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NOTE

Throughout the present report, references to the annexes are indicated by a letter immediately followed by a number: the letter denotes the relevant annex and the number the paragraph therein. Within each annex, references to its scientific bibliography are indicated by numbers.

Symbols of United Nations documents are composed of capital letters combined with figures. Mention of such a symbol indicates a reference to a United Nations document.

ANNEX A

RADIO-ACTIVE CONTAMINATION OF THE ENVIRONMENT BY NUCLEAR TESTS

CONTENTS

Introduction

1. The purpose of the present annex is to evaluate the information on radio-active environmental contamination from nuclear explosions that became available to the Committee since its 1962 report[a] to the General Assembly[1,b] and to obtain revised estimates of the amount of radiation due to environmental contamination that is received by human populations. An updating is required because further contamination took place after the adoption of the 1962 report, although, following the cessation of atmospheric tests in December 1962, the levels of radio-activity due to short-lived nuclides have decreased substantially through 1963. In addition, improvements in knowledge of the mechanisms involved in the transfer of radio-active material from its production to man's environment deserves attention. The reader is referred to annex F of the 1962 report for those many aspects of the problem of environmental contamination on which little progress has been made since the publication of that report.

[a] *Official Records of the General Assembly, Seventeenth Session, Supplement No. 16* (A/5216); hereinafter referred to as the "1962 report".

[b] Superscripts refer to the corresponding entries in the bibliography at the end of the present annex.

I. Movement of artificial radio-nuclides in the earth's atmosphere

2. The major part of all fission products produced by nuclear explosions up to the end of 1962 was released into the stratosphere. Estimates of future deposition rates require a knowledge of the fission product inventory in the stratosphere as well as of the mechanisms by which it is brought down to the ground. Since the 1962 report a considerable amount of new data on the movement of debris in the atmosphere has been reported. This makes it advisable to review the main features of the processes involved, with special emphasis on recent advances.

RADIO-ACTIVE AEROSOLS

3. After a nuclear explosion, the fission products contained within the fireball are initially present in the form of vapour. As it rises and expands, the hot cloud cools by radiative heat losses, by adiabatic cooling, and by mixing with cooler air, causing the fission products to condense and form an aerosol of fine particles. Since most of the fission product activity injected during 1961 and 1962 was from high yield explosions, the greater part of the fission product debris that was formed was carried up well into the stratosphere.[2]

4. The partitioning of the fission product debris between local, tropospheric and stratospheric fall-out has been discussed in the 1962 report. Most of the radio-active debris produced during 1961 and 1962 was injected into the stratosphere, and this debris, together with that present in the stratosphere from previous tests, was the main source of subsequent world-wide contamination. Local fall-out is important only near the site of tests, while tropospheric fall-out will be deposited within a month or so after tests.

5. Radio-activity created by nuclear tests may be in either gaseous or particulate form. In the high atmosphere, above about 100 km, even very small particles will possess large settling speeds.[3,4] On the other hand, at high altitudes, gaseous substances are subjected to larger molecular diffusion rates than are particulates. In the lower troposphere, particulates are rapidly removed during precipitation. Shortly after a test, particles containing high radio-activity have been observed in ground level air and in fall-out.[29,35] But most measurements in the stratosphere below about 20 km, made many months after the cessation of nuclear tests, suggest that most radio-active particles are submicron in size and thus have negligible settling speeds.[5] The particles, in contrast to gases, may be removed by impaction or settling after coagulation with other aerosols.

6. Other work has shown that there is a correlation between the activity and the sulphate content of samples collected in the stratosphere.[6] This suggests coagulation, or perhaps that sulphate builds up on radio-active particles, which then grow in size. Storebø considered theoretically the growth of particle sizes during the rise of a nuclear cloud and found that terminal sizes may be sufficient for gravitational settling to be of some importance, in comparison with movements due to air exchange.[8] The measured particle size distribution in the stratosphere indicates that the bulk of the debris will be transported at these altitudes largely by air movements. However, in the lower troposphere an important growth in the size of the particles resulting from agglomeration may enhance significantly the rate of aerosol deposition.

Transport within the atmosphere

7. To understand the movement of radio-active debris within the atmosphere, a thorough knowledge of the general circulation of the earth's atmosphere is required. Such a knowledge is necessary to predict the spatial and temporal distribution of future fall-out, as caused by the injection of debris into the stratosphere at different latitudes, altitudes and times. At the present time our understanding of air movements within the stratosphere is incomplete in certain respects, particularly of those at high altitudes. However, some basic features of this motion are now fairly well established.

8. One marked feature of atmospheric circulation is the system of westerly jet streams situated in mid-latitudes at altitudes of about 10 km (figure 1). Velocities of 100-300 km per hour are usual in these regions. In middle and higher latitudes air is carried around the globe in a week or so and in one to two months in tropical regions.[7] Since in the stratosphere these times are short compared to transfer times in the meridional and vertical directions, the debris may be considered to be zonally well mixed so that, several months after a test, it will be uniformly distributed around a circle of latitude.[7] In the troposphere, vertical motions are rapid, but in the lower stratosphere these vertical motions, and hence the vertical transports, are much smaller.[7,8]

9. Fission products injected into the stratosphere during tests have been used extensively to trace air motions.[9,10] In particular, many surveys have been made of the Sr^{90} concentration in stratospheric air,[11] and the activities of W^{185} and Rh^{102} which were injected into the stratosphere during 1958 have also been monitored.[12,13,14] In addition, the distribution of the naturally occurring radio-nuclides Be^{7}, Pb^{210}, P^{32} and C^{14} have also been studied, as well as that of ozone and water vapour.[15,16] These studies have all contributed greatly to our understanding of air movements within the stratosphere.

Movement within the stratosphere

10. Measurements of ozone and water vapour concentrations in the stratosphere show that there is a poleward and downward transfer of material during winter and in the early spring months.[16,17,18] The distribution of ozone in the lower stratosphere suggests that there may be an upward motion of air in the equatorial regions of the lower stratosphere.[16] From the movement of W^{185} from equatorial to polar regions during 1958 Feely and Spar concluded that large-scale eddy diffusion was mainly responsible for this poleward transfer.[19]

11. Eddy diffusion would also explain the movement into equatorial regions of Sr^{90} and Mn^{54} injected into the north polar stratosphere in late 1961. However, Newell argues that the transfer along sloping surfaces (figure 1) must be due to both eddy mixing and mean meridional motions.[20] By studying the time trends of Rh^{102} in the stratosphere at high latitudes, Telegadas and List found that the debris descended from 20 km to 14 km between December 1959 and March 1960 and then remained stationary during the summer of the northern hemisphere.[21] A similar rate of descent was noted for Cd^{109} in the southern hemisphere between April and August 1963.[380] These observations suggest that downward motions during winter are mainly responsible for the vertical transport of fission products in the polar stratosphere.

12. It may be concluded that debris injected into the equatorial regions of the stratosphere below 30 km will move polewards and downwards into each hemisphere during the winter months. Material injected into the lower polar regions does not seem to move upwards to any great extent, but some of it moves into equatorial regions of the lower stratosphere. A number of models of stratospheric circulation have been proposed, but at the present time none of them is completely adequate to predict the transport of fission products.[9,31,412] At the moment it seems that both advective and diffusive processes are important in stratospheric circulation. The stratospheric transfers described above are shown in figure 1.

13. Very few data concerning the movement of air above 30 km are available. Rh^{102} was injected into the stratosphere by an explosion at about 43 km over Johnston Island during August 1958.[23] The radio-active cloud was estimated to have risen to at least 100 km. Concentrations of Rh^{102} at an altitude of 20 km in the northern hemisphere showed a large increase during the period October 1959-February 1960.[12,21] In the southern hemisphere the major increase in concentration occurred during the winters of 1959 and 1960, the concentration in this hemisphere being much the same as in the northern hemisphere after mid-1960. During 1960 and 1961 the concentrations at these altitudes remained fairly constant, probably being replenished from above.

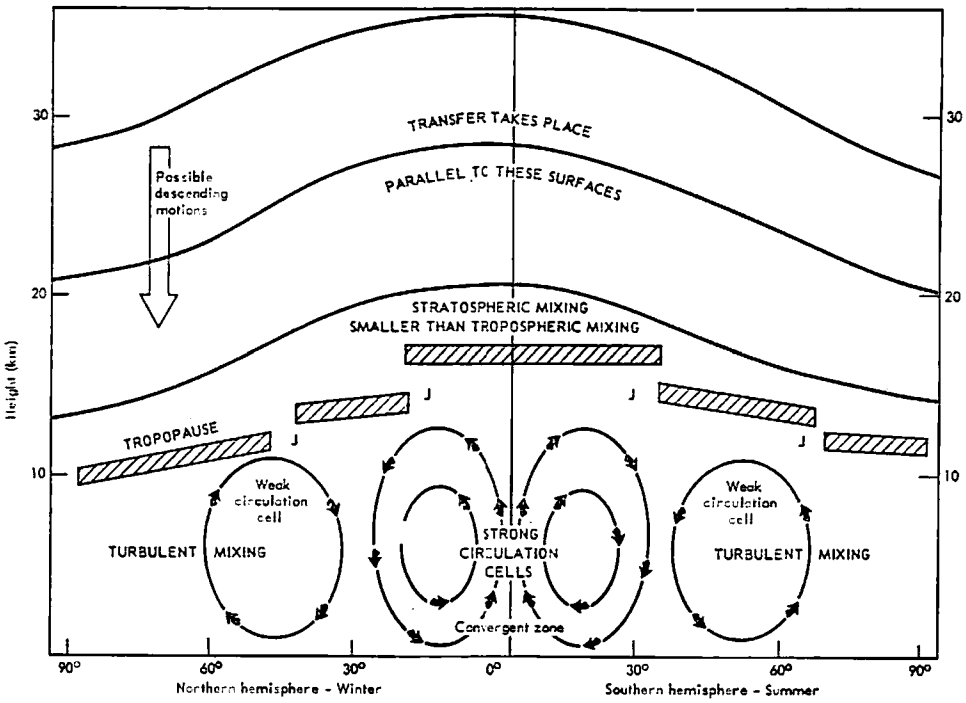


Figure 1. Schematic cross section displaying characteristics of meridional transport ("J" locates typical jet stream positions)

14. Recent stratospheric measurements of Cd^{109} activity, about 0.25 MCi of which was released above 400 km over Johnston Island at 17°N latitude in July 1962, show that some of this isotope moved down to 30 km after five or six months.[22, 24, 380] Not only did Cd^{109} appear earlier in the lower stratosphere of the southern hemisphere than in the northern hemisphere, but it was present there in greater quantities until August 1963—at least in mid-latitudes. At altitudes between 40 and 400 km, gravitational settling and, in the case of charged particles, electro-magnetic effects are expected to influence the descent of fission product debris.[53] Measurements of Rh^{102} originating from the high altitude rocket explosion (Orange), which was carried out during August 1958 in equatorial regions, indicate that Rh^{102} spread to the polar regions in both hemispheres and later descended to lower altitudes.[25, 26, 381]

15. There are many mechanisms which might account for the transfer of particulate radio-activity from the stratosphere to the troposphere. Machta compared the likely transfer of Sr^{90} by each mechanism with the subsequent observed Sr^{90} fall-out in the northern hemisphere in early 1960 and 1961.[34] The results can be summarized as follows:

(*a*) Heavy particles can settle through the tropopause, but the bulk of the radio-activity in the lower stratosphere is contained in particles too small for gravitational settling to contribute significantly to the downward transport through the tropopause.

(*b*) Vertical mixing through the tropopause and horizontal exchange through the tropopause gap (figure 1) could each account for the transport out of the stratosphere and thus explain the subsequent fall-out. The calculation assumes that a coefficient of diffusion represents the proportionality factor between the flux of Sr^{90} and the gradient of Sr^{90}. This diffusion coefficient describes various complex meteorological processes only grossly. There is also considerable uncertainty regarding the magnitude of the coefficient. The equality between diffusive transfer and subsequent fall-out is not necessarily convincing evidence of the reality or magnitude of this transport mechanism.

(*c*) The tropopause in temperate and polar regions rises to higher altitudes in the late winter and in the spring. If it is assumed that this process transfers stratospheric air into the troposphere, then its associated Sr^{90} may significantly contribute to subsequent fall-out. In 1960 and 1961 this mechanism could account for no more than one-quarter of the observed fall-out.

(*d*) Certain models of atmospheric circulation, such as the Brewer-Dobson model, imply descending motion through the tropopause in certain areas. Some of these models postulate subsiding movements whose downward transport of Sr^{90} can contribute part or all of the observed fall-out. But, as of this time, the reality of the model as well as the sense and magnitude of the vertical currents must be considered as questionable.

(*e*) Danielsen measured the radio-activity in certain thin layers of air at tropospheric altitudes. He demonstrated that these active layers represented parcels of stratospheric air extended into the troposphere.[32, 33] This process, a folding of the tropopause, is shown schematically in figure 2. After the "tongue" of stratospheric air with its high concentration of radio-activity is brought across the tropopause, diffusive mixing incorporates it into the troposphere. A quantitative estimate of the amount of Sr^{90} transferred into the troposphere made by Machta, using Staley's estimates of the frequency, intensity and areal coverage of the extrusion, suggests that this process could account for not more than about one-third of the observed stratospheric fall-out.[30, 34]

16. To predict the future deposition of long-lived fission products, the concept of mean residence time is useful. It is defined as the average time spent by fission products in the stratosphere before being transferred to the troposphere. Such a definition in no way implies that the material is well mixed within the stratosphere or that the hold-up during the transfer to the troposphere occurs

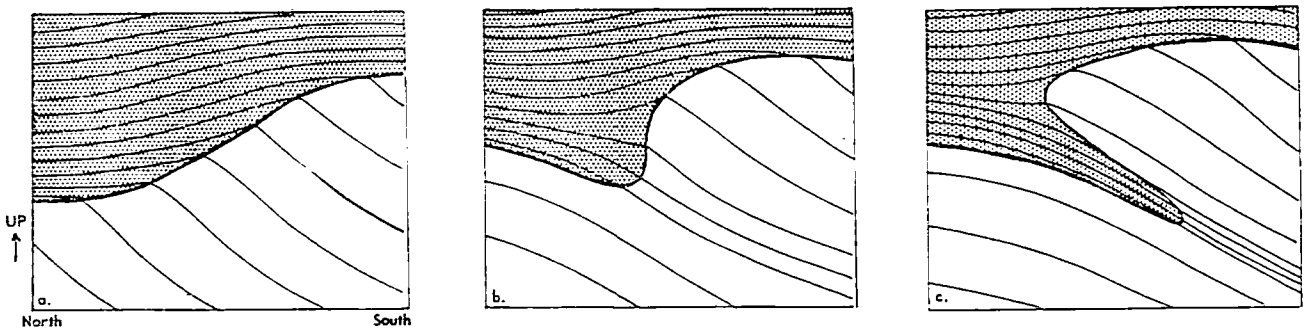


Figure 2. a, b, c. Vertical cross section, north to the left, showing in successive stages the steepening and folding of the tropopause. The thin lines are potential temperature isotherms. Air parcels tend to move along such isotherms during transit times of a few days[33]

at the tropopause.[7] Such conditions, which are needed to validate the use of first order kinetics, are not applicable to the stratosphere-troposphere transfer. However, the concept of a mean residence time is used to predict future fall-out.

17. Mean residence times may be computed for the transfer of stratospheric debris to the troposphere from published stratospheric inventories and annual deposits of Sr^{90} and W^{185} Three techniques were employed to produce the estimates in table I, as noted below the table. Each technique is subject to uncertainties. Method *b*, in particular, can yield meaningless residence times if the stratospheric distribution changes between measurement periods. The mean residence times for one hemisphere are unreliable if there is a significant transfer between hemispheres. Despite this, all three methods are consistent in suggesting longer mean residence times for the southern rather than for the northern hemisphere.

18. A periodicity of two years or of twenty-six months has been found in many meteorological parameters of the lower stratosphere.[38] This cycle appears in the ozone content of the atmosphere over Australia[37] and in the Be^7 concentration of the stratosphere of the southern hemisphere.[408] It is possible that fall-out may be partially modulated by the same cycle, at least in the southern hemisphere.

19. The mean stratospheric residence time of radioactive debris produced by an individual explosion will depend on the altitude, latitude, and possibly the time of injection. Thus, fission products in the lower polar stratosphere may have a mean residence time of six months or less, while debris from medium altitude explosions have mean residence times of perhaps two to three years.[39] At much higher altitudes, over 100 km, as illustrated by the Rh^{102} experiment, the residence time increases to five or ten years.[12, 381, 401] Theoretical models of transport and diffusion can qualitatively reproduce these differences. One such preliminary model by Bolin,[7] created to fit the observed ozone observations, produces reasonably plausible fall-out patterns as well. Ultimately, it is likely that predictions from such meteorologically consistent models will form the basis for fall-out forecasts.

20. The stratospheric distribution in January 1964 is roughly the same as in 1960 or early 1961. It is therefore considered reasonable to apply the observed mean residence times found during 1960 and 1961 to the stratospheric inventory in 1964 for the predictions in this report. Table I summarizes the mean residence times found in the 1960-1961 period. An average global value of two years is chosen for purposes of predicting Sr^{90}, Cs^{137} and C^{14} contamination after 1963. It is likely that, as the concentrations in the stratosphere become more uniform because of mixing, the mean residence time may tend to increase. The use of a constant rather than an increasing mean residence time will slightly over-estimate the doses due to Sr^{90} and Cs^{137}.

Movement within the troposphere

21. Once the radio-active debris enters the troposphere it is mixed fairly rapidly within the hemisphere of entry. Within the troposphere mixing by eddy diffusion and convection is much more rapid than in the stratosphere. As will be shown later, the Sr^{89}/Sr^{90} ratio in monthly precipitation was fairly constant in the different latitude bands of the northern hemisphere, between September and December 1961.[27, 376] Between 10° and 70°N the meridional mixing rate is rapid compared to the half-life of Sr^{89}, 50.5 days. As in the stratosphere, the fission product debris is mixed zonally quite rapidly. At latitudes of 40°N the air takes some twelve days to move around the earth in a westerly direction.[40] In the meridional plane there are two circulation cells within each hemisphere as shown in figure 1. In the tropical regions this cell is well developed with air rising in equatorial regions and descending into the 20°-30°N latitude region. At higher latitudes there is a weaker circulation cell with descending air at latitudes of 40°-50° and rising air at higher latitudes, while at middle and higher latitudes large scale eddies give rise to rapid meridional transport.

22. The gross beta activity of ground level air is measured at many stations throughout the world. These measurements, although of importance for surveillance purposes and also for meteorological studies, are of little value in estimating radiation doses from fission products. The activities in air of individual fission products have been reported from a number of countries.[41–47] Of particular interest are the activities in air measured at stations around the 80th meridian west. Figure 3 shows the mean bi-monthly Sr^{90} activities in the northern and southern hemisphere stations during the years 1958-1963.[28, 378, 379] During 1960 and part of 1961 when there was little testing, the activities of Sr^{90} in air in the two hemispheres tended to equalize. Sr^{90} activity in the northern hemisphere showed large peaks in the spring of each year, but in the southern hemisphere these peaks were not so marked.

23. A rapid rise in the Sr^{90} activity of air occurred in the northern hemisphere in late 1961 after testing was resumed. In the southern hemisphere the rise was slight until April 1962, when equatorial tests were resumed in the Pacific. Lockhart and Bleichrodt[41, 50] have reported the detection of debris from these Pacific tests in mid-latitudes of the northern hemisphere, and others have

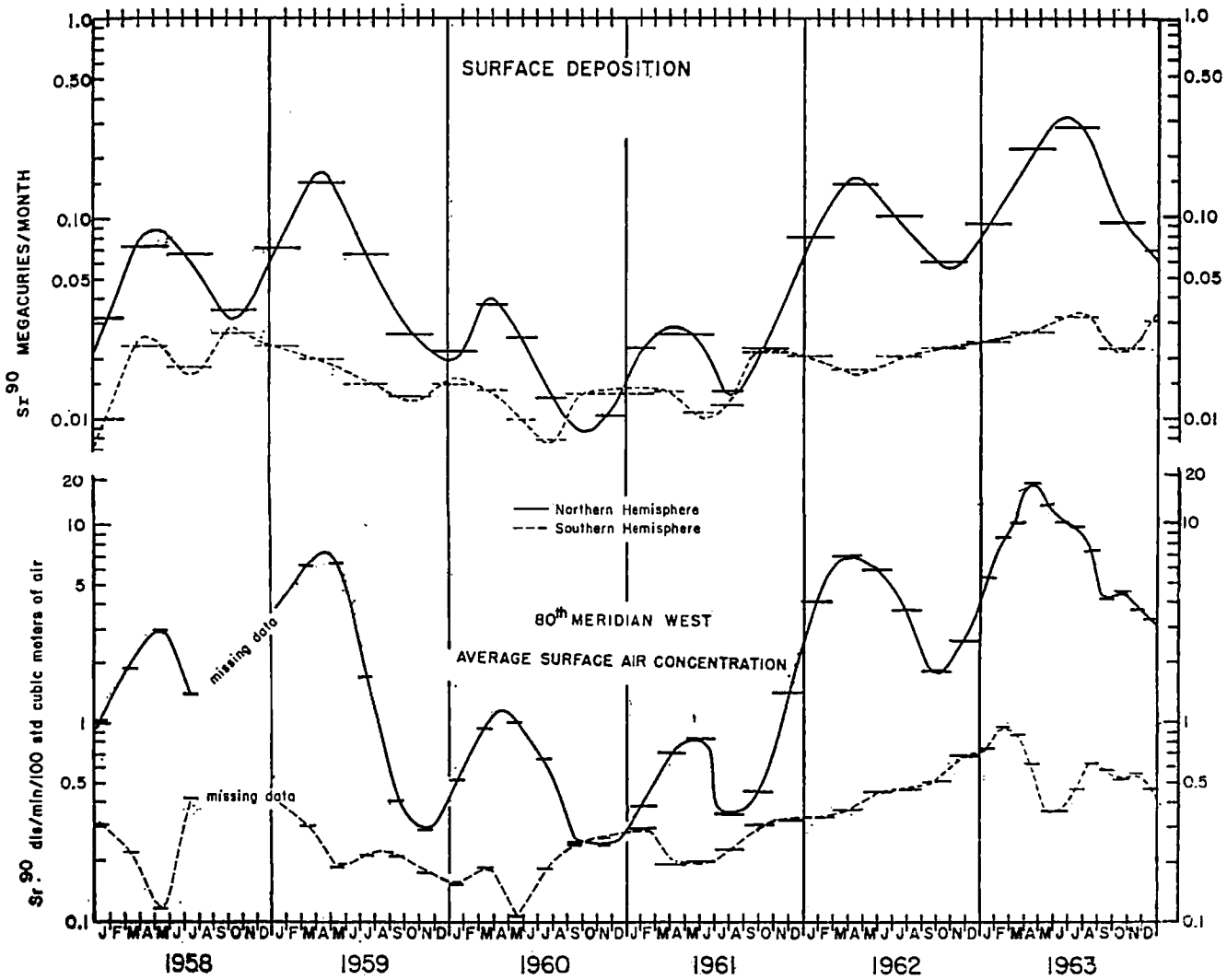


Figure 3. Strontium-90 deposition rate and its concentration in surface air[28, 378, 379]

reported the detection in May-June 1962 of Ba^{140} activity in rain at Westwood, New Jersey, United States.[48–50] Similar evidence has been noted in measurements made in the United Kingdom.[45] In 1962 the average Sr^{90} air activity in the northern hemisphere reached a peak of 0.03 pCi/m³ and a peak of 0.1 pCi/m³ in 1963. Measurements of total beta measurements in air within smaller regions of the earth's surface, e.g. in Norway, the United Kingdom and in the United States, indicated that the average activity in surface air did not vary greatly from place to place, in spite of large differences in rainfall.[45, 51, 52]

24. In the troposphere, the exchange of particulate radio-activity across the meteorological equator is impeded for two reasons. The first, convergence of low altitude air currents (figure 1), tends to keep air in the same hemisphere and also retards the exchange of gases. The second reason is the scavenging of particulates by showery precipitation in the convergent zone. A north-south profile of Sr^{89} along the 80th meridian west between September and December 1961 shows (figure 4) a sharp decrease in the convergent zone near the geographical equator.[41] This short-lived activity originated from explosions in temperate or high latitudes of the northern hemisphere. By contrast, figure 4 also displays the distribution of Sr^{90} whose origin is mainly the stratosphere of each hemisphere. The north-south distribution of Sr^{89} during and following nuclear explosions as shown in figure 4 is confirmed by profiles reported by Krasnopevtsev along 170°E over the Pacific Ocean (the profile for Zr^{95} being also shown in figure 4) and by Labeyrie and Lambert in the eastern Atlantic Ocean.[47, 65]

25. In the troposphere, the mean exchange time between hemispheres, defined as the mean time spent in the northern hemisphere by a molecule of air before transfer to the southern hemisphere, and *vice versa*, has been estimated by using various gaseous tracers.[54, 56–58, 409, 410] These estimates are listed in table II. The exchange times shown in table II are fairly consistent, except that based upon tritiated methane, and indicate that the exchange time is about 1.5 years.

26. Stewart estimated a thirty-day mean residence time for fission products injected into the troposphere.[59, 60] Evidence now suggests that in the lower, rain-bearing, layers of the atmosphere particulates reside for a period of the order of five days or less.[62] But for particulates located well above the rain-bearing layers, the residence time may be as high as forty days.[15, 60]

Mechanisms of deposition

27. After entering the troposphere from above, fission products are transported down to the level of the rain-

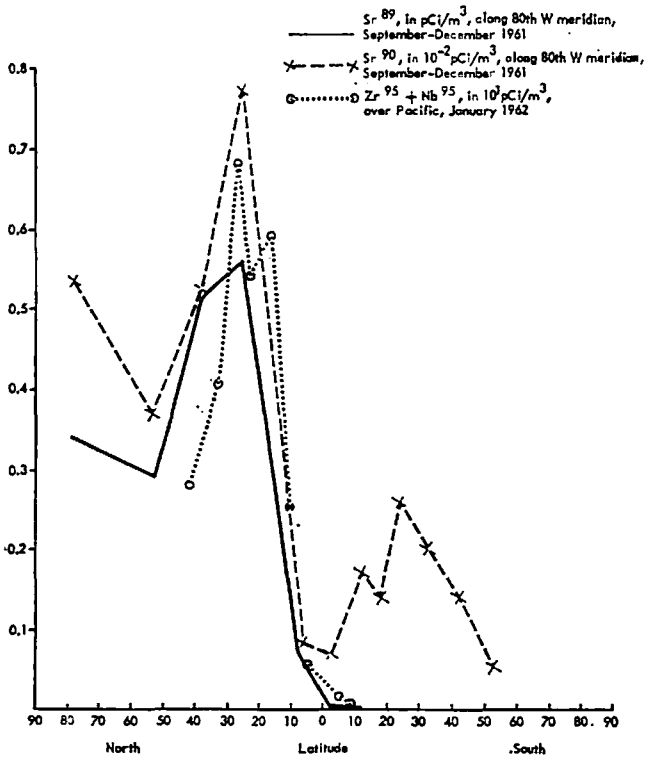


Figure 4. Latitudinal variation of the concentration of fission products in surface air[41, 47]

bearing clouds mainly by turbulent mixing. This downward movement is enhanced over anti-cyclonic systems and opposed over cyclonic systems.[52] Below this level the radio-active particles are rapidly washed out by precipitation and deposited upon the earth.[65] In addition, dry removal of fission products takes place through several mechanisms. Dry removal by sedimentation requires particles to be larger than about 5 microns and is important only in local fall-out. Dry deposition of world-wide fall-out makes an important contribution to the total fall-out only in areas of low rainfall.

28. The fission products can enter rain-water by processes within the cloud, the so-called rain-out, or by pick-up by raindrops below the cloud, the so-called wash-out. For aerosols of small particle size the wash-out process is relatively quite slow so that rain-out is probably the most important wet deposition process.[9, 63] The small contribution of wash-out processes to total deposition probably accounts for the fact that the activity of fission products in ground level air does not seem to be greatly influenced by precipitation rates.[51, 52] The rain-out of fission products may be enhanced by the presence of natural aerosols in the lower atmosphere, and it has been suggested that higher concentrations of sodium chloride in the maritime atmosphere may enhance the deposition rate over oceans.[63]

29. Experience indicates that time-averaged Sr^{90} deposition is roughly proportional to the amount of precipitation.[67] The relationship is only approximately valid when widely separate stations are compared, as for example all stations in a latitude band. The relationship becomes better when the stations are limited to the same general climatic region and becomes very good when the stations are close to one another. An example of the latter appears in figure 5 where the cumulative Sr^{90} soil deposition in Clallam County, Washington, United States in 1960 is plotted against precipitation.[66] In this case, the linear relationship between deposited activity and precipitation confirms the almost constant specific activity in rain at all these sites.

