
30-40 yr	9	1.44	7	0.98
40-50 yr	4	1.42	10	0.69
50-60 yr	4	1.15	19	0.74
60-70 yr	3	1.34	18	0.86
70-80 yr	4	1.38	11	0.87
80-90 yr			2	0.95
90-100 yr	2	1.76		
<u>Adult</u>				
≥ age 20 in 1971	37	1.46	70	0.83
≥ age 20 in 1954	19	1.40	62	0.80

TABLE 2

STRONTIUM-90 TO CALCIUM RATIOS IN HUMAN VERTEBRAE
NEW YORK - 1971

Age at death	HASL No.	No. of Specimens	pCi ⁹⁰ Sr/qCa	Age at death	HASL No.	No. of Specimens	pCi ⁹⁰ Sr/qCa
1-2 mo	HB4433	2	1.73	18 yr	HB4448	1	1.95
	HB4506	2	2.07		HB4449	1	1.19
					HB4450	1	2.18
2-4 mo	HB4434	3	2.19		HB4528	1	2.02
	HB4507	1	3.05		HB4529	1	1.92
					HB4530	1	2.92
1-2 yr	HB4435	1	3.25		HB4531	1	2.66
					HB4532	1	0.61
2 yr	HB4436	1	1.56		HB4533	1	1.78
	HB4508	1	1.91		HB4534	1	2.15
					HB5189	1	1.50
3 yr	HB4437	1	2.53	19 yr	HB4451	1	2.75
	HB4509	1	2.76		HB4452	1	1.36
					HB4453	1	1.18
4 yr	HB4438	1	2.53		HB4535	1	1.24
	HB4510	1	1.80		HB4536	1	2.03
	HB4511	1	1.67				
5 yr	HB4439	1	2.53	20-30 yr	HB4454	1	1.37
	HB4512	1	2.03		HB4537	1	1.35
					HB4538	1	1.41
6 yr	HB4513	1	2.30		HB4539	1	1.93
					HB4540	1	1.91
8 yr	HB4440	1	2.52		HB4541	1	1.54
					HB4542	1	1.58
9 yr	HB4514	1	1.99		HB4455	1	1.87
					HB4543	1	2.07
11 yr	HB4515	1	2.01		HB4456	1	1.45
					HB5188	1	1.44
13 yr	HB4516	1	2.04	30-40 yr	HB4544	1	1.61
	HB4517	2	2.61		HB4457	1	1.29 1.39*
14 yr	HB4518	1	2.09		HB4545	1	1.63
	HB4519	1	2.35		HB4546	1	1.85
	HB4520	1	1.91 2.01*		HB4547	1	1.52
					HB5207	1	0.84
15 yr	HB4441	1	1.70 1.91*		HB5176	1	1.65
	HB4522	1	2.79		HB5191	1	0.97
					HB5186	1	1.61
16 yr	HB4442	1	2.53	40-50 yr	HB4548	1	1.01
	HB4443	1	2.01		HB4549	1	1.20
	HB4523	1	2.08		HB5206	1	2.24
	HB4524	1	2.35		HB5197	1	1.22
17 yr	HB4444	1	1.82	50-60 yr	HB4550	1	1.28
	HB4445	1	2.40		HB4551	1	1.12 1.14*
	HB4446	1	1.90		HB5193	1	1.05
	HB4447	1	2.12		HB5182	1	1.12
	HB4525	1	1.70	60-70 yr	HB4552	1	1.24
	HB4526	1	1.37		HB4553	1	1.24
	HB4527	1	1.91		HB5149	1	1.53
*blind duplicate analysis				70-80 yr	HB4458	1	2.04
					HB4459	1	1.00
					HB4460	1	1.34
					HB4554	1	1.05
				90-100 yr	HB4555	1	1.89
					HB4556	1	1.62

TABLE 3

STRONTIUM-90 TO CALCIUM RATIOS IN HUMAN VERTEBRAE
SAN FRANCISCO - 1971

Age at death	HASL No.	No. of Specimens	pCi $^{90}\text{Sr}/\text{qCa}$	Age at death	HASL No.	No. of Specimens	pCi $^{90}\text{Sr}/\text{qCa}$
0-1 mo	HB4465	5	0.94	20-30 yr	HB4479	1	0.85 1.07*
	HB4466	7	0.67		HB4480	1	1.50
	HB4467	5	0.86		HB4481	1	1.20
	HB4468	6	0.88				
	HB4469	3	1.02	30-40 yr	HB4482	1	0.95
	HB4615	8	0.49		HB4483	1	0.77
	HB4616	6	0.56		HB4565	1	0.69
	HB4617	4	0.44		HB4566	1	1.82
	HB4618	5	0.51		HB4567	1	0.69 0.66*
	HB4620	7	0.61		HB4568	1	0.66
					HB4484	1	1.06 1.26*
0-4 mo	HB4621	9	0.72	40-50 yr	HB4569	1	0.41
2-3 mo	HB4470	3	1.28		HB4570	1	0.36
					HB4571	1	0.72
5-13 mo	HB4471	2	1.65		HB4572	1	0.49
1-2 yr	HB4472	1	2.19		HB4573	1	0.57
	HB4473	1	1.24		HB4574	1	0.68
	HB4622	1	2.01		HB4485	1	0.78
2-3 yr	HB4474	1	1.16		HB4486	1	0.63
					HB4575	1	0.47
3-4 yr	HB4623	1	1.22		HB4487	1	1.81
	HB4624	1	2.31	50-60 yr	HB4576	1	0.83
	HB4625	1	0.88		HB4577	1	0.72
4-5 yr	HB4626	1	1.23		HB4578	1	1.05
	HB4475	1	0.83		HB4579	1	0.63
	HB4476	1	2.23		HB4580	1	0.34
5-6 yr	HB4627	1	0.95		HB4581	1	0.62
	HB4628	1	2.53		HB4583	1	0.58
6-7 yr	HB4477	1	0.64 0.57*		HB4582	1	0.85 0.85*
					HB4584	1	0.54
7-8 yr	HB4629	1	1.62		HB4585	1	1.02
					HB4586	1	0.56
9-10 yr	HB4630	1	0.44		HB4488	1	0.96
	HB4631	1	0.62		HB4489	1	0.79
10-11 yr	HB4632	1	0.69		HB4587	1	1.17
11-12 yr	HB4561	1	0.81		HB4588	1	0.43
14-15 yr	HB4652	1	1.46		HB4589	1	0.78
18-19 yr	HB4563	1	1.03		HB4590	1	0.58
	HB4564	1	0.85		HB4591	1	0.61
					HB4612	1	0.97

*blind duplicate analysis

TABLE 3 (Cont'd)

Age at death	HASL No.	No. of Specimens	pCi $^{90}\text{Sr}/\text{qCa}$	Age at death	HASL No.	No. of Specimens	pCi $^{90}\text{Sr}/\text{qCa}$
60-70 yr	HB4599	1	0.77	60-70 yr	HB4592	1	0.58
	HB4600	1	1.09		HB4593	1	1.26
	HB4601	1	0.47		HB4594	1	0.54
	HB4602	1	0.92		HB4490	1	0.71
	HB4603	1	0.85		HB4491	1	1.20
	HB4604	1	0.85		HB4492	1	1.05
70-80 yr	HB4606	1	0.56		HB4595	1	1.42
	HB4607	1	0.75		HB4596	1	0.79
	HB4608	1	1.05		HB4597	1	0.47
	HB4609	1	0.50		HB4598	1	0.69
	HB4495	1	1.18		HB4493	1	0.94
	HB4496	1	1.07		HB4494	1	0.86
	HB4497	1	0.74				
	HB4498	1	0.94				
	HB4499	1	0.68				
	HB4500	1	1.10				
	HB4610	1	1.00				
80-90 yr	HB4611	1	1.02				
	HB4501	1	0.88				

Table 4

Dietary ^{90}Sr Intake¹

<u>Year</u>	<u>New York²</u>		<u>San Francisco³</u>	
	<u>per capita</u>	<u>adult</u>	<u>per capita</u>	<u>adult</u>
1954	1.0	1.0		
55	1.9	2.0		
56	5.0	5.2		
57	5.5	5.7		
58	6.4	6.6		
59	13.5	13.9		
60	13.7	14.1		
61	10.5	10.8	3.6	3.7
62	9.2	9.4	4.1	4.3
63	19.6	19.8	9.4	9.6
64	30.3	30.5	13.8	14.2
65	26.6	27.4	11.6	11.8
66	21.3	22.0	8.3	8.7
67	15.7	16.4	6.3	6.6
68	14.7	15.4	4.0	4.2
69	13.0	13.5	4.3	4.5
70	12.2	12.6	3.9	4.2
71	12.3	12.8	4.4	4.6

¹ Estimates (pCi/gCa) are for mid year of the previous year to mid year of the year listed. 1954-59 values are estimated from milk data(10). 1960-71 values are results of the HASL Quarterly Diet Sampling Program.

² Urban N.E. consumption statistics(11)

per capita milk consumption = 136 kg/yr

adult milk consumption = 93 kg/yr

³ Urban West consumption statistics(12)

per capita milk consumption = 108 kg/yr

adult milk consumption = 74 kg/yr

Table 5

Parameters of the Bone Model

Age (yr)	λ_i	c_i	g_i	Skeletal Calcium Cai (gCa)	Dietary Calcium D Cai (gCa/yr)	Relative Retention ($c_i + g_i$)/Cai ($\times 10^{-3}$)	Turnover Rate ($1 - e^{-\lambda_i}$) $\cdot .024$ (%/yr)
0-1	5.8	0	.076	100	320	.76	97
1-2	.89	0	.073	147	328	.50	57
2-3	.76	0	.067	179	336	.38	51
3-4	.67	0	.054	201	344	.27	46
4-5	.56	0	.046	219	352	.21	41
5-6	.57	0	.047	239	360	.20	41
6-7	.60	0	.050	264	368	.19	43
7-8	.60	0	.059	297	376	.20	43
8-9	.60	.007	.061	341	384	.20	43
9-10	.54	.029	.052	396	387	.20	39
10-11	.45	.045	.057	463	387	.22	34
11-12	.33	.052	.066	539	387	.22	26
12-13	.28	.043	.090	624	387	.21	22
13-14	.29	.029	.110	715	387	.19	22
14-15	.32	.039	.105	806	387	.18	25
15-16	.32	.035	.122	894	387	.18	25
16-17	.29	.043	.100	973	387	.15	23
17-18	.27	.051	.094	1039	376	.14	22
18-19	.26	.058	.083	1073	365	.13	20
19-20	.24	.063	.069	1078	354	.12	19
Adult	.23	.070	.054	1078	342	.12	18

E

STRONTIUM-90 FALLOUT IN UTAH

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ABSTRACT

The annual deposition rate of Sr-90 (mCi per km² per year) derived from monthly precipitation samples is the same at Salt Lake City and New York City from 1957 to 1971. Sr-90 deposition concentrations (mCi per km² per cm of rain) based on soil analyses up to 1971 are higher in Salt Lake City and other regions of Utah than in other areas of the United States. These data along with Sr-89 to Sr-90 ratios at appropriate sampling locations indicate that the stratosphere is the major source of Sr-90 fallout in Salt Lake City, although about 16 mCi per km² or 10 percent of the Sr-90 debris probably came from activities at the Nevada Test Site prior to 1957.

A limited topographic study in Utah in 1971 indicated that the highest Sr-90 deposition concentrations were found at sites closest to the windward side of a mountain front whereas the lowest concentrations were found at high elevation sites within the mountain range. However, we believe that topography plays a minor role and that preferential stratospheric intrusions are more likely the cause of the high deposition concentrations in Utah.

INTRODUCTION

One objective of the Health and Safety Laboratory and responsibility of the Atomic Energy Commission is to document the build-up of long-lived radioactivity from atmospheric nuclear testing on

a global basis, to observe the geographical distribution of nuclear debris, and to make reasonable estimates of the global deposit at various times. In the late 1950's the Health and Safety Laboratory established over 100 sites in the United States and overseas to collect precipitation and dry fallout. The monthly samples are sent to our laboratory for analysis of radiostrontium. This program is still continuing and the data are reported regularly in the HASL Fallout Program Quarterly Summary Reports(1). Several years earlier, with the cooperation of the U. S. Department of Agriculture, Soil Conservation Service, HASL began a soil sampling program to measure the integrated deposit of Sr-90(2). Although soil sampling is no longer carried out routinely on a global scale, these two programs have provided the major input for describing the geographical distribution of fallout from weapons tests.

In 1957 monthly fallout collections were begun in Salt Lake City at the Western Area Occupational Health Laboratory. A year later, a soil sampling site was selected near the University of Utah, about 4 miles north of the monthly fallout collector. Soil samples have been taken at this site at various times since.

Over the years we have observed that the Sr-90 fallout rate and the accumulated deposit in Salt Lake City have been similar to the fallout in New York City. We have been intrigued by this observation because the mean annual precipitation in Salt Lake City is less than half of that in the New York City area. In general our global network has shown that the amount of fallout is roughly proportional to the amount of rainfall for sites within the same ten degree band of latitude⁽²⁾. We would have expected to measure substantially lower Sr-90 fallout in Salt Lake City due to the drier climate.

Following the establishment of a soil sampling site near the University of Utah, other soil sites were selected in Utah and sampled at various times over the next 10 years. Although the University site always showed the highest fallout, other areas near the Great Salt Lake were higher than expected based on the amount of rainfall.

Finally, in June 1971, we collected 13 soil samples in eastern and north central Utah in an attempt to find out how variable the Sr-90 fallout was in other regions of the state. This paper summarizes what we know about the fallout history based on the rate measurements in Salt Lake City and the cumulative deposits determined from soil sampling.

Sr⁹⁰ FALLOUT RATES

Monthly Sr-90 fallout sampling has been carried out in New York and Salt Lake City since 1957. The annual sums for these two sites are plotted in Figure 1. There is a striking similarity in fallout pattern from both a qualitative and quantitative standpoint. The influence of the large scale United States and Soviet weapons tests conducted up to 1959 and then in 1961 and 62 is clearly evident at both sites. In Figure 2 we have accumulated the annual values for both cities and plotted them on the same graph. It is clear that the Sr-90 fallout has been practically identical over the period from 1957 through 1971. Because it has been demonstrated that the fallout in New York is related to the stratospheric burden of radioactive debris injected outside the conterminous United States(3) by high yield nuclear weapons tests it follows that the fallout in Salt Lake City must have an identical origin since 1957.

Further evidence that global fallout was the source of Sr-90 deposition in Salt Lake City during the '57-'71 period can be demonstrated by comparing the Sr-89 to Sr-90 ratios in Salt Lake City with the average ratios for our monthly fallout sites in the 50 - 30 degree north latitude band. The 50 day half-life Sr-89

Figure 1

ANNUAL Sr-90 FALLOUT RATE

Figure 2

CUMULATIVE MONTHLY Sr-90 FALLOUT FOR SALT LAKE CITY —
AND NEW YORK CITY ---- (1957-71)

has been measured in our monthly fallout samples during periods of weapons testing. The available monthly data plotted in Figure 3 show remarkably coincident fluctuations. There are 102 pairs of Sr-89 to Sr-90 ratios for Salt Lake City and the 50 - 30 degree latitude band. We used a t-test to show that the average difference between the 102 pairs of data was not significantly different from zero. Fluctuations in this ratio can be correlated with the major U. S. and U.S.S.R. weapons tests series conducted through 1962 and with the Chinese tests since 1964. Most of the above-ground tests at the Nevada Test Site were carried out before 1959 and so it also seems clear that resuspension from NTS has not influenced Sr-90 fallout in the Salt Lake City area during the '57 through '71 period.

Examination of the cumulative fallout or soil measurements that have been made in Salt Lake City and other areas sheds some light on the fallout history prior to 1957.

REPETITIVE SOIL SAMPLING

Figure 4 shows the locations of soil sites in Utah that have been sampled at various times by the Soil Conservation Service for HASL. The location of the Nevada Test Site is also shown. The soil Sr-90 values for these sites and New York City

Figure 3

Figure 4

for comparison are presented in Table 1 (4).

The Utah data are plotted as a function of time in Figure 5. The cumulative Sr-90 deposit is always highest at the University of Utah site. The Brigham and Heber sites are about 15 percent and 35 percent lower, respectively, although the mean annual precipitation for the three sites is similar. The temporal build-up of Sr-90 fallout shows a similar pattern for these three sites; a steep increase following the U. S. and U.S.S.R. nuclear tests in 1961-62 and then a plateau after 1965. The effect of Chinese testing since 1966 has been very slight, probably just balancing the decay of Sr-90. The cumulative deposit of Sr-90 at Cedar City was about 1/3 of that at the University of Utah.

Figure 6 compares the University of Utah and New York soil data. Considering that the probable error of sampling and analysis is $\pm 10\%$ (5), it appears that the rate of increase, at the two sites is very similar from 1959-1971, but that the University of Utah site is higher by a constant 10-15 mCi per km². This observation is partially confirmed by monthly fallout rate measurements which have demonstrated identical deposition at the two sites since 1957 (Figures 1 and 2).

Table 1
Sr⁹⁰ in Soil at Sampling Sites in Utah and New York City

Year	- Month -		----- millicuries Sr ⁹⁰ per km ² -----				
	Utah Sites	N. Y.	Salt Lake City* (41)†	Brigham City (46)†	Heber City (37)†	Cedar City (23)†	New York City (99)†
1958	Nov		29				
1959	Oct.	Aug.	39				25
1960	Oct.	Sept.	38				25
1962	Oct.		49	48	27		
1963	Aug.	Oct.	74			32	56
1964	Sept.	Dec.	101	93	63	34	70
1965	Sept.		104	91	69	38	
1967		June					85
1970		Sept.					98
1971	June		109	92	71		

*Univ. of Utah Site

†Mean annual precipitation (cm)

Figure 5

CUMULATIVE DEPOSIT OF Sr-90 AT 4 UTAH SITES
 FROM SOIL ANALYSES

Figure 6

CUMULATIVE DEPOSIT OF Sr-90 IN SALT LAKE CITY AND
 NEW YORK FROM SOIL ANALYSES

SOURCES OF Sr-90 FALLOUT

We can summarize the discussion up to this point as follows:

1. The amounts of Sr-90 fallout in Salt Lake City and New York from 1957 through 1971 were practically identical. This implies that the fallout in the two areas must have originated from the same global source of debris. 2. The cumulative Sr-90 fallout as measured in soil samples from the University of Utah is 10 - 15 mCi per km² higher than the cumulative Sr-90 fallout as measured in New York City soil. The implication here is that Salt Lake City area must have received Sr-90 fallout from another source, presumably the Nevada Test Site, prior to 1957. We can calculate this excess fallout in Salt Lake City in the following way: from the smoothed curve soil data in Figure 6 the incremental deposit between 1959 and 1971 is 73 and 78 mCi per km² for Salt Lake City and New York, respectively. Because the cumulative deposit in New York in 1959 which is 21 mCi per km² represents global fallout, by simple proportion it follows that the global fallout contribution in Salt Lake City in 1959 must have been about 20 mCi per km². Then by subtracting 20 from the 36 mCi/km² measured in Salt Lake City in 1959 the 16 mCi/km² difference must represent Sr-90 fallout from another source which we presume to be the Nevada Test site.