30. One method of calculating the dry fall-out in a region having places with variable amounts of precipitation depends on obtaining a relationship between deposition and the amount of precipitation, and extrapolating the relationship to zero precipitation. Thus, if the straight line in figure 5 is extended to zero rainfall, a dry deposit of 7 mCi/km² is obtained in 1960 on the West Coast of the United States. A similar analysis of the cumulative Sr^{90} deposit in Norway during 1959 yields about 5 mCi/km² due to dry deposition.[69] This indirectly observed amount of fall-out computed by extrapolation of fall-out precipitation curves to zero precipitation may express the maximum dry fall-out. Miyake argues that the fall-out precipitation relationship departs from a straight line towards lower fall-out at very low precipitation amounts.[61] It appears likely that the amount of dry deposition and the specific activity of Sr^{90} in precipitation will vary with climatic conditions and the air concentration. Many factors affect dry deposition such as microturbulence and the extent of vegetation cover.[64]

II. Inventory and deposition of artificial radio-nuclides

Strontium-90

31. Inventory estimates for individual nuclides would ideally be based on a knowledge of the amounts injected into the atmosphere. These can be deduced from the yields of the explosions and such estimates of yields have been published (table III)[70] but their reliability cannot be assessed on the basis of the information available to the Committee. In the present report, therefore, as in the

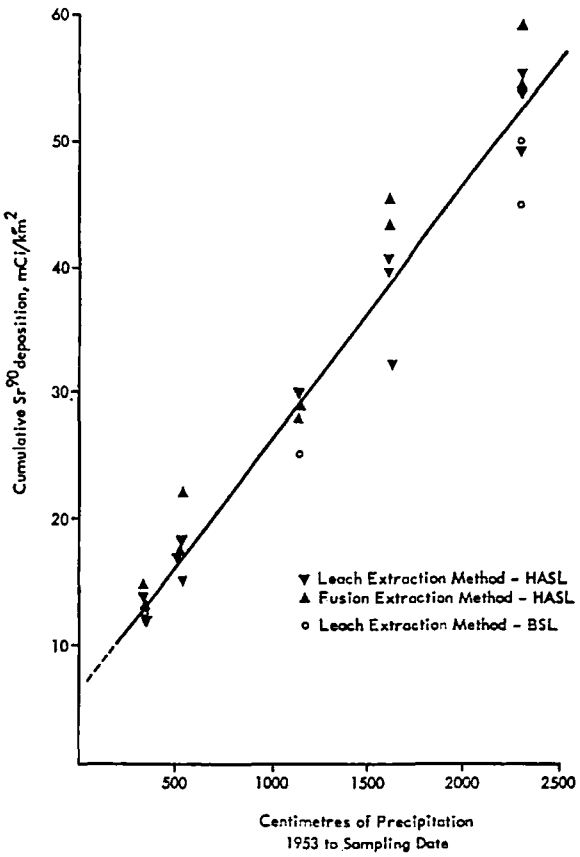


Figure 5. Strontium-90 deposition determined from soil analysis in 1960 as a function of precipitation[66]

1962 report, inventories will be estimated from actual measurements.

Atmosphere

32. To estimate the Sr^{90} inventory in the stratosphere, a considerable number of air samples have been collected by aircraft between the tropopause and 21 km.[11,14,71,72] Between 21 and 30 km inventories were established through balloon sampling at two sites only, over San Angelo, Texas, United States, and over Mildura, Australia.[73] Estimates of the Sr^{90} inventory above 20 km must be regarded as somewhat approximate. In estimating the stratospheric inventory from these spot measurements, it is assumed that there is fairly rapid zonal circulation in the stratosphere and hence that the specific activity depends solely upon latitude and altitude at any one time.[23] Sr^{90} activities in the stratosphere at different altitudes and latitudes during 1961 and 1963, are shown in figures 6, 7, 8 and 9.[22,23,34] Isolines are used for integration purposes in estimating the total inventory. For the balloon data, only the crudest integration is possible.

33. Figure 6 shows that the Sr^{90} concentrations in the troposphere are several orders of magnitude less than in the stratosphere. To estimate the tropospheric inventory of Sr^{90}, an average value of activity is assumed for each hemisphere. The large concentration gradients present in the stratosphere can cause uncertainties in the inventory estimates. Another possible source of error is the sparsity of data available above 21 km. This is particularly significant in estimating the 1963 inventory, as it is believed that concentrations were considerable above 21 km at latitudes higher than 31°N.[23] It should be noted, however, that there is only 4 per cent of the atmosphere above 21 km, and only 1 per cent above 30 km.

34. To check on zonal uniformity within the stratosphere, Cs^{137} activities measured over the United Kingdom were compared with Sr^{90} activities measured over Canada and the United States, using the ratio 1.7 for conversion. Although this comparison did not conclusively show that there was no zonal variation, no systematic difference was noted.[23] It has been estimated that the over-all error in the stratospheric inventory of Sr^{90}

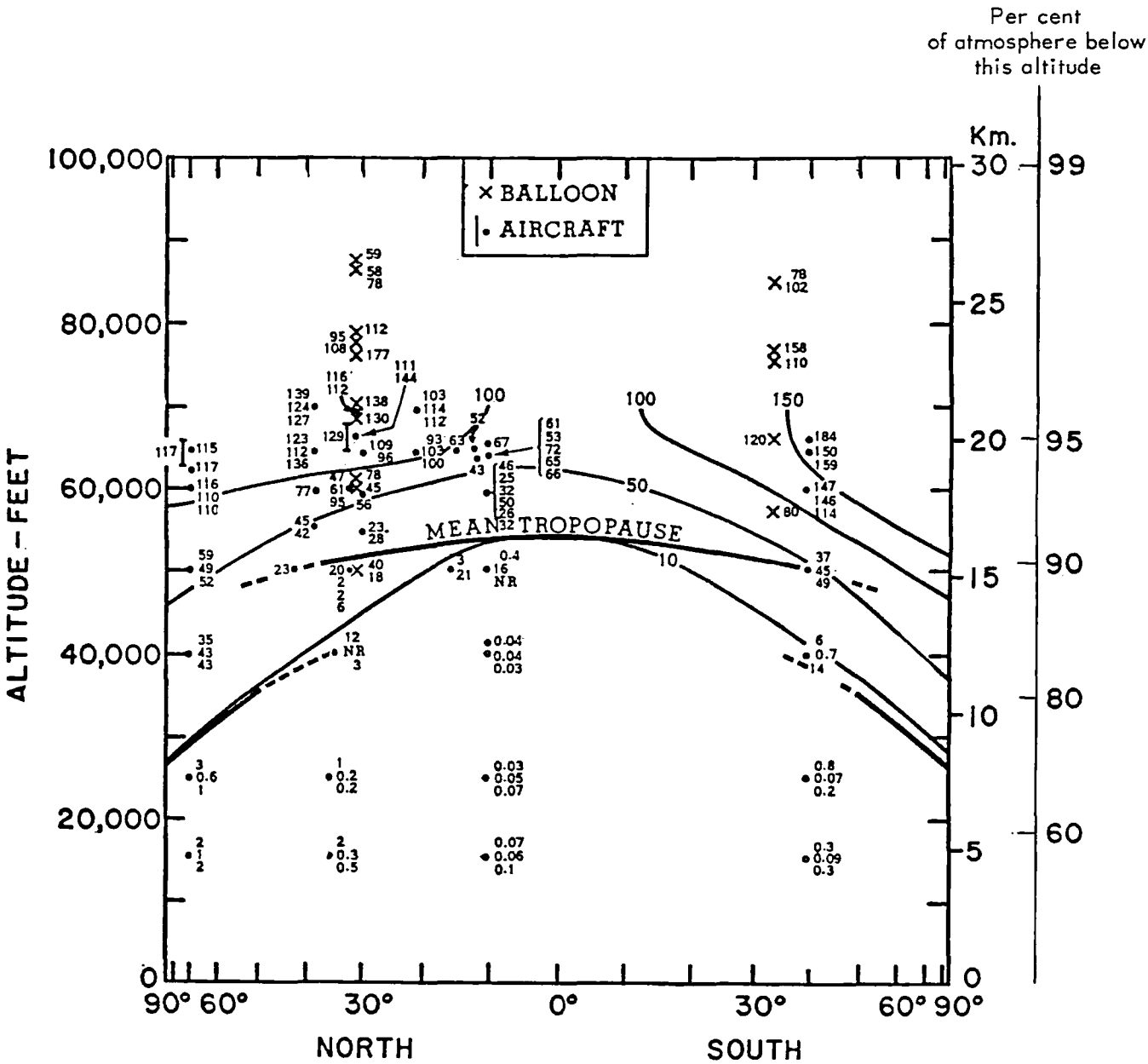


Figure 6. Strontium-90 activity in the atmosphere, May-July 1961 in dpm Sr^{90}/1000 scf (1000 scf = 35 kg)[23,34]

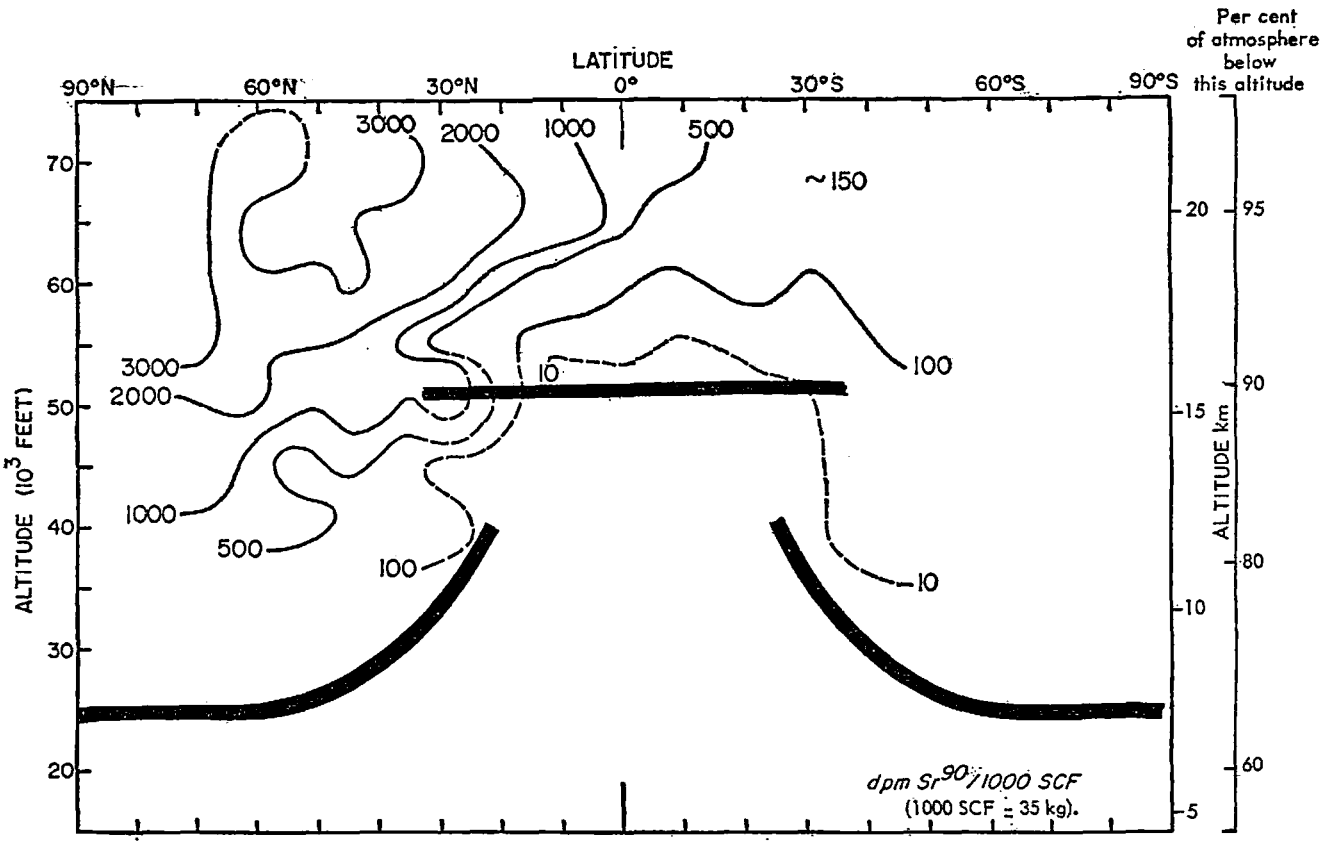


Figure 7. Strontium-90 activity in the atmosphere, December 1962-February 1963[23, 34]

is ± 50 per cent at a probability level of 90 per cent.[28] Table IV shows the global Sr^{90} inventory for different years up to January 1964.[22, 23, 34, 377]

Measurements in precipitation and soils

35. Much information has been published on Sr^{90} fall-out and the Committee has received much data from many countries throughout the world.[26, 42, 45, 46, 74–104] As an example, the monthly Sr^{90} deposition at New York City is shown in figure 10.[75] Figure 11 shows the cumulative Sr^{90} deposit at a number of sites.[45, 59, 68, 69, 75, 76, 89, 96] The monthly and annual average Sr^{90} fall-out for different regions of the Soviet Union during 1961, 1962 and 1963 are shown in table V.[81, 418] The deposition measurements from the network operated by the United Kingdom Atomic Energy Authority[45] are consistent with the results shown in table VI and obtained from the more extensive network operated by the United States Atomic Energy Commission. Figure 12 shows the 1962 latitude distribution of Sr^{90} deposition.[27]

36. The annual deposition in each 10° latitude band between 50°S and 80°N during 1961, 1962 and 1963 is shown in table VI.[27, 105, 376, 419] Few data are available for the higher latitudes, but the deposition there does not contribute appreciably to the dose commitment since the population density at these high latitudes is small. The totals were computed by averaging the annual deposition at the fall-out stations in each latitude band. Telegadas[28, 407] has compared the results of this calculation with those obtained by multiplying the specific activity of Sr^{90} in rain by the average annual rainfall for the latitude band. He found little difference between the results of the two methods of estimation.

37. The annual Sr^{90} depositions in each hemisphere for 1961, 1962 and 1963 are shown in table VII, together with the cumulative deposit up to December 1963. The latter figures were computed by adding in the cumulative values for 1960 from the 1962 report and correcting for decay. In 1963, 2.5 MCi of Sr^{90} were deposited upon the earth's surface, the highest annual deposit ever recorded.

38. Figure 3 shows the Sr^{90} fall-out rates in each hemisphere, together with Sr^{90} air concentrations for the years 1953-1962.[28, 378, 379] A strong correlation between Sr^{90} deposition and air concentrations is apparent. The Sr^{90} deposition rate in the northern hemisphere has been consistently higher, sometimes by one order of magnitude, than that in the southern hemisphere, and only during 1960 and early 1961 did the rates in both hemispheres tend to equalize.

39. Estimates of the cumulative deposition of Sr^{90} have in the past been largely based upon the measured Sr^{90} content of soil samples taken to sufficient depth to ensure that most of the accumulated Sr^{90} is recovered.[68, 106] The results of a new global survey of Sr^{90}, compiled in 1963, have become available since the adoption of the 1962 report.[103] The Sr^{90} analysis of soils at 96 sites has now been completed[103] and the cumulative deposits at these sites are displayed on a world map in figure 13. The cumulative deposit of Sr^{90} in each hemisphere has also been estimated using the Sr^{90} monthly deposition rates at stations of the United States global fall-out network.[27, 105, 379] The cumulative deposit of Sr^{90} in each hemisphere so obtained is plotted in figure 14 for the years 1954-1962.

40. Estimates of cumulative deposits of Sr^{90} in latitude bands, obtained from the 1963 soil survey, are compared in table VIII with estimates based upon measurements in precipitation for the years 1961-1963 combined with soil data for 1960. The two sets of estimates agree reasonably well, except in the latitude bands 10°-20°N and

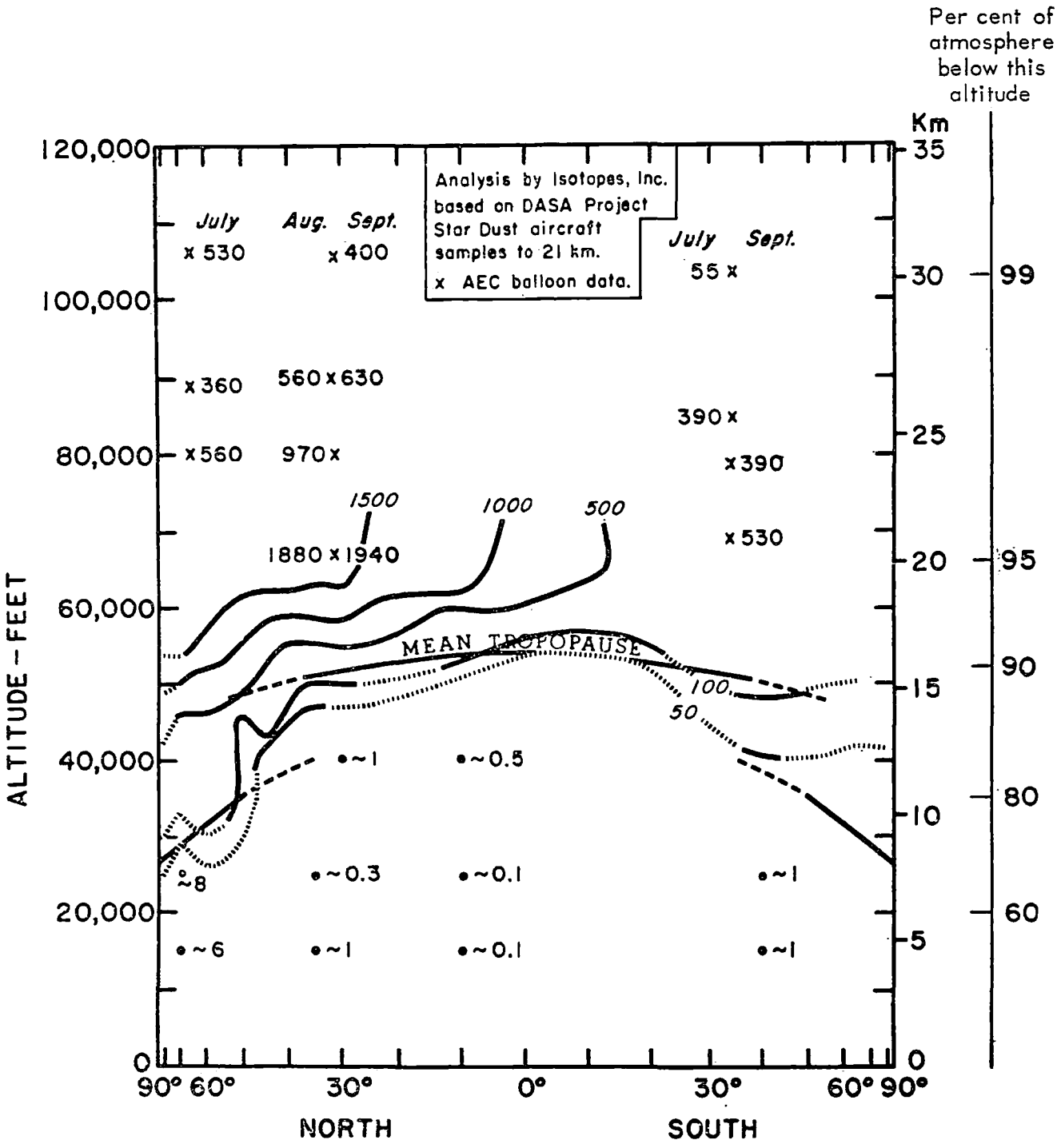


Figure 8. Strontium-90 activity in the atmosphere, September 1963 in dpm Sr^{90}/1000 scf (1000 scf = 35 kg)[23, 34]

20°-30°N, where the number of soil sampling sites was quite small. This conclusion is in agreement with the results of the 1960 Sr^{90} soil survey, which showed that, in the 20°-70°N latitude band, estimates of deposition obtained from precipitation data did not differ significantly from those obtained from soil data. For the calculation of doses, the mean value 9.6 MCi is used.

41. The extent to which results for the world-wide network of soil sampling sites correctly represent the global deposition cannot be precisely assessed. However, a detailed analysis of possible causes of error[23] suggests that uncertainties in this regard are likely to be small relative to those in the assessment of other parameters. There may be a systematic bias in the Sr^{90} global deposition estimate which could in particular be caused by the geographical distribution of the sampling sites. Possible inequality between fall-out rates over oceans and continents could also give rise to a corresponding systematic error.

Rivers and lakes

42. The Sr^{90} and Cs^{137} concentrations in the rivers of several countries have been reported.[52, 107-109, 383] Measurements on waters of Lake Grosetvann in Norway during 1958 and 1959 gave Sr^{90} concentrations about 10 per cent of those in precipitation. During early and late winter, however, with the melting of snow, the Sr^{90} concentrations of the inflowing waters increased substan-

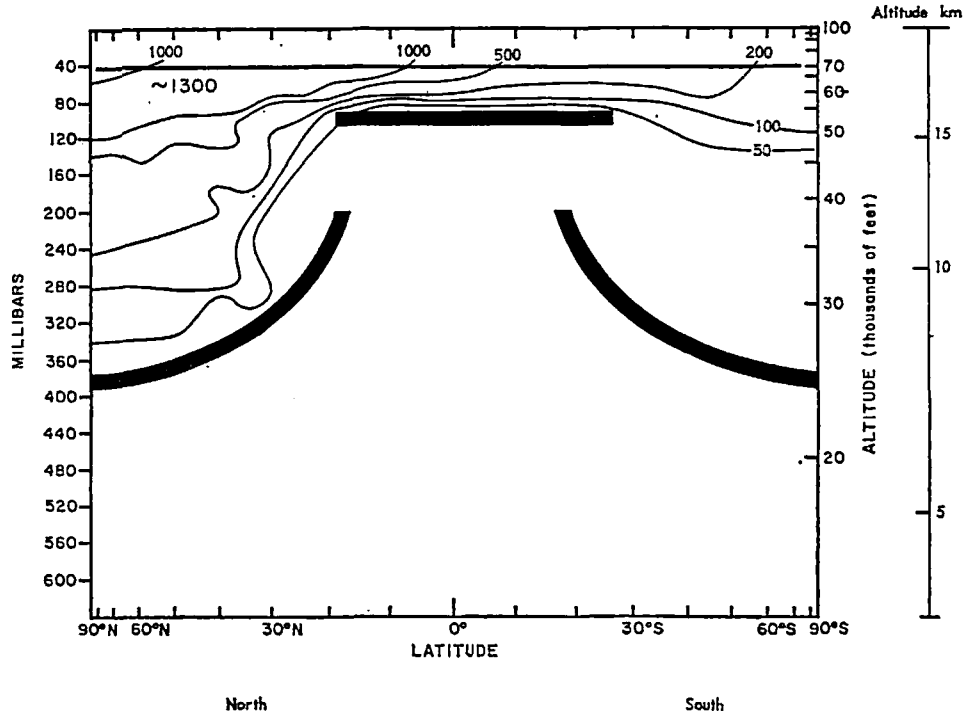


Figure 9. Strontium-90 activity in the atmosphere, January 1964 in dpm Sr^{90}/1000 scf (1000 scf = 35 kg)[22]

tially, indicating that during these periods surface water was exchanging less of its Sr^{90} with soil before moving into the lake. A similar result was noticed in river waters of the Soviet Union, where the Sr^{90} activities measured during flooding were 5-10 times greater than during the low water period.[108] Average values for the Sr^{90} concentrations in 45 rivers of the European part of the Soviet Union were 0.5 pCi/l during the second half of 1961 and 0.9 pCi/l during the first three quarters of 1962. The average values in 37 rivers of the Asian part of the Soviet Union were 0.6 pCi/l and 0.8 pCi/l, respectively.

43. Both this study in the Soviet Union and a similar study on Sr^{90} in the river waters of Japan indicate that some 5-10 per cent of freshly deposited Sr^{90} is carried off in river waters, but the removal rate of the cumulative deposit of Sr^{90} is much smaller, being in the range 0.2-1.5 per cent per year.[107,403] It can be concluded that most of the Sr^{90} that is taken up by the soil will remain there until it decays.

Oceans

44. Oceans cover some 60 per cent of the earth's

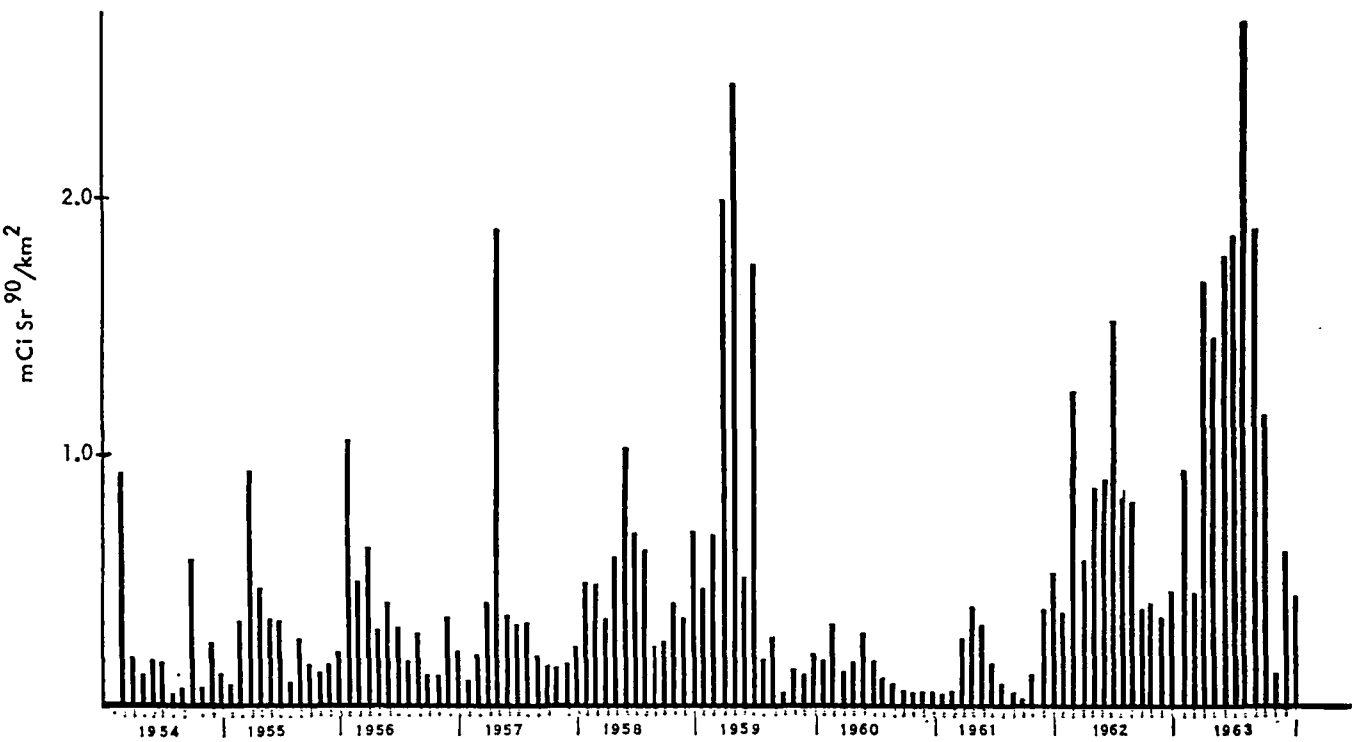


Figure 10. Monthly strontium-90 deposition in New York City[75]

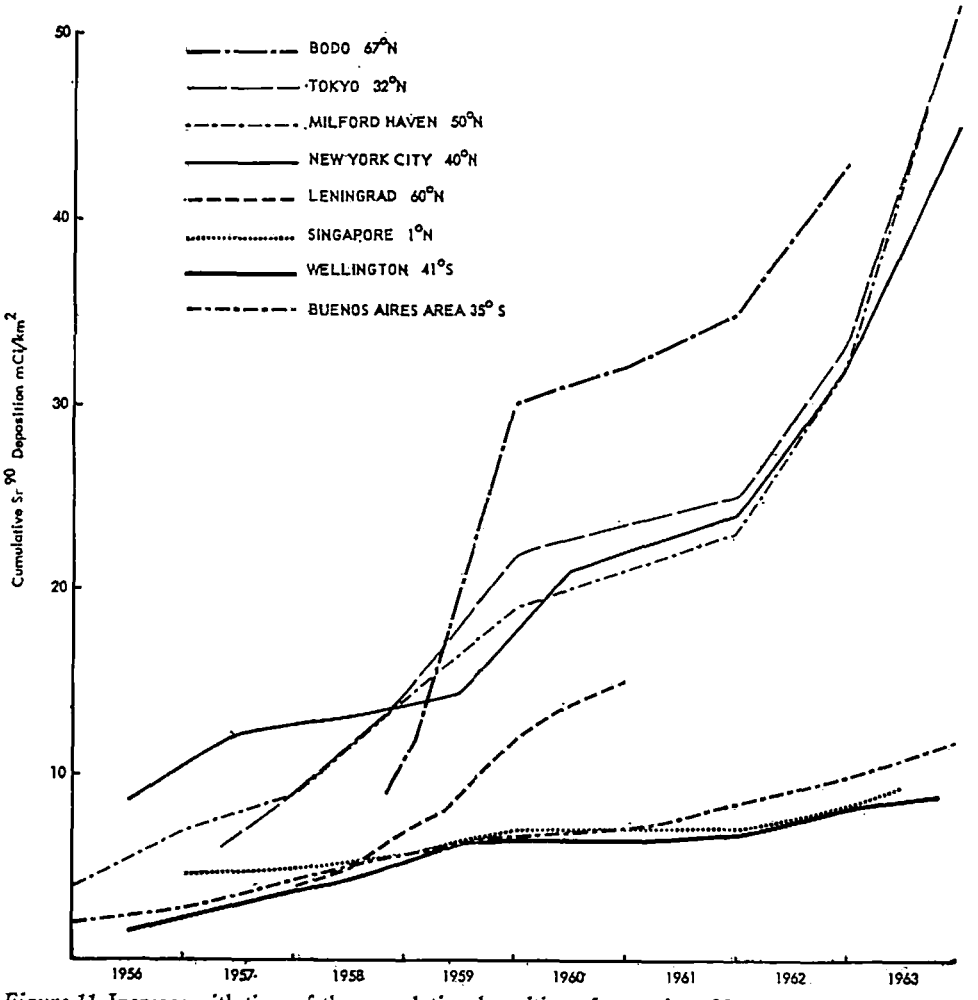


Figure 11. Increase with time of the cumulative deposition of strontium-90[27, 45, 68, 69, 89, 96, 426, 429]

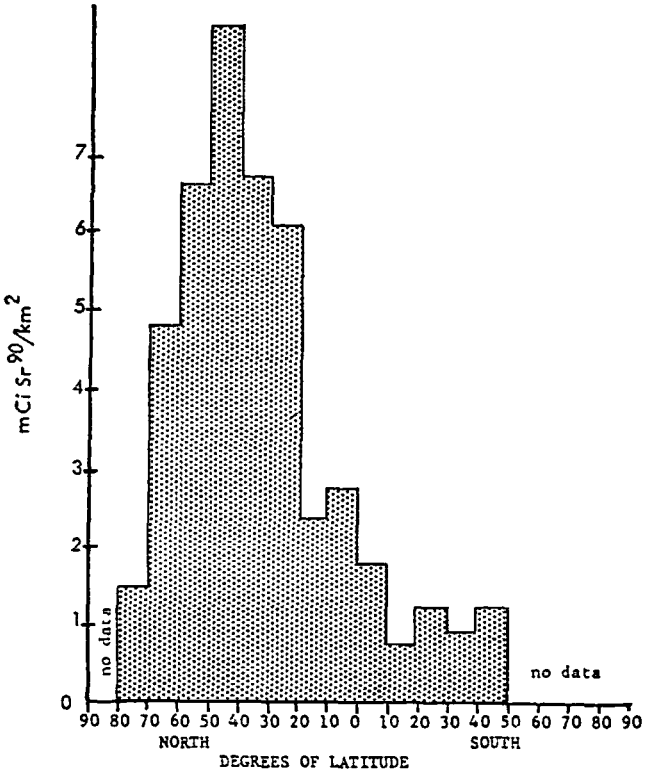


Figure 12. Total strontium-90 deposition during 1962 versus latitude band[27]

surface in the northern hemisphere and about 85 per cent in the southern hemisphere. Since predictions of the future fall-out of Sr^{90} over land are based upon the atmospheric inventory, any difference between the fall-out rates over oceans and over land could cause a corresponding error in future fall-out predictions.