This amounted to 45 percent of the total deposit in 1959 but only 11% in 1971. We can then reconstruct the cumulative Sr-90 fallout history in Salt Lake City as shown in Figure 7.

It is possible that a substantial fraction of the Sr-90 fallout at Cedar City originated from the Nevada Test Site. Figure 5 showed a time trend during 1963 through 1965 that was quite different from that observed at the other three Utah sites. Cedar City was also sampled by the Soil Conservation Service in 1957 and at that time the cumulative Sr-90 deposit was 14 mCi per km² (4). This was relatively high for such a dry area since New York City fallout in 1957 was only 12 mCi per km² (6).

TOPOGRAPHICAL STUDY

The question still remains as to why the amount of global fallout in Salt Lake City is unexpectedly high relative to higher rainfall areas such as New York. There are a number of possible explanations which we shall discuss later. We felt however, that cumulative fallout levels were needed in other regions of Utah to determine the geographical extent of this phenomenon. Soil samples were collected at thirteen sites in Utah during June 1971. Figure 8 shows the locations of these sampling sites. The predominant topographic features of the state are shown by the cross-hatched altitude contours. Five sites were sampled west of the

Wasatch range (Nos. 1 through 5), four in valley areas east of Salt Lake City (Nos. 6 through 9), and one at relatively high elevation in the Uinta mountains (No. 10). We also collected samples near Moab in southeastern Utah about 200 miles from Salt Lake City. Site No. 11 is in the dry Spanish Valley, site No. 12 is at higher elevation in the Manti-Lasal National Forest, and site No. 13 is in a valley area to the southeast of the mountains. Sites 3, 5, and 6 at the University of Utah, Brigham, and Heber were the same as those sampled previously. Figure 9 shows the location of Site 2 where soil was sampled for the first time at Liberty Park in Salt Lake City. This site is about 2 miles southwest of the University site and about 500 feet lower in elevation. The location of the HASL monthly fallout collector is also shown.

The soil samples were collected and analyzed for Sr-90 using procedures already described (7). We sampled to a depth of 30 cm to insure that all of the fallout Sr-90 was included. Duplicate samples were taken at the University of Utah site and the analytical results reflect the overall sampling and analytical reproducibility. Table 2 shows that the cumulative Sr-90 deposit was measured at this site with a precision of 3.7 per cent. Duplicate aliquots of single soil samples were also analyzed

Figure 9

SALT LAKE CITY SHOWING LOCATIONS OF
SOIL AND MONTHLY SAMPLING SITES

Table 2

DUPLICATE SOIL SAMPLES
Univ. of Utah Site 1971

Sample	mCi per km ²	
	<u>Sr⁹⁰</u>	<u>Cs¹³⁷</u>
1	107	170
2	111	150
Deviation	3.7%	12.5%

blind and the average reproducibility for 5 sets was 4.3 per cent as can be seen in Table 3. The Sr-90 analyses were carried out at HASL. The samples were also analyzed for Cs-137 by Ge-Li diode spectrometry at HASL. The Sr-90 and Cs-137 results for these soils sampled in 1971 are presented in Table 4.

Except for Sites 1 and 11, the Cs-137 to Sr-90 ratios are within the range expected for fallout (8). The measured Sr-90 deposition for Site 1 was much too low based on the Cs-137 assay. The soil was found to be highly calcareous and, based on past experience, it was reasonable to assume that a significant amount of the total Sr-90 deposited, had moved downward below the 30 cm sampling depth (9). Therefore a Sr-90 value was calculated for Site 1 based on an assumed Cs-137 to Sr-90 ratio of 1.5.

REGIONAL VARIATIONS IN Sr-90 FALLOUT

The accumulated Sr-90 deposits at the five sites west of the Wasatch mountains range from 86 mCi per km² at Liberty Park in Salt Lake City to 180 mCi per km² in the Cache National Forest near Ogden. Dividing by the mean annual precipitation for each site, the average concentration for these five locations is 2.5 ± 0.6 mCi per km² per cm. This is a markedly higher Sr-90 deposit per unit of rainfall than is found at other sites in the

Table 3
BLIND DUPLICATE ANALYSES FOR Sr^{90}
1971 Utah Soils

<u>Location</u>	<u>Aliquot</u>	<u>Wt. (g)</u>	<u>mCi Sr⁹⁰ per km²</u>	<u>Deviation</u>
Heber	1	100	72	2.8%
	2	200	70	
Univ. Utah-1	1	100	110	5.6%
	2	200	104	
Univ. Utah-2	1	100	112	1.8%
	2	200	110	
Lib. Pk-SLC	1	100	87	3.5%
	2	200	84	
Brigham	1	100	88	7.6%
	2	200	95	
Avg. % dev.				4.3%

Table 4
CUMULATIVE DEPOSIT OF Sr^{90} AND Cs^{137}
in 1971 Utah Soils

Map Site No.	Location	Site	Mean ann. precip. (cm)	Alt. (ft.)	Lat. °N	Long. °W	mCi per km ² Sr ⁹⁰ Cs ¹³⁷		ratio Cs ¹³⁷ Sr ⁹⁰	mCi Sr ⁹⁰ per km ² per cm
SITES WEST OF THE WASATCH MTNS										
1	Provo	Utah State Hospital	39	4600	40.2	111.6	93*	140	1.5	2.4
2	Salt Lake City	Liberty Park	39	4300	40.8	111.9	86	140	1.6	2.2
3	Salt Lake City	Univ. of Utah	41	4800	40.8	111.8	110	160	1.4	2.7
4	Ogden	Cache Nat'l Forest	53	5200	41.2	111.9	180	240	1.3	3.4
5	Brigham	Tabernacle	46	4500	41.5	112.0	92	150	1.6	2.0
VALLEY AREAS EAST OF SALT LAKE CITY										
6	Heber	Tabernacle	37	5600	40.5	111.4	71	100	1.4	1.9
7	Marion	Cemetery	63	6600	40.7	111.2	150	180	1.2	2.4
8	Wanship	Rockport Lake	42	6100	40.8	111.4	93	150	1.6	2.2
9	Henefer	Meadow	38	5500	41.0	111.5	83	150	1.8	2.2
MOUNTAIN AREA										
10	Uinta Mtns.	Trial Lake	76	9500	40.7	110.9	79	130	1.6	1.0
MOAB AREA										
11	Spanish Valley	B.L.M. area	20	5300	38.4	109.4	67	150	2.2	3.4
12	Manti Lasal N.F.	Geyser Pass	81	9500	38.5	109.3	83	160	1.9	1.0
13	Manti Lasal N. F.	Lasal G. S.	41	7400	38.4	109.2	75	89	1.2	1.8

*measured value was 59 mCi Sr^{90} per km^2 (see text)

United States as shown in Figure 10. These other U. S. soil samples were taken in the fall of 1970 and the data presented in another HASL report (10). Site 4 is nearly 1000 ft. above the Ogden commercial area and is located on the slope of the mountains. The Sr-90 deposit and concentration are highest at this site.

The valley areas east of Salt Lake City range between 71 mCi per km² at Heber to 150 mCi per km² at Marion. The average deposition concentration for these 4 sites is 2.2 ± 0.2 mCi per km² per cm, which is not significantly different from the average of sites on the windward side of the mountains. The Sr-90 fallout at Marion is the highest of the valley sites. Marion is located in the Kamas Valley less than a half mile from the mountain front to the east.

Site 10 is well into the Uinta mountains some 3000 to 4000 feet higher in elevation than the valley sites. The precipitation is also higher at this site but the Sr-90 deposit is not proportionately higher. The concentration, 1.0 mCi per km² per cm, is about the same as New York.

These data indicate, in a qualitative way at least, that fallout per unit of precipitation increases as one approaches the western front of the mountains and diminishes as one ascends

Figure 10

CUMULATIVE mCi Sr-90/km² PER cm MEAN ANNUAL PRECIPITATION
(based on 1971 soil data and mean annual precip.)

to higher elevations. We decided to sample in the Moab area to find out if this behavior could be demonstrated in another region of the state. Site 11, located in the dry Spanish Valley on the windward side of the Manti Lasal mountains showed the highest Sr-90 deposit per unit of precipitation, 3.4 mCi per km per cm. Proceeding eastward into the mountains some 4,000 feet higher in elevation, the deposition concentration was only 1.0 mCi per km² per cm - the same value as found for site 10 in the Uinta mountains and for New York. On the leeward side of the mountains, site 13, the deposition concentration increased to 1.8 mCi per km² per cm.

DISCUSSION

We showed earlier that only about 10 percent of the present level of accumulated Sr-90 fallout in the Salt Lake City area can be attributed to contamination from the Nevada Test Site. Furthermore, this excess Sr-90 was delivered before 1957 which means that deposition since 1957 originated from the same source as global fallout, namely the stratospheric reservoir. Nevertheless, the amounts of global Sr-90 deposited in Salt Lake City and some other areas of Utah which we have investigated are high relative to the mean annual precipitation values.

One theory proposed (11) is that Salt Lake City represents an area which regularly receives precipitation from unpurified air masses while to the east, beyond the Wasatch mountain range, it is more likely that the air producing precipitation has been cleansed of nuclear debris. Thus, rainfall from a cloud passing over Salt Lake City would carry with it larger quantities of fission products than later rain from the same cloud as it is lifted over the mountains. The main point is that bomb debris particles are excellent condensation nuclei for water vapor condensation (12). When condensation and precipitation start in an air mass, most of the debris will be rapidly deposited. Further rain from this air mass would cause little increase in deposited radioactivity because the cloud is already purified to a high degree. Since Salt Lake City is located at the eastern edge of a desert it could regularly receive precipitation from un-purified air masses. We thought we could illustrate this theory by the soil samples we collected on the windward (sites 1 through 5) and leeward (sites 6 through 9) sides of the mountains. Obviously this mechanism is not playing an important role in fallout at the sites we have studied in Utah. Otherwise we should have observed marked differences in deposition concentrations. On a micro-meteorological basis, however, it is possible that the high deposition concentrations observed at

sites 4, 7, and 11 are in part attributable to the abrupt scavenging of debris laden air masses coming from the west. The high mountain sites, Nos. 10 and 12, show the lowest deposition concentrations which would be expected if this process were operating.

Quite probably the explanation for the overall picture of high fallout in the Salt Lake City area is associated with the direct intrusion of stratospheric air into the troposphere. Danielson (13), (14) has demonstrated that under certain meteorological conditions in the mountainous western areas of the United States the tropopause folds and stratospheric air with its high concentrations of radioactivity can penetrate the troposphere to relatively low altitudes even possibly to the earth's surface. Such stratospheric extrusions occur with a maximum frequency in the spring in regions parallel to the Rocky Mountain range in Idaho, Utah, Colorado, New Mexico and Arizona (15). The lowest tropopauses exist over Colorado and the stratospheric air enters the troposphere west of the continental divide.

CONCLUSIONS

The unexpectedly high Sr-90 fallout in north central Utah east of the Great Salt Lake is largely of stratospheric origin, representing nuclear debris from weapons testing conducted outside the conterminous United States. A number of climatic conditions in the area may be operating to bring down unusually large amounts of bomb debris. Topography may play a role by causing the abrupt scavenging of fallout from rain bearing air masses coming from the west. It is more likely that the phenomenon of direct intrusion of stratospheric air is the dominant operator in this region.

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We are grateful for the cooperation of Dr. Russel Hendricks, Western Area Occupational Health Laboratory, Salt Lake City in maintaining the monthly fallout collector for the past 15 years.

Finally we would like to thank Dr. L. T. Alexander, consultant to AEC, for his part in collecting most of the Utah soil samples prior to 1971 and for his advice in writing this report.

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PLUTONIUM FALLOUT IN UTAH

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ABSTRACT

Accumulated plutonium fallout in the north central and southeastern sections of Utah was measured in soil samples collected in June 1971. The maximum values in Utah of the deposition (mCi Pu-239,240 per km²) and deposition concentration (mCi per km² per cm of precipitation) were 2.2 and 3.8 times the maximum values found anywhere else in the United States. By comparing the Pu-239,240 to Sr-90 activity ratios of the Utah soils with the average activity ratio of 32 Northern Hemisphere soils collected in 1970-71, we estimate that up to 60 percent of the total Pu-239,240 activity deposited at some Utah sites was from a source other than the stratospheric reservoir. Soil samples taken at a site near the University of Utah from 1959 through 1971 revealed that the excess plutonium was delivered prior to 1959. Mass isotopic analyses indicate that the Nevada Test Site is the probable second source and that about 3.5 mCi Pu-239,240 per km² or twice the level expected from global fallout, deposited in the Salt Lake City area from NTS. Excess plutonium was not evident at sites north of Salt Lake City and due east in the valley regions beyond the Wasatch range.

INTRODUCTION

Presently there is considerable interest on the part of the Atomic Energy Commission and affiliated laboratories in documenting current levels of plutonium in the environment. Most of the Pu-239, 240 on the surface of the earth arrived as fallout from atmospheric

nuclear weapons tests. The accidental destruction of a SNAP generator in April 1964 resulted in the dispersal of Pu-238 which nearly tripled the global deposit of this isotope by 1970 (1). Localized contamination by weapons grade plutonium has occurred in the Rocky Flats region near Denver, Colorado (2) and in the vicinity of Palomares, Spain (3) and Thule, Greenland (4). The Health and Safety Laboratory has measured the accumulated deposits of plutonium at many sites throughout the world through the collection and analysis of soil samples (1). Depending upon latitude and climatic conditions, the deposits of Pu-239,240 for example, vary from 0.7 mCi per km² to 2.6 mCi per km² in the conterminous United States as shown in Figure 1.

In June 1971 a special soil survey was made in the north central and southeastern sections of Utah to investigate unusually high Sr-90 fallout (5). The samples were also analyzed for Pu-239, 240 and Pu-238. These data showed an unexpectedly large variability in plutonium deposition among the Utah sites. Subsequent analyses of soil samples collected in Salt Lake City since 1959 indicated that plutonium from a source other than the stratospheric reservoir had significantly contributed to the plutonium fallout. In this report we discuss the available data on plutonium fallout in Utah and present the evidence to demonstrate this second source.

Figure 1

CUMULATIVE DEPOSIT OF Pu-239,240, mCi PER km² FROM ANALYSES OF 1970-71 SOILS

1971 SOIL SAMPLES

Thirteen sites were sampled in Utah during June 1971.

Figure 2 shows the locations of these sampling sites. The predominant topographic features of the state are illustrated by the shaded altitude contours. Five sites were sampled west of the Wasatch range (Nos. 1 through 5), four in valley areas east of Salt Lake City (Nos. 6 through 9), and one at relatively high elevation in the Uinta Mountains (No. 10). Samples were also collected near Moab in southeastern Utah about 200 miles from Salt Lake City. Site No. 11 is in the dry Spanish Valley, site No. 12 is at higher elevation in the Manti-Lasal National Forest, and site No. 13 is in a valley area to the south east of the mountains.

The sampling method has been described in detail elsewhere (6). One thousand gram aliquots of the samples were acid leached using Pu-236 as a tracer and following separation and electrodeposition, the Pu-239,240 and Pu-238 were determined by alpha spectrometry(7). It is not possible to distinguish between the activities of Pu-239 and Pu-240 by alpha pulse height analysis because their energies cannot be resolved. The large aliquot size was necessary to measure the activities with counting errors of 5 percent or less.

Figure 2
1971 SOIL SAMPLING SITES IN UTAH

1. Provo	8. Wanship (Rockport Lk.)
2. Salt Lake City (Lib. Pk.)	9. Henefer
3. Salt Lake City (Univ. Ut.)	10. Uinta Mtns. (Trial Lk.)
4. Ogden	11. Moab (BLM)
5. Brigham	12. Manti Lasal N.F. (Geyser Pass)
6. Heber	13. Manti Lasal N.F. (GS)
7. Marion	

The plutonium analyses were carried out by Teledyne Isotopes, Palo Alto, California. We sampled to a depth of 30 cm to insure that all of the deposited plutonium and Sr-90 was collected (8).

Duplicate soil samples were taken at site 3, the University of Utah in Salt Lake City to reflect the overall sampling and analytical reproducibility. Table 1 shows that the cumulative Pu-239,240 and Pu-238 deposits were measured with precisions of about 2 and 6 percent, respectively.

<u>Table 1</u>		
<u>DUPLICATE SOIL SAMPLES</u>		
- University of Utah Site -		
1971		
<u>Sample</u>	<u>mCi per km²</u>	
	<u>Pu-239,240</u>	<u>Pu-238</u>
1	5.2	0.17
2	5.3	0.16
	difference 1.9%	6.1%

From a conservative standpoint then, we have assumed that the error terms associated with all the measurements made in this study are on the order of 10 percent.

The plutonium data for the 13 sites are presented in Table 2. The isotope ratios, Pu-239,240 to Sr-90 and Pu-238

TABLE 2

CUMULATIVE DEPOSIT OF Pu-239,240 AND Pu-238 IN 1971 UTAH SOILS

Map Site No.	Location	Site	Mean Ann. Precip. (cm)	Alt. (ft.)	mCi per km ²		Ratios		mCi Pu-239, 240 per km ² per cm
					Pu-239, 240	Pu-238	Pu-239, 240	Pu-238	
							Sr-90	Pu-239, 240	
Sites West of the Wasatch Mtns.									
1	Provo	Utah State Hospital	39	4600	5.8	0.14	0.062	0.024	0.15
2	Salt Lake City	Liberty Park	39	4300	4.1	0.11	0.048	0.027	0.11
3	Salt Lake City	Univ. of Utah	41	4800	5.2	0.16	0.047	0.031	0.13
4	Ogden	Cache Nat'l. Forest	53	5200	5.5	0.20	0.030	0.036	0.10
5	Brigham	Tabernacle	46	4500	2.9	0.14	0.032	0.048	0.06
Valley Areas East of Salt Lake City									
6	Heber	Tabernacle	43	5600	3.0	0.094	0.042	0.031	0.08
7	Marion	cemetery	63	6600	4.6	0.15	0.031	0.033	0.07
8	Wanship	Rockport Lake	42	6100	2.9	0.12	0.031	0.041	0.07
9	Henefer	meadow	38	5500	2.9	0.12	0.035	0.041	0.08
Mountain Area									
10	Uinta Mtns.	Trial lake	76	9500	2.7	0.11	0.034	0.041	0.04
Moab Area									
11	Spanish Valley	B.L.M. area	20	5300	3.0	0.084	0.045	0.028	0.15
12	Manti Lasal N.F.	Geyser Pass	81	9500	3.3	0.11	0.040	0.033	0.04
13	Manti Lasal N.F.	Lasal G.S.	41	7400	2.3	0.093	0.031	0.040	0.06

to Pu-239,240 are also included as well as the mean annual precipitation and altitude for each site.

REGIONAL VARIATIONS IN PLUTONIUM FALLOUT

The most striking observation is that the accumulated deposits of Pu-239,240 at the 13 Utah sites range up to 2.2 times the highest plutonium fallout measured at other sites in the United States less than a year earlier (see Figure 1). The highest deposit, 5.8 mCi Pu-239,240 per km² was found at Provo (site 1) and the lowest deposit, 2.3 mCi Pu-239,240 per km² at site 13 in southeastern Utah.

The comparison of plutonium fallout in Utah with other areas of the United States becomes even more dramatic when we consider the fact that precipitation is the predominant process by which nuclear debris particles are brought down to the earth's surface(9). Dividing by the mean annual precipitation for each site, the average Pu-239,240 deposition concentration for sites 1 through 9 (last column of Table 2) is 0.09 ± 0.03 mCi per km² per cm. Figure 3 shows that the deposition concentrations in other areas of the United States range from 0.01 to 0.05 mCi per km² per cm. In the present samples, only the high mountain sites (Nos. 10 and 12) approach the values found outside of Utah.

ANOTHER SOURCE OF PLUTONIUM FALLOUT

Comparison of the Pu-239,240 to Sr-90 ratios measured in the Utah soils (Table 2) with the average ratio of 0.028 ± 0.003 found for 32 soils collected in the Northern Hemisphere in 1970-71⁽¹⁾ indicates that another source of plutonium has contributed to the deposit at some of the Utah sites.

The contributions from global fallout and this other source were calculated for each site as a first approximation by the following equations and are reported in Table 3:

$$(Pu)_F = \frac{0.028}{R} (Pu)_T$$

and

$$(Pu)_2 = (Pu)_T - (Pu)_F$$

where $(Pu)_F$, $(Pu)_2$, and $(Pu)_T$ equal the Pu-239,240 activity from global fallout, from the additional source, and the total measured activity, respectively, at each site. The symbol R is the measured Pu-239,240 to Sr-90 ratio.

It is clear from Table 3 that significant amounts of excess plutonium fallout occurred at Provo and Salt Lake City (sites 1 through 3) and probably at Heber (site 6) as well as sites 11 and 12 in the Moab area. It appears that little if any excess plutonium fallout occurred further north of Salt Lake City (sites 4

TABLE 3

COMPONENTS OF PLUTONIUM FALLOUT IN 1971 UTAH SOILS

Map Site No.	Location	Site	mCi Pu-239,240 per km ²	
			Global	Excess
<u>Sites West of Wasatch Mtns.</u>				
1	Provo	Utah State Hospital	2.6±0.4	3.2±0.7
2	Salt Lake City	Liberty Park	2.4±0.3	1.7±0.5
3	Salt Lake City	Univ. of Utah	3.1±0.4	2.1±0.6
4	Ogden	Cache Nat'l. Forest	5.0±0.7	0.5±0.9
5	Brigham	Tabernacle	2.6±0.4	0.3±0.5
<u>Valley Areas East of Salt Lake City</u>				
6	Heber	Tabernacle	2.0±0.3	1.0±0.4
7	Marion	cemetery	4.2±0.6	0.4±0.8
8	Wanship	Rockport Lake	2.6±0.4	0.3±0.5
9	Henefer	meadow	2.3±0.3	0.6±0.4
<u>Mountain Area</u>				
10	Uinta Mtns.	Trial Lake	2.2±0.3	0.5±0.4
<u>MOAB Area</u>				
11	Spanish Valley	B.L.M. area	1.9±0.3	1.1±0.4
12	Manti Lasal N.F.	Geyser Pass	2.3±0.3	1.0±0.4
13	Manti Lasal N.F.	Lasal G.S.	2.1±0.3	0.2±0.4

and 5) or in the valley areas due east of Salt Lake City (sites 7 through 10). Table 3 indicates that at some sites this excess plutonium fallout contributes up to 60 percent of the total measured deposition.

CHRONOLOGY OF PLUTONIUM DEPOSITION

We were fortunate to have in storage, aliquots of soils sampled at the University of Utah site from 1959 through 1965. These were sent to Teledyne Isotopes in Palo Alto for plutonium analysis. The data are presented in Table 4. The Pu-239,240 to Sr-90 and the Pu-238 to Pu-239,240 ratios are also given. The Sr-90 data for this site were reported in another publication (5).

<u>Table 4</u> <u>CUMULATIVE DEPOSIT OF PLUTONIUM</u> University of Utah: 1959 - 1971					
Sampling Time		mCi per km ²		<u>Ratios</u>	
<u>Year</u>	<u>Month</u>	<u>Pu-239,240</u>	<u>Pu-238</u>	<u>Pu-239,240</u> <u>Sr-90</u>	<u>Pu-238</u> <u>Pu-239,240</u>
1959	Oct.	4.2	0.094	0.11	0.022
1960	Oct.	3.8	0.091	0.10	0.024
1962	Oct.	4.2	0.11	0.086	0.025
1963	Aug.	4.5	0.11	0.060	0.024
1964	Sept.	4.9	0.11	0.048	0.023
1965	Sept.	4.7	0.12	0.045	0.026
1971	June	5.2	0.16	0.048	0.030

Table 4 shows that the Pu-239,240 deposit at the University of Utah site in 1959 was as high as 80 percent of the deposit measured in 1971. The Pu-239,240 to Sr-90 ratios which drop from 0.11 in 1959 to 0.048 in 1971 are all significantly greater than the average value of 0.028 ± 0.003 found for 32 Northern Hemisphere soils in 1970-71. These data indicate that the excess plutonium fallout was delivered prior to 1959. It is plausible to assume that this second source of plutonium fallout is the Nevada Test Site. The test site is about 350 miles southwest of Salt Lake City and has occasionally been a source of short-lived fission products in Utah following atomic tests (10, 11).

The excess plutonium for this site reported in Table 3 assumes that all the Sr-90 deposited was from global fallout. However, it has been concluded that in 1959 about 16 mCi Sr-90 per km^2 were present in Salt Lake City from a second source independent of global fallout(5). By 1971 this second source component would have decayed to 12 mCi per km^2 which, when subtracted from the total measured Sr⁹⁰ deposit in 1971, yields $109 - 12 = 97$ mCi per km^2 as the integrated deposit in Salt Lake City from all previous global fallout.

Multiplying 97 mCi Sr-90 per km^2 by the average Pu-239,240 to Sr-90 ratio in 1970-71 for integrated global fallout (0.028) gives

2.7 mCi per km² as the global fallout component of the Pu-239, 240 deposit. The difference from the total measured plutonium deposit is 2.5 mCi per km² which is the contribution from the second source. This second source may well be the Nevada Test Site. Similar calculations can be made from the monthly Sr-90 deposition data at Salt Lake City from 1959-1971 (12) to give reasonably comparable estimates of 2.3 and 2.9 mCi Pu-239,240 per km² as the global fallout and second source components, respectively.

It has been demonstrated that mass spectrometric analysis of plutonium in soil can differentiate between global fallout plutonium and plutonium from another source (13). Table 5 gives the Pu-240 to Pu-239 mass ratios of the 1971 University of Utah soil, the global fallout reference sample collected at the Brookhaven National Laboratory and three surface soil samples from areas at the Nevada Test Site. The comparison of the University of Utah Pu-240 to Pu-239 ratio with the global fallout reference ratio is further strong evidence that the plutonium deposited in Salt Lake City could not be entirely from global fallout.

Table 5

MASS ISOTOPIC COMPOSITION

<u>Soil Sample</u>	<u>Pu-240/Pu-239</u>
Salt Lake City: Univ. of Utah	0.0846 $\pm$ 0.44%
Global Fallout Reference (a)	0.1801 $\pm$ 0.24%
Surface Sample No.1 from NTS (b)	0.0497 $\pm$ 0.4%
Surface Sample No.2 from NTS (b) (Project '57 area)	0.0628 $\pm$ 0.2%
Soil Sample No.3 from NTS (c)	0.0539 $\pm$ 0.4%

(a) collected at Brookhaven National
Laboratory, 1970

(b) samples supplied by Mr.G. Hamada,
Reynolds Electric & Engineering Co.,
Las Vegas, Nevada

(c) G.M. Leies, AFTAC, Dept. of the Air Force,
Personal Communication, May 1972

Krey and Krajewski(13) derived an equation to calculate the relative mass contribution of a second source of plutonium to global plutonium. Modifying this equation to give the

relative activity contribution yields:

$$\frac{\text{Pu activity from a 2nd Source}}{\text{Pu activity from global fallout}} = R = \frac{C_1 - C_2}{C_2 - C_3} \left(\frac{1 + 3.60 C_3}{1 + 3.60 C_1} \right)$$

where:

C_1 = Pu-240 to Pu-239 mass ratio from global fallout

C_2 = Pu-240 to Pu-239 mass ratio in Univ. of Utah soil

C_3 = Pu-240 to Pu-239 mass ratio from second source

We can calculate the relative plutonium activity contributions of the two source from the above equation, provided that the constants are evaluated. From Table 5: $C_1 = 0.1801$, $C_2 = 0.0846$, and $C_3 \approx 0.05$. This approximate assignment of C_3 assumes that the second source was either debris from some of the safety tests in which plutonium was physically dispersed or tests in which little fission occurred. The three soil samples in Table 5 were collected in areas contaminated mainly by debris from safety tests. From these assignments $R \approx 2$. Since the measured plutonium deposit from Table 2 was 5.2 mCi per km², the global fallout plutonium = 1.7 mCi per km² and plutonium from the second source = 3.5 mCi per km². This estimate of the second source contribution is only about 1/3 greater than those calculated from the Sr-90 measurements which is reasonable agreement under the assumptions of the computation.

PLUTONIUM FALLOUT IN OTHER AREAS

We showed in Figure 1 and Table 2 that the accumulated Pu-239,240 deposit in other areas of the United States is less than in the Salt Lake City area. Soil samples collected in Cedar City, Utah in 1963,64 and 65, and previously analyzed for Sr-90 were subsequently analyzed for Pu-239,240. Cedar City is about 225 miles south-southwest of Salt Lake City and about 175 miles east of the Nevada Test Site. It is in a lower rainfall area than Salt Lake City and the cumulative plutonium fallout was only about $\frac{1}{4}$ of that observed at Provo and the University of Utah as can be seen from Tables 6 and 2. The Pu-239,240 to Sr-90 ratio, however, indicates that some plutonium from the Nevada Test Site must have fallen out here also. On the other hand, Bozeman, Montana (340 miles north of Salt Lake City), Rapid City, South Dakota (500 miles northeast), and Denver, Colorado (360 miles east) showed no evidence of a second source of plutonium. The Pu-239,240 to Sr-90 ratios for these last three regions were essentially the same as we found for other areas of the

world where only global fallout had occurred. These data emphasize our earlier suggestion that plutonium from the Nevada Test Site did not deposit north of the Salt Lake City area or further east than the Utah - Colorado border.

Table 6

CUMULATIVE DEPOSIT OF PLUTONIUM
AT OTHER SITES

Sampling Time		mCi Pu ^{239,240}	Pu ^{239,240}
Year	Month	per km ²	Sr⁹⁰
Cedar City, Utah			
annual precip.: 23 cm			
1963	Sept.	1.4	0.044
1964	Sept.	1.5	0.043
1965	Sept.	1.4	0.038
Bozeman, Montana			
annual precip.: 43 cm			
1965	Sept.	1.9	0.025
Rapid City, South Dakota			
annual precip.: 45 cm			
1965	Sept.	2.5	0.026
Denver, Colorado			
annual precip.: 37 cm			
1965	Sept.	1.5	0.024
1970	Oct.	1.8	0.027

CONCLUSIONS

Plutonium isotopes, injected into the stratosphere following atmospheric nuclear weapons tests, are dispersed globally and eventually reach the ground by a variety of meteorological and climatological processes. The predominant source of plutonium fallout then, in most locales, is the stratospheric reservoir. The cumulative deposits of Pu-239,240 as measured by soil samples collected in the United States in 1970-71 range from 0.7 to 2.6 mCi per km².

Analyses of soils collected in north central and south eastern Utah in June 1971, however, revealed cumulative Pu-239,240 deposits that were twice expected levels at some sites. Furthermore, the Pu-239,240 to Sr-90 ratios at these sites were significantly higher than we found in 32 soils sampled in the Northern Hemisphere in 1970-71. Excess plutonium fallout was clearly demonstrated at Provo, Salt Lake City, and Heber but not at Ogden and Brigham City further north. We could find no evidence of excess plutonium in the valley areas due east of Salt Lake City or at higher elevation in the Uinta mountains. Two sites in the Moab area also showed evidence of excess plutonium fallout.

A series of 7 soil samples collected between 1959 and 1971 at the University of Utah showed that the cumulative deposit of Pu-239,240 was higher than expected from global fallout throughout the entire period. This indicated that prior to 1959, plutonium from a second source-presumably the Nevada Test Site - contaminated the Salt Lake City area. A component analysis of the Pu-239,240 fallout demonstrated that a chronic contamination through resuspension could not have taken place after 1959. We estimate that the excess plutonium fallout at the University of Utah is equal to or perhaps a factor of two greater than the global plutonium. This estimate is supported by the mass ratio of Pu-240 to Pu-239 measured in the University of Utah soil compared with the mass ratios of global fallout and debris from the Nevada Test Site.

It is possible that our estimates of the second source plutonium fallout are low because the soils were acid leached. Some fraction of the plutonium in Nevada Test Site debris is not acid extractable although we have no supporting data for the Utah soils. Nevertheless, global fallout plutonium can be acid extracted from soil(8) and so our estimates of plutonium from this source are probably reliable.

We could find no evidence that excess plutonium had deposited in Bozeman, Montana; Rapid City, South Dakota, or Denver, Colorado which verified our observation that plutonium contamination from the Nevada Test Site had not occurred north of Salt Lake City or further east than the Utah - Colorado border.

ACKNOWLEDGEMENTS

We are grateful to those who made it possible for us to obtain the soil samples in June 1971. Mr. William Wertz of the Forest Service in Ogden, Utah arranged the contacts with Forest Service and State Parks and Recreation Commission personnel. Dr. T. B. Hutchings, State Soil Scientist, arranged the Soil Conservation Service contacts. Mr. Warren L. White, Superintendent of Parks, Salt Lake City and Mr. David Lofgren, Superintendent of General Services, University of Utah, made it possible to collect samples in Liberty Park and the University golf course, respectively.

We appreciate the cooperation and interest of Dr. Russel Hendricks, Western Area Occupational Health Laboratory, Salt Lake City in maintaining the monthly fallout collector for the past 15 years.

Dr. L. T. Alexander, consultant to AEC, collected most of the soil samples prior to 1971 and provided valuable advice as to sampling locations for the 1971 investigation.

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PART II

✓ HASL FALLOUT PROGRAM DATA

1. Fallout Deposition

1.1 Monthly Precipitation

1.11 Sr^{90} and Sr^{89} in Monthly Deposition at World Land Sites

Precipitation and dry fallout are collected over monthly periods at stations in the United States and overseas. The samples are analyzed for Sr^{90} and prior to 1971 for Sr^{89} whenever possible. A description of the sampling network and available data for each site are given in the Appendix, Section A.

1.12 Other Isotopes at Selected Sites

At a number of stations in the United States, monthly deposition collections were analyzed for radiostrontium and other nuclides of interest to the Atomic Energy Commission. Multinuclide analyses were discontinued as of July 1967 and the complete data reported in HASL-193, p. II-4 thru II-25.

Plutonium analyses of monthly deposition were carried out at New York City, Melbourne, Seattle, Honolulu, Salisbury, Durban, and Rio de Janeiro. This program has been terminated and the complete data are given in HASL-237 on pages II-4 thru II-13.

1.2 Sr^{90} and Sr^{90} Deposition at Atlantic Ocean Weather Stations

Measurements of radiostrontium in precipitation and dry fallout collections at four U. S. Coast Guard Stations in the North Atlantic Ocean are carried out for comparison with land stations in the same latitude band. A description of the stations and available data are given in the Appendix, Section B.

2. Surface Air Sampling Program

The Health and Safety Laboratory has been collecting surface air particulate samples at stations in the Western Hemisphere since January 1963. The filters are analyzed for a number of fission and activation product radionuclides as well as stable lead. A description of the program and available data are given in the Appendix, Section C.

3. Project Airstream

The Health & Safety Laboratory measures radioactivity in the lower stratosphere employing the RB-57F aircraft as a sampling platform. The aircraft are flown by the 58th Weather Reconnaissance Squadron under the direction of the 9th Weather Wing of the Air Weather Service. The missions are scheduled quarterly and the coverage extends from 75°N to 51°S latitude in the Western Hemisphere. Air filter samples are collected from 12 to 19 km altitude and analyzed for a number of radionuclides. A more complete description of the program and available data are given on pages II-8 to II-119 of HASL-249, April 1972.

4. High Altitude Balloon Sampling Program

Balloon borne filtering devices are used to collect nuclear debris at altitudes from 21-32 km. Balloon launchings are conducted annually at Fairbanks, Alaska, 65°N; Sioux City, Iowa 42°N; Alamogordo, N.M., 33°N; and Panama C.Z., 9°N and quarterly at Mildura, Australia, 34°S. Filters are analyzed for a number of radionuclides. A more complete description of the program and available data are given on pages II-120 to II-182 of HASL-249, April 1972.

5. Radiostrontium in Milk and Tap Water

Sr-90 levels in both powdered and fresh milk distributed in New York City and tap water sampled at the Health & Safety Laboratory, have been measured on a monthly basis since 1954. These data are summarized in tabular and graphical form in the Appendix, Section D.

6. Strontium⁹⁰ in Diets

Quarterly estimates of the annual dietary intake of Sr-90 of New York City and San Francisco residents have been made based on analyses of foods purchased at these cities every three months since 1960. Sampling in Chicago was discontinued in 1967. The program is described and available data reported on p. II-4 to II-6 of this report.