45. Some measured concentrations of Sr^{90} in the Pacific, Atlantic and Indian Oceans during the last five years appear to be too high to be accounted for by the same fall-out rates that are measured over the land.[110] Bowen and Sugihara in 1957 and 1958 found that Sr^{90} was well mixed in the top 100 metres of the Atlantic Ocean.[111] Between 100 and 400 metres, there was a steep gradient in concentration with appreciable concentrations at depths greater than 1,000 metres. Later measurements appeared to confirm the presence of Sr^{90} activity at these great depths.[112, 117] Some profiles of Sr^{90} concentrations in the Atlantic Ocean in 1960 and in 1961 are shown in figure 15. Shvedov, using some of Bowen's results, estimated that the cumulative Sr^{90} fall-out over the Atlantic in the 30°-40°N latitude band was between 28 and 42 mCi/km² in 1957 and in 1958, against an estimated 10 mCi/km² from measurements over land.[113] It has been reported that the Sr^{90} concentrations in the deep waters of the western Pacific were even higher than those measured in the Atlantic.[404]

46. Rocco and Broeker, however, reported profile measurements for Sr^{90} and Cs^{137} in the Atlantic and Pacific Oceans that showed little activity below 300 metres.[114] At levels below 1,000 metres a considerable

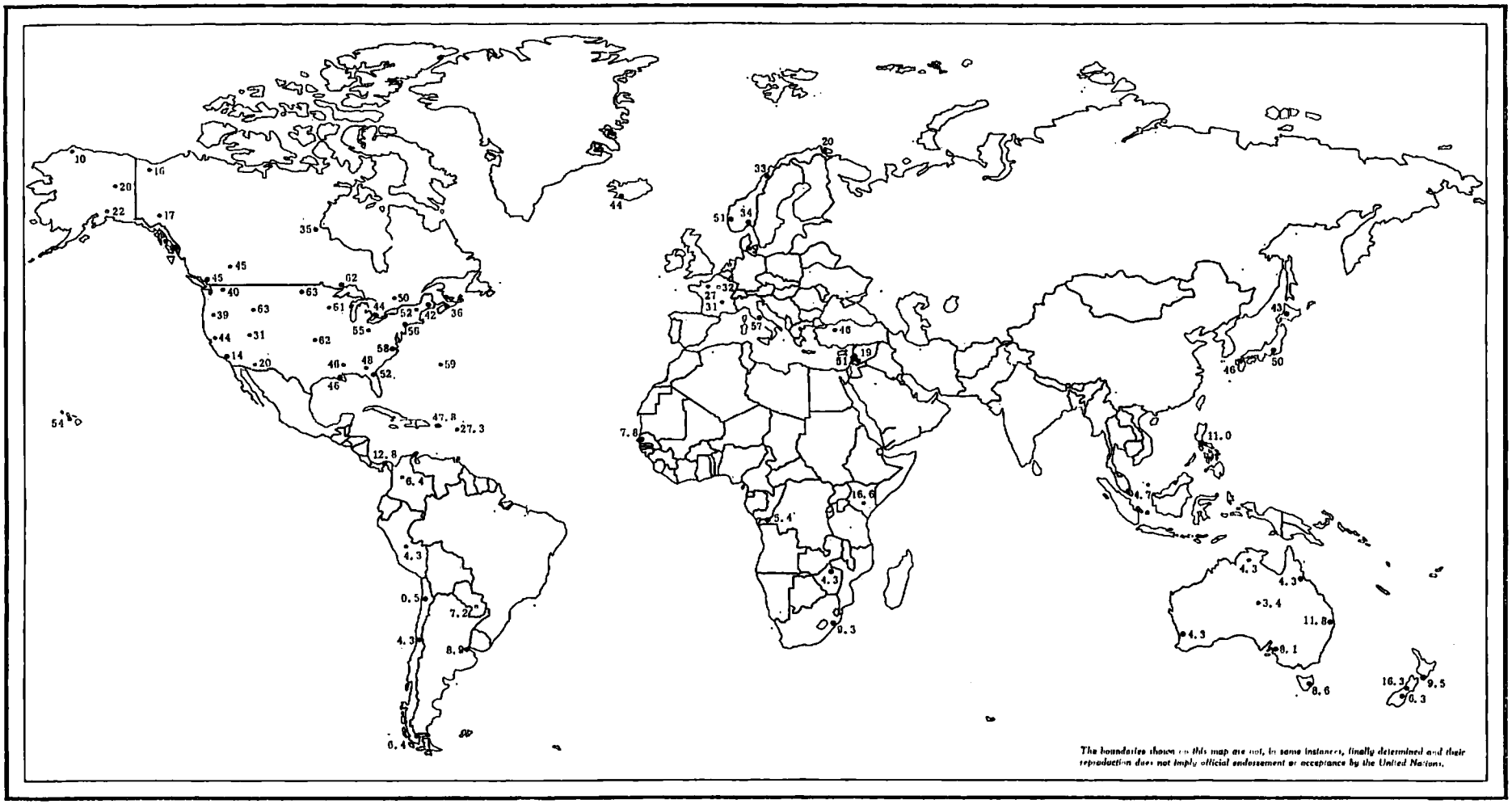


Figure 13. Cumulative deposition of strontium-90 determined from soil samples collected in 1963, mCi/km^2 [103]

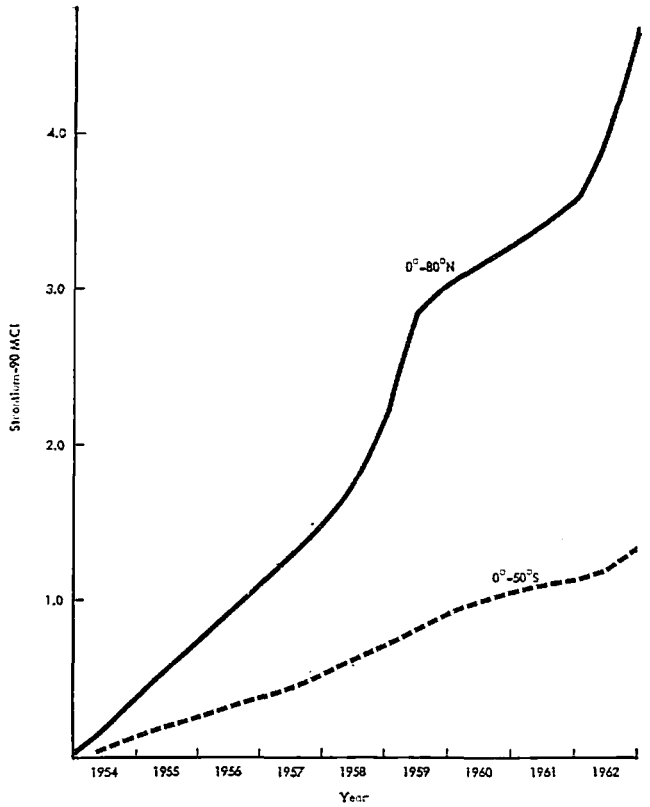


Figure 14. Cumulative deposition of strontium-90 (based upon measurements at the United States fall-out collection network stations. Before 1958 the number of collection stations was relatively small)[27,104]

increase in the concentration of these nuclides was observed, but these measurements were not considered to be sufficiently reliable by the authors. Only in the Antarctic Ocean did they consistently detect significant activities of Sr^{90} and Cs^{137} at greater depths. These latter profiles were more compatible with the ocean circulation patterns suggested by C^{14} measurements.[115,116] Integration of the Sr^{90} concentrations to a depth of 1,000 metres yields deposits of 11 mCi/km² for the Caribbean Sea at 18°N; 6 mCi/km² for the eastern Pacific at 0°S, and 10 mCi/km² for the Atlantic at 20°S. These figures do not show any marked increase over continental fall-out at similar latitudes. These workers also obtained a mean Cs^{137}/Sr^{90} ratio in ocean waters of 1.6, in agreement with fall-out and stratospheric air measurements.

47. Many measurements of the Sr^{90} concentration of surface ocean waters have been reported.[113,115,117-120,411] The surface concentrations of the Pacific Ocean in 1961 were much more uniform than in 1958, indicating considerable horizontal mixing. In all cases, the variation of concentrations with latitude in surface waters was much less marked than in air and precipitation.[117] In the western Pacific between 1957 and 1959, average concentrations of 1.7 pCi of Sr^{90} per litre were reported in surface waters.[411]

48. Indirect evidence on the differences between oceanic and continental fall-out rates may be obtained from the relative deposition over islands compared with that over continents. The Sr^{90} fall-out measured in 1962 at nine stations on small islands in the Atlantic and Pacific Oceans was compared with that measured in the same year at nine continental stations.[27] All these stations are situated in the latitude band 0°-40°N and form part of the United States world-wide Sr^{90} network. In addition the Sr^{90} cumulative deposition in soils was compared at a set of paired stations, one of each pair being near the ocean, the other continental.[420] At the same latitude, no significant difference between the fall-out at island and continental stations was apparent, in spite of the fact that the average rainfall at the island stations was almost three times as high as that at continental stations.

49. There are several additional pieces of contradictory evidence concerning excess fall-out over the oceans. Measurements in the Mediterranean Sea and in the Gulf of Gascony indicate a larger deposition of Zr^{95} over the sea than over adjacent areas.[421] Similar results have been obtained in the Black Sea for Sr^{90} fall-out.[120] On the other hand, O'Brien, using C^{14} as a tracer for stratospheric Sr^{90}, found agreement between pot determined Sr^{90} global fall-out and that leaving the stratosphere.[400] Thus, his findings in 1960, 1961 and 1963 required no excess Sr^{90} deposition over the ocean compared with adjacent land stations.

50. To summarize, much evidence seems to indicate that the fall-out rate of Sr^{90} over the ocean is about the same as that over land surfaces, but on the other hand a considerable number of measurements of appreciable activities of Sr^{90} in deep waters have been reported that are not compatible with present estimates of deposition. At the moment, there is no adequate explanation for these differences, and further work is needed to clarify the issue. For the purposes of dose estimation, the fall-out

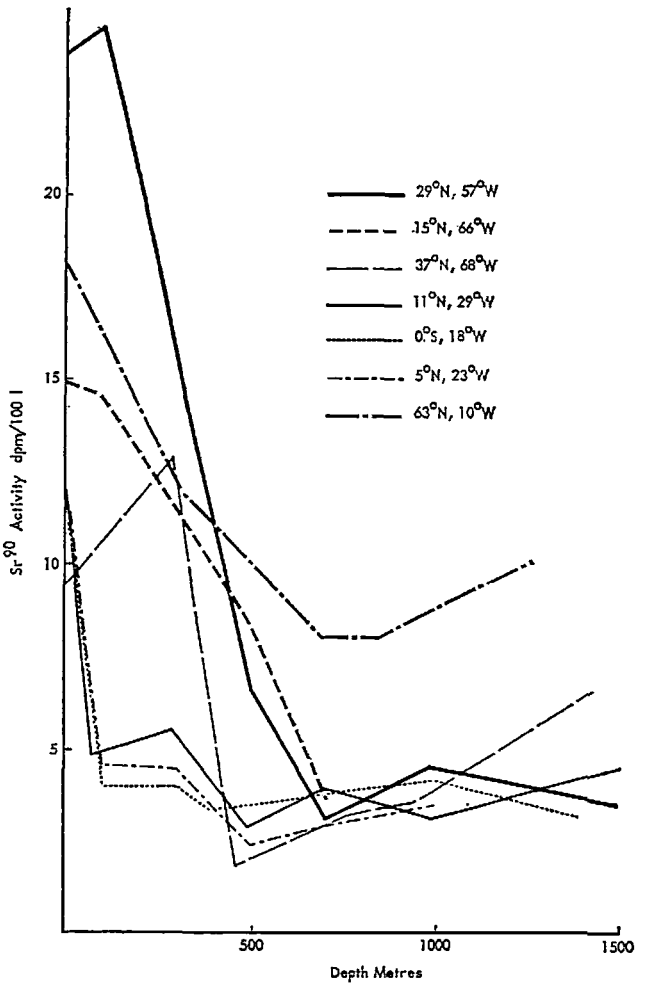


Figure 15. Strontium-90 concentrations in waters of the Atlantic Ocean during the period 1960-1961[112]

rate over the oceans will be assumed to be the same as that over the land since the use of this assumption will not underestimate the doses.

Caesium-137

51. Cs^{137} has not been measured in precipitation throughout the world on such an extensive scale as Sr^{90}, although the number of stations now reporting data on Cs^{137} is greater than before 1960. Because of this lack of world coverage, in the 1962 report the world-wide deposition of Cs^{137} was estimated by applying the mean Cs^{137}/Sr^{90} ratios for the various years under investigation to the global Sr^{90} deposition figures. This procedure is again used here.

52. The half-lives of Sr^{90} and Cs^{137}, 28 years and 30 years, respectively, are so similar that any change in the value of the Cs^{137}/Sr^{90} activity ratio due to radio-active decay over a period of ten years or less can be neglected. The initial Cs^{137}/Sr^{90} ratio estimated from fission yields varies between 1.0 and 3.0 for different fissile materials and for different neutron energies.[121] Measurements of Sr^{90} and Cs^{137} in precipitation indicated that there was also some variation in the ratio with geographical location.[45,89] Large numbers of measurements have been used below in order to obtain reliable values for the mean Cs^{137}/Sr^{90} ratio.

53. Figure 16 shows the mean quarterly Cs^{137}/Sr^{90} ratios for rain collected in the northern hemisphere at 20 stations of the United Kingdom precipitation collection network during the period January 1961-May 1963.[45] In this figure the Cs^{137}/Sr^{90} ratios of stratospheric air measured by balloon sampling over San Angelo, Texas, United States, from January 1961 to November 1963 are also shown.[73] It is evident that the ratio has diminished significantly since September 1961, possibly for the reasons mentioned in the preceding paragraphs. The mean values of the Cs^{137}/Sr^{90} ratios before and after September 1961 have been computed at stations where sufficient data were available. Table IX shows the mean Cs^{137}/Sr^{90} ratios in precipitation at the stations mentioned above, in stratospheric air above San Angelo, and in air measured in the northern hemisphere by aircraft. The measured reduction in the ratio since the resumption of tests is statistically significant.

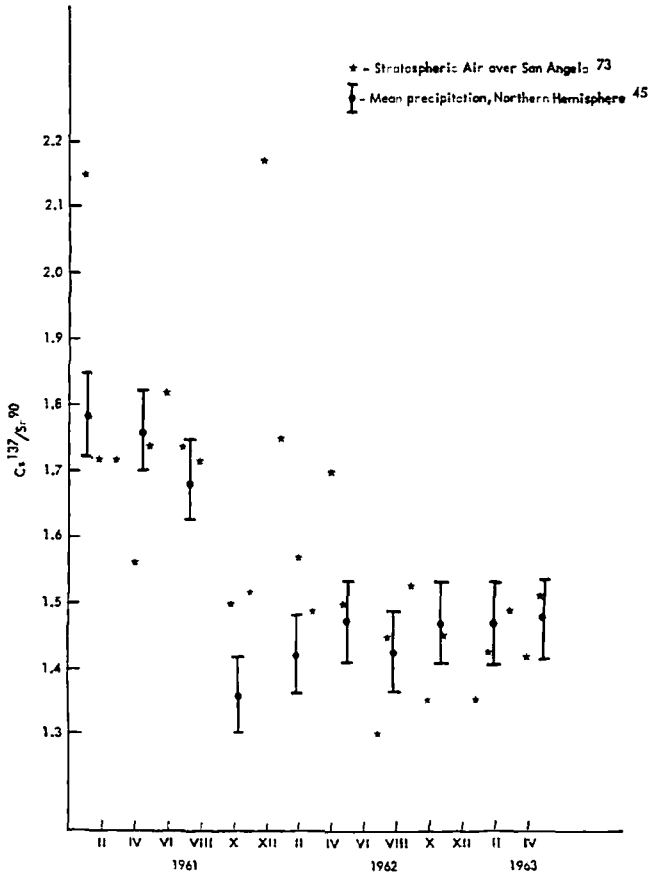


Figure 16. Cs^{137}/Sr^{90} activity ratio in stratospheric air and in precipitation

54. To estimate the total deposition of Cs^{137}, the Cs^{137}/Sr^{90} ratio has been taken as 1.7 through 1961 and as 1.5 for the period 1962-1963. The Sr^{90} deposition values shown in tables VII and VIII have been multiplied by these ratios, and the estimates of Cs^{137} deposition are shown in table X.

Krypton-85

55. The concentration of Kr^{85} in the atmosphere has been increasing steadily since 1954 [122,123,405] (figure 17) and by 1962 was 7 pCi/m^3 in the air of the northern hemisphere. From the known fission yield of Kr^{85} it appears that only a fraction of this activity has been contributed by tests, the remainder having presumably been released into the troposphere by nuclear plants. This is borne out by the fact that the concentration of Kr^{85} in air, unlike that of other fission products, shows neither seasonal fluctuations nor any correlation with tests.[122] Since Kr^{85} is a noble gas, almost all of it remains in the atmosphere and so measurements of its concentration in the air of both hemispheres could be used to study exchange mechanisms in the troposphere. The present concentration of Kr^{85} in the atmosphere is not sufficient to give rise to any significant dose to populations.

Short-lived fission products

Strontium-89

56. The deposition of Sr^{89} has, for some six years now, been measured at a large number of stations throughout the world.[27] Since the half-life of Sr^{89} is 50 days, its fall-out rate is a fairly good index of the amount of short-lived activity being deposited. Figure 18 shows the monthly mean Sr^{89}/Sr^{90} ratio for different latitudinal bands during the period September-December 1961.[27]

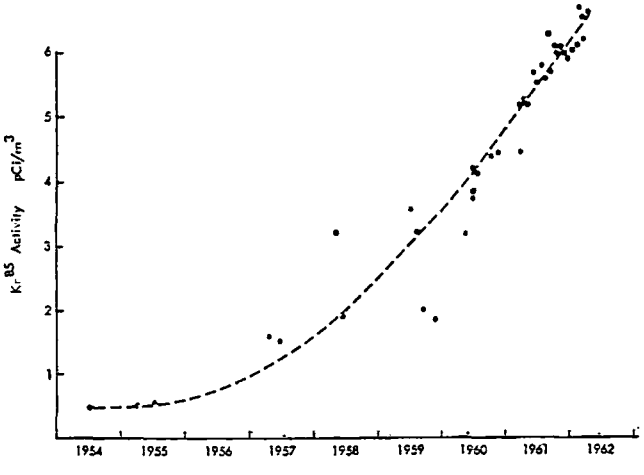


Figure 17. Krypton-85 activity in northern hemisphere air[122,123,405]

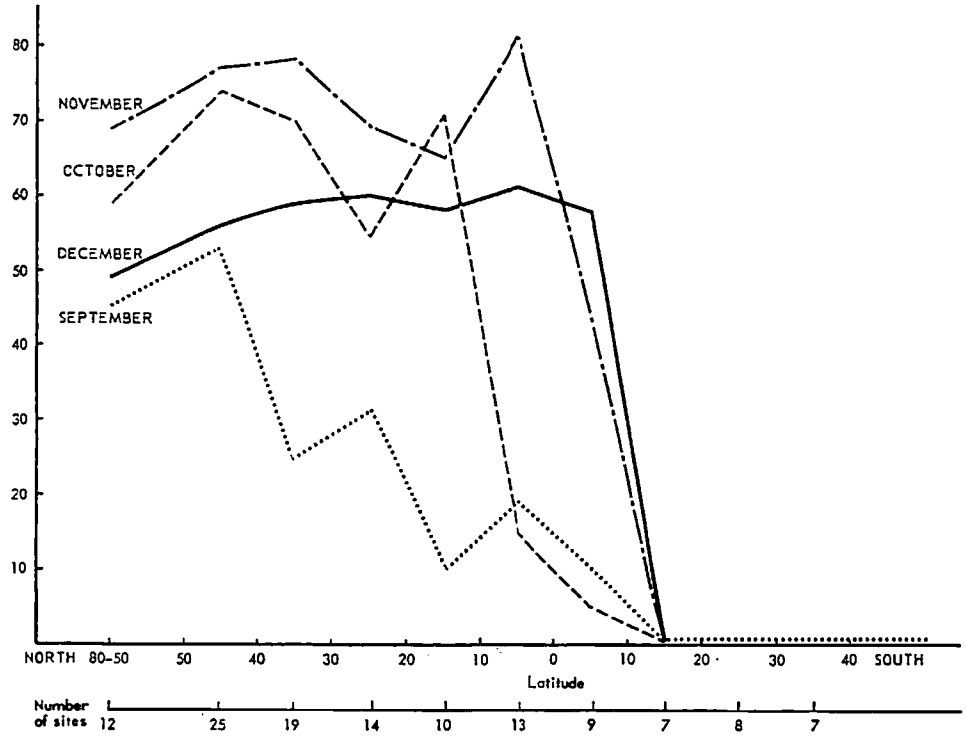


Figure 18. Average Sr^{89}/Sr^{90} ratio in precipitation in each 10° latitude band, 1961[27]

Even by December 1961 the Sr^{89}/Sr^{90} ratio was almost constant with latitude, indicating that the mixing along meridians within the northern hemisphere was relatively rapid.

57. The Sr^{89} fall-out totals in different latitudinal bands for the period September-December 1961, and for 1962 and 1963, are shown in table XI.[27,124,376] The deposition was at a maximum in the 30°-50°N band in 1962, about half as much being deposited in the tropical regions and even less at high latitudes. The monthly Sr^{89} deposition in different regions of the northern hemisphere, as well as the southern hemisphere averages, are plotted in figure 19.[75] It is apparent that the Sr^{89} fall-out rates for these three regions of the northern hemisphere were somewhat similar, indicating that the debris was zonally well mixed and that it was largely of stratospheric origin.

58. The Sr^{89} monthly deposition at mid-latitudes in the northern hemisphere reached a peak value of about 25 mCi/km² during January 1962 and passed through a minimum of some 3 mCi/km² during August 1962. The deposition rose again during the last part of 1962 and reached a peak of 20 mCi/km² during April 1963. Present measurements indicate that the deposit of Sr^{89} in 1964 will be practically zero. In the southern hemisphere the deposition rate for Sr^{89}, also shown in figure 19, was small until May 1962 when it increased to about 2 mCi/km² per month and remained approximately at that level during the rest of the year. Included in table XI are the annual deposits of Sr^{89} for each hemisphere during 1961 and 1962. During 1962, the deposition of Sr^{89} in the southern hemisphere was only one-sixth of that in the northern hemisphere.

Other short-lived fission products

59. A number of fission products with half-lives ranging between the 8 days of I^{131} and the 244 days of Ce^{144} are deposited in significant quantities upon the earth's surface. Monthly deposits of short-lived fission products at Milford Haven and Chilton in the United Kingdom are shown in table XII.[45] A number of these nuclides, $Zr^{95} + Nb^{95}$ in particular, contribute significantly to the external gamma dose commitment due to nuclear tests. Although I^{131} is measured very extensively in milk supplies, it has not been measured in precipitation at many sites. However, the deposition rate of Ba^{140} is a reasonably good index of I^{131} deposition. The activity of the short-lived fission products, Sr^{89}, Zr^{95}, Ru^{103}, Ru^{106}, I^{131}, Ba^{140}, Ce^{141} and Ce^{144}, deposited during 1962, are shown in table XIII.[45,75] The importance of dry deposition of short-lived fission products has been shown by measurements in the United Kingdom.[45] Apart from Sr^{89}, few measurements have been reported on the deposition of short-lived fission products in the southern hemisphere.

CARBON-14

Inventory

60. C^{14}, with a half-life of about 5,700 years, has always been present in the earth's atmosphere where it is produced by the action of cosmic ray neutrons on nitrogen atoms, both in the stratosphere and in the upper troposphere. The C^{14} in the atmosphere is observed almost exclusively as CO_2.[406] Before nuclear testing, the atmospheric content of C^{14} was about 40×10^{27} atoms. The normal distribution of stable carbon and of C^{14} among the different reservoirs of exchangeable carbon, prior to the industrial and atom bomb effects, is shown in table XIV. The specific activity of C^{14} in standard wood (wood grown during 1890) of 14.5 dpm/g C has been used to estimate the C^{14} content of each reservoir.[125] The C^{14} activity in the deep oceans and in humus is assumed to be 84 per cent of standard wood.[115] The natural production rate of C^{14} can be calculated by dividing the inventory (2170×10^{27} atoms, table XIV) by the mean life of C^{14} (8,300 years). The resultant production rate is 2.6×10^{26} atoms per year, which corresponds to 1.6 atoms cm^{-2} sec^{-1}.

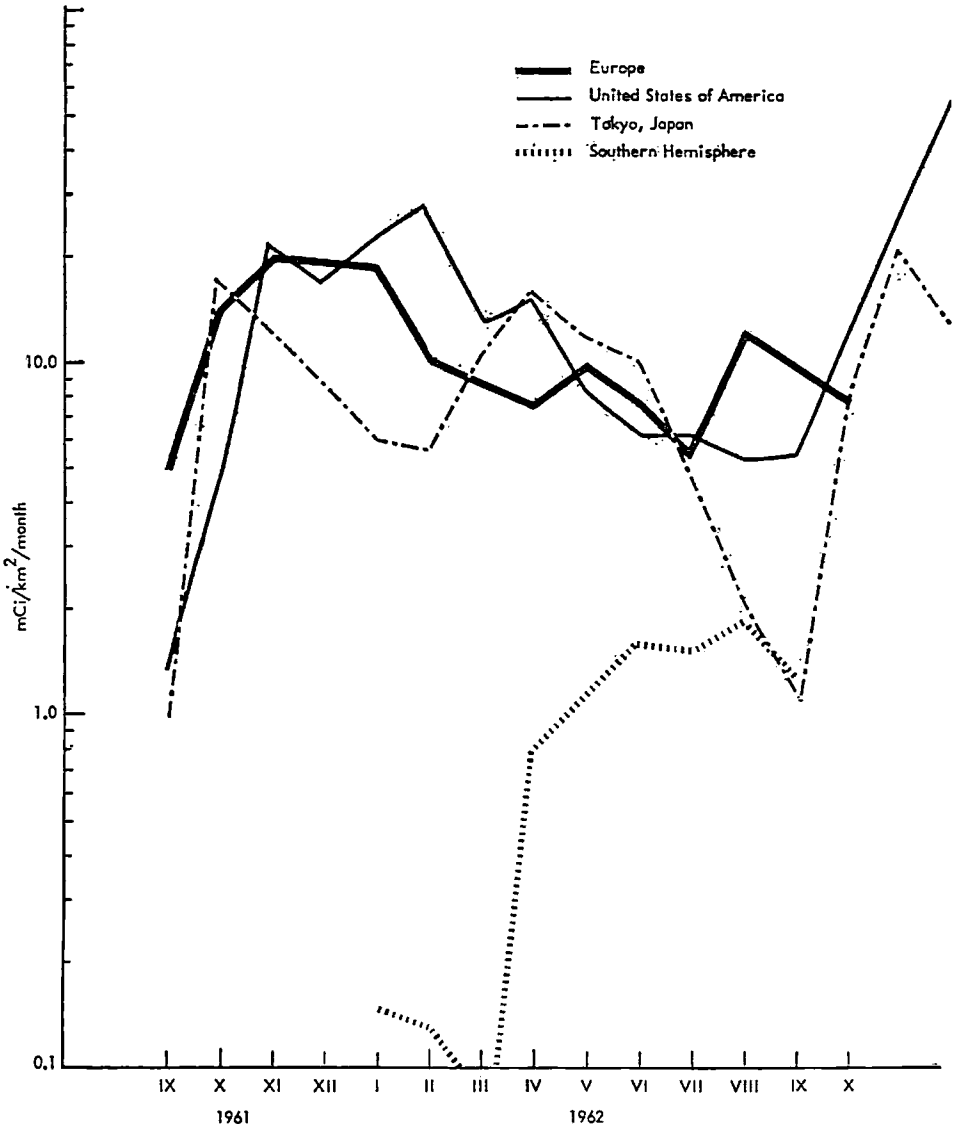


Figure 19. Average monthly strontium-89 deposition[75, 89]

61. Lal and Peters estimated the production rate, when computed from the C^{14} inventory, to be 1.6 atoms cm^{-2} sec^{-1} (when corrected for the new half-life of C^{14}) and 1.8 atoms cm^{-2} sec^{-1} when derived from cosmic ray data.[15, 139] Another estimate of the C^{14} production rate using cosmic ray data is 2.5 ± 0.5 atoms cm^{-2} sec^{-1}.[422] For purposes of risk assessment the lower figure for C^{14} production, 1.6 atoms cm^{-2} sec^{-1}, will be used here, as it will not under-estimate the dose commitment. As this production rate is about 25 per cent lower than that used in the 1962 report, its use will result in a correspondingly higher estimate of the dose commitment from C^{14} produced by tests.

62. Since 1954, large amounts of C^{14} have been produced during nuclear tests. Neutrons produced during nuclear explosions in the atmosphere react with atmospheric nitrogen, producing C^{14}. With underground explosions C^{14} production is essentially zero, while for surface or near-surface explosions the production can be assumed to be about half that due to air explosions. When explosions occur at very high altitude, a fraction of the released neutrons escapes into space and the C^{14} production is correspondingly reduced.