7. UNSCEAR - WHO Bone Program

Available Sr-90 data for human bone samples collected in 1969, 1970, and 1971 from countries in Latin America, Africa, and Asia were presented on pages II-4 to II-7 of HASL-245, Oct. 1971.

Sr⁹⁰ in Human Bone - 1971 Results

Specimens of human vertebrae from New York City and San Francisco have been made available for Sr-90 analysis since 1961. The results for 1971 are evaluated beginning on page I-51 of this report.

6. HASL Diet Studies: First Quarter 1972

Results of the measurements of the Sr-90 content of foods purchased in New York City and San Francisco in the first quarter of 1972 are given in the following table. Estimates of the daily intake of Sr-90 based on these measurements and on the revised consumption statistics given in the most recently available U. S. Department of Agriculture Report⁽¹⁾, are also listed.

The estimates of daily Sr-90 intake are a continuation of the HASL Tri-City diet studies which were started in March of 1960. Results of the earlier measurements along with those made during 1972 are shown graphically in the figure on page II-6. A complete description of the sampling methods and philosophy of the HASL diet studies was given in HASL-147⁽²⁾. A discussion of the reasons for changes in the Tri-City diet studies made in 1968 was given in HASL-200⁽³⁾.

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STRONTIUM⁹⁰ IN NEW YORK CITY AND SAN FRANCISCO DIETS
- First Quarter 1972 -

Diet Category	kg/yr	gCa yr	% of yearly intake of Ca	New York City - February		% of yearly intake of Sr ⁹⁰	San Francisco - March		% of yearly intake of Sr ⁹⁰
				pCi Sr ⁹⁰ kg	pCi Sr ⁹⁰ yr		pCi Sr ⁹⁰ kg	pCi Sr ⁹⁰ yr	
Dairy Products	200	216.0	58	6.8	1351	31	1.7	344	22
Fresh Vegetables	48	18.7		12.2	585		5.4	258	
Canned Vegetables	22	4.4		7.9	174		3.6	79	
Root Vegetables	10	3.8		11.4	114		6.7	67	
Potatoes	38	3.8		8.6	328		2.0	78	
Dry Beans	3	2.1	9	19.5	58	29	10.2	31	32
Fresh Fruit	59	9.4		15.8	930		3.9	228	
Canned Fruit	11	0.6		1.3	14		0.9	10	
Fruit Juices	28	2.5	3	3.4	96	24	3.5	97	21
Bakery Products	44	53.7		6.4	283		3.3	147	
Flour	34	6.5		6.1	206		3.3	111	
Whole Grain Products	11	10.3		12.0	132		6.6	72	
Macaroni	3	0.6		4.2	13		3.5	11	
Rice	3	1.1		1.8	5		1.5	4	
			20			15			22
Meat	79	12.6		0.7	54		0.4	29	
Poultry	20	6.0		0.5	10		0.3	7	
Eggs	15	8.7		1.6	24		1.4	21	
Fresh Fish	8	7.6		0.5	4		N.D.	-	
Shellfish	1	1.6	10	1.2	1	2	0.8	1	4
Yearly Intake		370			4382			1595	
Daily Intake - pCi per g Ca					11.8			4.3	

N.D. = not detectable

Part III

DATA FROM SOURCES OTHER THAN HASL

Numerous fallout studies are conducted by other organizations in the United States and abroad. Some of these are sent to the editors for dissemination in these HASL Quarterly Reports. Submitted data are reproduced essentially as received and no interpretation by HASL is attempted.

Page

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Quarterly Report III-53

DEPARTMENT OF HEALTH
NEW ZEALAND

**FALLOUT FROM NUCLEAR WEAPONS TESTS
CONDUCTED BY FRANCE IN THE SOUTH
PACIFIC FROM JUNE TO AUGUST 1971**

and comparisons with previous test series

compiled by
L. P. Gregory

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

MARCH 1972

NOTICE

This report is devoted entirely to measurements of radioactive fallout resulting from France's nuclear test programmes conducted in the Tuamotu Archipelago in the South Pacific Ocean. The results of the 1971 special monitoring programme are given in full herein and comparisons are also made with results from similar special monitoring programmes which have been conducted by this Laboratory since France first tested nuclear weapons in this part of the world in 1966.

This report then conveniently summarises information previously included in many of the routine quarterly reports of this Laboratory.

The results of any future monitoring programmes covering a particular French nuclear test series will be published in a single report at the conclusion of the programme. Such results may be compared with those summarised in the present report which now represent the cumulative experience of five separate extended monitoring programmes throughout New Zealand and the Pacific Area since 1966.

The routine reports "Environmental Radioactivity in New Zealand" which are concerned more with the long term effects of global fallout and with special surveys will continue to be published as separate annual reports. 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.

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

UNITS OF RADIOACTIVITY

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

Radioactive fallout in rain is expressed as:

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

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

UNITS OF GAMMA RADIATION DOSE

mRAD millirad (For comparison purposes, a dose of about 120 mRAD per year may be attributed to the "average" natural background radiation).

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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. During the periods of nuclear weapons tests in the South Pacific, the Laboratory extended its routine measurements within New Zealand. Monitoring stations were also established in the Gilbert and Ellice Group, the Fiji Islands, Tonga, Western Samoa, Niue and the Cook Group. This was done with the willing co-operation of the local Governments, Administrations and their staffs whose assistance in collecting samples and taking readings on instruments supplied by the Laboratory we gratefully acknowledge. The co-operation of the officers of this and other Government Departments in New Zealand and of many private companies is also gratefully acknowledged. The continued assistance given by all has made possible the Laboratory's 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.

PUBLISHED WITH THE AUTHORITY OF THE DIRECTOR-GENERAL OF HEALTH

Fig. 1 MONITORING AND COLLECTING STATIONS IN NEW ZEALAND AND ON PACIFIC ISLANDS

POTENTIAL HEALTH HAZARD AND REFERENCE LEVELS

There are no internationally accepted 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.

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. These dose limits were established for individual members of the public so that the risks from 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 concentration reference levels have been derived which are in no case greater than one third of the concentrations which, if maintained indefinitely, would individually lead to the Dose Limits. In setting these reference concentrations, allowance has been made for the risk to children. 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 Concentration 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
--	-----------------

For those concentrations which can change rapidly with time, such as mixed fission products in air or in rain, or iodine-131 in milk, occasional transient values may greatly exceed the reference levels. The average concentrations over a year, however, should be compared with the reference levels.

Comparison of Reference Levels with Natural Radiation Background

The long term hazards of fallout radiation are best understood by comparison with the levels of background radiation to which the human race has always been exposed. Natural background radiation varies widely in different parts of the world, ranging from a fraction of the "average" to many times the "average" background.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in its latest (1969) report assessed the effect of all nuclear tests carried out before 1968 on the population of the temperate zone in the Southern Hemisphere. They conclude that the dose received from fallout up to the year 2000 would, in its production of hereditary effects, bone tumours, and leukaemias be equal to that caused by a doubling of the "average" natural radiation background for a period of 5, 8, and 7 months respectively. For the population of the Northern temperate zone the corresponding doses are between 3.3 and 3.6 times higher, while the corresponding figures for the whole world population are 11, 26 and 18 months respectively.

Stratospheric fallout levels are highest in the temperate zones of both hemispheres and decrease markedly towards the equator. Tropospheric fallout levels, however, tend to be higher at latitudes close to the latitude of injection. Global fallout levels, used as the basis of the UNSCEAR assessment, are averages which may differ significantly from levels at individual locations. In the present report radiation levels at individual locations are stated in terms directly related to the reference levels listed.

If the reference levels listed above were maintained indefinitely, they would each lead to a dose rate of the order of that received from the natural background radiation. Therefore, those genetic and somatic effects which can be attributed to the natural background radiation could be expected to increase in proportion.

NOTE:

The Reference Concentration Levels listed here are those used in the overall monitoring operations of this Laboratory. For the results published in this report, the reference levels for mixed fission products (total beta activity) in air and rain-water and for iodine-131 in milk are relevant.

Since mid-1959 long-lived radioactive components in global fallout have been routinely monitored in New Zealand and at some Pacific Islands by the Health Department's National Radiation Laboratory at Christchurch.

In addition, special monitoring programmes have been conducted by the Laboratory in New Zealand and throughout the Pacific Area to monitor short-lived fresh fission debris produced during, and for some months after, nuclear weapons tests. These special programmes were conducted to monitor the U.S.A. tests in the Northern and Central Pacific in 1962 and more recently the series of French Nuclear tests in the South Pacific since 1966.

The main objective of these monitoring programmes is the assessment of public health hazards from nuclear weapons tests carried out in the atmosphere.

Long Term Effects:

When nuclear devices in the megaton range are detonated at a sufficient height most of the radioactive debris is carried up to the stratosphere. Fine radioactive particles will there drift around the world for months or even years before being transferred to the troposphere where they will be subjected to precipitation processes. Such delayed (or stratospheric) fallout has two significant characteristics. The first is the absence of the shorter-lived radionuclides because of radioactive decay, and the second is the tendency for its deposition to occur in the mid-latitudes of the hemisphere in which the nuclear tests were conducted. Tropical Pacific Islands, therefore, will receive less global long-lived fallout than countries such as New Zealand in the temperate zone.

The major health hazard from nuclear weapons tests in the atmosphere is caused by the increase in levels of a few specific radionuclides such as strontium-90 and caesium-137 which are retained for prolonged periods in a particular organ of the human body or which have a long radioactive half-life. The routine monitoring operations of this laboratory, therefore, are mainly concerned with the levels of strontium-90 and caesium-137 in the New Zealand environment, although measurements of strontium-90 deposition are also made at Suva, Fiji and at Rarotonga on a routine basis. During periods of nuclear weapons testing, routine measurements for strontium-90 are extended to include also the shorter-lived strontium-89. The measurement 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 work.

The results of these measurements and several special surveys have been reported in quarterly and annual summary reports since June 1961 (1). The results of special monitoring programmes during periods of nuclear weapons testing in the Pacific Area have also been included in these reports. However, as already noted inside the front cover, and for the reason stated there, the results of routine long-term measurements will be presented separately in annual reports in the future, instead of in quarterly reports.

Results of measurements show that strontium-90 deposition in New Zealand reached a maximum during the second half of 1964 and the first quarter of 1965. This was caused by delayed fallout of stratospheric debris originating mainly in the large scale tests of the U.S.S.R. and

U.S.A. in 1961 and 1962 prior to the signing of the Partial Test Ban Treaty.

Since 1965, however, strontium-90 fallout steadily decreased in New Zealand to a minimum in 1968 when the country-wide average level was less than a quarter of the 1964 maximum. The French nuclear tests in the South Pacific have caused a slight increase since 1968, the levels remaining at about one-third of the 1964 maximum. The situation at Suva, Fiji has been similar.

Short Term Effects:

Since 1966 France has conducted nuclear tests at Mururoa and Fangataufa in the Tuamotu Archipelago each year except 1969. Special monitoring programmes have been conducted by the laboratory during, and for about three months after, each test series. These monitoring programmes are designed to obtain quick information about possibly hazardous levels of fallout of fresh fission debris deposited under adverse and unpredicted meteorological conditions.

Nuclear explosions in the kiloton range, detonated near ground level, release most of their debris into the troposphere and shorter-lived radionuclides will predominate in this fresh fission debris. Prevailing winds usually carry debris from France's South Pacific testing ground in an easterly direction so that South America is the first large land mass to receive such fallout. As the radioactive cloud progresses, however, it disperses and radioactive particles reach the surface in days or weeks depending on how soon the air carrying them encounters descending air currents or a rain-producing weather system. The radioactive cloud will take about three weeks to circle the world and it may go around more than once. Because of dispersion, precipitation, and radioactive decay the danger of any particular area receiving a high level of fallout lessens with the progress of the radioactive cloud.

Occasionally part of the radioactive cloud is caught in an anti-cyclonic eddy and diverted back towards the west. When this happens, slowly diffusing radioactive particles may be carried over islands in the Central South Pacific area in a matter of days. Higher levels of radioactivity in air will then be recorded and any rain occurring at that time will deposit fresh fission material and increase the local level of radiation significantly. The principal purpose of the Laboratory's special monitoring programme is to detect when such an event occurs and to determine whether it presents a significant health hazard or is of such intensity that remedial action is required.

The present report is concerned entirely with the short-term effects due to rapidly-decaying fresh fission debris from the 1971 nuclear tests in the Pacific, and a comparison of these levels with those during previous French test series since 1966. The detailed results of these measurements have been published in some previous issues in this report series (2). This report, however, presents all the results of the 1971 monitoring programme, and comparisons with previous programmes, under one cover and separates them from routine long term results for the first time. In future the results of each special monitoring programme will be presented similarly at the close of the programme.

A complete list of nuclear explosions in the atmosphere for each French Nuclear Test Series in the Pacific is given in Table 1, together with the duration of the laboratory's monitoring programme for each series.

Even those monitored Islands which are nearest to the testing site are sufficiently distant so that the chance of a hazardous situation arising is very unlikely. It is conceivable, however, that under the most adverse conditions significant fallout could occur which would justify more intensive investigations or even some remedial measures. The instruments provided to detect such an event are portable gamma ray monitors. Having thus provided means of early detection of fallout and having eliminated the possibility of any undetected immediate hazard, the rest of the monitoring programme aims at providing a continuous record of levels of radioactivity. These levels are determined by measuring the contamination in samples of air filters, rainwater, milk, and cattle thyroid which are sent to the Laboratory for analysis. The extent of the monitoring operations in New Zealand and throughout the Pacific area is shown in Fig.1.

1. Gamma Radiation Monitoring

Portable gamma radiation monitors are provided in duplicate at the six monitoring stations lying to the east of Fiji, which are nearest to the test site: Penrhyn, Aitutaki, Rarotonga, Apia (Samoa), Niue and Tonga.

The monitors are sufficiently sensitive to enable significant readings to be made even on natural background radiation. During the monitoring programme readings are made several times each day by the local meteorological observers concurrently with their meteorological observations. Reporting levels have been established, well below the levels that could possibly justify any remedial action, and the monitoring stations are in communication with the laboratory using the meteorological services radio communication system.

2. Daily Air Filter Samples for Total Beta Activity Assessment

These are collected at four Pacific Island stations: Nandi (Fiji), Suva (Fiji), Apia (Samoa), and Tonga, and also at four New Zealand stations: Auckland, Wellington, Hokitika and Christchurch. Air filters from the Pacific Island stations are sent by regular air mail to the Laboratory. Measurements are undertaken and results are assessed, therefore, with the minimum of delay.

The main value of this monitoring service lies in providing a continuous daily record of the short term changes in air radioactivity. The measurement is very sensitive and activities which are of negligible health hazard can be detected. Thus these samples usually provide the first evidence of the arrival of traces of fission products.

3. Weekly Rainwater Collections for Total Beta Activity Assessment

Samples are collected from nine Pacific Island stations: Tarawa, Funafuti, Nandi (Fiji), Suva (Fiji), Apia (Samoa), Niue, Tonga, Aitutaki, and Rarotonga, and also from four New Zealand stations: Auckland, Wellington, Greymouth and Christchurch.

The period of collection of each rainwater sample, about seven days, is much longer than for air filters. Moreover, some of

the collecting stations have not been on regular air services to New Zealand. This results in inevitable delays between collection and measurement. There are inherent difficulties, therefore, in the precise interpretation of sample activities resulting from mixtures of fission products of differing ages which are later measured at various times after sample collection.

Nevertheless, the measurements of total beta activity in these samples does allow an approximate assessment to be made of the external gamma radiation dose resulting from the deposition of radioactive fallout on the ground, and also of the internal radiation dose resulting from drinking such water.

4. Thrice Weekly Milk Collections for Iodine-131 Assessment

These samples are collected at Suva, Fiji and Apia, Samoa where there are significant dairy herds and also at the following seven stations in New Zealand: Auckland, New Plymouth, Wellington, Greymouth, Christchurch, Dunedin, and Invercargill.

Iodine-131 is a critical contaminant when fresh fission products are deposited because of the high yield produced in nuclear explosions, and its property of being selectively absorbed into the thyroid. The wide browsing habit of cows, moreover, leads to a concentration in milk within one day of pasture contamination. Furthermore, because of their small thyroids, children receive a higher dose than adults for the same intake and are likely to have a greater daily consumption of fresh milk. Because iodine-131 has a short half-life of 8 days the level of contamination rapidly decreases over a few weeks unless further deposition occurs. Because of the delay between manufacture and consumption, the iodine-131 content of most milk products can be expected to have decayed to a negligible level.

5. Weekly Cattle Thyroid Collection for Iodine-131 Assessment

Cattle thyroids are collected at the following eight New Zealand stations only: Moerewa, Hamilton, New Plymouth, Hastings, Palmerston North, Westport, Christchurch and Gore.

Because of the enhanced sensitivity of detection of radio-iodine in animal thyroid, these samples have been used as an indicator of the arrival of iodine-131 in New Zealand. Moreover, these measurements also allow a comparison between the levels in cattle thyroid and milk.

1. Gamma Radiation Monitoring

Three "gamma radiation action levels" have been set for this monitoring service. The first action level is a warning level which requires more frequent, more widespread, and increased reporting of monitor readings. The second and third action levels require a progressive increase in gamma monitoring, the provision of radioed instructions for suitable precautions, and, if necessary, urgent supervision of more extensive precautionary measures. These action levels have been fully discussed in a previous report of this Series (3).

Well below these action levels, a "reporting level" of 0.3 mRAD per hour has been set. At, or above, this level monitor readings are radioed to the Laboratory. Any hazard to health arising from fresh fission products at the reporting level is of minor significance. The main purpose of reporting this level of radiation is to alert the Laboratory staff to the situation and to provide the opportunity for initiating more widespread sampling for scientific interest, and to allow a closer observation of trends.

The reporting level has not yet been reached in any of the special monitoring programmes. Inspection of monitor log books show that the only increases in gamma radiation which have been significantly above the natural background level have occurred at Apia, Samoa on, and for about two weeks after, 16 September 1966, and a similar but much smaller increase at Niue during the same period.

The average daily gamma radiation levels at Samoa during the 1966 monitoring programme are shown in Fig.2. On 16 September gamma radiation levels suddenly increased to nearly 0.07 mRAD per hour (about one quarter of the reporting level). This increase, which was about 0.05 mRAD per hour above the "average" background level, was caused by a "rain-out" of four day old fission products from the nuclear test of 12 September. It is an example of the diversion of part of the cloud of radioactive particles towards the West as discussed in Chapter 1. Fig.2 also graphically illustrates the rapid rate of radioactive decay of such young fission products on the days following 16 September 1966.