63. Extensive surveys have been made of the C^{14} activity in stratospheric air in both hemispheres, using aircraft and balloons for sampling.[23, 84, 127] From these measurements, the stratospheric C^{14} inventory has been estimated in a manner similar to that used to estimate the Sr^{90} inventory. The estimates of stratospheric inventory of artificial C^{14} at different times between July 1957 and January 1964 are shown in table XV, together with the estimated distribution of artificial C^{14} in other reservoirs.[84, 426]

64. The excess activity of C^{14} in the troposphere as a percentage of the activity prior to tests is shown in figure 20, based on measurements made at a number of laboratories in different parts of the world.[71, 128–137, 141] As figure 20 shows, the C^{14} activity of atmospheric carbon dioxide began to rise appreciably above normal in 1956. Between 1956 and 1958 the level rose almost linearly to a peak in 1959. During 1960 and 1961 the tropospheric C^{14} activity remained fairly constant at about 22 per cent above normal.

65. From 1959 to 1961 there were small annual fluctuations in the tropospheric C^{14} activity.[141] These fluctuations were particularly noticeable in the northern hemisphere and were probably due to the fact that most of the artificial C^{14} was transferred from the stratosphere to the troposphere during the spring months, causing a peak activity in the northern hemisphere, while a sub-

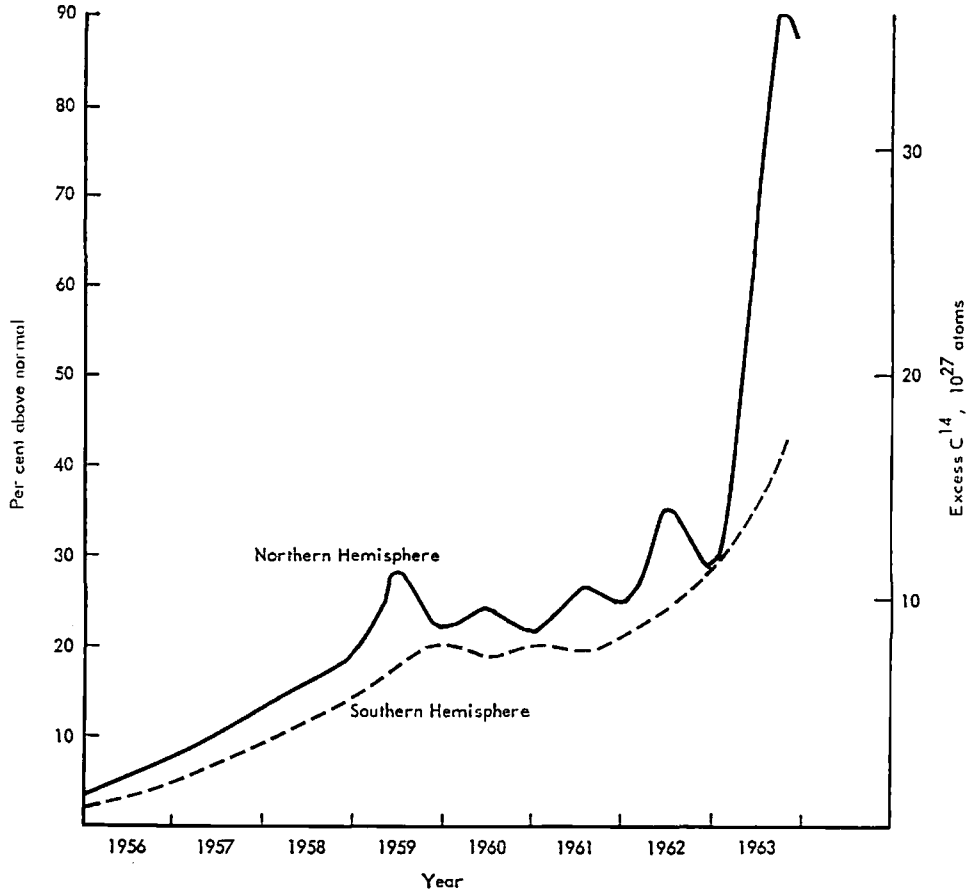


Figure 20. Tropospheric inventory of artificial carbon-14[71,128–137,141]

sequent transfer of some of this activity to the troposphere of the southern hemisphere caused a lowering of the northern hemisphere activity during the fall and winter. This explanation is supported by the fact that the fluctuations in the northern and southern hemispheres are out of phase by approximately six months. It will also be noticed in figure 20 that the peak C^{14} activity in the northern hemisphere in the years 1959-1961 occurred approximately three months later than the peak in the Sr^{90} fall-out rate, as shown in figure 3. The probable explanation is that C^{14} is removed so slowly from the troposphere that the mean tropospheric level tends to be proportional to the integrated amount transferred from the stratosphere.

66. Between 1955 and 1959 the tropospheric C^{14} activity in the southern hemisphere was some 4 per cent lower than that in the northern hemisphere (figure 20) probably because most artificially produced C^{14} had been injected into the northern stratosphere. However, the difference between the hemispheric levels became smaller during 1960-1961 (approximately 2 per cent difference). It has been estimated that the carbon dioxide exchange with oceans in the southern hemisphere is twice as great as in the northern hemisphere, which probably accounts for the residual differences in levels between the hemispheres.[138]

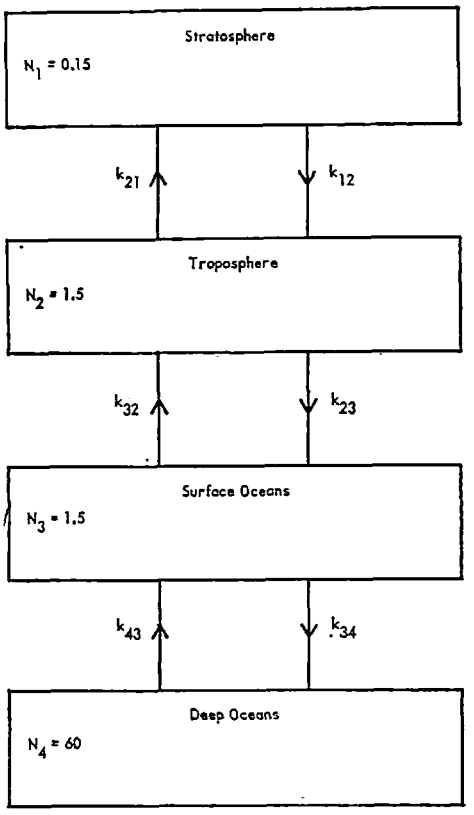
Circulation of carbon-14

67. The C^{14} in the atmosphere exchanges over a number of years with carbon present as bicarbonate in the surface layers of the oceans and with carbon in the biosphere. The carbon then exchanges more slowly with that dissolved as bicarbonate in the deep oceans. This last reservoir is by far the largest, as can be seen from table XIV, and most C^{14} decays while residing there.

68. Measurements of C^{14} in the northern troposphere from 1959 to 1961 have shown a definite variation with latitude.[141] This C^{14} variation and the annual fluctuations have been used to estimate the transfer of C^{14} along meridians, using a linear diffusion model.[141] Using the diffusion rate so obtained and assuming a two-compartment model for the mixing of northern and southern tropospheres, an exchange time between hemispheres of less than one year was estimated. The order of magnitude of the exchange time is borne out by the rapid fall in the northern hemisphere activity during late 1959.

Future levels of carbon-14

69. The future levels of artificial C^{14} in the atmosphere have been estimated on the basis of a four-compartment model representing C^{14} exchange between the different carbon reservoirs. This model is shown in figure 21. Many such models have been proposed in the literature, but for the purposes of predicting future atmospheric levels, there is little to be gained by using more than four compartments.[126,140] A four-compartment model makes more realistic predictions during the first few decades after injection than does a two-compartment model, as was used in the 1962 report. In the present four-compartment model, the biospheric carbon has been lumped in with the atmospheric reservoir, and the humus carbon with the deep ocean, since the atmosphere-biosphere exchange is fairly rapid and the atmosphere-humus exchange is very slow.[140] The move-



N_r = carbon capacity of reservoir r

Figure 21. A four-compartment model of carbon-14 exchange

ment of C^{14} between these reservoirs can be described by the set of four equations,

$$N_r\left(\frac{dA_r}{dt} + \lambda A_r\right) = k_{r-1,\,r}\,(A_{r-1} - A_r) - k_{r,\,r+1}\,(A_r - A_{r+1})$$
$$\text{with } r = 1, 2, 3, 4,$$

where

A_r = the C^{14} concentration in reservoir r,

$k_{r,\,r+1}$ = C^{14} transfer coefficient between reservoirs r and $r+1$, and $k_{01} = k_{45} = 0$,

N_r = the carbon capacity of the rth reservoir,

λ = decay constant of $C^{14} = 0.00012\ y^{-1}$.

70. It is assumed that fractionation effects between reservoirs are small and can be neglected in predicting future levels. These equations have been solved for A_2, the tropospheric concentration, for an initial injection of $C \times 10^{27}$ atoms of C^{14} into the stratosphere at time zero. The method is essentially the same as that used by Plesset and Latter.[140] Based upon the data in table XIV, the capacities of the C^{14} reservoirs are, in units of atmospheric capacity, 0.15, 1.5, 1.5 and 60 for N_1, N_2, N_3, N_4, respectively. The mean residence time of C^{14} in the stratosphere is assumed to be 2.0 years. The transfer coefficients, computed from the steady-state equations derived by Plesset and Latter[140] are, $k_{12} = 0.075$, $k_{23} = 0.27$ and $k_{34} = 0.082$, in atmospheric units per year. The solution giving the excess C^{14} of the troposphere in per cent above normal, after t years, is

$$A_2 = 0.83C\,[0.047e^{-0.00012t} + 1.15e^{-0.026t} + 1.34e^{-0.35t} - 2.54e^{-0.59t}]$$

71. Estimates of the bomb-produced C^{14} inventories in different carbon reservoirs for the years 1957-1963 are given in table XV. The increase due to testing in 1961 and in 1962 was about threefold. If 25×10^{27} out of a total estimated excess of 65×10^{27} C^{14} atoms are assumed to have been injected into the stratosphere in 1958 and the remaining 40×10^{27} atoms in 1962, the predicted future level of C^{14} in the troposphere, A_2, is given for t years after 1964, by

$$A_2 = [2.5e^{-0.00012t} + 64e^{-0.026t} + 26e^{-0.35t} - 26e^{-0.59t}]$$

per cent above normal. This equation predicts a peak excess C^{14} activity of about 70 per cent in 1964 or 1965; the level will then fall to some 60 per cent in seven or eight years' time. Between 1970 and 2040, the level will gradually fall to some 3 per cent and will remain below this level while the excess C^{14} decays radio-actively.

Other artificial radio-nuclides

72. Tritium (half-life 12.5 years) is not a fission product but large quantities of it have been released into the atmosphere by thermonuclear weapons during tests. During 1952 and 1953, before large-scale contamination by tests, typical concentrations of tritium in rain-water were 1-10 tritium units.[c,153] This "natural" tritium is produced by the action of cosmic rays upon the earth's atmosphere. Since thermonuclear weapons tests began, tritium concentrations in rain-water have increased greatly.[146-156,424] Concentrations of tritium in rain-water between 1953 and 1963 in Canada, France and Sweden are shown in figure 22.[143-146,153,156,384,424,425] Peak activities as high as 10,000 T.U. were recorded in Canada in mid-1963.[143] The average tritium concentration in waters of the Pacific Ocean during 1960 and 1961 was 8 T.U.[150] In the southern hemisphere, tritium activities measured in rain-water were much less than in the northern hemisphere, being in the range 5-20 T.U. during 1958 and 1960.[152]

73. Be^7 which has a 54-day half-life is produced naturally in the atmosphere, largely by the action of cosmic ray protons on oxygen and argon, and there is also the possibility of some production in nuclear explosions. Be^7 has been used as a natural tracer to study the movements of air in the stratosphere. Concentrations of both Sr^{90} and Be^7 in rain at Rijswijk during 1961 and 1962,[157] and also in air and rain at other sites, showed marked maxima during the spring months.[158-161] The Be^7 maxima in both years were of similar magnitude, unlike Sr^{90} which showed a much higher activity in 1962, indicating that most of the Be^7 deposited during 1961 and 1962 was of natural origin. Be^7 has also been measured fairly extensively in the stratosphere, and measurements during the period June 1960-May 1961 indicated that the average Be^7/Sr^{90} ratio in the lower stratosphere was 15.[84,157] Using this ratio, it can be estimated that at Rijswijk the deposition rate of Be^7 of stratospheric origin was 12 mCi/km² per year, whereas the deposition rate of tropospheric-produced Be^7 was 28 mCi/km² per year.

74. Measurements of Be^7 and Sr^{89} in stratospheric air over the Netherlands in 1962 suggest that some Be^7 was produced by nuclear tests in late 1961.[158] Be^7 activities above 5 pCi/kg of air showed a linear increase with the Sr^{89} concentration, the mean ratio of excess Be^7 activity to Sr^{89} activity being 0.04. Activities of Be^7 measured in stratospheric air samples collected by aircraft over the United States are shown in figure 23.[34] It is apparent that there has been an increase in Be^7 concentrations in

[c] 1 tritium unit (T.U.) corresponds to $T/H = 10^{-18}$.

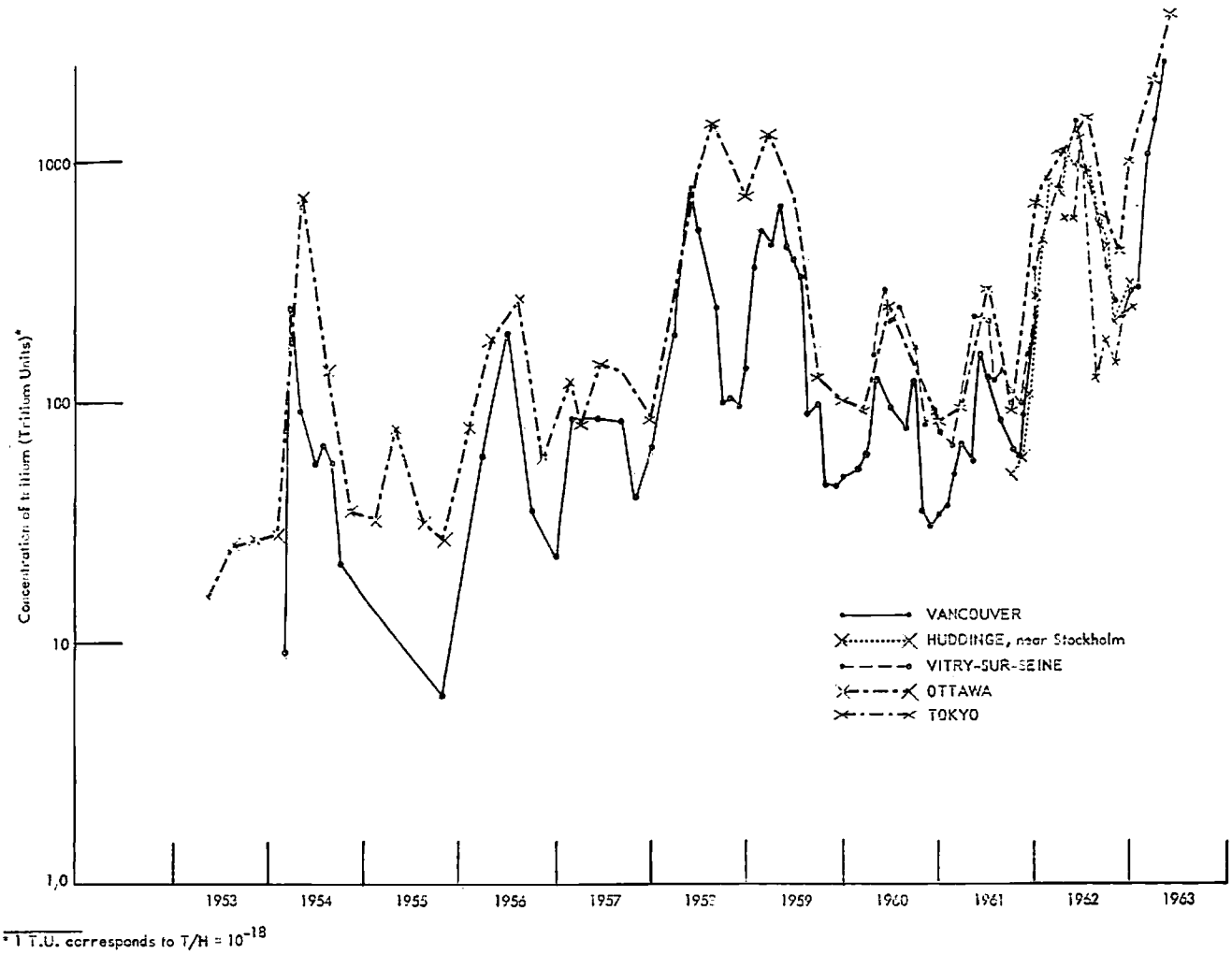


Figure 22. Concentration of tritium in precipitation[143-146,153,156,424,425]

the northern hemisphere where, during the period September 1961-December 1962, concentrations were often markedly greater than expected equilibrium concentrations. This evidence also suggests that Be^7 was produced artificially during tests in 1961 and in 1962. Various nuclear reactions involving Li^6 have been suggested as giving rise to Be^7.[158] By multiplying the above Be^7/Sr^{89} ratio of 0.04 by the figure for Sr^{89} deposition given in table XI, it is estimated that about 1 MCi of bomb-produced Be^7 was deposited in the northern hemisphere during 1962. This is equivalent to an average Be^7 deposition in the northern hemisphere of 4 mCi/km^2.

75. A number of other nuclides, which have either been deliberately added to nuclear devices or have been produced as a result of neutron activation during the explosion, have been measured in the atmosphere and in precipitation.[23,73,142] During tests in 1958, W^{181}, W^{185} and Rh^{102} with half-lives of 145 days, 74 days and 210 days, respectively, were injected into the equatorial stratosphere. Cd^{109} and Cd^{113} with half-lives of 1.6 years and 14 years, respectively, were added in 1962. These radio-nuclides have been measured in air and in precipitation, and the study of their movement in the stratosphere has contributed significantly to the understanding of its circulation.[14,23,73,142] However, the contribution to the dose in humans from these radio-nuclides is insignificant.

76. During tests in 1961 and in 1962, considerable quantities of Mn^{54} (310 days), Fe^{55} (980 days), Sb^{124} (60 days), Y^{88} (104 days) and Co^{58} (72 days) were injected into the stratosphere. The activities of these radio-nuclides in the stratosphere during 1962 are shown in figure 24 and are compared with those of Sr^{90} and Ce^{144}.[13] During the period July 1962-June 1963, 128 mCi/km^2 of Fe^{55} were deposited at Westwood, New Jersey, United States.[142] There is no evidence at the present time to indicate that doses from these radio-nuclides are of any significance.

77. There is evidence that nuclear explosions have added Na^{22},[36] and possibly Pb^{210},[34,417] to the existing naturally occurring background of these isotopes in the atmosphere, especially during 1961 and 1962. Various plutonium isotopes from nuclear tests have been observed in the atmosphere and in fall-out.[45,401,415,416,423] In addition, the possible burn-up of an isotopic nuclear power source for a space satellite in the stratosphere during April 1964 may have added to the burden of Pu^{238} in the atmosphere.[413,414] However, there is no evidence that the contribution to the dose in humans from these radio-nuclides is significant.

III. Contamination of food and human tissues

Strontium-90 and strontium-89

78. The levels of Sr^{90} in foodstuffs have increased since the resumption of nuclear tests in 1961. The levels of Sr^{90} in milk rose in the northern hemisphere in 1962, the mean yearly values being generally higher by a factor

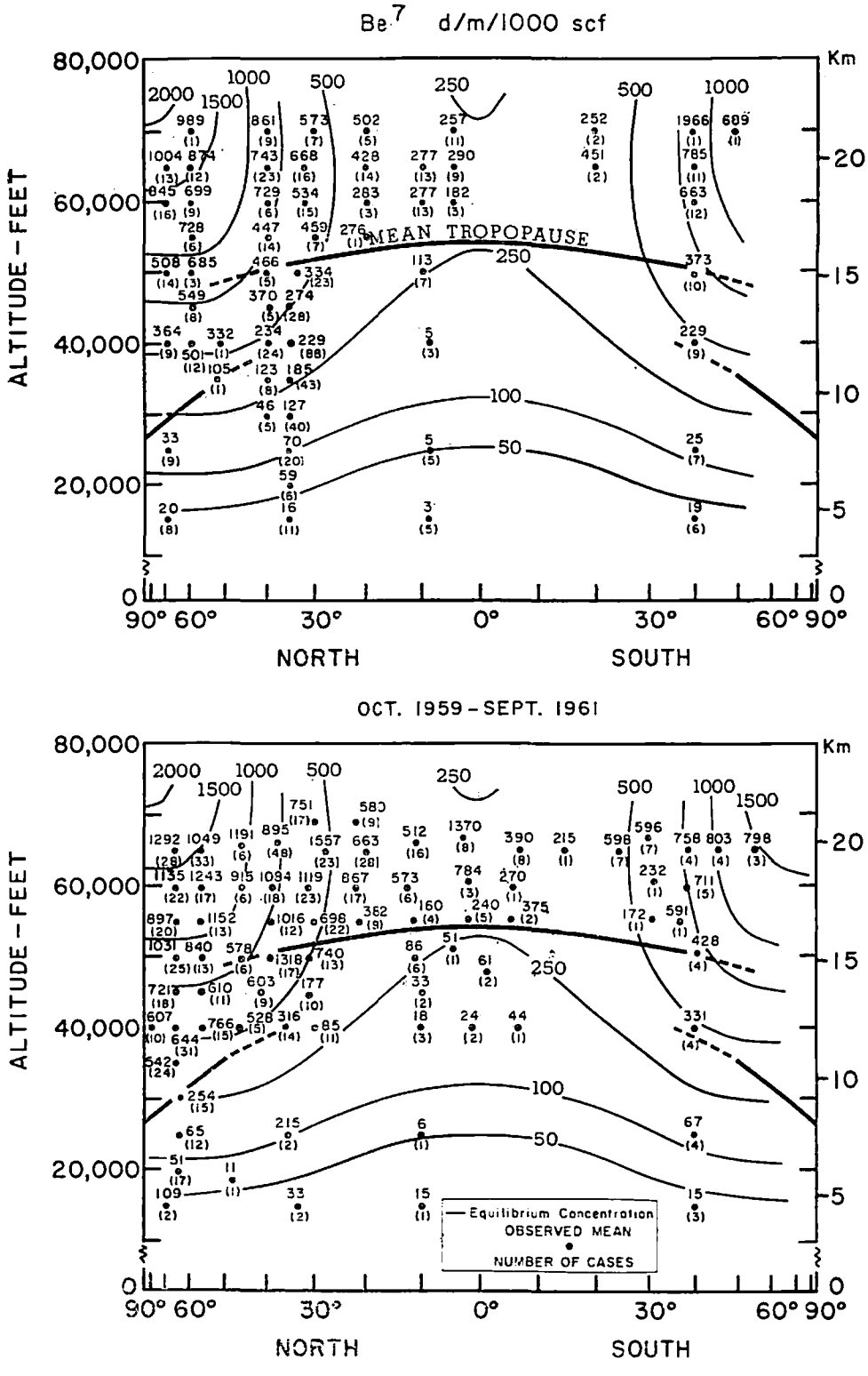


Figure 23. Beryllium-7 activity in the atmosphere[84]

of 2 than they were in 1961. The rise continued in 1963, and the available data show that in 1963 the yearly average was twice as high as it was in 1962 (table XVI). In the southern hemisphere the levels of Sr^{90} in milk rose much less in 1962 and 1963, as indicated by values from Argentina, Australia and New Zealand.

79. The available data on milk contamination by Sr^{89} are summarized in table XVII. During testing periods, high levels were measured in milk from the northern hemisphere. Because of the short half-life of Sr^{89}, milk levels fell sharply by the end of 1963.

80. In countries of the northern temperate zone the rise of the Sr^{90}/Ca ratio in total diet was similar to that in milk, average values for 1962 being higher than in 1961 by 70-100 per cent (table XVIII). The available data for 1963 (Denmark, United Kingdom, United States)

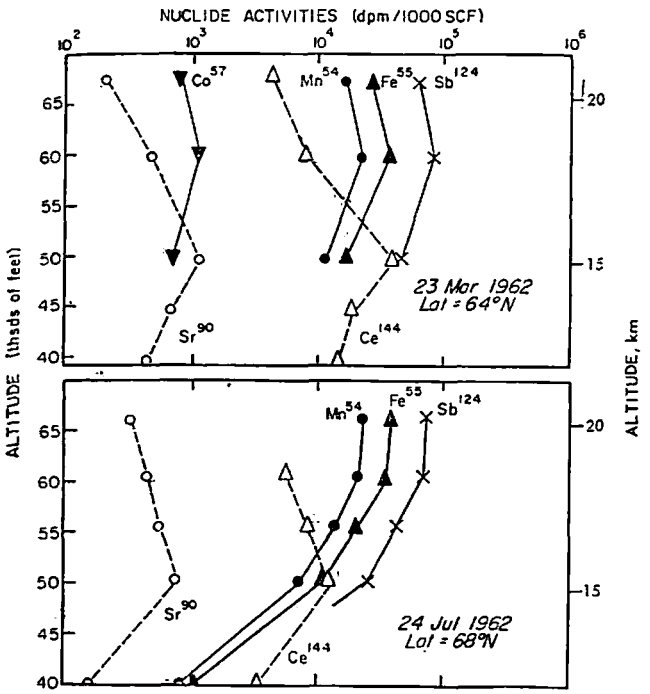


Figure 24. Vertical profiles of cobalt-57, iron-55, manganese-54 and antimony-124 activities (corrected to 15 October 1961) and of strontium-90 and cerium-144 activities (on collection date)[13]

show that the ratio was again doubled when compared with the available data for 1962.

81. Dietary information from regions other than North America and Europe is scanty. The Sr^{90}/Ca ratio in total diet in the United Arab Republic in 1961 and in 1962 was close to the lowest values reported from the northern temperate zone (Europe, United States). In 1963, however, the levels rose only slightly in the United Arab Republic and were on the average lower by a factor of 2 than most of the values reported from the northern temperate zone. Levels in Australia and Argentina were much lower, and only a slight increase in the period 1961-1963 was noted (tables XVI and XVIII).

82. The average Sr^{90}/Ca ratio in the diet in Japan (table XVIII) is close to the levels reported from the United States and Europe in spite of the entirely different composition of the average diet.[172]

83. The relationship between fall-out rate and cumulative deposit of Sr^{90} on the one hand, and milk concentrations of the isotope on the other, has recently been discussed[173,174] and has been expressed by the equation:

$$C = p_d F_d + p_r F_r,$$

where

C = yearly average Sr^{90}/Ca ratio in milk,

F_d = total accumulated deposit of Sr^{90} in soil in mCi/km^2,

F_r = yearly fall-out rate of Sr^{90} in mCi/km^2 in given year,

p_d and p_r are corresponding proportionality factors also called "soil" and "rate" factors.

The values of the soil factors calculated for England and Wales[173] and for the New York and San Francisco areas[174] tend to be lower than the value of 0.3 accepted for the world-wide situation in the 1962 report. On the other hand, it has been shown that values for both the soil and the rate factors may vary widely with local meteorological and agricultural conditions.[175,176] As the soil factor that had been adopted in the 1962 report does not tend to under-estimate the exposure, no change in its value seems justified.

84. Levels, however, vary even within countries. Thus, the yearly mean Sr^{90}/Ca ratio in milk in different regions of the United States differed considerably from the average of the results reported by all the stations.[162,163] The highest and the lowest yearly regional means in 1963 differed by factors of 2 and 6, respectively, from the arithmetical mean of the network.[164] In New Zealand in 1962, the yearly means for local stations differed by a factor of 6.[295] The average dietary levels as found in the Tri-City Study[165] varied systematically by a factor of 2 between New York and San Francisco. A similar degree of variation between average Sr^{90}/Ca ratios in diets from different regions of the country was found in Austria[166] and a smaller one in Denmark[97,167] and in the United Kingdom.[168,169,280] Data on the geographical variation of Sr^{90}/Ca ratios in total diet in Japan indicate values systematically higher than average in the western and northern parts of the country.[170]

85. It should be mentioned, however, that the range of variation observed between regions involving an appreciable fraction of the population of a country does not necessarily include the much higher values of Sr^{90}/Ca ratio found in milk and other dietary products of local origin in some places with particularly high rainfall and with special agricultural conditions. Such situations were investigated in the United Kingdom.[168,169,280] The concentrations of Sr^{90} in milk found there reached levels differing by a factor as high as 8 from the country-wide mean. These locations are usually confined to single farms and are not representative of the region as a whole, so that it is highly improbable that any large fraction of the population could be exposed to dietary contamination of this origin.[171] Broadly similar situations appear to exist in a number of cool regions in north temperate latitudes, e.g. the Faroe Islands[97,179] and northern Finland.[178]

86. The results of surveys in both Australia and New Zealand indicate that the ratio of Sr^{90}/Ca in milk relative to deposition is higher than it is in Europe and North America. In contrast to the majority of areas in Europe and North America, in Australia and New Zealand cattle derive the major part of their entire diet from grazing throughout the year, and it seems likely that this is one of the factors responsible for relatively high Sr^{90}/Ca ratios in milk.

87. Though information is scanty at the present time, it should be noted that in some areas potable water may contribute appreciably to the intake of Sr^{90}. According to observations made in Japan during 1962,[271] monthly determinations of Sr^{90} concentration in potable rainwater from twelve locations showed an average value of 4.4 pCi/l, while an average value of 0.2 pCi/l was observed in city water collected from twenty-five locations. An increase in the Sr^{90}/Ca ratio in diet of about 40 per cent was estimated to be due to this source.

88. The information available on the Sr^{90}/Ca ratio in the diet of infants is limited. Direct determinations of Sr^{90} and calcium in babies' food preparations in the United States indicate that on the average the Sr^{90}/Ca ratio in infants' diet in that country is essentially the same as in the average diet of adults.[181] The Sr^{90}/Ca ratios obtained in the course of a dietary survey limited

to children and adolescents in the United States[182,366] showed a range of values similar to that observed in adult surveys in the same country.