The significance of the fallout at Apia, Samoa is further discussed later in this chapter where the results of total beta activity in the weekly rainwater collection at Apia during 13 to 20 September 1966 are assessed for the associated gamma dose rate and these findings are then compared with the gamma monitor readings.

2. Daily Air Filter Samples for Total Beta Activity Assessment(a) 1971 Results

The first traces of fresh fallout from the 1971 nuclear tests were detected at Samoa on 19 June and thereafter at other stations as shown in Fig.3. These arrival dates, together with measurements of the age of the fission products in these early samples, indicate that part of the debris from the explosions of both 6 and 13 June travelled in a westerly direction with a transit time of about 11 days to Samoa. A second wave of air radioactivity resulting from these two explosions was detected about 10 days later from debris which had probably travelled around the world in an easterly direction with a transit time of about 3 weeks.

About 1200 daily air filters were measured during the 1971 monitoring programme. About 100 of these were selected for extra measurement of the rate of radioactive decay in order to determine the age of the fission products collected. In these samples the age of the fission products ranged from 11 days to about 2 months. The results of these measurements also indicated that traces of debris from all the 1971 nuclear tests were detected in the Central Pacific Area sooner than would be expected if all the debris from each nuclear test had first circled the world.

The average daily levels of total beta activity in air filters are listed in Table 2 and these values are also shown graphically in Fig.4. The highest level reached was 27.6 pCi/cubic metre at Apia, Samoa on 20 June. The highest level previously recorded was 73.5 pCi/cubic metre at Nandi, Fiji, on 17 September 1966. These transient increases, however, are of negligible health significance and average levels over longer periods are more meaningful.

(b) Comparison of Average Levels with Those During Previous Monitoring Programmes

The average monthly levels during each monitoring programme since 1966 are shown in Fig.5. It is apparent from this graph (and also from Fig.4) that levels are significantly higher at the four Pacific Island Stations than at the four New Zealand stations. It is also of interest to note that the highest monthly average levels, i.e. during September 1966 at Nandi (Fiji), and also during June 1971 at Apia (Samoa), occur after the detonation of nuclear devices in the low or middle power (kiloton) range. These increased levels in air result from tropospheric fallout which is noticeably higher in the tropics, at about the latitude of the nuclear tests than it is in New Zealand lying more to the south in the temperate zone.

(c) Comparison with the Reference Level

Table 3 lists the average levels over much longer periods, i.e. the average level at each station for each entire monitoring period since 1966. Inspection of this table shows that Apia, Samoa had the highest average level, 2.05 pCi/cubic metre, for the 5 months of the 1971 monitoring programme. This level is less than 1% of the reference level (300 pCi/cubic metre) which is based on continuous exposure. The significantly lower levels in New Zealand are again evident in Table 3.

3. Weekly Rainwater Collection for Total Beta Activity Assessment

(a) General

The inevitable delay in measuring the total beta activity in many of these samples, and the resulting difficulty of precise interpretation of results has been mentioned in Chapter 2. In the presentation of results in previous issues of these reports (2) the date of measurement was listed alongside the dates of collection for each sample. Although some samples, showing higher levels, were assessed for fission product age and activity at mid-collection time, in general no attempt was made to do this for the majority of samples collected.

In Table 4 in this report the results of fallout deposition (at the time of measurement) and the rainfall are presented in simplified form for the 1971 programme. In addition:

- (i) the external gamma radiation dose (integrated to infinity) arising from each test series is assessed.
- (ii) the average concentration of fission products in rain during each monitoring period is evaluated. This allows a comparison with the reference level so that the internal radiation hazard resulting from drinking such rainwater is assessed.

The results listed in Table 4 are presented graphically in Fig.6 as the average daily depositions during each collection period.

(b) The Evaluation of the External Gamma Radiation Dose from Weekly Fallout Deposition

This evaluation has been made for all stations except Rarotonga, Aitutaki, and Niue where sample transport delays were often excessive (a special evaluation was made for the single depositions at Samoa and Niue on 16 September 1966).

For the remainder of the collections the evaluation was made by first establishing the typical range of fission product ages at mid-collection times. This was done by measurement of the rate of radioactive decay on selected samples. This information, together with the known measurement delay, allowed the application of a formula, within known limits, which converted total beta activity deposition, as measured, to the equivalent gamma radiation dose.

The fallout was assumed to be deposited on an infinite, smooth, plane as a single deposition on the mid-collection day. The gamma dose rate associated with this deposition under these hypothetical and highest risk conditions was integrated to infinity and summed for all weekly deposit samples at each collecting station.

With the exceptions noted in the first paragraph of this section, inspection of Table 4 shows that since 1966 the total gamma dose at the various stations has ranged from 0.2 mRAD to 19.2 mRAD during the monitoring periods. The upper limit of this range is equivalent to an increase of 16% in average background for one year only. At individual stations, the average dose per monitoring period since 1966 has ranged from about 1 mRAD at a low rainfall station such as Nandi, Fiji to about 9 mRAD at Funafuti. In New Zealand, the corresponding range is from less than 1 mRAD at a low rainfall area such as Christchurch to about 4 mRAD at Greymouth. These numerical values represent very approximately the percentage increase in background radiation (for one year only) which would be equivalent to the gamma radiation from fallout deposited under these hypothetical and highest risk conditions.

Inspection of the results for Rarotonga, Aitutaki and Niue, where sample measurement was frequently delayed because of transport difficulties, indicate that the gamma doses at these places have been similar to those at the other stations, (except for the single deposition at Niue on 16 September 1966 which is discussed separately). Under the most pessimistic assumptions the doses are not likely to be greater than twice the average doses listed for the other stations and in all probability they lie within about the same range.

The assessments of gamma radiation dose made in this section are inevitably of an approximate nature but the calculations are probably correct to within a factor of two. They are, however, all unduly pessimistic assessments because they assume the worst possible conditions of deposition, not found in practice, and they neglect factors which attenuate the dose actually received. These attenuating factors are: shielding produced by irregularities of the surface, the presence of buildings, and weathering effects. These factors will reduce the actual radiation dose received by the whole body to about one quarter of that calculated (4).

The estimate of the gamma dose at Apia, Samoa, following the rain out on 16 September 1966, is known with much greater accuracy because the age and activity of the fission products on the day of deposition were established. The estimation is discussed in Table 4 (Apia, Samoa : Note 1). The dose to infinity from this single deposition was about 40mRAD. The estimated doses from the rest of the Samoan samples during the 1966 monitoring period gave an additional 12 mRAD. The total of 52 mRAD represents an increase of about 43% on the natural background level for one year only. At Niue, also on 16 September 1966, there was a similar single deposition with a dose calculated to be somewhat less than half that at Apia.

The single deposition at Apia of $7,700 \text{ mCi/km}^2$ on 16 September 1966 also provides an opportunity to compare the calculated dose rate with that shown by the portable gamma ray monitors. The formula (5) used for gamma dose assessment from total beta deposition ($1 \text{ Ci/metre}^2 = 10.6 \text{ RAD/hour}$) indicates an initial dose rate of 0.08 mRAD per hour from such a single deposition. The gamma monitors gave a reading of nearly 0.07 mRAD on 16 September or about 0.05 mRAD above background reading (Fig.2). This agreement is very satisfactory because although the monitor readings were made at a fixed site in the open away from shielding effects of buildings, some weathering effects and surface irregularities must be assumed. The slightly lower monitor readings even on the first day, before much weathering could take place, demonstrates that the assessment calculated from rainfall deposition under the hypothetical (worst possible) conditions is an over-estimate in the interests of safety.

(c) The Evaluation of the Internal Radiation Dose from Drinking Rainwater Containing Radioactive Fallout

Table 4 lists also the average concentration (at the time of measurement) of fission products in the rainwater during each monitoring period for the same stations that have also been assessed for gamma dose. This assessment is of particular value where rainwater is the sole source of drinking water as it enables the average levels during the monitoring period to be compared with the reference level (which is set for continuous consumption).

As already noted, the highest level of fallout deposition occurred at Apia on 16 September 1966. The concentration of the fission products in the rainwater sample of 13-20 September 1966 should not be compared with the reference level because the fission products were only 4 days old when deposited, and the reference level is applicable over the range of fission product ages of 10 to 80 days. The hazard assessment in this case, therefore, is made directly from the estimates of maximum permissible activity in water of

fission products of various ages (6). The concentration, as calculated at the time of measurement on 27 September, was 28,200 pCi/litre. Allowing for the radioactive decay which had occurred, this value adjusts to 135,000 pCi/litre of 4-day old fission products on 16 September, assuming that the deposition and the total rainfall for the week (6.41 cm) occurred on that day. This level is one third of the maximum permissible activity for continuous occupational exposure to 4-day old fission products in a controlled situation.

For members of the population at large, however, an additional safety factor of 30 is recommended. This level therefore, on the day of deposition was ten times the maximum permissible level for continuous exposure to the general public. The rate of radioactive decay would be such that in a further 24 days the level in this particular sample would have dropped to one-tenth, which is equal to the permissible level for the public. If this rainwater had been the sole source of drinking water during the interval from the day of collection to 24 days later, then the average concentration during this period would be about $2\frac{1}{2}$ times the permissible level set for continuous consumption for the public. If this rainwater had been the sole source of drinking water for the entire monitoring period, or indeed for the whole year, then the resulting exposure would be about equivalent to the permissible level (6).

However, this particular rainwater was not the sole source of drinking water and would have been diluted by rainfall already collected before the event, or by subsequent rainfall. For example, during the four weeks before this weekly collection, about 12cm of rain fell at Apia, and during the four weeks after this collection about 13cm of rain fell. The total rainfall for the monitoring period was 137cm. It has been conservatively estimated (7) that reasonable allowance for dilution would ensure an effective concentration not greater than $\frac{1}{4}$ of the reference level during the monitoring period, or not more than $\frac{1}{8}$ of the reference level for the whole year.

The average concentration of fission products in all the Samoan samples collected during the six months of the 1966 monitoring programme, except the sample of 13-20 September, was 232 pCi/litre. This average may be compared with the reference level for continuous consumption of fission products between 10 and 80 days old in drinking water (6,000 pCi/litre) and is about 4% of the reference level.

Similar considerations apply for the single deposition at Niue during the same time as already discussed under (b) in this section.

For the remaining Pacific Island stations average levels over a monitoring period range from 54 pCi/litre at Nandi (1967) to 530 pCi/litre at Funafuti (1967). In New Zealand, the range is from 35 pCi/litre at Christchurch (1967) to 155 pCi/litre at Auckland (1971). However, none of these stations, even if rainwater were the sole source of drinking water during the few months of any monitoring period, would have an average contamination level as great as 10% of the reference level for continuous consumption. The same considerations apply also for Rarotonga, Aitutaki, and for Niue after 1966.

(d) Some Arrival Times for Fission Products in Rain During 1971

Measurements of radioactive decay on samples indicate those occasions when some of the debris travelled in a westerly direction and arrived over the Central South Pacific earlier than would be expected if all the fission debris had circled the world in an easterly direction:

The Samoan collection, 19 - 26 June, contained fission products which appeared to be a mixture from the first two tests of 6 and 13 June.

The Samoan collection of 10 - 17 July, although not noticeably high in activity (see Fig.6) contained fission products from the test of 5 July. However, the higher level of activity at Suva at about the same time, 9 - 16 July, indicated fission products 4 weeks old from the test of 13 June.

The collection at Funafuti, 21 - 28 June, contained fission products originating in the test of 13 June.

4. Iodine-131 in Thrice-Weekly Milk Collections

(a) 1971 Results

The results are listed in Table 5 for the 7 New Zealand stations, and for Suva (Fiji) and Apia (Samoa). Iodine-131 was first detected in samples at the same time as the increases in total beta activity of air filter samples. The highest levels recorded were: At Apia, Samoa - 453 pCi/litre on 26 June; At Suva, Fiji - 75 pCi/litre on 9 July, and at a New Zealand collecting station, 23 pCi/litre at New Plymouth on 9 July. The highest level previously recorded was 708 pCi/litre at Apia, Samoa on 25 July 1967. These transient increases, however, are of slight health significance and average levels over longer periods must be used in hazard assessment. In New Zealand the levels have been relatively low during 1971.

(b) Comparison of Levels with Those During Previous Monitoring Programmes

Fig.7 shows the rapidly changing levels of iodine-131 in milk at the two Pacific Island stations and New Zealand for all monitoring programmes since 1966. Inspection of Fig.7 shows that levels at the Pacific Island stations have been significantly higher than in New Zealand (compare also the total beta activity of air filters). The pattern of levels corresponds quite well with the pattern of nuclear weapons tests except at Samoa where samples are taken from dairy herds at different localities on the different sampling days so that the level measured on a particular day does not necessarily represent the average level.

(c) Comparison of Average Levels with the Reference Level

Table 6 lists the average concentration of iodine-131 in milk during each monitoring period since 1966. Except at Suva and at Apia in 1966, these monitoring periods were of sufficient duration to allow measurement of all the positive levels of iodine-131 (above the minimum detectable level) for each nuclear test series.

The average level for each year in which nuclear tests were conducted can be calculated, therefore, because levels outside the monitoring periods are essentially zero. Such average values for each complete year are also listed in Table 6 and it is these yearly averages which are compared with the reference level based on continuous contamination.

The evaluation of the levels at Suva and Apia in 1966 is explained in Table 6 (see NOTE). These evaluations represent the highest levels measured to date. During 1966 they were approximately 25% and 20% of the reference level at Suva and Apia respectively. Since 1966, however, the average yearly levels at the two Pacific Island stations have ranged from 4% to 11% of the reference level. Average yearly levels in New Zealand have been of the order of 1% of the reference level.

5. Iodine-131 in New Zealand Cattle Thyroid

The results for 1971 are listed in Table 7 for the eight New Zealand collecting stations. Results for earlier years have been published in tabular and graphical form in previous issues of these reports (2). The maximum level reached in an individual sample during each of the five monitoring periods were:

1966	726 pCi/g	at Gore on 31 October.
1967	169 "	at Westport on 14 August.
1968	356 "	at Palmerston North on 12 August.
1970	696 "	at Hastings on 15 June.
1971	248 "	at Moerewa on 10 August.

The average, maximum, and minimum levels for iodine-131 in New Zealand milk and cattle thyroid are compared in Fig.8 on the same time scale. While there is some obvious correlation between the levels in milk and cattle thyroid (i.e. the average concentration in milk, expressed as pCi/litre, is approximately equal to one-tenth the average concentration in thyroid, expressed as pCi/g) the peak activities do not necessarily coincide in time - the rise and fall of the thyroid activity usually lagging slightly behind that of the milk. This effect may perhaps be more noticeable in the similar comparison graphs published for earlier monitoring programmes (2).

TABLE 1 FRENCH NUCLEAR TESTS IN THE SOUTH PACIFIC 1966 - 1971			
Year	New Zealand Date	Power of Device *	Duration of Monitoring Period
1966	3 July 20 July 12 September 25 September 5 October	25-30 kiloton 70-80 kiloton about 120 kiloton about 150 kiloton 200-300 kiloton	1 July to 31 December
1967	6 June 28 June 3 July	low yield low yield low yield	1 June to 30 September
1968	8 July 16 July 4 August 25 August 9 September	medium power medium power medium energy Hydrogen Bomb (2 megaton) Hydrogen Bomb (2 megaton)	4 July to 30 November
1969	NO NUCLEAR TESTS IN THE PACIFIC		
1970	16 May 23 May 31 May 25 June 4 July 28 July 3 August 7 August	low power low power high power low power Hydrogen Bomb low power low power low power	16 May to 31 October
1971	6 June 13 June 5 July 9 August 15 August	low power middle power low intensity low intensity Hydrogen Bomb (1 megaton)	4 June to 31 October

* In the graphical presentation of results in this report, low or medium power devices in the kiloton range are represented by an arrow ↓ Hydrogen bombs in the megaton range are represented by a larger arrow ↓

TABLE 2

TOTAL BETA ACTIVITY OF AIR FILTER SAMPLES

1971

In Picocuries per Cubic Metre on Day of Measurement

Collection: From 9.00 a.m. on the date shown to 9.00 a.m. on the following date. Stated in New Zealand Standard Time, i.e. G.M.T. + 12 hours.

Measurement: Routinely 4 days after the end of collection, unless otherwise noted in brackets after the result.

N.S.: No sample received.

Date	PACIFIC ISLANDS				NEW ZEALAND			
	Nandi Fiji	Suva Fiji	Apia Samoa	Tonga	Auck- land	Welling- ton	Hokitika	Christ- church
May 31					0.03(6)	0.04(7)	0.04(6)	0.05(6)
June 1					0.03(6)	0.04(7)	0.04(6)	0.05(6)
" 2					0.07	0.02	<0.01	0.03
" 3					0.07	0.02	<0.01	0.03
" 4	0.06				0.02	0.04	0.03	0.01
" 5	0.06		0.03(5)	<0.01(9)	0.03	0.01	0.08	0.01
" 6	0.04		0.02	0.01(8)	0.02	0.01	0.02	0.01
" 7	0.05(20)		0.03(3)	0.03(7)	0.08(3)	<0.01(3)	0.05(3)	0.01(3)
" 8	0.02(19)		0.01(5)	0.03(6)	0.06(5)	0.04(5)	0.05(5)	0.03(5)
" 9	0.06		0.04	0.03(5)	0.05	<0.01	0.04	0.02
" 10	0.03(6)		0.02	0.01	0.07	0.07	0.02	0.04
" 11	0.02(5)		0.04	0.02(6)	0.06	0.02	<0.01	0.03
" 12	0.02		0.02(8)	0.01(5)	0.07	0.01	0.06	0.04
" 13	0.03(7)		0.06(7)	0.02	0.02	0.03	0.04	0.04
" 14	0.03(7)		0.04(6)	0.01(9)	0.04(3)	0.02(3)	0.04(3)	0.08(3)
" 15	N.S.		0.05(5)	0.02(8)	0.05(5)	N.S.	0.02(5)	0.03(5)
" 16	0.03(5)	0.06	0.03	0.05(7)	0.03	0.02	0.02	0.03
" 17	0.03	0.06	0.03	0.03(6)	0.02	<0.01	0.03	0.03
" 18	0.04(6)	0.06(5)	0.05	0.05(5)	<0.01	0.04	0.02	0.04
" 19	0.04(5)	0.02	6.74(5)	0.05	0.03	0.04	0.04	0.05
" 20	0.02	0.03	27.55	0.10	0.02	<0.01	0.04(3)	0.04
" 21	0.05(6)	0.10(3)	19.57(3)	0.13(7)	0.04(3)	0.02(3)	0.03(3)	0.05(3)
" 22	0.35(5)	0.49(6)	20.56(5)	0.21(6)	0.08(5)	0.03(5)	<0.01(5)	0.04(5)
" 23	1.28	2.30(5)	10.57	0.73(5)	0.15(5)	0.05	0.05(5)	0.07
" 24	1.33	1.73(7)	2.78	0.27	0.17	0.04	0.03	0.04
" 25	1.01	1.20(6)	2.34	0.46(17)	0.13	0.13	0.17	0.11
" 26	0.95	0.89(5)	2.61(5)	0.28(16)	0.07	0.06	0.03	0.07
" 27	0.86	1.00	10.10	0.36(15)	0.12	0.13	0.04	0.12
" 28	0.64(6)	0.80(6)	9.13(6)	0.40(14)	0.12(6)	0.04(6)	<0.01(6)	0.08(6)
" 29	0.51(5)	0.62(5)	12.49(5)	1.88(13)	0.16(5)	<0.01(5)	0.04(5)	<0.01(5)
" 30	0.27	3.53(5)	10.28	3.58(12)	0.36	<0.01	<0.01	0.02(5)
Jun. Av.	0.30	0.86	5.20	0.34	0.07	0.03	0.04	0.04
July 1	0.42	1.18	3.00	2.89(11)	0.65	0.04	N.S.	0.08
" 2	2.15	1.84(5)	2.98	2.55(10)	0.49	0.14	0.52	0.21
" 3	1.05	1.89	2.15(5)	1.12(9)	0.10	0.04	0.03	0.04
" 4	2.04	1.53	1.51	0.92(8)	0.16	0.10	0.03	0.08
" 5	1.06(3)	0.74(3)	3.37(3)	0.70(7)	0.09(3)	0.04(3)	0.04(3)	0.06(3)
" 6	0.96(5)	0.83(5)	2.22(5)	0.92(6)	0.19(5)	0.03(5)	0.04(5)	0.04(5)
" 7	1.14	1.54	1.28	1.78(5)	0.11	<0.01	0.06	0.03
" 8	0.99	0.72(6)	1.65	1.65	0.08	0.05	0.23	0.07
" 9	0.83	0.61(5)	1.02	0.74(10)	0.14	0.06	0.42	0.24
" 10	0.83	1.10	1.00(5)	0.34(9)	0.11	0.05	0.27	0.24

(continued)

Date	Nandi Fiji	Suva Fiji	Apia Samoa	Tonga	Auck- land	Welling- ton	Hokitika	Christ- church
July 11	0.63	0.90	1.71	0.72(8)	0.41	0.32	0.48	0.33
" 12	1.75(3)	1.73(6)	1.63(3)	1.49(7)	0.34(3)	0.16(3)	0.64(3)	0.32(3)
" 13	0.97(5)	1.59(5)	1.32	1.74(6)	0.36(5)	0.26(5)	0.48(5)	0.23(5)
" 14	0.23(5)	1.18(5)	0.98(3)	1.32(5)	0.36	0.05	0.05	0.04
" 15	0.03	0.47	5.43(5)	0.69(6)	0.23	0.04	0.15	0.08
" 16	0.06	0.84	21.27	1.58(5)	0.11	0.12	0.23	0.13
" 17	0.12	N.S.	12.97(5)	2.31	0.09	0.64	0.44	0.44
" 18	0.16	1.81	9.07	0.53(7)	0.27	0.27	0.47	0.60
" 19	1.23(3)	2.48(3)	5.02(3)	1.42(7)	0.44(3)	0.53(3)	0.70(3)	0.84(3)
" 20	1.50(5)	1.80(5)	2.87(6)	0.76(6)	0.61(5)	0.40(5)	1.23(5)	0.81(5)
" 21	1.42	1.38	0.98(5)	0.68(5)	0.74	0.59	0.25	0.79
" 22	1.43(5)	1.29	1.40	0.17	0.47	0.56	0.56	0.91
" 23	1.29	1.24	0.88	1.47(6)	0.47	0.33	0.79	0.70
" 24	0.66	0.78	0.77(5)	0.48(5)	0.29	0.20	0.79	0.53
" 25	0.66	0.86	0.94	1.30	0.53	0.41	0.56	0.60
" 26	0.35(3)	0.61(3)	1.03(3)	2.26(10)	1.80(3)	0.58(3)	0.82(3)	0.89(3)
" 27	0.15(5)	0.34(5)	0.72(5)	1.90(9)	0.89(5)	0.45(5)	0.28(5)	0.59(5)
" 28	0.24(13)	0.56	1.91	1.39(8)	0.90	0.58	0.38	0.32
" 29	0.77	1.30	1.12	1.29(7)	1.02	0.40	0.32	0.46
" 30	1.26(5)	1.36(5)	0.89	1.17(6)	0.44	0.18	0.09	0.16
" 31	0.85	1.27	N.S.	0.58(5)	0.33	0.13	0.17	0.30
Jul. Av.	0.88	1.19	3.10	1.25	0.43	0.25	0.38	0.36
Aug. 1	1.25	1.08	1.01	0.72	0.31	0.25	0.63	0.30
" 2	0.86(3)	1.04(3)	1.10(3)	1.09(7)	0.38(3)	0.11(3)	0.98(3)	0.25(3)
" 3	0.34(5)	0.52(5)	1.14(5)	0.95(6)	0.78(5)	0.10(5)	0.85(5)	0.16(5)
" 4	0.45	0.75	0.55	0.93(5)	0.72	0.24	0.24	0.16
" 5	0.47	0.22(5)	0.30(5)	0.33	0.36	0.39	0.15	0.56
" 6	0.11(5)	0.12(5)	0.48	0.33(5)	0.09	0.17	0.10	0.24
" 7	0.09	0.26(5)	0.25(8)	0.13	0.08	0.10	0.21	0.08
" 8	0.45	0.93(7)	0.12(7)	0.56	0.34	0.15	0.17	0.49
" 9	1.05(3)	1.09(6)	0.32(6)	0.84(7)	0.48(3)	0.23(3)	0.16(3)	0.67(3)
" 10	1.13(5)	1.01(5)	0.35(6)	0.71(6)	0.13(5)	0.21(6)	0.22(5)	0.32(6)
" 11	N.S.	0.80	0.37(5)	1.06(5)	0.37(5)	0.10(5)	0.38(5)	0.17(5)
" 12	N.S.	0.47(5)	0.35	0.62	0.30	0.12	0.35	0.31
" 13	N.S.	0.47(5)	0.22	0.50(10)	0.35	0.23	0.14	0.31
" 14	N.S.	0.58	0.17(5)	0.45(9)	0.43	0.16	0.14	0.13
" 15	N.S.	0.57	0.14	0.51(8)	0.39	0.18	0.12	0.17
" 16	0.30(3)	0.28(3)	0.12(3)	0.28(7)	0.17(3)	0.22(3)	0.17(3)	0.12(3)
" 17	0.09(5)	0.13(5)	0.76(5)	0.64(7)	0.05(5)	0.12(5)	0.12(5)	0.06(5)
" 18	0.14	0.44	1.27	0.61(6)	0.04	0.13	0.08	0.06
" 19	0.06(5)	0.48	0.66	0.58(5)	0.06	0.25	0.38	0.14
" 20	0.03	0.28	0.78	0.39	0.24	0.26	0.37	0.37
" 21	0.10	0.37	0.89	0.16	0.30	0.13	0.20	0.65
" 22	0.36	0.41	0.49(5)	0.38	0.24	0.15	0.12	0.80
" 23	0.18(3)	0.43(3)	0.42	0.44(10)	0.26(3)	0.16(3)	0.10(3)	0.36(3)
" 24	0.59(5)	0.70(5)	0.30(5)	0.40(9)	0.17(5)	0.19(5)	0.11(5)	0.16(5)
" 25	0.49	N.S.	0.48	0.37(8)	0.31	0.19	0.28	0.22
" 26	0.23	0.55(7)	0.37(5)	0.40(7)	0.20	0.19	0.29	0.50
" 27	0.30(5)	0.99(6)	0.13	0.35(6)	0.35	0.25	0.27	0.38
" 28	0.47	0.48(5)	0.44(5)	0.88(5)	0.34	0.20	0.15	0.28
" 29	0.52	0.79	0.52	0.71	0.29	0.09	0.08	0.21
" 30	0.66(3)	0.68(6)	0.37(3)	0.41(7)	0.37(3)	0.29(3)	0.15(3)	0.17(3)
" 31	0.78(5)	0.72(5)	0.37(5)	0.64(6)	0.14(5)	0.09(5)	0.12(5)	0.03(5)
Aug. Av.	0.44	0.59	0.49	0.56	0.29	0.18	0.25	0.28
Sept. 1	0.75(5)	0.53(7)	0.36	0.76(5)	0.14	0.07	0.08(5)	0.05
" 2	0.58	0.47(6)	0.59(5)	0.50	0.20	0.06	0.08	0.10
" 3	0.47(5)	0.27(5)	4.19	0.51(9)	0.10	0.08	0.10	0.13
" 4	0.47	0.83	0.45(5)	0.74(8)	0.22	0.18	0.18(5)	0.14

(continued)

Date	Nandi Fiji	Suva Fiji	Apia Samoa	Tonga	Auck- land	Welling- ton	Hokitika	Christ- church
Sept. 5	0.76	0.80	0.99	1.09(7)	0.27	0.10	0.04	0.08
" 6	0.77(3)	0.63(3)	0.49(3)	1.22(6)	0.40(3)	0.09(3)	0.07(3)	0.43(3)
" 7	1.41(5)	0.69(6)	0.60(6)	2.05(5)	0.15(5)	0.27(5)	0.18(5)	0.14(5)
" 8	0.94	0.97(5)	1.28(5)	2.06(8)	0.29	0.08	0.29	0.16
" 9	N.S.	2.12	1.53	1.12(7)	0.39	0.23	0.24	0.46
" 10	1.53(5)	1.40	1.02	1.37(6)	0.52	0.25	0.35	0.37
" 11	0.60	1.18	0.85(5)	0.78(5)	0.49	0.36	0.43	0.16
" 12	0.91	0.96	2.07	0.91	0.20	0.07	0.05	0.16
" 13	0.94(3)	0.37(6)	0.87(3)	0.22(14)	0.18(3)	0.02(3)	0.07(3)	0.06(3)
" 14	0.58(5)	0.78(5)	0.78(5)	0.85(13)	0.08(5)	0.06(5)	0.08(5)	0.11(5)
" 15	0.20	0.51	0.90	0.73(12)	0.10	0.06	0.07	0.09
" 16	0.04(21)	0.37	1.36(7)	1.19(11)	0.23	0.07	0.11	0.17
" 17	0.16(10)	0.40(6)	0.58(6)	1.45(10)	0.22	0.10	0.14	0.12
" 18	0.49	0.67(5)	0.91(5)	1.40(9)	0.31	0.17	0.25(5)	0.25
" 19	0.50	0.72	0.74	0.79(8)	0.60	0.29	0.22	0.22
" 20	0.54(7)	1.42(6)	0.96(3)	0.59(7)	0.14(3)	0.23(3)	0.16(3)	0.12(3)
" 21	1.38(5)	0.37(5)	1.34(5)	0.59(6)	0.35(5)	0.21(5)	0.26(5)	0.19(5)
" 22	1.96(5)	2.23	1.17	1.81(5)	0.37	0.16	0.13	0.10
" 23	2.23	2.30(5)	0.97	0.39	0.18	0.05	0.11	0.12
" 24	2.12	2.18	0.65	1.23(9)	0.15	0.06	0.11	0.11
" 25	1.61	1.64	0.34(8)	1.69(8)	0.40	0.24	0.08	0.11
" 26	1.50	1.70	0.58(7)	1.70(7)	0.40	0.12	0.19	0.27
" 27	1.46(6)	1.49(6)	0.55(6)	0.92(6)	1.04(3)	0.31(3)	0.15(3)	0.16(3)
" 28	0.78(5)	0.98(5)	1.27(6)	1.27(5)	0.24(5)	0.05(5)	0.05(5)	0.11(5)
" 29	1.05	1.24	1.88(5)	1.22(5)	0.11(5)	0.08(5)	0.13	0.06
" 30	1.15	1.08	0.80	1.07	0.12	0.06	0.14	0.09
Sept. Av.	0.96	1.04	1.04	1.07	0.29	0.14	0.15	0.16
Oct. 1	1.10(5)	1.12(5)	0.80	0.64(10)	0.23	0.16	0.20	0.20
" 2	0.97	1.13	1.09(5)	0.40(9)	0.28	0.17	0.40	0.14
" 3	0.66	0.51(8)	0.79	0.56(8)	0.44	N.S.	0.24	0.14
" 4	0.15(6)	0.21(7)	0.52(3)	0.67(7)	0.81(3)	0.45(3)	0.29(3)	0.06(3)
" 5	0.12(6)	0.25(5)	0.27(6)	0.66(7)	0.62(5)	N.S.	0.13(5)	0.13(5)
" 6	0.41(5)	0.80	0.42(5)	0.46(6)	0.25	0.23	0.09	0.04
" 7	0.13	0.11(7)	0.23	0.43(5)	0.08	0.04	0.13	0.07
" 8	N.S.	0.07(6)	0.39	0.29(9)	0.27	0.10	0.16	N.S.
" 9	0.07(5)	0.26(5)	0.31(8)	0.33(8)	0.15	0.10	0.14	N.S.
" 10	0.12	1.17	0.72(6)	0.82(7)	0.21	0.10	0.14	0.08
" 11	0.33(6)	N.S.	0.72(6)	0.99(10)	0.13(6)	0.08(6)	0.10(6)	0.08(6)
" 12	N.S.	0.11(5)	0.49(5)	0.68(9)	0.15(5)	0.07(5)	0.08(5)	0.08(5)
" 13	0.24	0.19	0.44(5)	0.79(8)	0.37	0.13(5)	0.19	0.21
" 14	0.12(7)	0.23(7)	0.60	0.89(7)	0.30	0.13	0.17	0.17
" 15	N.S.	0.43(6)	0.40(3)	0.62(6)	0.25	0.17	0.16(6)	0.19
" 16	0.63	0.70(8)	0.27(5)	0.48(5)	0.28	0.16	0.20	0.19
" 17	0.63	0.70(8)	0.38	0.60	0.41	0.18	0.13	0.19
" 18	0.44(7)	0.59(7)	0.29(3)	0.33(10)	0.38(7)	0.22(7)	0.15(7)	0.14(7)
" 19	0.45(6)	0.48(6)	0.25(6)	0.50(9)	0.24(6)	0.13(6)	0.14(6)	0.12(6)
" 20	0.21(5)	0.33(5)	0.20(5)	0.57(8)	0.22(5)	0.10(5)	0.15(5)	0.19(5)
" 21	0.10	0.06(11)	0.18	0.54(7)	0.18	0.04	0.03(5)	0.22(5)
" 22	0.37	0.19(10)	0.29	0.73(6)	0.24	0.14	0.07	0.14
" 23	0.23	0.22(5)	0.42	0.48(5)	0.10	0.09	0.25	0.14
" 24	0.25	0.31	0.31	0.36	0.07	0.14	0.31	0.14
" 25	0.26(7)	0.16(6)	0.35(6)	0.31(6)	0.17(6)	0.11(6)	0.18(6)	0.14(6)
" 26	0.25(5)	0.22(5)	0.48(5)	0.31(12)	0.26(5)	0.09(5)	0.18(5)	0.08(5)
" 27	0.27	0.32	0.33	0.45(11)	0.31	0.11	0.18	0.19
" 28	0.43	0.40	0.27	0.44(10)	0.34	0.04	0.07	0.03(6)
" 29	0.07(5)	0.14	0.37	0.30(9)	0.11	0.05	0.08(6)	0.08
" 30	0.14	0.14	0.17(5)	0.33(8)	0.12	0.06	0.07	0.08
" 31	0.16	0.14	0.11	0.08(7)	0.15	0.10	0.07	0.08
Oct. Av.	0.33	0.39	0.41	0.52	0.26	0.13	0.16	0.12

<p><u>TABLE 3</u> <u>AVERAGE LEVEL OF AIR RADIOACTIVITY FOR EACH</u> <u>MONITORING PERIOD - 1966-1971 (TOTAL BETA</u> <u>ACTIVITY - pCi/m³)</u></p>								
Monitoring Period	Nandi Fiji	Suva, Fiji	Apia, Samoa	Tonga	Auck- land	Welling- ton	Hokitika	Christ- church
1966 1 July - 31 Dec.	1.39				0.26	0.17		0.18
1967 1 June - 30 Sept.	0.38	0.37	1.15		0.11	0.07		0.08
1968 4 July - 30 Nov.	0.97	1.22	1.30	0.81	0.22	0.19		0.14
1970 16 May - 31 Oct.	0.56	0.62	1.06	0.60	0.22	0.16	0.18	0.14
1971 4 June - 31 Oct.	0.58	0.81	2.05	0.75	0.27	0.15	0.20	0.19

TABLE 4 TOTAL BETA ACTIVITY OF WEEKLY RAINWATER SAMPLES 1971

Deposition in millicuries per square kilometre (at
time of measurement)

Collection: From date shown to start of next
collection.

N.S.: No sample received.