89. In Argentina during the years 1961-1963,[265] average levels of Sr^{90}/Ca in babies' food preparations were almost the same as in milk. Indirect estimates, taking account of the more important role of milk as a source of calcium and Sr^{90} in children's diet,[168,169,183] also indicate that the Sr^{90}/Ca ratios in the average diets of infants and young children are unlikely to exceed that estimated for adult diets. It must be emphasized, however, that, although much information is available for areas where the intake of calcium is relatively high and milk is an important component of the diet, little information is available for countries in which other types of diet are consumed.

90. In the 1962 report, the ratio

$$\frac{Sr^{90}/Ca \text{ total diet}}{Sr^{90}/Ca \text{ milk}}$$

was used to predict Sr^{90}/Ca ratios in diet from those in milk in areas where insufficient information was available to estimate the dietary intake directly. Although this method is not used in the present report, it is of interest to note that the ratios in the years 1960-1963 (table XIX) do not differ substantially from those given in the 1962 report. However, some remarks are necessary:

(*a*) In Japan, where the diet has a very low milk content, the ratio was 2 in 1962, somewhat lower than that given for 1960 in the 1962 report.

(*b*) In Poland, where the average calcium intake is high and where cereals, whole-meal bread and potatoes contribute a relatively high proportion of calcium and Sr^{90} to the average diet,[183,184] the ratio is higher than in countries where milk is the main source of calcium. A similar situation might exist in a large part of eastern and south-eastern Europe.

91. In the 1962 report, it was concluded that the Sr^{90}/Ca ratio in bone was largely determined by the Sr^{90}/Ca ratio in diet, and that, averaged over a period of several years, the ratio in bone would be about one-quarter of that in the diet from which the bone mineral had been derived (i.e., the OR was 0.25[d]). Recent investigations, which lend further support to this conclusion, have added appreciably to our understanding of the manner in which the metabolism of the two elements changes with age.

92. *Adults.* A value of 0.25 for adults appears to be reasonably acceptable, though somewhat lower values have been reported.[189,193] The best agreement between calculated and observed Sr^{90} levels in the adult skeleton is obtained by assuming that 2.0-3.5 per cent of bone calcium is replaced every year by that supplied by the diet.[201,202] Assuming, for the sake of simplification, a single compartment situation, the replacement rate in long bones (e.g. femur) should fall somewhere between 1.2 and 4.0 per cent per year,[187,188,193] most probably at the lower end of the range. In spongeous bone (vertebral bodies) several independent estimates yielded values close to 8-9 per cent per year.[187,188,193,210] Good agreement was found between dietary intake and bone levels when interpreted in terms of a power-function model, using parameters obtained from experimental kinetic studies in man with Sr^{85} as a tracer.[202,203]

93. *Infants.* Earlier indications that there is little discrimination between strontium and calcium in the very young have been supported by recent investigations in which ratios of stable strontium to calcium or Sr^{90}/Ca ratios have been measured in diet and in bone.[193,194] Detailed investigations in Argentina, employing both methods, indicated that at the age of 2 or 3 months the ratio of strontium to calcium in bone was about 0.8 of that in diet, the value decreasing to less than half this figure at the age of 9 or 10 months, and to about 0.25 in the second year of life.[265]

94. In the early weeks of life the consequence of small discrimination between Sr^{90} and calcium in their transfer from diet to bone is in part offset by the low Sr^{90}/Ca ratio in the foetus as a result of discrimination at the placental barrier. Moreover, when infants are breast-fed the Sr^{90}/Ca ratio in their intake is appreciably less than that in the diet of older age groups.

95. The rate of turnover of minerals in the bones of the young is a major factor affecting the radiation dose received from the Sr^{90} that is deposited in the early months of life. The best agreement between the Sr^{90}/Ca ratios observed in bones of infants and young children, and those predicted from measured dietary levels by giving various values to the relevant parameters (OR and yearly replacement rate of bone mineral), was obtained when a yearly replacement of about 50 per cent of bone mineral in 0-1 year old infants was assumed.[200] However, this figure is uncertain, and its true value might lie anywhere between 30 and 70 per cent. An almost complete replacement of skeletal mineral in the first and second year of life had been postulated by Bryant and Loutit.[187,193]

96. This high turnover rate will result in a rapid equilibration of the bone mineral with that in diet and consequently will lead to a relatively uniform distribution of Sr^{90} throughout the skeleton. It means also that the Sr^{90} accumulated in the early months of life, when little discrimination occurs, will have little, if any, effect on the total amount of Sr^{90} present in the second year of life or later, when the discriminating mechanism between Sr^{90} and calcium is operative in the same manner as in adults.

97. The over-all effect of changing discrimination on the exposure of infants to Sr^{90} has recently been examined in the United Kingdom, and the average Sr^{90}/Ca ratio in bone during the first year of life was found to be 0.25-0.3 of that in milk.[189] Since in the United Kingdom the Sr^{90}/Ca ratio in milk is close to that in the mixed diet and since the OR for adults is about 0.25, these results show that the lower discrimination between Sr^{90} and calcium in the first few months of life need not be taken into account in assessing the radiation dose from Sr^{90} over periods of a year or longer. This conclusion is further supported by the observation that the ratios between Sr^{90}/Ca in infant bone and milk in several countries in 1962 give an average value of 0.25, as shown in table XXI.

98. Evidence has been obtained that apart from its content of calcium, other components of diet may affect discrimination between strontium and calcium.[192,196] However, the relatively constant relationship between dietary and bone levels in different countries, as shown in the 1962 report, suggests that in practice any such effect is small.

[d] Observed ratio sample/precursor $= \frac{\text{Sr/Ca of sample}}{\text{Sr/Ca of precursor}}$.[264]
This ratio is meaningful when the sample (e.g. bone or total body) is in a state of metabolic equilibrium with the precursor (e.g. diet).

99. The information on Sr^{90}/Ca ratio in human bones in the years 1961-1963 is summarized in table XX. The majority of data comes from Europe, North America and Australia. No data are available from Africa and Central America. Very limited information was obtained from South America and Asia.

100. In view of the strong age effect in the 0-4 year age group and of the varying proportion of bone samples of each age within the group, whenever possible data have been arranged in five groups covering yearly intervals from about 1 month up to 5 years of age, in addition to the group of new- and stillborn children.

101. When sufficiently detailed information is available (Australia, Denmark, Norway, Poland, United Kingdom), it can be seen that the Sr^{90}/Ca ratio in bone was highest either in the 1-month to 1-year group or in the 1-year group ($>$ 12 to $<$ 24 months) and always lower by 40-50 per cent in still- and newborns (figure 25). The lower Sr^{90}/Ca ratio in bones of still- and newborns is due to the discrimination by the placenta which favours the passage of calcium from mother to foetus by a factor of about 2 in comparison with strontium.[191,193,204] In older groups, the Sr^{90}/Ca ratio diminishes gradually, as was already apparent in the 1957-1960 data, until it reaches a plateau at above 20-30 years of age, indicating that the skeletal turnover rate becomes independent of age.

102. *Time trends.* Results from the United Kingdom and the Federal Republic of Germany indicate that the average levels in new- and stillborns decreased in 1961 and in the first half of 1962 (figure 26). A sharp increase was noted in the second half of 1962 when Sr^{90} from recent test series entered the diet.

103. After a fall in 1960 and in 1961, the levels in infants and 1-year old children rose again in 1962. The main increase was observed in the second half of 1962 and in the first half of 1963, as is apparent from figure 27, based on the British data. When compared on a yearly basis, however, the increase over the 1961 level observed in different countries in 1962 varied from almost 0 to about 100 per cent (table XX). The highest group means for Sr^{90} at this age were reported from New York City and Denmark, amounting in both cases to 3.8 pCi/g Ca. The 1963 data that are available (United States, United Kingdom, Soviet Union) indicate a marked increase of Sr^{90}/Ca ratios in infant bones over the levels of 1962 (table XX).

104. In the 2-4 and 5-19 year age groups, varying but usually small increases in levels from 1961 to 1962 can be seen where a sufficient number of samples are available (United Kingdom, New York City). From 1961 to 1962, the increases ranged from almost 0 (Canada, Japan) to about 60 per cent (San Juan, P.R., United States). In 1963 a marked increase occurred in the 2-4 year age group as compared with 1962, judging from the data that are available for comparison. A somewhat lower relative increase was noted in the 5-19 year age group, but the data are still sparse.

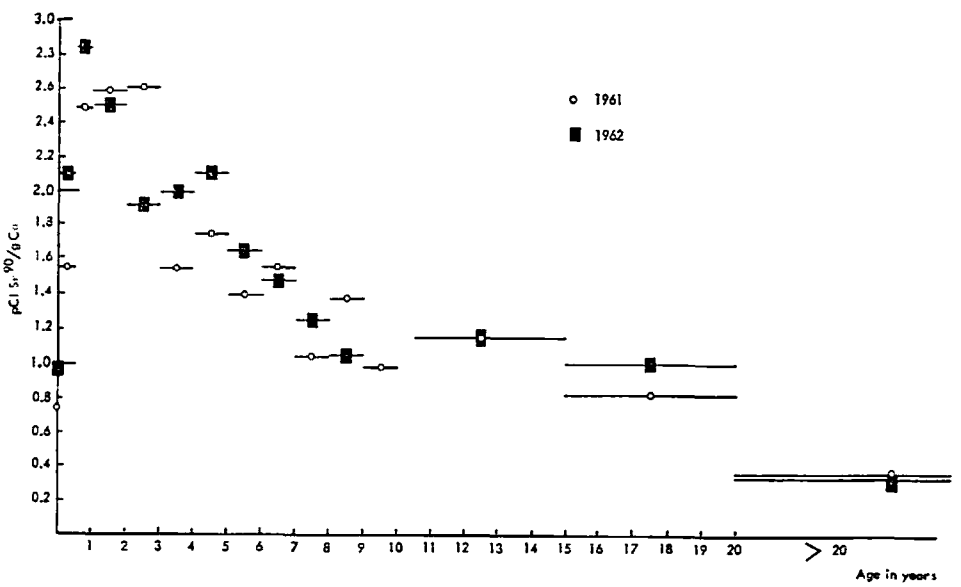


Figure 25. Age distribution of Sr^{90}/Ca ratio in human bones (United Kingdom)[329-331,373]

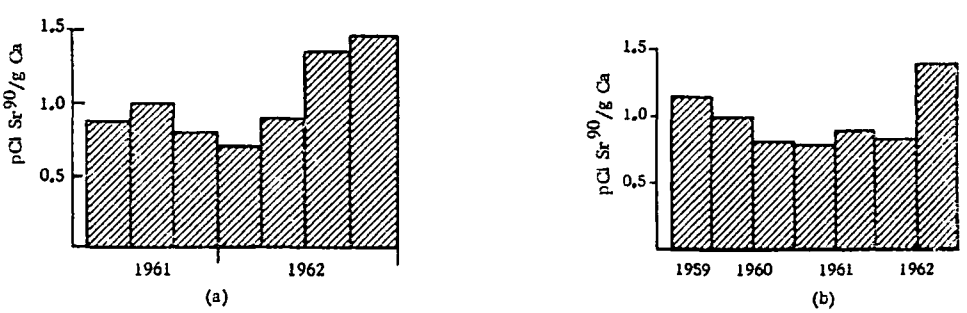


Figure 26. Sr^{90}/Ca ratio in bones of still- and newborn children in the period 1959-1962
(*a*) Stillborns in the Federal Republic of Germany in consecutive quarters of 1961-1962[204,324]
(*b*) Still- and newborns in the United Kingdom in consecutive half-year periods of 1959-1962[331]

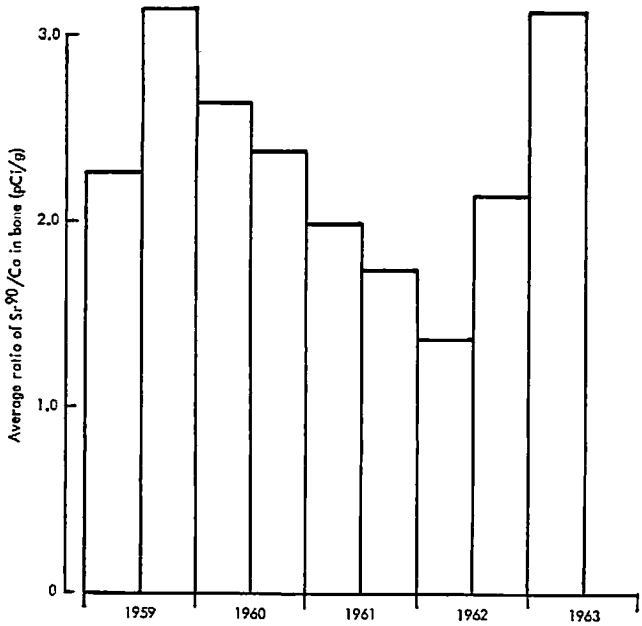


Figure 27. Average ratios of Sr^{90}/Ca in bones of infants, between the ages of 7 days and 1 year, in the United Kingdom (1959-1963)

105. Above 20 years of age, slight increases occurred in some countries (Canada, Poland, United States) from 1961 to 1962, while in others levels were almost steady (Australia, Japan, United Kingdom). A slight increase in the skeletal content of Sr^{90} over this period should be expected on the basis of the current concepts on bone turnover in adults.[187, 201-203, 205] However, biological variability, possible sampling bias and analytical errors may obscure this tendency, especially when only a limited number of samples is available. Data from 1963 are too limited to permit final conclusion.

106. *Skeletal distribution.* In contrast to children (paragraph 96), the distribution of Sr^{90} in the adult skeleton is not uniform. The highest Sr^{90}/Ca ratios are measured in predominantly spongeous bones (vertebrae, ribs) and the lowest in mostly ivory ones (e.g. femur shaft). Normalization procedures were developed in the years 1958-1959[206] which made it possible to compare Sr^{90} concentrations in different bones. Since it is expected that normalization factors will change with time, the use of the same values over extended periods is not justified. Because of these differences, the Sr^{90}/Ca ratios in bones for adults have been given in table XX in their original form, together with the type of bone analysed. For the same reason, comparisons of bone Sr^{90}/Ca ratios for adults will be made only for vertebrae when sufficiently large numbers of samples are available.

107. *Geographical variations.* The average levels of Sr^{90} in human bone from different regions of large countries, e.g. the Soviet Union (nine areas in Europe and Asia)[399] and the United States (New York City, San Francisco and Chicago),[320, 321, 322] do not differ from the mean by more than a factor of 2. In 1961 the average concentration of Sr^{90} in vertebrae of adults from the northern hemisphere (arithmetical unweighted mean of values given in table XX) was 0.8 pCi/g Ca as compared with 0.6 in Australia. In 1962 the corresponding values were 1.0 and 0.6 pCi/g Ca, though these values are not strictly comparable, as the bones from the northern hemisphere were not necessarily collected in the same areas. Nonetheless, they show that the Sr^{90} level in adult bones from Australia is lower than in those from the northern hemisphere (mainly the 30°-60°N latitude).

108. A similar pattern is observed for children's bones. The arithmetic means[e] for the northern hemisphere in the 0-1 year group were 1.7 and 2.4 pCi/g Ca in 1961 and in 1962, respectively. In Australia, the corresponding values were 1.1 and 1.4. As has already been mentioned for milk, the difference in bone levels between Australia and the northern temperate zone is much less than the corresponding difference in fall-out rate and accumulated deposit of Sr^{90}.

109. Comparison of diet and bone levels supports the method of calculation of dose commitment from diets of various types. The extent to which dietary and bone data in infants support the accepted value of OR (0.25) has been discussed in paragraph 97.

110. The Sr^{90}/Ca ratio in bone in adults cannot be directly compared with the corresponding dietary ratios to derive the OR value because the adult skeleton is not in equilibrium with the diet. However, the validity of dietary estimates can be evaluated by comparing the Sr^{90}/Ca ratios in diet with corresponding estimates of Sr^{90}/Ca ratios in adult bone. Such comparisons are shown in table XXII. Despite differences in dietary levels and in methods of estimation, the values given in this table are reasonably constant. It may be concluded, therefore, that the diet estimates as given in table XVIII form a satisfactory basis for calculation of dose commitment. Again, the values observed in the period 1961-1963 are close to those calculated from fall-out rate and deposit of Sr^{90} by means of the proportionality factors for diets of different types as used in the 1962 report.

Caesium-137

Food chain mechanisms

111. When the 1962 report was issued, only limited quantitative information was available on the mechanisms by which Cs^{137} was transferred along the food chain to man. It was thought that concentrations of this fission product in milk were dependent mainly on the current rates of fall-out as a result of direct deposition of the debris on plants with subsequent foliar and plant-base absorption. From the behaviour of Cs^{137} levels in humans during the period 1959-1961, it had been suggested that Cs^{137} levels in the total diet as well as in man also followed the current fall-out rate.[207] This was supported by observations showing very limited availability for root absorption of caesium atoms which, once mixed with soil minerals, become progressively and almost irreversibly bound by clays.[208, 209]

112. However, the concentrations of Cs^{137} in milk do not follow closely the current fall-out rates everywhere. In some areas, levels of Cs^{137} in milk remained higher in 1960 and in 1961 than would have been expected if they had been proportional to the current deposition that had greatly diminished in that period.[212, 213] In Scandinavia the ratio of Cs^{137} and Sr^{90} concentrations in milk remained almost constant over the period 1958-1960.[214] Since the levels of Cs^{137} in milk follow relatively closely the actual contamination of the fodder because of the rapid turnover of caesium in cows,[215] the constancy of the ratios can only be explained by assuming that, as in the case of Sr^{90}, the absorption of previously deposited Cs^{137} plays a significant role among the mechanisms responsible for the transfer of Cs^{137} to milk.

[e] Omitting locations where less than 5 samples were measured.

113. That caesium became fixed almost completely in all soils was disproved by Frederiksson[217] who investigated a large series of tropical soils from South America; in those with a low content of micaceous clays, no evidence of appreciable fixation was found. A high level of organic matter in soil can enhance the absorption of caesium by plants.[218] It was suggested therefore that in some permanent pastures a high content of organic material in the upper layer of the soil might reduce the binding of Cs^{137} by clays, thus prolonging its availability to plant roots. The potassium content of the soil is also an important factor, absorption being greatest when the concentration of that ion in the soil is low.[208]

114. The relationship between the concentration of Cs^{137} in milk and the pattern of fall-out varies between different areas, depending not only on soil factors and on the extent to which the deposit is retained by vegetation, but also on the fraction of the diet of animals which comes from concentrated foods, grain or hay produced in the previous year. It has been found in the United Kingdom that the average country-wide concentration of Cs^{137} in milk in any given year could be correlated to the deposit of Cs^{137} over the current and previous two years.[219] The relationship can be expressed by the empirical formula:

$$C = p'_r F_r + p'_{2c} F_{2c},$$

where

C = average country-wide concentration of Cs^{137} in milk in pCi/l in given year,

F_r = fall-out rate of Cs^{137} in given year in mCi/km^2,

F_{2c} = total Cs^{137} accumulated over the previous two years in mCi/km^2,

p'_r and p'_{2c} = proportionality factors for Cs^{137} fall-out over current year and for total deposit over the previous two years in (pCi/l)/(mCi/km^2).

The country-wide average values for p'_r and p'_{2c} were estimated to be 3.6 and 0.65, respectively, and relatively similar values were obtained when the average levels of milk for a number of stations in the United States were examined. Evidence of the effects of climate and agricultural factors on the magnitude of the proportionality factors was, however, obtained by comparing regions of high and low rainfall in the United Kingdom. The expected levels of Cs^{137} in milk calculated on this basis agreed closely with the observed values, whereas the agreement was less good when the total accumulated activity of Cs^{137} per unit area was used instead of the fall-out deposit over the previous two years.

115. In Sweden a generally similar method of analysis has been found to be applicable, but the values for both proportionality factors are greater and the relationship between observed and calculated values is somewhat improved if the deposit in the previous year only is used to derive the second proportionality factor.[266]

116. The relationships between monthly levels of Cs^{137} in milk and the recent deposit of fall-out have been examined in the Midwest of the United States.[220] A good correlation was found between the concentration of Cs^{137} in milk in any one month during the grazing season and the deposit in the previous four months: similarly, for times of the year when animals were fed on stored food a relationship was established with the deposit at the time the fodder was grown. This finding is not inconsistent with the use of the equation given in paragraph 114, since the small magnitude of p'_{2c} compared to p'_r is compatible with the levels of Cs^{137} in milk being largely determined by recent fall-out. In Argentina it appears that the contribution of Cs^{137} deposited in the previous year is extremely small, since a close linear correlation has been established between the levels of Cs^{137} in milk and in rain-water during the years 1960-1963.[394]

Caesium-137 levels in foods

117. Cs^{137} concentrations in milk in 1961 were generally slightly lower than in 1960. The levels in the northern hemisphere rose sharply in the spring of 1962 (table XXIII), and the average yearly concentrations in that year were higher by a factor of 3 than they were in 1961. Such data as are available indicate that the average yearly concentrations of 1962 were again doubled in 1963. In the southern hemisphere (Argentina) the level of Cs^{137} in milk rose only slightly over the period 1960-1962, and absolute values were lower than those from the northern hemisphere.

118. Considerable attention has been given to the situation in some arctic regions where the levels of Cs^{137} in food and man may exceed the average for northern temperate latitudes by factors of more than 100.[178, 225, 226, 243, 244, 368-372, 398] These situations are attributable both to dietary factors and to local conditions which enhance the transfer of Cs^{137} through food chains. The most striking of these conditions are the high levels of Cs^{137} in lichens and other native vegetation on which reindeer and caribou graze. These high levels are not due to unusually high rates of fall-out but to the accumulation of Cs^{137} by these slowly growing plants.[177, 227, 229, 398] In northern Europe and Asia the highest body burdens of Cs^{137} have been found in reindeer breeders for whom reindeer meat constitutes the major part of the diet. In North America the situation is similar for Eskimos who consume caribou meat in large quantities. Considerable variations in the dietary intake of Cs^{137} occur within these areas mainly because of variations in dietary habits, and it is not possible to estimate the number of persons who are exposed to the highest levels. However, the reindeer breeding groups in Finland, Norway and Sweden constitute only a small fraction of the total Lapp population, which amounts to about 35,000 people.

119. In the subarctic regions of these countries there is also a substantial non-Lapp population which shows Cs^{137} uptakes considerably higher than the country-wide average. Dietary levels of Cs^{137} appreciably above the average have also been reported in the Faroe Islands,[98, 179] the west coast of Norway[222, 223, 224] and on a very local scale in other countries. These situations are attributable to high levels of Cs^{137} in pastures grazed by cattle.

Metabolism of caesium in man

120. Although the retention of a single administration of Cs^{137} is best described by an equation with two exponential terms, one of these, with a short half-period, contributes only a negligible fraction of the dose and can therefore be ignored.[230-232] The biological half-life of the long-term component of retention, as determined in apparently normal adults by means of whole body counting techniques, can be estimated to be on the average about 100 days (table XXV). The absorption of tracer amounts of caesium from the gastro-intestinal tract in man is close to 100 per cent.[231, 233]

121. Two studies of the biological half-life of caesium in children [226, 234] led to values of about 44 and 38 days, thus at least partially accounting for the concentrations of Cs^{137}/gK and Cs^{137}/kg body weight being lower in children than in adults. The information on the turnover

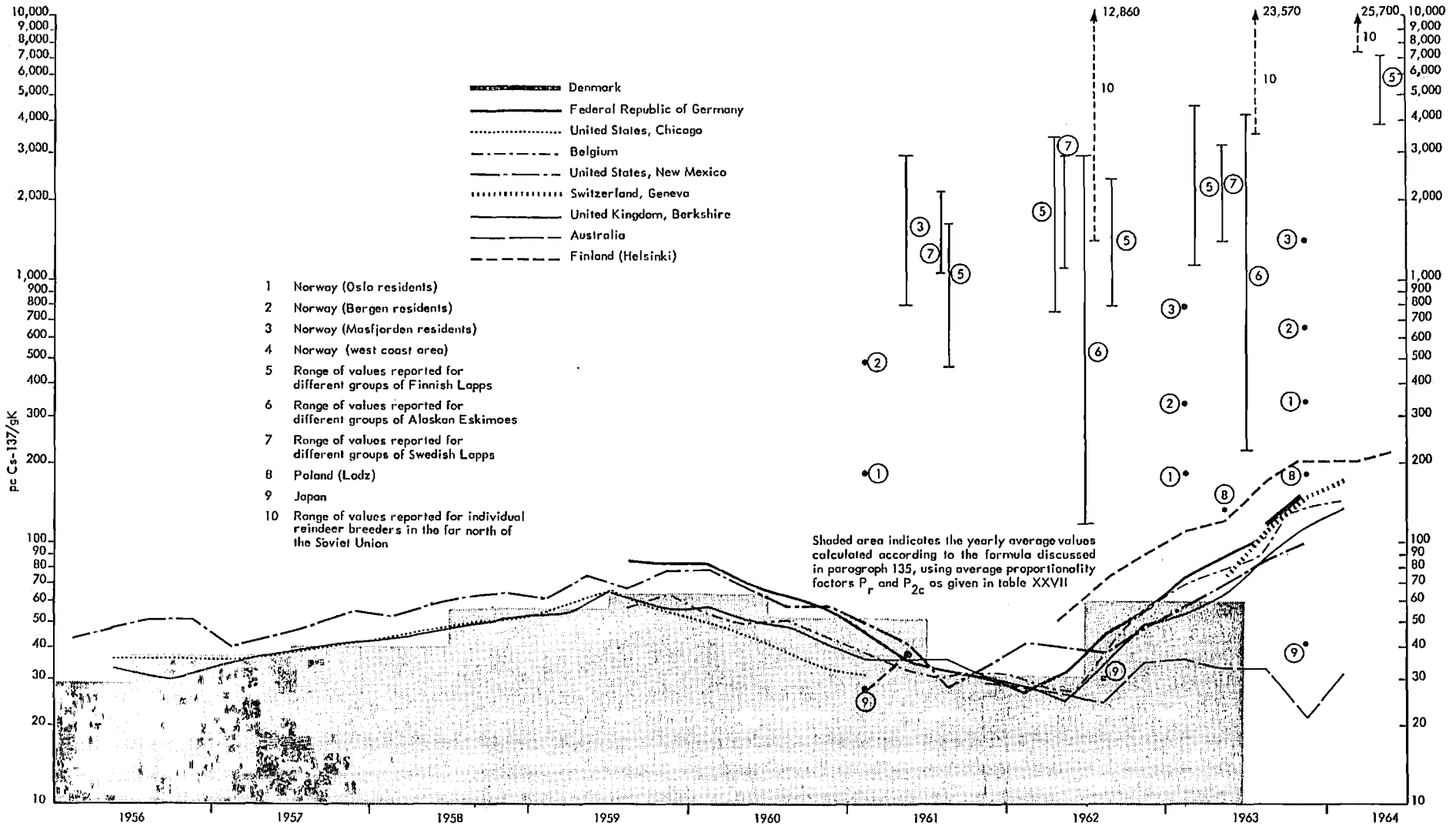


Figure 28. Caesium-137 levels in man during the period 1956 to early 1964

rate of caesium in early infancy is limited to two studies, giving values for half-life of 9.6, 6.6 days,[234] 21 and 25 days[375] in the four subjects investigated.

122. In the 1962 report it was assumed that concentrations of Cs^{137} per gramme fresh bone tissue were higher than in muscles by a factor of 2.2. Further investigations[236, 240] did not confirm this difference.

Observed levels in man

123. Extensive investigations showed[235] that the concentration of Cs^{137}/kg body weight was about 50 per cent higher in adult males than in females. This is apparently due to the higher average proportion of fat tissue in the female body. It is known that concentrations of potassium and caesium in this tissue are very low as opposed to muscles, parenchymatous organs, etc. When expressed in pCi/gK, Cs^{137} levels in males are only 10-15 per cent higher than in females.

124. All available data on Cs^{137} levels in the human body are collected in table XXVI. Values are expressed in pCi/gK because:

(*a*) Age and sex differences are minimal.[235] This is important when the sex-ratio and the age composition of the group investigated are not known.

(*b*) Values correlate closely with Cs^{137} concentration per unit of lean body mass which seems to be a more important parameter for dosimetric purposes than the whole body mass.

Use of the Cs^{137}/gK ratio naturally does not imply that the metabolism of these elements is as closely linked as that of calcium and strontium.

125. The levels from different locations in the northern hemisphere, as shown in table XXVI and figure 28, are remarkably close, with the exception of the relatively isolated and sparsely populated subarctic regions and of the coastal areas of Norway (see paragraphs 118-119). Regional differences within countries have not been extensively described except in the study of Anderson *et al.*[220] in the United States, who showed only slight differences in Cs^{137} body levels between regions with very different deposition rates and milk levels of Cs^{137}.[164]

126. After a peak in 1959 and in 1960, the Cs^{137} content in man declined to the lowest levels in late 1961 and then began to rise in the first half of 1962, reflecting the increased fall-out rates and dietary levels in 1962 and 1963. In those areas of the northern hemisphere where surveys were performed systematically, the levels in late 1963 were 2 to 4 times higher than the average levels in 1961.

127. Data from the Far East, the Middle East and the Pacific region are too scanty to permit meaningful comparisons with the northern temperate zone. Limited data from Japan, collected by means of the whole body counting technique,[241, 242] show values lower than in Europe and North America. This observation is consistent with the corresponding differences in the average intake of Cs^{137} as given in table XXIV. In the southern hemisphere data are available only from Australia.[317] Late in 1961 and in early 1962 the levels were fairly close to those observed in the northern temperate zone. In 1963 and early 1964, however, only a very slight increase occurred, so that body levels of Cs^{137} in Australia were lower by a factor of 3-6 than those reported at that time from the northern hemisphere.