Collection	Rain (cm)	Deposition (mCi/km ²)	Comparison Previous Tests		
<u>TARAWA:</u>					
4 June	6.1	0.5		<u>Total</u>	<u>Dose to</u>
11 June	1.2	0.4		<u>Deposition</u>	<u>Infinity</u>
18 June	2.3	1.3		<u>mCi / km²</u>	<u>mRAD</u>
25 June	2.6	3.7	1966	82.8	3.1
2 July	2.3	1.7	1967	185.1	7.0
9 July	1.9	1.7	1968	43.2	1.6
16 July	0.3	1.8	1970	41.2	1.6
23 July	2.8	2.8	1971	24.8	0.9
30 July	2.0	1.2			
6 August	1.3	0.5			
13 August	1.0	0.6			
20 August	<0.1	0.3			
27 August	0.2	0.3			
3 September	0.1	0.8			
10 September	1.8	2.6			
18 September	1.5	0.6			
24 September	0.6	0.5			
1 October	0.3	0.9			
8 October	0.4	0.8			
15 October	6.5	1.4			
22 October	2.9	0.4			
TOTAL:	38.2	24.8			
<u>FUNAFUTI:</u>					
4 June	0.4	0.5		<u>Total</u>	<u>Dose to</u>
7 June	1.0	0.4		<u>Deposition</u>	<u>Infinity</u>
14 June	5.8	0.4		<u>mCi / km²</u>	<u>mRAD</u>
21 June	4.6	4.2	1966	257.7	9.8
28 June	2.6	1.8	1967	504.6	19.2
5 July	1.8	1.5	1968	220.6	8.4
12 July	1.2	3.4	1970	147.6	5.6
19 July	4.7	8.7	1971	78.7	3.0
26 July	4.9	3.3			
2 August	7.3	3.3			
9 August	3.4	1.8			
16 August	1.8	1.1			
23 August	4.6	3.0			
30 August	3.0	5.7			
6 September	7.1	16.0			
12 September	5.7	5.7			
20 September	2.5	2.5			
27 September	6.7	3.5			
4 October	7.7	4.3			
11 October	3.8	3.0			
18 October	0.2	0.2			
25 October	7.5	4.3			
29 October	1.5	0.1			
TOTAL:	89.8	78.7			
			<u>Average Concentration</u>		
			<u>pCi / litre</u>		
			1966	95	
			1967	523	
			1968	113	
			1970	142	
			1971	65	

(continued)

Collection	Rain (cm)	Deposition (mCi/km ²)	Comparison Previous Tests	
<u>NANDI, FIJI:</u>				
4 June	0.3	0.2		
16 June	NIL	0.2		
21 June	1.9	0.6		
6 July	1.3	1.9		
12 July	NIL	0.9		
19 July	0.1	0.3		
26 July	1.3	1.3		
9 August	NIL	<0.1		
15 August	5.7	1.4		
23 August	NIL	0.1		
31 August	0.4	2.8		
6 September	1.6	0.2		
13 September	4.6	2.4		
20 September	2.5	2.6		
27 September	TRACE	0.2		
4 October	12.6	4.5		
13 October	2.8	1.9		
18 October	5.8	3.3		
26 October	2.3	2.1		
TOTAL:	43.2	27.0		
			<u>Total Deposition</u> mCi / km ²	<u>Dose to Infinity</u> mRAD
			1966	32.4
			1967	8.1
			1968	81.4
			1970	31.9
			1971	27.0
			<u>Average Concentration</u> pCi / litre	
			1966	73
			1967	54
			1968	277
			1970	96
			1971	63

<u>SUVA, FIJI:</u>				
15 June	1.8	0.9		
22 June	2.2	2.5		
29 June	1.2	17.7		
1 July	2.1	12.9		
9 July	8.7	26.5		
16 July	1.6	8.5		
23 July	0.8	8.2		
30 July	-	N.S.		
6 August	4.2	9.8		
15 August	2.4	5.2		
20 August	1.7	3.0		
27 August	<0.1	1.3		
3 September	1.1	2.8		
10 September	1.5	3.0		
17 September	9.7	7.4		
21 September	0.2	1.9		
27 September	10.1	5.4		
5 October	18.5	6.5		
9 October	16.1	4.8		
15 October	7.8	5.0		
21 October	5.8	4.2		
28 October	4.3	3.8		
TOTAL:	101.9	141.3		
			<u>Total Deposition</u> mCi / km ²	<u>Dose to Infinity</u> mRAD
			1966	179.0
			1967	49.9
			1968	137.0
			1970	144.2
			1971	141.3
			<u>Average Concentration</u> pCi / litre	
			1966	297
			1967	108
			1968	277
			1970	139
			1971	139

(continued)

Collection	Rain (cm)	Deposition (mCi/km ²)	Comparison Previous Tests	
<u>APIA, SAMOA:</u>				
5 June	7.1	0.8		
12 June	3.0	0.5		
19 June	3.0	33.6		
26 June	0.2	6.7		
3 July	3.7	8.8	1966	See Note 1 52.0
10 July	1.3	6.5	1967	88.3 3.4
17 July	0.1	4.0	1968	144.7 5.5
24 July	<0.1	0.6	1970	121.7 4.6
31 July	2.2	3.6	1971	111.4 4.2
7 August	3.3	2.4		
14 August	0.1	0.8		
21 August	1.0	1.8		
28 August	0.9	6.6		
4 September	5.4	9.0		
11 September	-	6.5		
18 September	0.9	1.9		
25 September	8.8	6.0		
2 October	1.6	2.9		
9 October	0.4	3.8		
17 October	0.3	1.2		
23 October	3.8	3.4		
TOTAL:	(47.2)	111.4		
			<u>Average Concentration</u> <u>pCi / litre</u>	
			1966	see pp.13, 14
			1967	111
			1968	128
			1970	163
			1971	236
<u>NIUE:</u>				
5 June	0.5	0.3		
15 June	0.3	0.6		
22 June	NIL	0.6		
29 June	2.7	4.2		
6 July	4.4	1.1		
13 July	2.4	11.1		
20 July	0.4	2.0		
30 July	0.1	2.4		
3 August	1.6	5.4		
11 August	3.7	4.8		
17 August	1.9	2.1		
24 August	0.7	2.2		
31 August	0.6	3.9		
7 September	0.3	3.6		
14 September	1.6	4.8		
21 September	31.5	18.2		
30 September	0.8	2.6		
5 October	NIL	1.4		
12 October	8.6	9.3		
20 October	0.3	1.3		
26 October	6.8	2.4		
TOTAL:	69.2	84.3		
			See Note 2 and pp. 13, 14	

NOTE 1 : The highest deposition measured during any of these monitoring programmes was at Apia, Samoa in the weekly collection 13-20 September 1966. Gamma ray monitoring indicated that the deposition occurred on 16 September. Allowing for radioactive decay, the measured activity adjusted to a deposition on 16 September of about 7,700 mCi/km² of 4-day old fission products from the nuclear test of 12 September 1966. The dose rate to infinity for such a single deposition is about 40 mR. The dose rate calculated from the remaining Samoan samples is 12 mR, giving a total of 52 mR during the 1966 monitoring programme.

NOTE 2 : Calculations based on a similar single deposition of 3,400 mCi/km² at Niue on 16 September 1966 give a dose to infinity of about 18 mR (see NOTE 1).

(continued)

Collection	Rain (cm)	Deposition (mCi/km ²)	Comparison Previous Tests	
<u>TONGA:</u>				
5 June	1.6	0.3		
11 June	0.2	0.3		
18 June	0.2	0.3		
25 June	1.7	1.4		
2 July	0.4	2.1	1966	77.4 2.9
9 July	0.7	1.3	1967	21.5 0.8
16 July	TRACE	0.7	1968	116.1 4.4
23 July	0.6	1.4	1970	82.6 3.1
30 July	1.8	4.6	1971	53.2 2.0
6 August	5.9	2.4		
8 August	<0.1	0.7		
13 August	3.2	2.2		
20 August	0.1	0.6		
27 August	<0.1	0.5		
3 September	TRACE	0.5		
10 September	2.9	7.5		
17 September	9.6	10.6		
21 September	6.9	5.0		
24 September	0.4	1.8		
1 October	0.3	2.1		
8 October	8.4	3.3		
15 October	0.2	1.0		
22 October	0.2	0.4		
29 October	10.6	2.2		
TOTAL:	56.0	53.2		

<u>AITUTAKI:</u>				
14 June	TRACE	0.3		
21 June	0.9	3.5		
28 June	2.1	2.1		
5 July	0.3	1.1		
12 July	2.1	13.9		
19 July	0.2	2.8		
26 July	TRACE	1.1		
2 August	0.3	3.6		
9 August	5.8	3.6		
12 August	0.4	0.4		
16 August	0.3	0.8		
23 August	7.8	5.8		
28 August	8.4	6.0		
30 August	5.1	11.0		
6 September	0.5	2.2		
14 September	TRACE	1.2		
20 September	9.5	13.3		
28 September	0.4	3.2		
4 October	0.3	2.1		
11 October	1.2	2.2		
18 October	1.8	1.0		
25 October	0.6	1.2		
TOTAL:	48.0	82.4		

See pp. 12, 14

(continued)

Collection	Rain (cm)	Deposition mCi / km ²	Comparison Previous Tests
<u>RAROTONGA:</u>			See pp. 12, 14
8 June	0.1	0.2	
15 June	1.4	<0.1	
22 June	0.4	3.5	
29 June	2.0	2.9	
6 July	<0.1	1.6	
13 July	3.8	6.9	
20 July	1.6	8.5	
27 July	1.3	1.8	
3 August	2.6	4.3	
10 August	1.9	1.3	
17 August	0.5	1.5	
24 August	10.4	8.3	
7 September	0.3	1.9	
14 September	0.6	3.1	
21 September	4.4	2.0	
28 September	2.4	3.2	
5 October	-	N.S.	
12 October	2.9	3.8	
19 October	0.6	<0.1	
TOTAL:	37.3	54.9	

AUCKLAND:		
4 June	2.6	0.3
11 June	0.9	0.2
18 June	1.2	0.9
25 June	1.8	1.6
2 July	8.0	6.3
9 July	0.5	0.6
16 July	<0.1	0.3
23 July	2.6	13.8
30 July	2.4	2.0
6 August	2.4	0.5
13 August	0.3	3.5
20 August	0.2	3.0
27 August	4.9	1.4
3 September	4.7	8.1
10 September	2.9	5.2
17 September	2.1	4.1
24 September	1.7	4.2
1 October	1.8	7.0
8 October	1.4	5.3
15 October	4.2	6.5
22 October	3.9	3.4
TOTAL:	50.6	78.2

	<u>Total Deposition mCi / km²</u>	<u>Dose to Infinity mRAD</u>
1970	94.7	3.6
1971	78.2	3.0

<u>Average Concentration pCi / litre</u>	
1970	124
1971	155

(continued).

Collection	Rain (cm)	Deposition mCi / km ²	Comparison Previous Tests	
<u>WELLINGTON:</u>				
4 June	0.3	0.1	<div><div><u>Total Deposition</u> <u>mCi / km²</u></div><div>1970 68.9</div><div>1971 59.4</div></div> <div><div><u>Average Concentration</u> <u>pCi / litre</u></div><div>1970 88</div><div>1971 80</div></div>	<div><div><u>Dose to Infinity</u> <u>mRAD</u></div><div>2.6</div><div>2.3</div></div>
11 June	1.8	0.6		
18 June	2.0	0.3		
25 June	4.4	0.5		
2 July	3.4	0.7		
9 July	3.6	2.0		
16 July	1.3	1.2		
23 July	3.5	5.7		
30 July	0.9	1.8		
6 August	<0.1	0.7		
13 August	14.2	6.9		
20 August	1.7	3.2		
27 August	2.3	0.8		
3 September	0.3	0.9		
10 September	3.5	1.1		
17 September	2.6	2.5		
24 September	2.6	2.5		
1 October	6.5	10.7		
8 October	12.1	6.6		
15 October	5.7	5.9		
22 October	1.4	4.7		
TOTAL:	74.2	59.4		

GREYMOUTH:		
5 June	11.5	0.6
12 June	3.4	0.7
19 June	1.4	1.3
26 June	6.9	3.4
3 July	3.8	1.2
10 July	NIL	0.2
17 July	NIL	<0.1
24 July	4.5	7.3
31 July	0.1	0.7
7 August	3.6	6.2
14 August	4.8	2.2
21 August	7.0	3.9
28 August	4.9	9.0
4 September	1.6	1.0
11 September	6.3	2.4
18 September	3.6	1.2
25 September	16.6	8.0
2 October	6.1	10.2
9 October	8.9	8.7
16 October	5.4	6.9
23 October	5.9	11.7
TOTAL:	106.3	76.9

	<u>Total</u> <u>Deposition</u> <u>mCi / km²</u>	<u>Dose to</u> <u>Infinity</u> <u>mRAD</u>
1966	106.3	4.0
1967	37.4	1.4
1968	192.1	7.3
1970	114.1	4.3
1971	76.9	2.9

	<u>Average Concentration</u> <u>pCi / litre</u>
1966	116
1967	63
1968	144
1970	79
1971	72

(continued)

Collection	Rain (cm)	Deposition mCi / km ²	Comparison Previous Tests	
<u>CHRISTCHURCH:</u>				
4 June	0.8	0.2	<u>Total</u>	<u>Dose to</u>
11 June	1.6	0.3	<u>Deposition</u>	<u>Infinity</u>
18 June	<0.1	<0.1	<u>mCi / km²</u>	<u>mRAD</u>
25 June	0.8	0.2	1966	28.2
2 July	2.1	0.3	1967	5.9
9 July	2.2	0.8	1968	21.7
16 July	3.3	2.9	1970	19.9
23 July	0.2	0.9	1971	16.2
30 July	0.4	1.6		
6 August	<0.1	0.2		
13 August	TRACE	0.5		
20 August	1.1	0.5		
27 August	0.4	0.6		
3 September	0.3	0.4		
10 September	0.9	1.0		
17 September	0.3	0.3		
24 September	1.3	1.7		
1 October	0.2	0.7		
8 October	0.5	0.5		
15 October	2.0	1.5		
22 October	1.4	0.5		
29 October	1.3	0.5		
TOTAL:	21.2	16.2		
			<u>Average Concentration</u>	
			<u>pCi / litre</u>	
			1966	106
			1967	35
			1968	123
			1970	71
			1971	76

TABLE 5		IODINE-131 IN MILK							1971	
Picocuries per Litre (at noon on day of collection)										
(N.S. - No Sample Received)										
Date	NEW ZEALAND							PACIFIC IS.		
	Auck-land	New Plymouth	Wellington	Grey-mouth	Christ-church	Dunedin	Inver-cargill	Suva, Fiji	Apia, Samoa	
June 7	<2	<2	<2	<2	<2	<2	<2			
" 9	<2	<2	<2	<2	<2	<2	<2		<2	
" 11	<2	<2	<2	<2	<2	<2	<2			
" 12									<2	
" 14	<2	<2	<2	<2	<2	<2	<2			
" 16	<2	<2	<2	<2	<2	<2	<2		<2	
" 18	N.S.	<2	<2	<2	<2	<2	<2	<2		
" 19									<2	
" 21	<2	<2	<2	<2	N.S.	<2	<2	<2		
" 23	<2	<2	<2	<2	<2	<2	<2	<2	127	
" 25	<2	<2	<2	<2	<2	<2	<2	7		
" 26									453	
" 28	3	2	<2	4	<2	<2	<2	N.S.		
" 30	4	4	<2	6	<2	2	<2	47	329	
July 2	5	N.S.	<2	6	<2	<2	<2	32		
" 4									39	
" 5	N.S.	N.S.	<2	6	<2	2	2	N.S.		
" 7	14	17	2	6	<2	<2	4	65	71	
" 9	9	23	<2	3	<2	N.S.	<2	75		
" 10									139	
" 12	7	11	5	5	<2	3	<2	N.S.		
" 14	6	10	2	5	<2	<2	3	41	75	
" 16	8	9	3	3	<2	<2	3	41		
" 17									86	
" 19	4	7	2	2	<2	<2	<2	43		
" 21	6	5	<2	<2	3	<2	<2	53	138	
" 23	5	6	<2	4	<2	3	<2	53		
" 24									138	
" 26	N.S.	3	<2	<2	3	<2	<2	46		
" 28	8	4	3	<2	<2	<2	<2	38	28	
" 30	10	8	7	4	<2	<2	<2	27		
" 31									22	
Aug. 2	7	8	N.S.	4	<2	<2	2	N.S.		
" 4	N.S.	N.S.	4	4	<2	5	<2	14	12	
" 6	10	6	3	6	3	<2	<2	N.S.		
" 7									41	
" 9	6	6	4	6	<2	<2	<2	8		
" 11	N.S.	3	<2	4	2	<2	<2	9	26	
" 13	5	2	3	3	3	<2	3	5		
" 14									29	

(continued)

Date	NEW ZEALAND							PACIFIC IS.	
	Auck- land	New Plymouth	Welling- ton	Grey- mouth	Christ- church	Dunedin	Inver- cargill	Suva, Fiji	Apia, Samoa
Aug. 16	4	<2	<2	<2	<2	<2	<2	4	
" 18	4	2	2	<2	<2	5	3	4	8
" 20	4	3	4	2	3	2	2	4	
" 21									5
" 23	N.S.	2	<2	<2	<2	<2	N.S.	<2	
" 25	<2	<2	<2	<2	<2	<2	<2	<2	11
" 27	<2	<2	<2	6	<2	<2	N.S.	<2	
" 28									10
" 30	2	3	<2	2	3	<2	N.S.	N.S.	
Sept. 1	3	2	3	<2	<2	<2	<2	2	4
" 3	5	<2	<2	<2	<2	<2	N.S.	7	
" 4									3
" 6	N.S.	<2	<2	<2	<2	<2	<2	2	
" 8	N.S.	3	<2	<2	<2	<2	N.S.	19	33
" 10	11	4	3	4	<2	<2	<2	24	
" 11									N.S.
" 13	N.S.	6	4	3	<2	<2	<2	N.S.	
" 15	N.S.	N.S.	3	2	2	<2	<2	30	N.S.
" 17	6	2	3	2	N.S.	<2	N.S.	25	
" 18									6
" 20	N.S.	<2	<2	4	2	<2	N.S.	29	
" 22	N.S.	2	<2	2	<2	<2	N.S.	17	65
" 24	9	4	4	3	2	<2	N.S.	N.S.	
" 25									41
" 27	N.S.	4	<2	<2	2	2	N.S.	19	
" 29	<2	4	2	6	<2	<2	<2	9	2
Oct. 1	4	<2	<2	<2	<2	<2	<2	17	
" 2									N.S.
" 4	N.S.	2	<2	<2	2	<2	<2	9	
" 6	<2	<2	<2	<2	2	<2	<2	7	3
" 8	3	N.S.	N.S.	<2	<2	<2	<2	9	
" 9									N.S.
" 11	2	<2	2	<2	N.S.	<2	<2	6	
" 13	N.S.	2	2	<2	<2	<2	N.S.	N.S.	3
" 15	<2	<2	2	<2	<2	<2	<2	N.S.	13
" 16									9
" 18	N.S.	2	<2	<2	<2	<2	N.S.	N.S.	
" 20	<2	<2	<2	<2	<2	<2	<2	N.S.	<2
" 22	<2	<2	<2	<2	N.S.	<2	N.S.	N.S.	
" 23									<2
" 25								N.S.	
" 27								<2	5
" 29								<2	
" 30									2
Nov. 1								<2	
Average June to October	5	4	2	3	1	1	1	18	47
NEW ZEALAND COUNTRY-WIDE AVERAGE 2.4									

<p>TABLE 6 <u>IODINE-131 IN MILK 1966-1971</u> <u>HAZARD ASSESSMENT</u></p>				
	YEAR	NEW ZEALAND COUNTRY-WIDE AVERAGE	SUVA, FIJI	APIA, SAMOA
Average Level During The Monitoring Period (pCi/litre)	1966 1967 1968 1970 1971	7 <5 5 5 2	See Note * 23 36 25 18	See Note * 68 28 43 47
Average Level During The Entire Year (pCi/litre)	1966 1967 1968 1970 1971	4 1 2 2 1	(50) 8 12 10 8	(40) 23 9 17 20
% of Reference Level	1966 1967 1968 1970 1971	2% <1% 1% 1% <1%	(25%) 4% 6% 5% 4%	(20%) 11% 5% 9% 10%

* NOTE:

It was not originally intended to include milk from the Pacific Islands in this monitoring programme because of the small production and consumption of fresh milk in the Islands. After the increase in air radioactivity at Fiji on 17 September 1966, and in rainwater from Samoa collected during the week 13-20 September 1966 it was decided to obtain milk samples for measurement of radioiodine. The first samples were collected at Suva on 8 October and at Apia on 6 October 1966, and an attempt has been made to assess the levels existing during the three weeks prior to collection by extrapolation of measured values back to 17 September. The bracketed values for the 1966 average level, and the percentage of maximum permissible level, at Suva and Apia are based on these calculations and are only approximate. They are probably correct to within a factor of two.

TABLE 7		IODINE-131 IN CATTLE THYROIDS						1971
Picocuries per Gram Wet Weight at Time of Slaughter								
Date	Moerewa	Hamilton	New Plymouth	Hastings	Palmerston North	Westport	Christchurch	Gore
May 31		<0.1	<0.1					<0.1
June 8	<0.1	<0.1	<0.1	N.S.	N.S.	<0.1		<0.1
" 9							<0.1	
" 14	<0.1	<0.1	<0.1	N.S.		<0.1	N.S.	<0.1
" 17					<0.1			
" 21	2	<0.1			<0.1	<0.1	N.S.	<0.1
" 22				<0.1				
" 23			<0.1					
" 28	75	12	9	N.S.	8	17	N.S.	3
July 5	176	25	58	65	43	90	N.S.	13
" 12	197	48			67	93		N.S.
" 13			53	136			1	
" 19		83		86	94	112	N.S.	35
" 20	206		53					
" 26	115	88		86		87	N.S.	35
" 27			37		62			
Aug. 2	N.S.	63		138		75		20
" 3					174			
" 4			84				72	
" 9		92		106	N.S.	63	57	20
" 10	248							
" 11			68					
" 16		38			N.S.	82		10
" 17	161		34				63	
" 18				61				
" 23	23	19		35	N.S.	18		9
" 24			21					
" 25							15	
" 30	15	23				39		6
" 31			11	N.S.	N.S.			
Sep. 1							12	
" 6	9	17				27		3
" 7			12	N.S.	N.S.		N.S.	
" 13	110	46				33		8
" 14			N.S.	N.S.	N.S.		14	
" 20	98	23		51		39	13	16
" 21			23		N.S.			
" 27	36	50				35	12	9
" 28			24	N.S.	N.S.			
Oct. 4	25					44		12
" 5		N.S.		12	N.S.		N.S.	
" 7			23					
" 11	25			22				
" 12							23	
" 18				15			4	
Nov. 2							6	

N.S. - No Sample

Fig. 2 GAMMA RADIATION LEVELS AT APIA, SAMOA - 1966

Fig. 3 DATES OF ARRIVAL OF THE FIRST TRACES OF FRESH FISSION PRODUCTS IN AIR - 1971

Fig. 4

DAILY AIR RADIOACTIVITY (TOTAL BETA ACTIVITY)
 DURING THE 1971 MONITORING PROGRAMME

Fig. 5

AVERAGE AIR RADIOACTIVITY (TOTAL BETA ACTIVITY)
DURING EACH MONITORING PROGRAMME SINCE 1966

Fig. 6

DEPOSITION OF FISSION PRODUCTS IN RAIN (TOTAL BETA ACTIVITY) DURING THE 1971 MONITORING PROGRAMME

Fig. 7

IODINE-131 IN NEW ZEALAND MILK AND CATTLE THYROID
DURING THE 1971 MONITORING PROGRAMME

PICOCURIES I-131 PER LITRE AT NOON ON DAY OF COLLECTION (Note Log Scale)

Fig. 8

IODINE-131 IN MILK DURING EACH MONITORING PROGRAMME
SINCE 1966

1. Gamma Radiation Monitoring

Two portable monitors are provided at each station. These instruments have 3 ranges of response. The greatest range of response is 0 to 50 mRAD per hour. The most sensitive range, however, is 0 to 0.5 mRAD per hour, enabling significant readings even on the natural background radiation (i.e. 0.01 to 0.02 mRAD per hour). The reporting level which has been set at 0.3 mRAD per hour, is, therefore, within the most sensitive range of the monitors. During the monitoring period readings are made three times each day at evenly spaced intervals. The readings are made at a fixed point three feet above ground level, in the open and away from the shielding effects of buildings. Should readings reach the reporting level the operators are instructed to check the level using the spare monitor, to take readings at other places, and to increase the frequency of taking and reporting readings.

Before despatch to the monitoring station the monitors are checked for linearity of response on all range settings. They are then calibrated using a 25 mCi cobalt-60 source on a "gamma range". The monitors are adjusted to read to within 10% of the correct gamma dose rate at 3 mRAD per hour. A beta emitting "check source" is attached to the side of the monitor, and the operation of the monitor is checked using this source prior to every measurement of gamma radiation level at the monitoring station.

2. Air Filter Sampling

The samplers are portable, motor-driven, positive displacement pumps operating at 230 volts 50 cycle A.C. Sampling involves the collection of 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. Individual samplers are calibrated using gas meters before despatch to the monitoring station. 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 airmailed to the Laboratory and the total beta activity of the entire filter is measured using the five inch 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 per cubic metre. The counter is calibrated using a KCl standard prepared and measured under similar geometry.

3. Rainwater Collection

Samples are collected by means of a polyethylene funnel and bottle collector. The collecting bottles contain "carrier solution" for mixed fission products and the funnels have a diameter of 17.0 cm at the New Zealand stations, and 9.9 cm at the Pacific Island stations. Each rainwater sample is despatched to the Laboratory in its collection bottle, and is then transferred quantitatively by means of acid washes to a beaker for evaporation to a sufficiently small volume. The sample is then transferred quantitatively to a 4.5 inch diameter stainless steel planchette and evaporated to dryness. The total beta activity

is measured using the 5 inch detector of the Beckman Beta Counting System (as for air filter measurement). The beta counter is calibrated using a KCl standard prepared and measured under the same geometry conditions as the rain planchette samples. The sample beta activity, and funnel collecting area, are the basic data from which the deposition (mCi/km^2) is calculated. The concentration of fission products in the rainwater is calculated from the deposition result, using also the measurement of rainfall which is independently assessed during the collection period.

4. Milk Collection for Iodine-131 Assessment

The iodine-131 in fresh milk is extracted by passing one litre of milk through a column containing 40 ml of De Acidite FF anion exchange resin, (14 to 52 mesh, in the chloride form). After washing the resin free of milk residues with distilled water, the resin is transferred to a polyethylene bottle, which is placed in the well of a 102 mm (diam.) x 102 mm crystal coupled to a 130 mm (diam.) phototube. The activity of iodine-131 is measured in a gamma spectrometer using a Nuclear Data pulse height analyser. Measurements of the photopeaks in the appropriate channels are made, in particular a 70 keV wide channel centred on 0.364 MeV, where the major peak occurs. The gamma spectrometer is calibrated using standard -131 solutions extracted by anion exchange resin and measured under the same geometry conditions as for samples. The limit of detection is 2 picocuries per litre.

The advantages of this procedure are twofold. Firstly, an increase in sensitivity results from concentrating the iodine-131 by ion exchange extraction, thus allowing measurement in the well of the crystal. Secondly, interference due to naturally-occurring potassium, and any possible interference due to cationic radionuclides in the sample is eliminated by using anion exchange resin for extracting the radioiodine.

Milk collected at the New Zealand stations is sent by air to the Laboratory for immediate analysis. At the Pacific Island stations, however, the milk is extracted for radioiodine by the local Health Departments, and the ion exchange resin is air-mailed to the Laboratory for measurement. All results are adjusted to the activity at noon on the day of collection.

5. Cattle Thyroid Collection for Iodine-131 Assessment

Each sample, containing thyroid glands from a number of cattle, is cut into small pieces and a 60 ml polyethylene bottle is then filled by random selection of the pieces. The bottle containing the sample is then placed in the well crystal of the gamma spectrometer and measured for iodine-131 (as for milk-resin samples). The spectrometer is calibrated using standard iodine-131 solutions measured under the same geometry conditions as for samples. The lower limit of detection for this measurement is 0.1 pCi/gram of wet thyroid. The measured activity is adjusted to the activity at time of slaughter.

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

X Cesium-137 in Various Chicago Foods*

(Collection Months January ~~1972R~~ and April 1972)

S. S. Brar

Radiological Physics Division
Argonne National Laboratory
Argonne, Illinois 60439

Since April, 1961, the ^{137}Cs and potassium content of the Chicago portion of Tri-City Diet Sampling Program has been determined¹⁻⁴ in bulk food samples by gamma ray spectrometry using a 4" x 4" NaI (Tl) crystal. The individual food components were counted for a minimum of 100 minutes, and from these measurements composite daily and yearly food intakes were obtained. Cesium-137 activity in food, now, is an order of magnitude lower than it was a few years ago; consequently, a new procedure for these measurements has been adopted in order to improve accuracy. The same variety of foods (all fresh vegetables, all fresh fruits, etc.) are composited before measurement, and the samples are counted a minimum of 400 minutes. The results for the January, 1972 quarter are tabulated in Tables I and II.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

Table I

Cesium-137 in Chicago Diets

(Adults)

January, 1972

	kg/yr	Potassium g/kg	^{137}Cs pCi/kg	Potassium g/yr	^{137}Cs pCi/yr
White Bread	37	1.1	15	41	555
Whole Wheat Bread	11	2.5	28	28	308
Eggs	16	1.3	0	21	0
Fresh Vegetables	43	2.4	0	103	0
Root Vegetables	17	2.8	0	48	0
Milk	221	1.5	12	332	2652
Poultry	17	2.6	10	44	170
Fresh Fish*	8	3.4	37	27	296
Flour	43	1.1	12	47	516
Macaroni	3	2.1	18	6	54
Meat	73	3.0	12	219	876
Dried Beans	3	12.9	11	39	33
Fresh Fruit	68	2.1	0	143	0
Potatoes	45	5.0	0	225	0
Canned Fruits	26	0.9	0	23	0
Canned Fruit Juices	19	1.7	7	32	133
Canned Vegetables	20	1.2	0	<u>24</u>	<u>0</u>
Total/yr				1402	5593
Total/day				3.8	15

* It is assumed in arriving at the average that nine times more ocean fish is consumed than fresh water fish.

Table II

Cesium-137 in Chicago Diets

(Infants)

January, 1972

	kg/yr	Potassium g/kg	^{137}Cs pCi/kg	Potassium g/yr	^{137}Cs pCi/yr
Evaporated Milk	137	3.1	28	425	3836
Formula Milk	37	1.7	14	63	578
Cereals	8	9.5	41	76	328
Fruits	23	0.7	7	16	161
Meats	17	1.9	23	32	391
Vegetables	23	1.5	6	<u>35</u>	<u>138</u>
Total/yr				647	5372
Total/day				1.8	15

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Cesium-137 in Various Chicago Foods^{*}

(Collection Month April, 1972)

S. S. Brar

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Argonne National Laboratory
Argonne, Illinois 60439

Since April, 1961, the ^{137}Cs and potassium content of the Chicago portion of Tri-City Diet Sampling Program has been determined¹⁻⁴ in bulk food samples by gamma ray spectrometry using a 4" x 4" NaI (Tl) crystal. The individual food components were counted for a minimum of 100 minutes, and from these measurements composite daily and yearly food intakes were obtained. Cesium-137 activity in food, now, is an order of magnitude lower than it was a few years ago; consequently, a new procedure for these measurements has been adopted in order to improve accuracy. The same variety of foods (all fresh vegetables, all fresh fruits, etc.) are composited before measurement, and the samples are counted a minimum of 400 minutes. The results for the April, 1972 quarter are tabulated in Tables I and II.

^{*} Work performed under the auspices of the U. S. Atomic Energy Commission.

Table I

Cesium-137 in Chicago Diets

(Adults)

April, 1972

	kg/yr	Potassium g/kg	^{137}Cs pCi/kg	Potassium g/yr	^{137}Cs pCi/yr
White Bread	37	1.1	9	41	333
Whole Wheat Bread	11	2.5	23	28	253
Eggs	16	1.4	0	22	0
Fresh Vegetables	43	3.9	11	168	473
Root Vegetables	17	4.0	6	68	102
Milk	221	1.5	9	332	1989
Poultry	17	2.5	13	43	221
Fresh Fish*	8	3.1	62	25	496
Flour	43	1.1	25	47	1075
Macaroni	3	1.8	19	6	57
Meat	73	3.1	18	226	1314
Dried Beans	3	12.4	8	37	24
Fresh Fruit	68	2.7	6	184	408
Potatoes	45	4.7	6	212	270
Canned Fruits	26	1.0	5	26	130
Canned Fruit Juices	19	1.5	12	29	228
Canned Vegetables	20	1.1	0	<u>22</u>	<u>0</u>
Total/yr				1516	7373
Total/day				4.2	20

* It is assumed in arriving at the average that nine times more ocean fish is consumed than fresh water fish.

Table II

Cesium-137 in Chicago Diets

(Infants)

April, 1972

	kg/yr	Potassium g/kg	¹³⁷ Cs pCi/kg	Potassium g/yr	¹³⁷ Cs pCi/yr
Evaporated Milk	137	3.0	25	411	3425
Formula Milk	37	1.8	17	67	629
Cereals	8	10.0	62	80	496
Fruits	23	1.1	8	25	184
Meats	17	2.7	31	46	527
Vegetables	23	2.0	0	<u>46</u>	<u>0</u>
Total/yr				675	5261
Total/day				1.8	14

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EURATOM JOINT NUCLEAR RESEARCH CENTRE

ISPRA ESTABLISHMENT

Protection Service

Site Survey and Meteorology Section

QUARTERLY REPORT

EUR/C-IS/394/70e.

The Euratom Ispra Establishment is located in Northern Italy 58 Km NW from Milan and 14 Km W from Varese.

The activity levels shown in this report represent worldwide fallout, and do not reflect any contamination from the site.

SAMPLE COLLECTION

a. Air

Air is drawn by pumps through paper filters at the rate of at least, 500 m³/day, measured by gas meter.

The single daily filters are measured for gross beta radioactivity and then pooled to give monthly samples, for gamma spectrometry and radiochemical analyses.

b. Wet and dry deposition

These samples are collected monthly by means of four 1 m² stainless steel funnels, with the bottom always covered with de-ionized water. Water in excess of a pre-fixed level drains through a filter and a double (cationic and anionic) ion-exchange column. The eluate of the resins and the filters are submitted to the analyses. This procedure is described in detail in the paper by M.C. de Bortoli and P. Gaglione: "Sampling of radioactive deposition through ion-exchange resins", *Giornale di Fisica Sanitaria*, 13, 219-224 (1969).

c. Milk

Milk is collected twice a week in four small local dairies to give 8 liters/month. About six liters are dried and submitted to gamma spectrometry and two liters ashed for radiochemical determination of strontium-90.

EUR/C-IS/394/70

CHEMICAL PROCEDURES AND COUNTING TECHNIQUES

- a. Strontium-90 is separated by the fuming nitric acid precipitation and then purified through hydroxides and chromates precipitations. The activity of the final strontium carbonate and yttrium oxalate precipitates is measured in low level antineutrino beta counters.
- b. Cesium-137 is measured by direct gamma spectrometry on the unprocessed or dried samples and, whenever it is necessary, by gamma spectrometry after chemical separation. This is performed by filtration of the solution, obtained dissolving the sample, through a thin AMP (ammonium molybdophosphate) layer, by which cesium is retained. Details of this procedure may be found in the paper by E. Van der Stricht issued on "Radiochimica Acta" 3, 193-199 (1964).
- c. Gamma emitting nuclides are measured by direct gamma spectrometry, using, also the spectrum stripping technique.
- d. Plutonium isotopes are separated by anion exchange and electrodeposition; details of the procedure may be found in the paper by M.C. deBortoli: "Radiochemical determination of plutonium in soil and other environmental samples", Anal.Chem. 39, 375 (March 1967).

The activity is measured in a Frish grid ionisation chamber connected to a multichannel analyser.

EXTRAPOLATION OF THE DATA

Except when otherwise stated, the data presented in this report are extrapolated to the last day of the collecting period.

EUR/C-IS/394/70e.

AIR RADIOACTIVITY

SITE : I S P R A

LAT. 45° 49' N

LONG. 8° 37' E

ALT. 250 m

Month	Gross beta pCi/m ³	⁹⁰ Sr 10 ⁻³ pCi/m ³	⁸⁹ Sr 10 ⁻³ pCi/m ³	¹³⁷ Cs 10 ⁻³ pCi/m ³	²³⁹ Pu 10 ⁻⁵ pCi/m ³	²³⁸ Pu 10 ⁻⁵ pCi/m ³
<u>1971</u>						
September	0.21	1.7	1.5	2.6	3.4	✖
October	0.15	1.3	1.5	2.2	2.3	0.18
November	0.09	0.86	0.42	1.2	1.6	0.32
December	0.09	0.61	0.74	0.74	1.0	0.17
<u>1972</u>						
January	0.14	0.83	3.7	1.3	1.8	0.33
February	0.06	0.50	1.1	0.9	2.1	0.27
March	0.13	-	-	-	-	-

✖ Data not available.

- Data not yet available.

FALLOUT DEPOSITION

SITE : I S P R A

LAT. 45° 49' N

LONG. 8° 37' E

ALT. 250 m

Month	Gross beta (1)		⁹⁰ Sr	⁸⁹ Sr	¹³⁷ Cs	²³⁹ Pu	²³⁸ Pu	Precipitation mm
	mCi/Km ²	date (2)	mCi/Km ²	mCi/Km ²	mCi/Km ²	μCi/Km ²	μCi/Km ²	
<u>1971</u>								
September	2.0	5-10	0.030	0.030	0.057	0.90	×	13.4
October	1.3	17-11	0.013	0.010	0.032	0.61	0.048	39.0
November	4.2	17-12	0.064	0.055	0.11	0.83	0.17	191.2
December	1.5	20- 1	0.027	0.024	0.051	0.55	0.094	58.0
<u>1972</u>								
January	1.0	8- 2	0.022	0.062	0.029	0.60	0.11	85.0
February	3.2	22- 3	0.10	0.16	0.15	0.96	0.12	337.4
March	2.9	24- 4	-	-	-	-	-	242.4

(1) Potassium-40 equivalent (40 mg/cm²).

(2) Day and month of the gross beta measurement.

× Data not available.

- Data not yet available.

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