128. As has already been noted and discussed in paragraph 118, exceptionally high levels of Cs^{137} in food and in population were observed in some areas. In some groups of Finnish and Swedish Lapps[226, 243, 244] average body burdens in 1961 reached levels 40 to 60 times higher than the average for northern temperate regions, with some individuals showing body concentrations up to 150 times higher. The average levels for groups of different occupational and dietary habits were essentially proportional to their estimated intake which, in turn, largely depended upon consumption of reindeer meat highly contaminated with Cs^{137}. It has been calculated,[226] and later confirmed by direct measurements,[178] that, because of the increased meat consumption in winter, levels in reindeer-breeding Lapps would have doubled in the spring of 1962, even without further contamination of the environment. Comparably high body burdens of Cs^{137} were found in 1962 among Alaskan Eskimos,[225] one group of whom showed an average of 3,000 pCi/gK. From April 1962 to April 1963 the average increase in Cs^{137}/K ratio in Swedish Lapps from Jokkmokk amounted to about 30-40 per cent.[371] A similar increase was observed in Alaskan Eskimos during summer periods in 1962 and 1963.[368] In early 1964 one group of Lapps reached the average level of 7,000 pCi/gK,[369] and in some individuals in subarctic regions the total body burden in 1963 and in 1964 exceeded the value of 3.5 microcurie of Cs^{137} (table XXVI).[398]

129. Values intermediate between those reported from subarctic regions and the averages for the northern temperate zone were observed in other regions of Scandinavia. Thus in the first quarter of 1961[222] and of 1963, 480 and 332 pCi/gK were measured in Bergen. In Masfjorden[222] where most of the food consumed is locally produced, an average concentration of about 1,400 pCi/gK was observed in 1963. Levels in Oslo[224] in 1961, in 1963 and in 1964 were lower, but still higher by a factor of 2-3 than in other locations in central and western Europe and in continental United States.

Relation of caesium-137 in fall-out and diet with body burden in man

130. Because the biological half-life of caesium in man is of the order of $\sim$ 100 days (table XXV), changes in dietary intake are fairly rapidly reflected in the levels of this nuclide in the body. To obtain close agreement between observed and predicted body burdens of Cs^{137}, detailed information about the intake of the nuclide over short intervals is necessary. In general, however, such information is lacking, so that it is unavoidable to use average levels over longer periods of time, e.g. yearly, to study correlations between dietary levels or fall-out pattern and body concentrations.

131. Even so, allowance should be made for the lag between dietary and body values. When average yearly levels of Cs^{137} in the body (New Mexico)[220] are divided by average milk levels determined on a 12-month basis, the most constant ratio is obtained by allowing for a 9-month lag (e.g. January-December 1961 average body values are compared with average milk levels computed over the March 1960-March 1961 period).

132. An empirical relationship between levels of Cs^{137} in man and the fall-out pattern, similar to that found for milk in the United Kingdom (paragraph 114), was found by Bartlett and Mercer using data from Berkshire, United Kingdom.[219] The agreement between observed and predicted values was closer than when proportionality with current yearly fall-out deposition and accumulated deposit of Cs^{137} was assumed.

133. As was pointed out in paragraph 125 and shown in figure 28, concentrations of Cs^{137} in man in the northern temperate zone (30°-60° N), excluding Norway where special ecological mechanisms operate, are very close, probably as a consequence of the extensive redistribution of marketed foodstuffs within and between most countries. As the fall-out deposition is highest in the northern temperate zone between 30°-60° N, it seems reasonable to assume that, apart from the exceptional situations mentioned in paragraphs 118-119, 128-129, which involve only a small percentage of the world population, the levels of Cs^{137} in man in this band represent an upper limit of the expected real world-wide average.

134. Because of the geographical uniformity of Cs^{137} levels in man in the latitudinal band from 30°-60° N, the average Cs^{137} deposition in this band, as derived from the Sr^{90} deposition over the period 1953-1963,[104,180] will be used here to estimate the empirical relationship between fall-out and body burden in man. The yearly average body burden will be assumed to be directly proportional to the current fall-out and to the amount deposited over the two previous years. This relationship can be expressed by the formula,

$$Q = P_r F_r + P_{2c} F_{2c},$$

where

Q = yearly average concentration of Cs^{137} in man in pCi Cs^{137}/gK,

F_r = fall-out rate of Cs^{137} in a given 12-month period in mCi/km^2,

F_{2c} = total Cs^{137} accumulated over the previous two years in mCi/km^2,

P_r and P_{2c} = proportionality factors in (pCi Cs^{137}/gK)/(mCi/km^2).

135. The proportionality factors P_r and P_{2c} estimated for Belgium, the Federal Republic of Germany, Berkshire (United Kingdom), and New Mexico (United States) are given in table XXVII. When average factors (arithmetic means of the local factors) are used to calculate the average concentrations of Cs^{137} in man in the latitudinal band 30°-60° N, these concentrations are consistent with the observed values, as is shown by figure 28, where observed values do not differ from the predicted average by more than some ± 20-30 per cent. When yearly mean body concentrations of Cs^{137} are linearly related to the current rate of fall-out only, or to both the current rate and the total cumulative deposit, very poor agreement is obtained between results predicted on the basis of the relationships so established and those observed.

IODINE-131

Iodine-131 in food

136. I^{131} was detected in air, rain and milk in late 1961 and in mid-1962. Levels rose sharply in September and October 1961 and declined to detection limits in January 1962. A second peak followed in most countries in the period August-December 1962.[97,168,169,245-249] However, in southern Italy where for climatic reasons the grazing period for cattle, unlike that in central and northern Europe, extends into winter, I^{131} was detected as late as February 1963.[247] Typical concentration profiles of I^{131} in milk from several countries in Europe, North America and Japan are presented in figures 29-31.

137. Detailed reports on the I^{131} content in milk are limited to twelve countries of the northern hemisphere

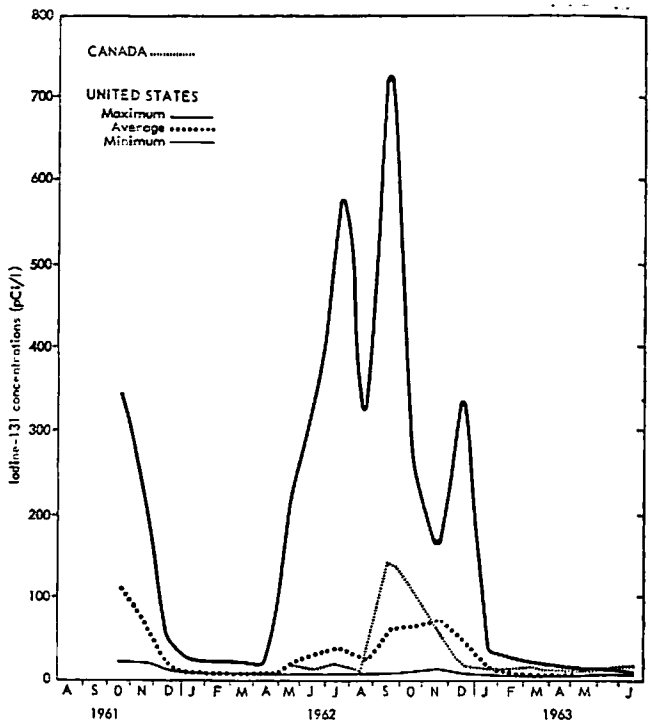


Figure 29. Iodine-131 in milk in North America, 1961-1963[245]

in 1961 and to fourteen in 1962 (table XXX). Values are expressed in pCi d/l (picocuries × days per litre) as a time integral of the concentration. In the southern hemisphere I^{131} was not detected in 1961 but was detected in 1962 (Argentina, Australia). These data indicate that levels of I^{131} in milk were lower by a factor of 10 in Australia, and by a factor of 2-3 in Argentina, compared to those observed in the northern temperate zone. It must be mentioned that average I^{131} concentrations in milk from different countries, even in similar geographical latitudes, vary by a factor of 3-4. Within large countries, such as the United States, the yearly average concentrations reported from different regions differ by a factor of 10.[164] It is easily understood that the deposition of short-lived isotopes from fall-out is more dependent upon transitory meteorological conditions over short periods of time than is the case with such long-lived fission products as Cs^{137} and Sr^{90}.

138. In the State of Utah (United States), high concentrations of I^{131} in milk were detected for several weeks starting 12 July 1962.[250] Assuming a daily intake of one litre of milk, the average total intake of I^{131} during this period was estimated at 58,000 pCi with a maximum value of 800,000 pCi. Available evidence[251-253] points to the local fall-out from test explosions in the nearby Nevada test site as the source of massive contamination of pastures with I^{131}.

139. It has been established that the main path of transfer of I^{131} to the urban population in the United Kingdom and in the United States was through milk and its fresh products (e.g. cottage cheese), the role played by other foodstuffs being negligible.[248,249,254] Only a few per cent, if any, of the measured thyroid burden could be due to inhalation of I^{131} contained in the air.

140. In Japan, however, because of dietary habits (average per capita consumption of milk in adults being only 0.05 l/day), the major contribution of I^{131} was from fresh leafy vegetables.[255] It has been calculated that in 1961 the maximum possible intake with air and milk may

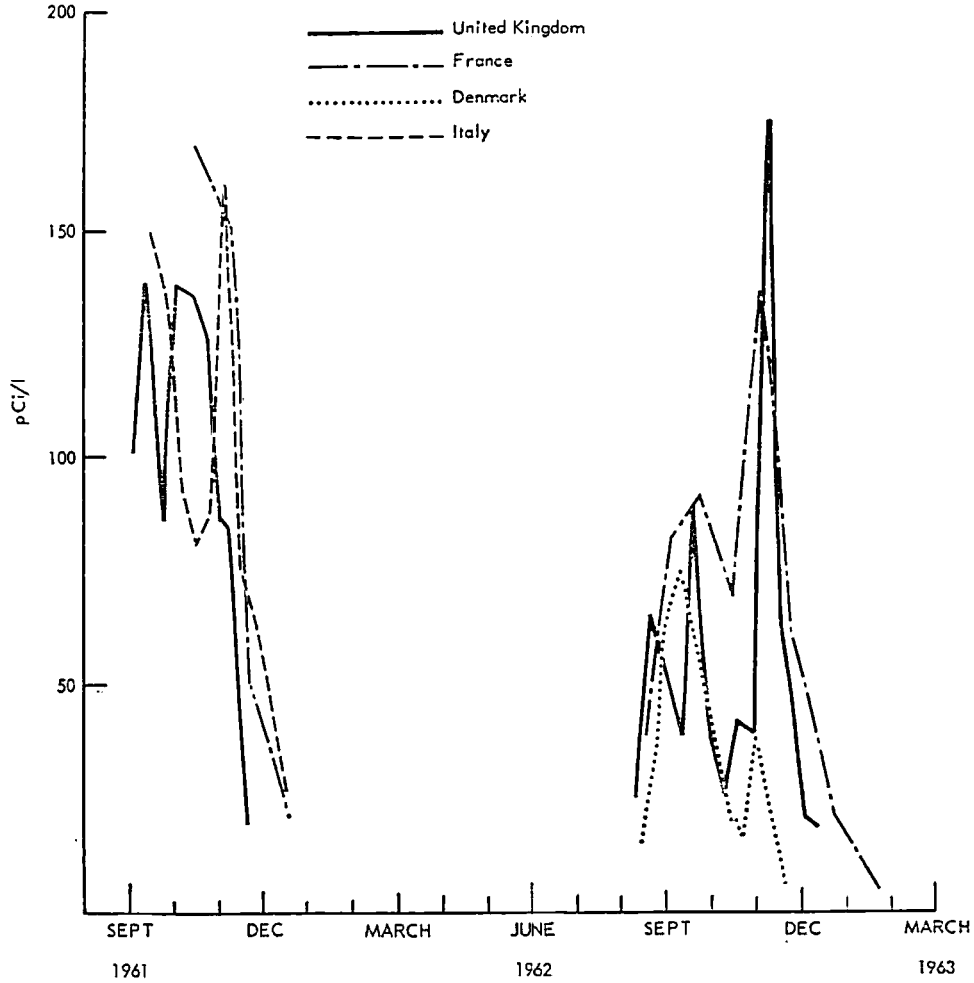


Figure 30. Iodine-131 in milk in several European countries, 1961-1963

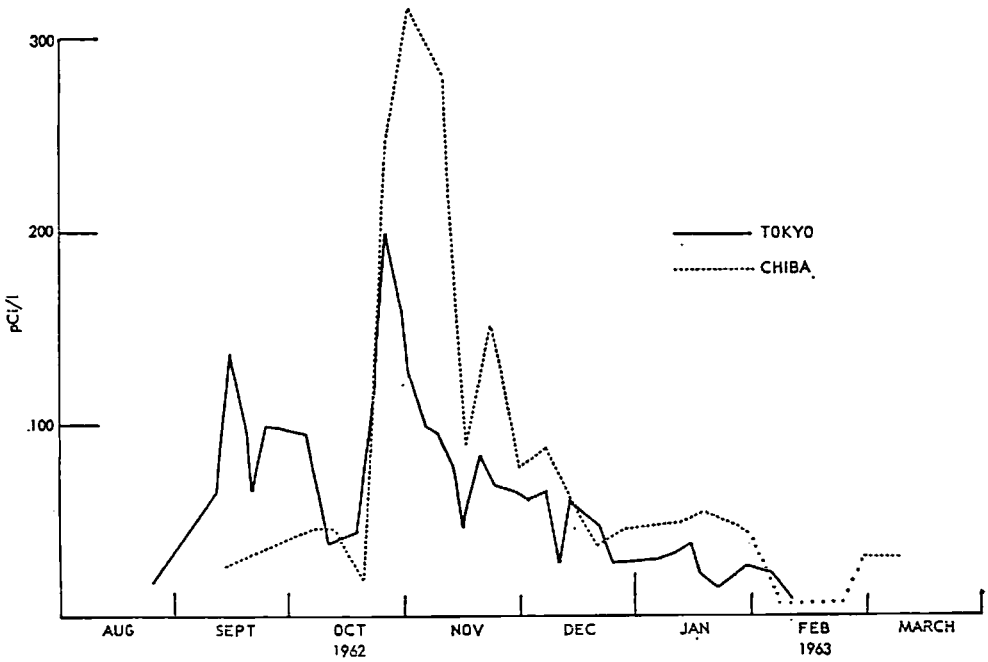


Figure 31. Iodine-131 in milk in Japan, 1962-1963

have accounted for 27 and 12 per cent, respectively, of the I^{131} detected in Japanese thyroids, the rest coming from vegetables. It has also been shown in Germany that unprocessed drinking water from cisterns can substantially add to the intake of I^{131} in periods of fresh fall-out.[256]

Iodine-131 in human thyroids

141. I^{131} concentrations in the thyroids can be determined in living subjects or *post mortem* and can also be estimated indirectly from the levels of food contamination. The various methods have been discussed by Eisenbud *et al.*[249]

142. Surveys by *in vitro* counting of thyroids taken at *post mortem* examinations were made on hospital patients and on victims of accidents dying in the period when I^{131} was present in the milk.[248,255,256] Results of *in vitro* measurements are presented in table XXVIII. The conclusion reached by Eisenbud *et al.*[249] was that, most probably for dietary reasons, hospital patients were not representative of the population as a whole. On the other hand, results obtained from accident victims seemed to be biased by socio-economical factors, as revealed by the comparison with results of *in vivo* counting of persons with controlled consumption of milk. This study indicated that the results from *in vitro* counting in accident victims might appreciably under-estimate concentrations as compared with the population averages, expected on the basis of milk consumption.

143. Measurements made in foetuses at different stages of prenatal life[249] showed that specific activities were higher in foetal than in maternal thyroids by a factor of 1.3-8.2 (5 measurements). In a 12-weeks-old foetus, a concentration as high as 630 pCi/g of thyroid was observed. Because of the age-dependence of thyroid weight, of milk consumption and of I^{131} uptake by the gland, the most critical age in post-natal life from the dose point of view has been estimated to be around 7 months,[257] or between 6 months and 2 years of age.[258]

144. Sensitive low-level gamma spectrometric techniques have been developed and used for *in vivo* measurements of fall-out of I^{131} in human thyroids.[259,260] Measurements showed wide individual variations of I^{131} levels in human thyroids so that large numbers of properly sampled subjects of different ages must be examined to obtain results valid for the population at large. This is hardly possible in the case of rapidly changing fall-out situations. In comparison with the *in vitro* counting, an additional uncertainty in dose evaluation is introduced by geometrical factors (detector-gland) which play a critical role in this type of measurements, and by uncertainties regarding the weights of individual thyroids. The levels of I^{131} in thyroids, obtained by this method in the Federal Republic of Germany, New York City, Boston, and the State of Utah are given in table XXIX.

145. Indirect estimates of thyroid burdens can be obtained when results of representative and frequent sampling of milk are available.[249,261] The average dose can be calculated when the following factors are known:

(*a*) Average consumption of milk in groups of population at different ages.

(*b*) Iodine uptake in thyroid as a function of age.

(*c*) Mass of thyroid as a function of age.

(*d*) Biological half-life of I^{131} in thyroid.

The average total intake of I^{131} with milk in different countries in 1961 and in 1962, if one litre is consumed daily, is given in columns 3 and 4 of table XXX. The total intake in any given group of population may be derived by multiplying these figures by the average consumption of milk in litres per day. As data on milk consumption in specific age groups are lacking, the average consumption of milk by infants and young children has been assumed to be about 0.7 litre per day. For lack of data, no assumption has been made with respect to adults, though it can be stated that their I^{131} intake is generally much lower than in children.

146. A calculation based on the levels of I^{131} in milk appears to be the most satisfactory means of estimating thyroid doses to various sections of the population. Moreover, it is applicable where direct measurements of I^{131} in human thyroids are not available.

IV. Doses from environmental and internal contamination allowance for the distribution of fall-out and population

147. For the purpose of this report "dose commitment" is defined as the integral over infinite time of the average dose rate in a given tissue for the world's population, as the result of a specific practice, e.g. a given series of nuclear explosions. The actual exposures may occur over many years after the practice and may be received by individuals not born at the time of the period of practice. On the basis of a linear dose-effect relationship with no dose threshold and no dose-rate effect, and assuming a stable population, the expected number of late somatic injuries and hereditary defects would be the same for a practice with a given dose commitment as for a practice which would result in an instantaneous dose of the same magnitude to all members of the population.

148. Since we are concerned in this report with average doses to populations, it is necessary to weigh the average fall-out deposition according to population distribution. It is convenient to define a population factor Z, defined according to the equation,

$$\overline{F}_N = Z \times \overline{F}_A,$$

where $\overline{F}_A$ is the mean deposition in the area concerned and $\overline{F}_N$ is the mean deposition weighted by population in the same area. $\overline{F}_N$ is computed from the formula,

$$\overline{F}_N = \frac{\Sigma N_i F_i}{\Sigma N_i}$$

The population factor Z could be computed for the whole world, for one hemisphere, or for any other local area of interest.

149. The population factor may be expressed as the sum of several partial population factors. For example, by breaking the area into three smaller areas, there are three partial factors:

$$Z = Z_1 + Z_2 + Z_3.$$

Z_1 is defined as $Z_1 = \dfrac{\Sigma N_a F_a}{F_A (N_1 + N_2 + N_3)}$,

where the summation is taken over area 1. For the other two factors Z_2 and Z_3, the summation is taken over areas 2 and 3, respectively. For estimating the internal dose commitment from Sr^{90}, the world is divided into three areas according to three basic diet types, and three partial population factors are used.

150. The local deposition F_i varies considerably from place to place, and this can be described by a "geographical factor" G_i, defined as

$$G_i = F_i/\overline{F}_a,$$

where $\overline{F}_a$ is the mean global deposition. Such a factor can be used to estimate doses in local areas. In the 1962

report a curve showing the variation of G_i with latitude was given. It is of interest to note that the global average of the local geographical factor G_i weighted by population equals the global population factor Z.

151. Since some 90 per cent of the world's population resides in the northern hemisphere, the estimated global Z factor will depend upon the fraction of fall-out deposited in each hemisphere. When the debris is largely deposited in the northern hemisphere, the Z factor will be about 2, but will be approximately 1.2 for equal fall-out in both hemispheres. Using mean deposition data from the northern and the southern hemispheres, separate estimates of mean deposition weighted by population for each hemisphere have been computed.

152. Table XXXI shows the estimated world population distribution[f] and the relevant data on Sr^{90} and Sr^{89} deposition. The data from table XXXI have been used to calculate the Z factors for both hemispheres according to the formula given above. A summary of these calculations, together with the Z factors obtained for various years, is shown in table XXXII. It can be seen from table XXXII that in the northern hemisphere the factors were fairly constant from 1960 to 1962 with a maximum variation of only 8 per cent compared with 35 per cent for the global Z factors during the same period. The slight variation in the northern hemisphere was probably due to the tropospheric fall-out in 1962, while in 1961 the newly deposited Sr^{90} was largely of stratospheric origin. It is remarkable that in the northern hemisphere the same numerical factors are obtained for Sr^{89} as for Sr^{90}.

153. In the southern hemisphere the Sr^{90} fall-out distributions gave fairly constant population factors of approximately 1.00, but the factor obtained for Sr^{89} deposition was higher and amounted to 1.45 in 1962. This is because considerable amounts of Sr^{89} diffused into the southern hemisphere from the northern troposphere and were deposited in the 0°–10° S latitude band where about half the population of the southern hemisphere lives.

154. In the case of Sr^{90} and Sr^{89}, the dose commitments are computed by dividing the world population into three groups according to dietary habits. Since C^{14} is uniformly distributed in the troposphere, no allowance for population distribution is necessary. To compute the dose commitments due to other nuclides, two population factors are used, 1.2 for the northern hemisphere, and 1.0 for the southern hemisphere.

155. In calculating dose commitments, the total radiation emitted by deposited radio-nuclides must be considered. Data in tables VII and X represent the cumulative levels of Sr^{90} and Cs^{137} on the ground at a particular time allowing for radio-active decay. To compute dose commitments, the concept of "integrated deposition", i.e., the total deposition uncorrected for decay and weathering losses, has been introduced. The integrated deposits of Sr^{90} and Cs^{137} up to December 1963 are shown in table XXXIII, together with the predicted future deposit.

External doses

Measured dose rates in air

156. Direct measurements of air doses have been reported from Japan, Sweden and the United Kingdom.[351–354] The annual doses for the years 1961-1963 are shown in table XXXIV. The Japanese measurements were made with scintillation counters that were calibrated against an ionization chamber. The counter at Tokyo was situated 7 m above the roof of a three-storied concrete building but was calibrated against an air equivalent ionization chamber situated 1 m above the ground. All the other measurements were made by using ionization chambers. These instruments measure the total gamma dose rate in the air. The dose rate from fall-out is obtained by subtracting the contribution from cosmic rays and from naturally occurring gamma emitters. The measurements at Leeds were made at 10 feet above ground and the results corrected to 1 metre.[355, 356] The averages for each area of Sweden are based on measurements made at several stations.[352]

157. The gamma dose rate has also been estimated from measured deposits of gamma-emitting fission products. Gustafson used deposition figures based upon soil analyses to estimate the gamma dose rates at Argonne, Illinois, United States.[357–359] Collins estimated the external dose rates from Zr^{95}, Ru^{106}, Cs^{137} and Ce^{144} in the United States at Westwood (New Jersey), Pittsburgh (Pennsylvania) and Richmond (California), using deposition figures based upon measurements in precipitation.[360–362] Since these three radio-nuclides account for at least 80 per cent of the external dose rate, the dose rates so obtained are meaningful. Dose-rate estimates based upon deposition data have been plotted in figure 32.

Short-lived fission products

158. Estimates of dose commitments to the world population could be obtained by using average global deposition estimates for short-lived fission products, together with the appropriate dose-rate factors. However, the deposition of short-lived fission products are not measured at most collection stations. To estimate the deposition of the short-lived fission products, the northern hemisphere deposition of Sr^{89} is used, together with estimates of the ratios,

$$R_j = \frac{\text{Annual northern hemisphere deposit of short-lived radio-nuclide}}{\text{Annual northern hemisphere deposit of } Sr^{89}},$$

determined for each fission product in each year. The ratios R_j have been estimated from the local ratios computed at seven stations in the northern hemisphere. The mean of the ratios at these stations is used as an estimate of the R_j's for individual nuclides. The local ratios and the corresponding average ratios for 1962 are shown in table XXXV.[27, 45, 75, 76, 91]

159. It must be noted that the stations lie in a narrow latitude band but that this particular latitude region is highly populated. Although the ratios have no fundamental significance, if the fission product debris is well mixed within the hemisphere, they should not vary greatly from place to place during periods of steady testing except perhaps for ratio involving the very short-lived radio-nuclides I^{131}, Ba^{140} and Ce^{131}. After testing is completed, the annual ratios will change owing to radio-active decay.

[f] The absolute figures apply to 1951. Absolute figures would naturally be different now but are not available by latitudinal band. The relative magnitude, however, is unlikely to have changed.

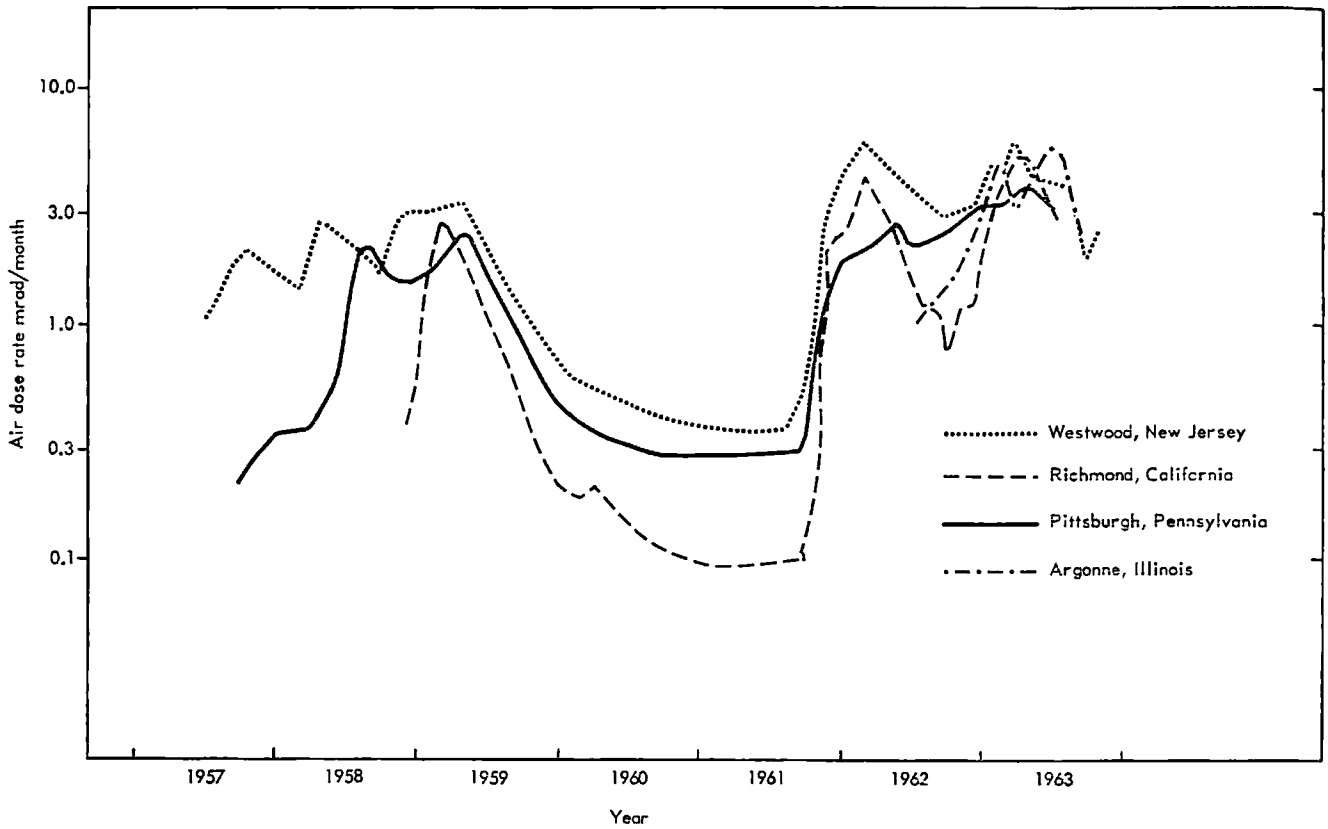


Figure 32. Gamma ray air dose rate, at one metre above ground, from fall-out as estimated from fission product deposition[357, 362]

160. Available measurements of short-lived isotopes in the southern hemisphere are insufficient to obtain reliable estimates of the ratios in that hemisphere. But since only 10 per cent of the world population lives in the southern hemisphere and since less than 20 per cent of the Sr^{89} global fall-out is deposited there, the contribution of short-lived fission products deposited in this hemisphere to the world dose can only be a few per cent.

161. The external gamma dose commitment is computed for each nuclide by using the formula

$$D_j = K_j \times B_j \times Z \times T_j \times R_j \times \overline{F}_{89},$$

where $K_j \times B_j$ = gamma-ray dose constant, including build-up factor for fission product j (mrad/y per mCi/km²); Z = population factor; T_j = mean life on the ground of fission product j; R_j = ratio defined in paragraph 158 for fission product j; $\overline{F}_{89}$ = average annual northern hemisphere deposit of Sr^{89} (mCi/km²). The details of the air dose calculations for the fission products Zr^{95}, Ru^{103}, Ru^{106}, I^{131}, Ba^{140}, Ce^{141} and Ce^{144} are shown in table XXXVI. The ratios R_j for 1962 are taken from table XXXV and the ratios for 1961 are estimated in a similar manner. Since complete deposition data for some short-lived fission products in 1963 were not available, the doses from Ru^{106} and Ce^{144} have been computed by using the average Ru^{106}/Ce^{144} and Ce^{144}/Sr^{90} ratios, together with the 1963 estimates of Sr^{90} deposition.

162. The total measured air dose in the years 1961-1963 from Cs^{137} and short-lived fission products weighted by population was 54 mrads. By deducting the contribution from Cs^{137} for this same period, namely 15 mrads, the contribution from the short-lived fission products is 39 mrads. This figure is in reasonable agreement with the computed figure of 46 mrads that can be inferred from table XXXVI after deduction of the dose to be delivered after 1963. It should be noted that the dose commitment for each of the years does not correspond exactly to the annual doses, since some part of the dose commitment is received in subsequent years. Allowance must be made for doses received in 1964 from material deposited in 1963 and also from material still to be deposited. These additional doses are estimated to be about 10 mrads, making a total dose commitment of 49 mrads for testing in 1961 and 1962. The dose commitment for short-lived isotopes due to testing up to 1960 was given in the 1962 report as 55 mrads. The total air dose commitment for all tests to December 1963 is therefore 104 mrads.

163. Shielding by buildings and screening by the human body were considered in the 1962 report. A shielding factor of 0.2 was adopted as a world average. Assuming that seventeen hours per day on average were spent indoors, the over-all dose-reduction factor due to shielding was taken to be 0.4. The same value will be used in the present report, together with a body screening factor for the gonads and bone marrow of 0.6, as was also adopted in the 1962 report. The combined shielding and screening factor (0.2), applied to the air dose commitment, yields a tissue dose commitment from short-lived fission products of 21 mrads.

Caesium-137

164. The external doses from Cs^{137} are computed by using a combined dose-rate constant and build-up factor ($K_j \times B_j$) of 0.12 mrad/y per mCi/km² of Cs^{137}. The Cs^{137} data in table X, corrected for the fourteen-year effective mean life of Cs^{137} on the ground due to decay and weathering,[382] are used to compute the annual doses in the period 1961-1963. The Cs^{137} air doses weighted by population in these years were 4, 5 and 6 mrads, respectively.

165. The air dose commitment from Cs^{137} can be estimated from the predicted total integrated deposit of Cs^{137} as shown in table XXXIII. This figure, the same as that in the 1962 report, is justified by results of measurements of the dose rates made in the United Kingdom over plots of soil contaminated with Cs^{137}. [363] The estimate of air dose commitment from Cs^{137} contributed by all tests up to the end of 1962 is 143 mrads. Using a combined shielding and screening factor of 0.2, the dose to gonads and bone marrow is 29 mrads.

Internal doses

Strontium-90

166. *Integrated dietary levels.* The estimates of mean Sr^{90}/Ca ratios in diets are obtained from the relationship,

$$C(t) = p_d F_d(t) + p_r F_r(t), \text{ pCi } Sr^{90}/\text{g Ca},$$

where $F_d(t)$ is the cumulative mean deposit of Sr^{90} (mCi/km^2) and $F_r(t)$ the mean annual deposition rate (mCi/km^2/y) at time t. p_d and p_r are the proportionality factors discussed in paragraph 83. As in the 1962 report, the world population is divided into three groups (table XXXVII) according to their dietary habits, and proportionality factors have been computed for each group. The same factors are used in this report, although there is some evidence that the rate factor (p_r) for the Japanese diet which is of type III may be somewhat less than the average value for other diets of that type.[427] The values of p_d used are probably over-estimates rather than under-estimates.

167. The mean integrated level of Sr^{90} in diet is given by

$$\int_0^\infty C(t)dt = p_d \int_0^\infty F_d(t)dt + p_r \int_0^\infty F_r(t)dt.$$

If the effective mean life of Sr^{90} in the soil is T_m years, it can be shown that

$$\int_0^\infty F_d(t)dt = T_m \int_0^\infty F_r(t)dt = T_m F,$$

where F is the integrated amount of Sr^{90} deposited on the ground (mCi/km^2). The mean integrated level in diet is therefore

$$\int_0^\infty C(t)dt = (p_d T_m + p_r)F, \text{ pCi years of } Sr^{90} \text{ per g Ca.}$$

168. For a 2 per cent annual loss of Sr^{90} from the soil through leaching and removal by crops, the effective mean life of Sr^{90} in the soil is twenty-one years.[402] The expected total integrated deposit of Sr^{90} between latitudes of 50° S and 80° N is 14.2 MCi (table XXXIII). This is equivalent to an average deposit (F) of 31.7 mCi/km^2 and leads to estimated integrated dietary levels of 310, 480 and 530 pCi years of Sr^{90} per g Ca, for diet types I, II and III, respectively.

169. The composite integrated dietary level of Sr^{90} weighted by population is obtained, as in the 1962 report, by adding the integrated levels in the three dietary types multiplied by the respective partial population factors 0.7, 0.5 and 0.7. These coefficients reflect the fact that most of the world's population resides in the latitude bands of the northern hemisphere where the deposition of Sr^{90} is about twice the global average. The composite integrated global level in diet is 830 pCi years of Sr^{90} per g Ca.

170. *Dose commitment.* The dose commitment from Sr^{90} is computed as in the 1962 report. The dose dD delivered to the bone over the balance of the lifespan by Sr^{90} from an intake due to exposure to environmental contamination between times t and $t + dt$ at age u years was shown by Lindell[365] to be

$$dD = \theta c(t)dt\alpha(u)\int_u^m \frac{1}{B(\tau)}\exp[-k_1(\tau - u)]d\tau \text{ (mrad)},$$

where θ = dose-rate constant in bone (mrad/y per pCi Sr^{90}/g Ca); $c(t) = OR \times C(t) = Sr^{90}/Ca$ ratio in bone mineral deposited at time t (a bone/diet OR of 0.25 is used here); $\alpha(u)$ = rate of calcium uptake by bone at age u years; $B(\tau)$ = total weight of calcium in bone at age τ years; k_1 turnover rate of Sr^{90} in bone; m = life expectancy. This equation can be written

$$dD = \theta c(t)\, dt\, F_m(u).$$

171. The lifetime dose increment $d\bar{D}$ averaged over the whole population, assuming uniform age distribution at the time of Sr^{90} uptake, is given by

$$d\bar{D} = \theta c(t)dt \frac{1}{m}\int_0^m F_m(u)du = \theta c(t)dt\bar{F}_m.$$

The dose commitment to the population contributed by a finite period of testing is then given by

$$\bar{D} = \theta\bar{F}_m \int_{-\infty}^{+\infty} c(t)dt.$$

Lindell computed the dose-increment factor $\bar{F}_m$ for different assumed Sr^{90} turnover rates in bone and for different life expectancies.[365] The values of $\bar{F}_m$ so obtained have been plotted in figure 33, which shows that $\bar{F}_m$ is not strongly dependent on the turnover rate nor on life expectancies higher than twenty years.

172. The reason for the small variation of $\bar{F}_m$ is the compensating effect of changes in turnover and life expectancy. For example, a more rapid turnover rate will reduce the retention of Sr^{90} taken up by a child but will increase the uptake and exposure of adults. Similarly, with shorter life expectancies, a larger proportion of the population will be in the younger age group with a high uptake of Sr^{90}, but the total lifetime exposure will be reduced. As in the 1962 report, a dose-increment factor of 0.6 is here being used.

173. As in the 1962 report, dose-rate factors (θ) of 2.7, 1.4 and 0.7 mrad/y per pCi Sr^{90}/g Ca are used for computing the doses to bone, cells lining bone surfaces, and bone marrow, respectively. The estimates of dose commitment contributed by Sr^{90} from all tests up to the end of 1962 are therefore 336 mrads to bone, 174 mrads

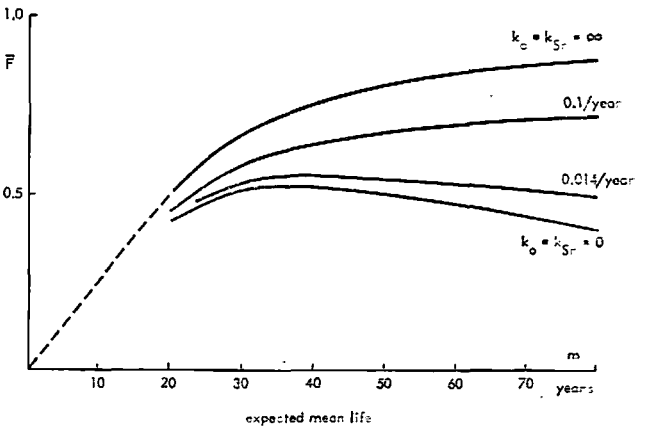


Figure 33. The population average of the dose increment factor for various biological turnover rates as a function of the expected mean life[365]

to cells lining bone surfaces and 87 mrads to bone marrow. Some 90 per cent of these doses will have been delivered by the year 2000.

174. In addition to the dose commitments, the annual dose to new bone is also of interest and can be calculated from the dietary contamination by using a discrimination factor of 0.25 (paragraphs 91-97). While new bone constitutes the whole skeleton during the first year of life, the freshly deposited bone mineral is only a small fraction of the total skeleton in adults. The composite world average level of Sr^{90} in diet during 1961, 1962 and 1963 can be calculated from the cumulative and the annual Sr^{90} deposits for each of these years (table VII). The yearly dietary levels weighted by population were 17, 26 and 38 pCi Sr^{90}/g Ca in these years. The resulting dose in 1963 was 25 mrads in new bone. This cannot be compared directly with doses to other tissues for which dose commitments are calculated.

Strontium-89 and barium-140

175. Since the metabolism of Sr^{89} is the same as that of Sr^{90}, Sr^{89} doses can be calculated from the mean Sr^{89}/Sr^{90} ratios in milk by using the appropriate dose-rate factors. The Sr^{89} dose-rate factors for doses to bone and bone marrow are, respectively, 1.5 and 0.33 mrad/y per pCi Sr^{90}/g Ca in bone. The mean dose-increment factor $\overline{F}$ for Sr^{89} is 0.005. These values are the same as in the 1962 report. The average Sr^{89}/Sr^{90} ratios in milk, as estimated from the data in tables XVI and XVII, for the northern hemisphere in 1961, 1962 and 1963, were 2.6, 4.5 and 1.8, respectively. Using these ratios as typical for total diet (this will tend to over-estimate doses), together with the mean diet levels of Sr^{90} for 1961, 1962 and 1963 as given in paragraph 174, the annual diet levels of Sr^{89} weighted by population are computed to be 44, 117 and 68 pCi Sr^{89}/g Ca for these years.

176. The dose commitments computed by using the last formula in paragraph 171 with the relative dose-rate factors for Sr^{89} deposited in 1961, 1962 and 1963 are 0.43 and 0.09 mrad to bone and to bone marrow, respectively. During 1961 and 1962, some 7 MCi Sr^{90} were injected into the atmosphere, while the total amount injected up to 1960 had been 5 MCi. The dose commitments due to Sr^{89} from all tests up to the end of 1962 can therefore be estimated to be

$$\frac{12}{7} \times 0.22 = 0.74$$

to bone and 0.15 mrad to bone marrow.

177. As for Sr^{90}, in addition to the dose commitments, the annual doses from Sr^{89} in new bone can be calculated. The average annual doses in 1961 and in 1962 were about one-third of the average doses to new bone from Sr^{90} during these years. This estimate is based on a diet of fresh milk and will therefore over-estimate the average dose from Sr^{89}. It should also be noted that the exposure to Sr^{90} is continuing while the Sr^{89} doses are limited to a few years.

Caesium-137

178. The dose commitment from internal irradiation due to Cs^{137} is calculated on the assumption that the yearly average Cs^{137}/K ratio in the body (Q_i) can be related to the deposition of Cs^{137} by the formula given in paragraph 134 and by using the average proportionality factors P_r and P_{2c} given in table XXVII. The total integrated body burden in the northern hemisphere, Q_n, will be

$$Q_n = \sum_{i=1}^{\infty} Q_i = (P_r + 2P_{2c}) \sum_{i=1}^{\infty} f_i = (P_r + 2P_{2c})\, F_{cc},$$

where F_{cc} is the total expected deposit of Cs^{137} (mCi/km^2) in the northern hemisphere. The total integrated body burden for the southern hemisphere, Q_s, is computed in a similar manner. Weighting these Q_n and Q_s values by population and total expected deposition in each hemisphere, a weighted average world-wide integrated body burden of Cs^{137} of 640 pCi/y/gK, due to all tests performed so far, is obtained.

179. As discussed in paragraph 122, for purposes of dosimetry it can be assumed that the distribution of Cs^{137} in the body is uniform. The dose rate from one pCi Cs^{137}/g tissue maintained at constant level is assumed to be 10 mrad/y, or, assuming an average body content of 140 gK, 0.02 mrad/y per pCi/gK, as given in the 1962 report. The calculated dose commitment due to internal irradiation by Cs^{137} is therefore 13 mrads for all tests performed up to the end of 1962.

180. The assumptions used here in the calculation of the dose commitment from internally deposited Cs^{137} differ from those used in the 1962 report. The resulting figures are therefore not directly comparable. It is believed, however, that the present estimate based upon recent information is more satisfactory.

Iodine-131

181. The total accumulated radiation dose to the thyroid (D) can be expressed by the formula

$$D = \frac{K \times I \times F \times T}{m}$$

where K = dose-rate factor in mrad/d per pCi/g tissue; F = fraction of ingested I^{131} reaching the thyroid; I = total integrated intake of I^{131} in picocuries over any given period of time; T = mean effective time of I^{131} storage in the gland; m = mass of the thyroid. To calculate the accumulated thyroid dose to the population of infants and young children (table XXX, columns 6-8), the following values for the parameters of the above equation have been assumed:

K = 0.010 mrad/d per pCi/g; F = 0.3; I = product of values given in columns 3-5 of table XXX and assumed consumption of 0.7 l/d milk; T = 11 days[341]; m = 2g in the first two years of age.

The thyroid doses given in table XXX, based upon a daily consumption of 0.7 l of milk, apply to the highest exposed population group, i.e., those young children who during their first year of life are brought up on fresh milk.

182. It should be pointed out that slightly lower thyroid masses[342] and lower values for fractional uptake of I^{131} than those assumed above[250, 257, 343-345] have been reported in recent studies. Furthermore, it should be noted that there are three sources of milk in infants' diet: human milk, fresh milk from animals such as goats and cows, and dried or evaporated (stored) milk. Only fresh milk of animal origin contributes I^{131} to this diet. In the United States it has been shown that about 50 per cent of the infants consume fresh milk,[216] and a similar figure probably holds for much of Europe.[364] For these reasons, the figures in table XXX are substantially greater than the average total dose to the thyroids of infants.

183. For lack of adequate data on milk consumption in adults, doses from I^{131} have not been calculated in this age group. It can be noted, however, that they should have been one or two orders of magnitude lower than

the doses in infants since the mass of the gland is approximately 10 times larger in adults than in children and because the average consumption of milk is probably much lower.

Radio-nuclides in the respiratory and gastro-intestinal tracts

184. Only a few determinations of Pu^{239} and fission products in the respiratory tracts of a very few individuals have been published. The fragmentary information available is summarized in table XXXVIII. The average dose from all insoluble nuclides over the whole respiratory system as estimated by using the data tabulated by the International Commission on Radiological Protection,[341] was of the order of a few millirads per year in 1962 and 1963, assuming that the concentrations of the nuclides as given in table XXXVIII were maintained over the whole period. As the measurements were mostly done in periods of peak concentration of debris in the air, the effective mean concentration in the period 1961-1963 and the corresponding mean doses in the organ would be lower than those in the table. Where nuclides were determined separately in lungs and tracheo-bronchial lymph nodes, the concentrations in the latter were higher by an order of magnitude, implying a correspondingly higher dose rate.

185. No data on the total ingested activity of artificial origin during the period 1961-1963 are available at present. As noted in the 1962 report, it is likely that the dose to the intestines from fission products in the gastro-intestinal tract is negligible.

Carbon-14

186. The natural production rate of C^{14}, as was shown in paragraph 60, is 2.6×10^{26} atoms per year. The radiation dose rate due to this natural C^{14} is 1.64 mrad/y to the bone, 1.15 mrad/y to cells lining bone surfaces, and 0.71 mrad/y to bone marrow and soft tissue. These quantities are the same as used in the 1962 report.

187. As shown in the 1962 report, the dose commitment D_∞ is given by

$$D_\infty = \gamma_o \frac{Q}{B},$$

where γ_o is the dose rate due to natural C^{14}; B is the natural production rate of C^{14}; and Q is the total artificial C^{14} inventory. As shown in table XV, the inventory of artificial C^{14} at the end of 1963 was about 65×10^{27} atoms. The dose commitment due to testing up to the end of 1963 is therefore 410 mrads to bone cells, 290 mrads to cells lining bone surfaces, and 180 mrads to soft tissue and bone marrow.

188. The dose received by year $1964 + t$

$$D_t = 10^{-2}\gamma_o \left[220 + \int_o^t f(t)dt\right],$$

where $f(t)$ represents the air activity of excess C^{14} in per cent above the natural level at time t years after 1964. The dose is given by

$$D_t = 10^{-2}\gamma_o \left[220 + \int_o^t (2.5e^{-0.00012t} + 64e^{-0.026t} + 26e^{-0.35t} - 26e^{-0.59t})dt\right].$$

For $t = 36$, that is by the year 2000, the dose received will be about 7 per cent of the dose commitment.

V. Summary

189. In this annex, most of the doses are expressed as dose commitments. This concept has been used because it would permit the calculation of the number of injuries expected in the future as a result of any given test series if the population size to whom the dose commitment applied and if the appropriate proportionality factors characterizing a linear dose-effect relationship with no threshold were valid and known. The number of injuries would then simply be the product of population size, proportionality factor and dose commitment.

190. As discussed in the 1962 report, when the proportionality factor is not known, an alternative to the calculation of the total number of injuries is through the evaluation of comparative risks by reference to doses from natural sources of radiation.

191. In the 1962 report, doses and dose commitments were expressed in rems. Since that time, the rem has been re-defined by the ICRU and is no longer an appropriate unit for the purposes of the Committee. In the present report dose commitments are expressed in rads. For radiations resulting from nuclear explosions, rad, as used here, and rem, as defined in the 1962 report, are numerically equivalent. In this report, doses from natural radiation also are expressed in rads, and will therefore be numerically slightly smaller than in the 1962 report where they were expressed in rems. They are 99, 96 and 95 millirads to gonads, cells lining bone surfaces and bone marrow, respectively.

192. The inherent difficulty in comparing dose commitments from nuclear tests with doses from natural sources of radiation, arises from the arbitrary period over which the natural radiation dose must be integrated. In principle, several alternatives are possible:

(1) The dose commitment could be compared with the natural radiation dose delivered over a period of time equal to that over which a substantial part of the dose commitment is delivered. This comparison could be misleading in the sense that exposures from future nuclear tests might overlap this period.

(2) As in the 1962 report, a comparison could also be made with the natural radiation dose delivered during the period of testing, with the justification that it is the commitment incurred during this period which is relevant, irrespective of the radiation source. However, this comparison may also be considered unsatisfactory because the period is not easy to define.

(3) A direct comparison between dose commitments (millirads) and annual dose rates from natural radiation (millirad/year) is hardly justified.

(4) An alternative approach, which was also used in the 1962 report and is followed here, is to express the dose commitments in terms of the period of time during which natural radiation would have to be doubled to give a dose increase equal to the dose commitment.

193. The dose commitments to the world population, due to radio-activity released into the atmosphere as a consequence of nuclear explosions carried out to the end of 1962, when such tests ceased, are summarized in table XXXIX. The dose commitments are given for specific tissues for the most important of the radio-active substances released into the environment through nuclear tests. The dose commitments computed in the 1962 report for the period of testing 1954-1960 are tabulated for comparison. For C^{14} it has seemed appropriate to include only the dose which is accumulated up to the year 2000, at which time the doses from the other nuclides are essentially delivered in full. The *total* dose commit-

ments for C^{14} which will be delivered over thousands of years are given in a footnote to the table.

194. If the northern and southern hemispheres are considered separately, it is found that the dose commitments for the northern hemisphere (excluding the contribution from C^{14} after the year 2000) are slightly larger than those for the whole world population. On the other hand, the dose commitments for the southern hemisphere are much smaller than the world average (amounting to 20 per cent).

195. For all tests carried out before January 1963, the periods of time during which natural radiation would have to be doubled to give a dose increase equal to the dose commitment to the world population amount to approximately 9 months for the gonads, 32 months for the cells lining bone surfaces and 20 months for the bone marrow. These periods are not directly comparable with the periods given in the 1962 report because they only take into account that part of the dose from artificial C^{14} which is delivered before the year A.D. 2000. In addition, the periods given in the 1962 report related to the test period 1954-1961 and involved an assumption regarding the testing practice in 1961.

TABLE I. SOME ESTIMATES OF MEAN STRATOSPHERIC RESIDENCE TIMES COMPUTED BY ALTERNATIVE METHODS

Nuclide	*Year of measurement*	*Hemisphere*	*Mean residence time, T_m, in years*	*Method of calculation*	*Reference*
W^{185}	1959–1960	Northern	0.6	[a]	23
Sr^{90}	1960	Northern	2.0	[b]	23, 27
Sr^{90}	1961	Northern	1.2	[b]	23, 27
Sr^{90}	1963	Northern	2.1	[b]	23, 419
Sr^{90}	1959, 1961	Northern	1.4	[c]	27
W^{185}	1959–1960	Southern	1.8	[a]	23
Sr^{90}	1959	Southern	2.3	[b]	23, 27
Sr^{90}	1960	Southern	2.8	[b]	23, 27
Sr^{90}	1961	Southern	2.0	[b]	23, 27
Sr^{90}	1959, 1961	Global	2.0	[c]	27
Sr^{90}	1960	Global	2.5	[b]	23, 27
Sr^{90}	1961	Global	1.8	[b]	23, 27
Sr^{90}	1963	Global	2.0	[b]	23, 419

[a] Calculated from $T_m = 1/\ln(I_1/I_2)$, where I_1 is the stratospheric inventory for May 1959 and I_2 for May 1960.
[b] Calculated from $T_m = 1/[\ln I/(I-F)]$ where I is the stratospheric inventory in January and F the subsequent annual deposit.
[c] Calculated from $T_m = 1/\ln(F_1/F_2)$, where F_1 and F_2 are the total deposits in 1959 and 1961.

TABLE II. ESTIMATES OF THE MEAN TROPOSPHERIC EXCHANGE TIME BETWEEN HEMISPHERES

Author	*Tracer used*	*Exchange time years*
Fergusson[56]	Dilution of C^{14} in atmosphere by burning of fossil fuels	< 1.8
Vogel and Münnich[57]	Bomb-produced C^{14}	> 1–2
Münnich and Vogel[141]	Bomb-produced C^{14}	< 1
Bolin and Keeling[64,58]	Fossil fuel CO_2	> 0.9
Junge[58] using data of Bishop *et al.*[410]	Tritiated methane	3.4

TABLE III. APPROXIMATE FISSION AND TOTAL YIELDS (MEGATONS) OF NUCLEAR WEAPONS TESTS CONDUCTED IN THE ATMOSPHERE BY ALL NATIONS [70]

Years	*Fission yield*		*Total yield*	
	Air	*Surface*	*Air*	*Surface*
1945–51	0.02	0.5	0.2	0.6
1952–54	1	37	1	59
1955–56	5.6	7.5	11	17
1957–58	31	9	57	28
1959–60				
1961	25		120	
1962	76		217	
TOTAL	140	54	406	105

TABLE IV. GLOBAL Sr^{90} INVENTORY [22, 23, 430]
(*Megacuries*)

	May 1960	*May 1961*	*April 1962*	*January 1963*	*September 1963 (prelim.)*	*January 1964 (prelim.)*
Stratosphere						
Northern hemisphere						
To 21 km	0.25	0.22	1.11	4.51	2.61	2.7
21–30 km	0.25	0.12	0.13	1.21	1.22	0.7
Southern hemisphere						
To 21 km	0.25	0.26	0.21	0.42	0.70	0.4
21–30 km	0.19	0.12	0.05	0.10	0.43	0.2
TOTAL, stratosphere	0.94	0.72	1.50	6.24	4.96	4.0
Troposphere	0.03	0.03	0.16	0.32	0.20	0.30
TOTAL, atmosphere	1.0	0.8	1.7	6.6	5.2	4.3
World-wide deposition[a]	5.0	5.2	5.8	6.7	8.6	9.0
TOTAL	6.0	6.0	7.5	13.3	13.8	13.0

[a] Estimates from soil samples have been increased by 15 per cent over those given in reference 23 to account for incomplete radio-chemical extraction. [105] These figures are an independent assessment of the world-wide Sr^{90} deposition and are not the ones used in tables VII and VIII.

TABLE V. AVERAGE MONTHLY AND ANNUAL Sr^{90} DEPOSITION IN THE USSR [81, 83, 418]

Region of sampling	*1961 mCi/km² per month*	*1962 mCi/km² per month*				*1962*	*1963 mCi/km² per month*				*1963*
	4th quarter	*1st quarter*	*2nd quarter*	*3rd quarter*	*4th quarter*	*Annual total mCi/km²*	*1st quarter*	*2nd quarter*	*3rd quarter*	*4th quarter*	*Annual total mCi/km²*
Murmansk region	0.22	0.29	2.1	1.3	0.70						
Leningrad region	0.23	0.22	2.4	0.93	0.34		0.3	1.5	2.3	0.22	13.0
Moscow region	0.15	0.33	1.7								
Kiev				0.40	0.40		1.8	1.6	3.0	0.6	21.0
Krasnojarsk territory		0.11					0.5	3.0	2.3	0.4	18.6
South Sakhalin	0.24	0.19	1.0	1.0	1.1		1.7	2.9	3.0	0.9	25.8
Latitude regions of European and mid-Asian USSR											
60–70°N							0.7	2.7	2.6	0.5	19.5
50–60°N							1.1	3.4	2.9	0.7	24.3
40–50°N							1.1	3.3	2.9	0.8	24.3
37–40°N							1.2	2.2	1.1	0.6	15.3
Average for USSR mCi/km²		0.23	1.5	0.8	0.7	9.6	1.1	3.0	2.8	0.7	22.5

TABLE VI. LATITUDINAL DISTRIBUTION OF Sr^{90} ESTIMATED FROM MONTHLY FALL-OUT COLLECTIONS [27, 124, 376, 419]

Latitude band	*1961 mCi/km²*	*1962 mCi/km²*	*1963 mCi/km²*	*Latitude band*	*1961 mCi/km²*	*1962 mCi/km²*	*1963 mCi/km²*
80–70°N	[a]	1.5	4.0	10–0°N	0.7	2.7	3.7
70–60°N	[a]	4.8	10.6				
60–50°N	1.4	6.6	14.9	0–10°S	0.58	1.8	1.2
50–40°N	2.0	8.6	16.3	10–20°S	0.53	0.74	0.78
40–30°N	1.6	6.7	10.9	20–30°S	0.87	1.2	1.1
30–20°N	1.4	6.0	11.0	30–40°S	0.96	0.91	1.5
20–10°N	0.6	2.4	4.5	40–50°S	0.72	1.3	1.5

[a] Insufficient data available.

TABLE VII. ANNUAL AND CUMULATIVE DEPOSITION OF STRONTIUM-90 [27, 104, 376, 379, 419]

Period	Northern Hemisphere 0–80°N		Southern Hemisphere 0–50°S		Total 50°S–80°N
	MCi	mCi/km²	MCi	mCi/km²	MCi
1961	0.31	1.2	0.15	0.77	0.46
1962	1.3	5.2	0.23	1.2	1.5
1963	2.3	9.1	0.23	1.2	2.5
Cumulative total to 31 December 1963[a]	7.9	31	1.5	7 7	9.4

[a] Corrected for decay.

TABLE VIII. CUMULATIVE Sr^{90} DEPOSITION BY LATITUDE BAND AS ESTIMATED FROM SOIL DATA AND MONTHLY FALL-OUT MEASUREMENTS [27, 104, 124, 376, 407, 419]

Latitude	(Preliminary) Estimated from analysis of soil samples collected between June 1963 and March 1964[a]		Estimated from 1960 soil data plus precipitation up to December 1963[a]
	mCi/km²	MCi	MCi
70–80°N	21	0.2	0.15
60–70°N	32	0.6	0.6
50–60°N	51	1.3	1.1
40–50°N	58	2.0	1.6
30–40°N	47	1.7	1.6
20–30°N	40	1.6	1.7
10–20°N	24	1.0	0.7
0–10°N	8	0.3	0.5
Northern Hemisphere		8.7	8.0
0–10°S	5	0.2	0.3
10–20°S	5	0.2	0.2
20–30°S	7	0.2	0.3
30–40°S	9	0.3	0.3
40–50°S	7	0.2	0.3
Southern Hemisphere		1.1	1.4
TOTAL		9.8	9.4

[a] All the results from soil analysis have been increased 15 per cent to compensate for incomplete chemical extraction.

TABLE IX. AVERAGE Cs^{137}/Sr^{90} RATIOS IN STRATOSPHERIC AIR AND IN PRECIPITATION

	Before September 1961	After September 1961
Mean for precipitation collected at 20 sites in northern hemisphere[45, 76]	January–August 1961 1.74±0.05[a] (36 cases)	September 1961–June 1962 1.42±0.04 (84 cases)
In stratospheric air over San Angelo, Tex.,[73] by balloon sampling[b]	January–August 1961 1.77±0.06 (8 cases)	January 1962–May 1963 1.51±0.03 (21 cases)
In stratospheric air from aircraft sampling[11, 408]	January 1959–March 1960 1.71±0.03 (217 cases)	March 1962–October 1963 1.59±0.02 (114 cases)

[a] Standard error of the mean.
[b] Each monthly ratio was based upon samples collected at several altitudes.

TABLE X. DEPOSITION OF Cs^{137} AS COMPUTED FROM Sr^{90} DATA GIVEN IN TABLES VII AND VIII

Period	Northern Hemisphere 0–80°N		Southern Hemisphere 0–50°S		Total 50°S–80°N
	MCi	mCi/km²	MCi	mCi/km²	MCi
1961	0.5	2.0	0.25	1.3	0.78
1962	1.9	7.5	0.30	1.5	2.2
1963	3.5	14	0.30	1.5	3.8
Cumulative to 31 December 1963[a]	13.2	52	2.5	13	15.7

[a] Corrected for decay.

TABLE XI. DEPOSITION OF STRONTIUM-89 [27, 124, 376]

Latitude band	1961		1962		1963	
	mCi/km²	MCi	mCi/km²	MCi	mCi/km²	MCi
80–70°N	[a]	[a]	13	0.16	5.4	0.06
70–60°N	[a]	[a]	90	1.7	70	1.3
60–50°N	[a]	[a]	105	2.7	81	2.1
50–40°N	58	1.8	135	4.2	103	3.3
40–30°N	44	1.6	135	4.9	93	3.4
30–20°N	33	1.3	107	4.3	80	3.2
20–10°N	15	0.65	61	2.6	27	1.2
10–0°N	16	0.73	49	2.2	28	1.2
0–80°N	31	6.1	95	24	63	15.8
0–10°S	13	0.59	29	1.3	12	0.52
10–20°S	0.0	0.0	16	0.69	1.4	0.06
20–30°S	0.0	0.0	15	0.60	2.9	0.12
30–40°S	0.0	0.0	9.2	0.33	2.7	0.10
40–50°S	0.0	0.0	7.7	0.24	1.8	0.06
0–50°S			16	3.2	4.4	0.86

[a] No data available.

TABLE XII. DEPOSITION OF Cs^{137}, Zr^{95}, Ba^{140} AND Ce^{144} (mCi/km²) AT MILFORD HAVEN AND CHILTON, UNITED KINGDOM, AND OF I^{131} AT CHILTON [45]

Date	Milford Haven					Chilton					
	Rain cms	Cs^{137}	Zr^{95}	Ba^{140}	Ce^{144}	Rain cms	Cs^{137}	Zr^{95}	Ba^{140}	Ce^{144}	I^{131}
1962											
January	12.1	1.2	25	5.1	21	10.6	0.91	26	3.2	9.8	[a]
February	2.3	2.3	6.8	0.3	5.2	0.9	0.15	2.8	0.14	2.2	[a]
March	9.6	2.1	26	0.5	17	3.3	0.54	7.8	0.10	6.9	[a]
April	5.4	1.1	4.3	[a]	8.8	4.1	0.95	8.7	[a]	10.7	[a]
May	6.6	1.7	3.0	[a]	16	4.3	0.80	5.3	[a]	10.3	[a]
June	3.4	1.0	4.2	[a]	12	0.5	0.27	1.3	[a]	3.8	[a]
July	4.5	1.2	3.2	[a]	7.5	2.8	0.81	3.1	[a]	6.7	[a]
August	11.4	1.5	5.5	3.5	18	11.3	1.3	4.4	1.2	14	[a]
September	13.7	1.2	7.1	18	17	8.1	0.77	6.6	13	6.7	40
October	3.3	0.38	6.2	13	5.5	3.5	0.29	3.4	8.4	3.3	8.4
November	8.68	1.0	14	33	14	8.3	0.73	13	34	14	7.5
December	8.75	1.2	20	35	23	5.2	0.51	20	21	12	12
1963											
January	2.3	0.4	7.9	3.7	6.8	2.8	0.62	13	8.5	15	1.2
February	5.5	1.6	16	4.5	21	1.0	0.57	5.8	1.0	8.3	[a]
March	12.8	4.5	27	2.6	54	10.0	3.4	27	1.5	37	[a]
April	10.9	3.9	24	0.1	46	5.6	2.9	15	[a]	32	[a]
May	4.8	4.1	15	[a]	52	2.2	1.5	5.0	[a]	19	[a]
June	9.6	4.9	19	[a]	50	5.7	3.1	11	[a]	40	[a]
July	5.2	2.0	4.8	[a]	26	4.4	2.1	4.2	[a]	25	[a]

[a] Not detected.

TABLE XIII. SUM OF MONTHLY DEPOSITS (mCi/km²) OF SHORT-LIVED ISOTOPES DURING 1962

Collection station	Sr^{89}	Zr^{95}	Ru^{103}	Ru^{106}	I^{131}	Ba^{140}	Ce^{141}	Ce^{144}
United States								
Westwood, N.J.[27]	240	390					160	305
Pittsburgh, Pa.[27]	190	290					360	290
Richmond, Cal.[27]	90	110		41			53	73
Houston, Tex.[27]	180	340				330	220	300
United Kingdom								
Milford Haven[45]	161	125				108		165
Chilton[45]	63	103			68	81		100
Italy								
Ispra[91]	131	270	190	190			110	350

TABLE XIV. DISTRIBUTION OF CARBON AND NATURAL C^{14} BETWEEN EXCHANGEABLE RESERVOIRS [126]

Carbon reservoir	*Mass of carbon* (g/cm^2)[a]	*Natural C^{14} content* (10^{27} *atoms*)
Atmosphere	0.12	40
Biosphere (terrestrial)	0.06	19
Humus	0.20	55
Surface waters of ocean (above thermocline)	0.18	55
Remainder of ocean	7.5	2,000
TOTAL	8.1	2,170

[a] Grammes per square centimetre of the earth's surface.

TABLE XV. DISTRIBUTION OF EXCESS C^{14} BETWEEN RESERVOIRS AND TOTAL INVENTORY [1, 23, 34, 123]
(10^{27} *atoms*)

Reservoir	*July 1957*	*July 1958*	*July 1959*	*November 1960*	*May–June 1961*	*March–April 1963*	*July 1963*	*January 1964*
Stratosphere	7.4	8.4	12.0[a]	6.4	8.1	23.6	26.7	22.0
Troposphere	2.5	4.0	6.7	10.5	11.8	24.5	28.4	26.0
Ocean[a]	0.5	1.2	2.2	5.1	6.2	12.1	13.4	15.4
Biosphere[a]	0.1	0.2	0.4					
TOTAL	10.5	13.8	20.0	21.4	25.3	60.2	68.5	63.4

[a] Computed. In the case of ocean uptake, it is based on an annual 20 per cent oceanic uptake of the tropospheric C^{14} content.

TABLE XVI. Sr^{90} TO CALCIUM RATIO IN MILK

The values are given in pCi/g Ca and represent yearly averages unless otherwise indicated

Types of study: A—Systematic widespread survey
B—Systematic local survey
C—Irregular sampling

Region, area or country	*Latitude*	*1961*	*1962*	*1963*	*Type of study*	*Reference*
NORTH AMERICA	>15°N					
Canada	40–55°N	8.4[a]	19.4[a]	27.8[a]	A	262, 263
United States	25–48°N	7±2[b]	11±4[b]	19±6[b]	A	164
Alaska	62°N	7	9	18	A	164
New York City, N.Y.		6.7	12	26	B	165
Chicago, Ill.		4.3	7.0	14.1	C	165
San Francisco, Cal.		1.7	3.5	10.2	C	165
Mexico	~15–30°N		0.9	0.9[c]	B	267
EUROPE	>30°N					
Austria	47–49°N	10.3	16.9		A	268, 386
Belgium	~50°N	4.2[d]			A	79
Czechoslovakia	48–51°N	4.6[e]	8.4[f]		C	269
Denmark	55–60°N	4.1	10.1[g], 8.1[h]	23.8[g], 24.1[h]	A	97, 167, 179
Faroes	60–70°N		68	131	A	98, 179
Federal Republic of Germany	43–55°N			17.4[s]	*	387
Finland	60–67°N	5.6[b]	13.0[b]	22.7[b]	A	270
France	42–50°N	7.9	16.8	26.7[i]	A	282
Ireland	52–55°N		21.5[j]	23.7[k]	A	169, 272
Italy	37–47°N	5.7[l]	12.4[l]		A	42, 100, 101, 273
Netherlands	52–54°N	4.4	9.3[ss]	24.5[ss]	A	274, 275, 388
Norway	58–70°N	12.1[a]	18.5[a]		A	88, 276
Poland	50–55°N	5.8[b, n]	7.8[b, o]		A	183, 184
Sweden	55–70°N			26	C	277
Switzerland	~47°N	7.7–18.9[p]	16.7[a]		B	278, 279
United Kingdom	50–60°N	5.9[b]	11.7[b]	25.6[b]	A	168, 169, 280
USSR						
Moscow region	~55°N	4.4	6.4[m]		B	281
Ryazan region	~55°N	6.1[r]			C	
NEAR EAST	>30°N					
Israel			4.8[u]	8.7[m]	C	283
ASIA						
India, Bombay	20°N	1.4	2.6		B	284, 285
FAR EAST						
Japan	30–50°N		8.8	14.9	AC	186, 286, 287, 288, 289
PACIFIC						
United States, Hawaii	21°N	4	4	9	B	164
CENTRAL AMERICA						
United States, Puerto Rico	18°N	3	9	12	B	164
SOUTH AMERICA						
Argentina (littoral area)	~36°S	2.5	3.3	3.7	B	265
AFRICA						
United Arab Republic	20–30°N	4.6[z]	7.7[y]	16.0[y]	A	290, 291, 292
OCEANIA						
Australia	10–40°S	4.4[a]	5.9[a]	5.8[yy]	A	293, 294, 395
New Zealand	35–47°S	4.9[a]	6.1[a]	7.1[a]	A	295, 296, 389

* Type unknown.
[a] Unweighted mean for all stations.
[b] Country-wide mean weighted by population.
[c] February–July only.
[d] July–December only.
[e] Limited sampling over 9 months.
[f] Limited sampling over 4 months of 1962.
[g] Dried milk country-wide mean weighted by production.
[h] Fresh milk country-wide mean weighted by production.
[i] January–August, unweighted mean for 7 collecting stations.
[j] April–December only.
[k] September 1962–September 1963.
[l] Mean weighted by population.
[m] January–June only.
[n] August 1960–July 1961.
[o] August 1961–July 1962.
[p] Range of values for lowland and mountain regions, respectively.
[r] January–May only.
[u] April–December only.
[z] Delta region, July–December only.
[y] Average for delta region and Upper Egypt.
[yy] January–February only.
[s] January–September only.
[ss] Country-wide mean weighted by consumption.

TABLE XVII. Sr^{89} IN MILK IN THE YEARS 1961, 1962 AND 1963

The values represent yearly means in pCi/g Ca unless otherwise indicated

Type of study: A—Systematic widespread survey
B—Systematic local survey
C—Irregular sampling

Region, area or country	*Latitude*	*1961*	*1962*	*1963*	*Type of study*	*Reference*
NORTH AMERICA						
Canada	40–55°N		106[b, c]	32[b]	A	262, 263
United States	25–48°N	9 ± 6[a]	38 ± 34[a]	37 ± 21[a]	A	164
Alaska	62°N	14	45	25	B	164
EUROPE						
Denmark	50–60°N	18[b]	48[b]	56[b]	A	97, 167, 179
Faroes	60–70°N		333[c]	352	A	98, 179
Italy	37–47°N		63[a]		A	100, 101
Netherlands	52–54°N		44[b]	32[b, f]	A	246
United Kingdom	50–60°N	140[d, e]	60[e]	45[e]	A	168, 169, 280
CENTRAL AMERICA						
United States, Puerto Rico	18°N	13	61	59	B	164
PACIFIC						
United States, Hawaii	21°N	2	24	15	B	164

[a] Country-wide mean weighted by population ± standard deviation.
[b] Unweighted mean for all sampling stations.
[c] April–December only.
[d] October–December only.
[e] Country-wide mean weighted by production.
[f] January–June.

TABLE XVIII. Sr^{90} AND CALCIUM IN TOTAL DIET AND ITS COMPONENTS

Ca in grammes per day in brackets. Sr^{90} in pCi per day. Sr^{90}/Ca ratio in total diet in pCi/g Ca. (column 10)

Types of study: A—Widespread survey of individual foodstuffs
B—Systematic widespread diet analyses
C—Regular local sampling
D—Irregular sampling

Region, area or country	*Latitude*	*Year*	*Milk and milk products*	*Cereals*	*Fruits and leafy vegetables*	*Root vegetables*	*Miscellaneous*	*Type of study*	*Total diet in pCi/g Ca*	*Reference*
NORTH AMERICA										
Greenland	> 60°N	1962	3.2	4.6	0.5[a]	0.2[b]	1.5–6.6[c]	A	6.6–9.9[e]	99
United States	25–49°N		(0.64)	(0.16)	(0.10)	(0.04)	(0.11)			
New York City, N.Y.		1961	4.8	1.8	1.1	1.0	1.4	C	9.7	165
		1962	6.7	2.5	1.6	1.1	1.7	C	12.8	165
		1963	18.4	6.6	2.6	1.3	2.8	C	30.0	165
Chicago, Ill.		1961	2.6	1.9	1.1	0.7	0.9	C	7.1	165
		1962	4.3	2.8	1.2	0.8	1.4	C	10.7	165
		1963	8.4	6.4	2.0	1.1	1.5	C	19.2	165
San Francisco, Cal.		1961	1.1	0.8	0.4	0.5	0.7	C	3.3	165
		1962	2.4	1.5	0.4	0.5	0.8	C	5.2	165
		1963	6.9	3.9	0.9	0.7	1.6	C	12.6	165
United States (institutional diet sampling)[t]		1961						B	7 (5–11[v])	366
		1962						B	10 (5–20[v])	366
		1963						B	22 (9–35[v])	366
United States, Alaska (institutional diet sampling)	62°N	1961						C	7	366
		1962						C	12	366
		1963						C	24	366

TABLE XVIII. Sr^{90} AND CALCIUM IN TOTAL DIET AND ITS COMPONENTS (*continued*)

Ca in grammes per day in brackets. Sr^{90} in pCi per day. Sr^{90}/Ca ratio in total diet in pCi/g Ca. (column 10)

Types of study: A—Widespread survey of individual foodstuffs
B—Systematic widespread diet analyses
C—Regular local sampling
D—Irregular sampling

Region, area or country	*Latitude*	*Year*	*Milk and milk products*	*Cereals*	*Fruits and leafy vegetables*	*Root vegetables*	*Miscellaneous*	*Type of study*	*Total diet in pCi/g Ca*	*Reference*
EUROPE	> 30°N									
Austria			(0.52)	(0.08)	(0.05)	(0.02)	(0.04)			
		1961	5.9	2.6	0.8	0.5		A	13.8	268
		1962						A	26.7[d]	297, 386
									32.7[e]	
		1963								
Denmark		1961	3.1	3.8	1.5[a]	0.5[b]	0.4	A, B	5.9	167
		1962	7.6	7.3	3.1[a]	0.5[b]	1.1	A	12.4	97
		1963	17.9	28.0	4.4[a]	0.9[b]	2.0	A	31.3	179
								B	30.8[f]	
Faroes		1962	27.8	7.5	1.5[a]	2.7[b]	4.8	A	26.9	98
		1963	54.0	27.8	2.2[a]	5.0[b]	7.1	A	58.5	179
Federal Republic of Germany		1962						C	19.8[g]	298
		1963								
France[u]	42–50°N		(0.54)	(0.07)	(0.09)	(0.04)				
		1961	3.9	1.6	0.9	0.4[b]		A	9.2	374
		1962	8.1	1.8	2.1	0.5[b]		A	16.9	374
Poland										
Towns			(0.43)	(0.16)	(0.04)	(0.03)	(0.04)			
		1961[h]	2.5	8.1	0.9	1.2[b]	0.4	A	18.2	184
		1962[i]	3.1	7.0	0.8	1.3[b]	0.4	A	17.8	183
		1963								
Rural areas			(0.88)	(0.22)	(0.07)	(0.04)	(0.02)			
		1961[h]	5.1	10.7	1.3	1.6[b]	0.1	A	15.4	184
		1962[i]	6.2	9.5	1.4	1.6[b]	0.1	A	15.2	183
		1963								
United Kingdom			(0.59)	(0.05)	(0.06)	(0.02)	(0.36)[k]			
		1961	3.4	1.0	0.6	0.6	1.0[j]	A	6.2	168
		1962	6.6	0.9	1.1	0.6	1.5[j]	A	9.9	169
		1963	14.6	3.4	2.2	1.3	3.2[j]	A	22.8	280
FAR EAST	30–45°N									
Japan		1961		2.7	3.0[l]	2.2	0.6[m]	D[n]	18.5	170, 221
				(0.05)	(0.14)	(0.08)	(0.20)			
		1962		1.3	5.6[l]	2.6	1.1[m]	D[o]	17.8	170, 221
				(0.07)	(0.28)	(0.05)	(0.20)			
		1963		1.7	9.4[l]	3.5	0.8[m]	D[p]	24.6	170, 221
				(0.05)	(0.31)	(0.07)	(0.20)			
AFRICA										
United Arab Republic (delta region)	< 30°N	1961						C[r]	5.6	290
		1962						C	10.8	291
		1963						B	13.7[s]	292
SOUTH AMERICA										
Argentina (littoral area)	~35°S		(0.45)	(0.02)	(0.11)	(0.02)	(0.06)			
		1963	1.7	0.5	1.2	0.4	0.5	B	6.5	265
OCEANIA										
United States, Hawaii (institutional diet sampling)	21°N	1961						C	8	366
		1962						C	10	366
		1963						C	16	366
Australia	10–40°S		(0.64)	(0.05)	(0.07)	(0.01)	(0.05)			
		1961	2.8	0.4	0.4	0.1	0.2	A	4.7	293
		1962	3.8	0.3	0.5	0.2	0.1	A	5.9	294

[a] Fruits and vegetables.
[b] Potatoes only.
[c] Depending on the source of drinking water.
[d] Towns.
[e] Country.
[f] Country-wide mean weighted by population.
[g] July–October sampling of daily diet in one of Munich's hospitals.
[h] August 1960–July 1961.
[i] August 1961–July 1962.
[j] Including drinking water and tea.
[k] Including *creta praeparata*.
[l] Including seaweeds.
[m] Including fish and shellfish, dairy products, eggs and meat.
[n] October 1961 in Tokyo only.
[o] Four sampling-series, at four locations each.
[p] Three sampling-series, at four locations each, January–June only.
[r] Second half of 1961 only.
[s] Average for Upper and Lower Egypt.
[t] Widespread dietary survey in 21 boarding schools in the United States based on composite diets of children and adolescents of 6–18 years of age.
[u] Representative of the southeastern region of France.
[v] Range of yearly averages reported for individual schools.

TABLE XIX. RELATIONSHIP BETWEEN RATIO OF STRONTIUM-90 TO CALCIUM IN MIXED DIET TO THAT IN MILK

Country, area or location	1960	1961	1962	1963	Reference
NORTH AMERICA					
United States (Tri-city study)					
New York City, N. Y.	1.5	1.4	1.3	1.3	165, 245, 309, 310
Chicago, Ill.	1.4	1.9	1.8	1.5	
San Francisco, Cal.	1.7	1.9	1.7	1.2	
United States (institutional sampling project)		1.5	1.2	1.4	182, 245, 309, 310
EUROPE					
United Kingdom	1.0	1.0	0.9	0.9	169, 280
Denmark	1.7	1.4	1.4		97, 167
Poland		2.5[a]	2.2[a]		183, 184
		3.2[b]	2.7[b]		
Austria		1.3			268
FAR EAST					
Japan	3.0		~2.0		1, 185, 186
AFRICA					
United Arab Republic (delta region)		1.2	1.4		290, 291
AUSTRALIA		1.2	1.1		293, 294

[a] Rural regions.
[b] Urban regions.

TABLE XX. Sr^{90} IN HUMAN BONE
pCi Sr^{90}/g calcium
(Number of samples in parentheses)

Region, country or area	Year	Newborn and/or stillborn	0–1 year	1 year	2 years	3 years	4 years	5–19 years	>19 years	Bone type studied (adults)	References
NORTH AMERICA											
30–50°N											
Canada	1961		2.11 (1)	———		1.99 (5)	———	1.86 (6)	1.00 (87)	Vertebrae	318, 319
	1962	1.25 (4)	2.20 (5)	———		3.24 (7)	———	1.61 (8)	1.21 (36)	Vertebrae	
United States											
New York City, N.Y.	1961		3.43 (8)	2.67 (5)	2.34 (2)	2.05 (5)	1.74 (4)	1.24 (35)	0.83 (7)	Vertebrae	320, 321, 322
	1962		3.81 (16)	3.05 (8)	2.68 (4)	2.61 (10)	1.93 (3)	1.84 (26)	1.00 (14)		
	1963 January–June			3.49 (1)	2.44 (3)	1.54 (1)	2.22 (1)	1.82 (16)	1.55 (2)	Vertebrae	
	1963 July–December		6.81 (10)	9.84 (1)	5.03 (3)	3.41 (2)		2.41 (10)	1.55 (21)	Vertebrae	
Chicago, Ill.	1961		1.40 (1)			2.26 (1)	2.08 (3)	1.15 (9)	0.55 (39)	Vertebrae	320, 321, 322
	1962			2.32 (1)		0.68 (1)	1.06 (1)	1.38 (10)	0.83 (50)		
	1963 January–June								0.74 (2)	Vertebrae	
	1963 July–December		3.51 (2)		3.70 (2)	2.76 (3)		2.42 (2)	1.19 (10)	Vertebrae	
San Francisco, Cal.	1961		0.49 (10)	0.79 (3)		1.33 (4)	2.15 (2)	0.92 (11)	0.48 (45)	Vertebrae	320, 321, 322
	1962		1.07 (26)	1.27 (2)	1.02 (6)	1.18 (5)	1.15 (4)	0.89 (19)	0.73 (9)	Vertebrae	
	1963 January–June		1.31 (11)	2.72 (2)	1.40 (6)	1.13 (5)	1.64 (2)	1.04 (11)	0.70 (5)	Vertebrae	
	1963 July–December		2.43 (21)		3.51 (1)		1.72 (3)	1.64 (16)	1.02 (17)		
CENTRAL AMERICA											
10–20°N											
United States											
San Juan, P. R.	1961							0.98 (23)	0.79 (28)	Vertebrae	320, 321
	1962							1.36 (33)	1.36 (13)	Vertebrae	

TABLE XX. Sr^{90} IN HUMAN BONE (*continued*)

pCi Sr^{90}/g calcium

(Number of samples in parentheses)

Region, country or area	*Year*	*Newborn and/or stillborn*	*0–1 year*	*1 year*	*2 years*	*3 years*	*4 years*	*5–19 years*	*>19 years*	*Bone type studied (adults)*	*References*
SOUTH AMERICA											
> 20°S											
Argentina (littoral area).	1961		0.71 (17)	0.77 (6)	0.75 (4)					Vertebrae	265
	1962		0.83 (7)	0.66 (7)	0.76 (2)					Vertebrae	
	1963	0.77 (23)								Vertebrae	
EUROPE											
45–70°N											
Czechoslovakia.....	1961		3.2 (3)	3.7 (1)		2.3 (1)	2.5 (1)	1.6 (1)			323
Denmark.....	1961							1.04 (19)	0.82 (45)	Vertebrae	97, 167, 179
	1962		3.80 (9)	2.68 (1)	1.66 (2)		1.61 (1)	0.94 (20)	0.81 (78)	Vertebrae	
	1963	2.80 (11)			4.23 (18)			2.17 (13)	1.53 (20)	Vertebrae	
Federal Republic of Germany.....	1961	0.88 (136)			1.23 (35)			1.12 (17)	0.38 (30)	Tibiae	204, 324
	1962	1.16 (118)			1.87 (25)						
Norway.....	1961	1.43 (11)	1.91 (27)		2.16 (17)			1.59 (25)	1.18 (14)	Vertebrae	325
	1962	0.99 (9)	3.60 (6)		1.83 (3)			1.99 (17)	1.05 (5)	Vertebrae	
	1963	1.80 (3)	7.1 (1)					3.7 (2)		Vertebrae	
Poland.....	1961		1.77 (58)	2.59 (12)	2.19 (8)		1.92 (5)	2.04 (28)	1.18 (191)	Vertebrae	326, 327
	1962	1.54 (26)	1.96 (29)	2.20 (3)	4.00 (1)			1.78 (9)	1.40 (160)	Vertebrae	
Switzerland.....	1961	1.10 (12)							0.80 (39)	Vertebrae and sternum	278, 279
	1962								0.58 (16)	Ribs	
	1962								0.92 (21)	Vertebrae	
	1962								0.68	Ribs	
United Kingdom.....	1961[a]	0.81 (282)	1.67 (105)	2.60 (24)	2.54 (18)	1.71 (7)	1.67 (12)	1.10 (68)	0.33 (25)	Femora	328, 329, 330, 331, 373
	1961[b]	0.69 (9)			1.83 (47)			1.00 (30)	0.68 (48)	Vertebrae	
	1962	0.99 (230)	2.00 (132)	2.38 (22)	2.55 (10)	1.75 (3)	2.37 (6)	1.19 (44)	0.32 (11)	Femora	
	1963 January–June	1.5 (56)	3.3 (73)	3.7 (10)	4.0 (6)	2.0 (8)	2.1 (8)	1.4 (35)	0.5 (9)	Femora	
USSR[c].....	1961	1.41 (13)	1.17 (7)		1.41 (2)			1.09 (6)	0.52[d] (112)	Different (normalized)	399
	1962	1.62 (62)	2.13 (52)		2.51 (14)			1.77 (1,661)	0.85[d] (2,071)	Different (normalized)	399
	1963		5.00 (6)		4.23 (7)			1.88 (1,567)	1.05[d] (4,142)	Different (normalized)	399
FAR EAST											
30–45°N											
Japan.....	1961	1.68 (2)			1.36 (9)			1.38 (51)	0.43 (92)	Ribs	332
	1962	0.88[e] (5)		1.86 (19)				1.38 (36)	0.44 (124)	Ribs	
	1963	1.35 (17)	1.68 (26)		1.43 (12)			1.40 (44)			
OCEANIA											
Australia											
20–40°S.....	1961	0.64 (226)	1.10 (273)	1.52 (34)	1.15 (24)	1.15 (27)	0.75 (12)	0.68 (191)	0.56 (879)	Vertebrae	293, 294
	1962	0.69 (203)	1.36 (234)	2.04 (27)	1.06 (21)	1.20 (11)	1.15 (12)	0.81 (234)	0.55 (751)	Vertebrae	

[a] AERE, Scottish and Cambridge results combined.
[b] West London survey.
[c] Including 4 foetuses.
[d] Skeletal averages obtained from different bones. In 1961 normalized according to Kulp and Schulert, [396] in 1962 and 1963 according to factors developed by the authors. [400]
[e] Average values for 9 areas in European and Asian territory of the USSR.

TABLE XXI. RATIOS OF Sr^{90}/Ca IN INFANTS' BONE TO THAT IN MILK FOR THE YEAR 1962

Country or location	Bone Sr^{90}/Ca / Milk Sr^{90}/Ca	Country or location	Bone Sr^{90}/Ca / Milk Sr^{90}/Ca
Argentina	0.25	Poland	0.25
Australia	0.24	United Kingdom	0.17
Canada	0.11	United States	
Denmark	0.42	New York	0.32
Japan	0.19	San Francisco	0.30
Norway	0.20		

TABLE XXII. COMPARISON OF Sr^{90} IN DIET AND ADULT BONES (VERTEBRAE) IN THE PERIOD 1961–1962
(Number of bone samples in parentheses) [a]

Country or location	Sr^{90}/Ca diet / Sr^{90}/Ca bones 1961-1962	Country or location	Sr^{90}/Ca diet / Sr^{90}/Ca bones 1961-1962
Australia	9.4 (1630)	United States	
Denmark	11.1 (123)	New York City, N. Y.	12.2 (21)
Poland	13.9 (351)	Chicago, Ill.	13.0 (89)
United Kingdom	10.2[a] (48)	San Francisco, Cal.	7.1 (22)

[a] 1961 only.

TABLE XXIII. Cs^{137} IN MILK

The values are given in pCi/l and represent yearly averages unless otherwise indicated

Type of study: A—Systematic widespread survey
B—Systematic local survey
C—Irregular sampling

Region, area or country	*Latitude*	*1961*	*1962*	*1963*	*Type of study*	*Reference*
NORTH AMERICA						
Canada	40–55°N		81.4[a]	172[a]	A	262, 263
United States	25–48°N	10 ± 11[b]	43 ± 18[b]	111 ± 37[b]	A	164
United States, Alaska	62°N	10	37	117	B	164
EUROPE						
Austria	47–49°N	49[c]	100[c]		A	268, 386
Denmark	55–60°N	14[a]	43[c,d] 35[c,e]	107[c,d] 112[c,e]	A	97, 167, 179
Faroes	60–70°N		535[f]	974[f]	A	98, 179
Federal Republic of Germany	43–55°N			127[r]	*	387
Finland	60–67°N			210[g]	C	299
France	42–50°N	25[c,d]	67[c,d]	220[h]	A	428
Ireland	50–55°N		77[i]		A	169
Italy	37–47°N	32[b]	80[b]		A	42, 100, 101, 273
Netherlands	52–54°N		54[b]	155[b]	A	246, 275, 388
Norway	58–70°N		75[c,k]	150[c,k] 444[c,l]	A	223, 367
Sweden	55–70°N	30	75[m]	185[m]	A,B (1961)	214, 277
Switzerland, Geneva	~46°N			103[n]	B	300
United Kingdom	50–60°N	21[c]	62[c]	135[c]	A	168, 169, 280
CENTRAL AMERICA						
United States Puerto Rico	18°N	5	40	88	B	164
OCEANIA						
United States, Hawaii	21°N	10	27	73	B	164
Australia	10–40°S			30[b]	A	397
New Zealand	35–47°S			56 ± 10[a,s]	A	295, 296, 389
FAR EAST						
Japan	30–50°N		57	119	A[o]	186, 286–289
ASIA						
India, Bombay	19°N	9.0	8.8		B	284, 285
AFRICA						
United Arab Republic	20–30°N		12.0		A	291
SOUTH AMERICA						
Argentina (littoral area)	35–55°S	17	19	13	B	394

* Type unknown.
[a] Unweighted mean for all milksheds surveyed.
[b] Country-wide mean weighted by population ± standard deviation.
[c] Country-wide mean weighted by production.
[d] Dried milk.
[e] Fresh milk.
[f] Locally produced (average consumed in 1962—412 pCi/l).
[g] Non-weighted average of 3 milksheds for the period October 1962–July 1963.
[h] Described as "laits départementaux".
[i] April–December only.
[k] February–March only.
[l] March 1963–February 1964. 31 stations regularly surveyed.
[m] Country-wide mean weighted by consumption.
[n] Milk supply of Geneva, June–December only.
[o] Non-systematic sampling.
[r] January–September only.
[s] July–December only.

TABLE XXIV. Cs^{137} IN TOTAL DIET

Yearly average values are given in pCi/day unless otherwise indicated

Type of study: A—Widespread survey of individual foodstuffs
B—Systematic composite diet analyses
C—Irregular sampling

Region, area or country	*Latitude*	*Year*	*Milk and dairy products*	*Meat*	*Miscellaneous*	*Total*	*Type of study*	*Reference*
NORTH AMERICA								
Greenland	60–80°N	1962	9	43	16–21[a]	68–73	A	99
United States	25–49°N							
New York City, N. Y.		1963[b]	82	2	72	156	C	165
Chicago, Ill.		1963[c]	42	23	51	116	C	165
San Francisco, Cal.		1963[d]	36	26	116	278	C	165
United States (institutional diet sampling)[m]		1961				28 (11–134)[n]	B	366
		1962				49 (11–100)[n]	B	366
		1963				140 (45–270)[n]	B	366
United States, Alaska (institutional diet sampling)	62°N	1961				46	B	366
		1962				42	B	366
		1963				140	B	366
EUROPE								
Denmark	50–60°N	1962	20	27	19	66	A	97
		1963	50	94	114	258	A	179
Faroes	60–70°N	1962	166	401	84	651	A	98
Finland, Lapland	> 68°N							
Males		1961	210	4,330	460[e]	5,000	A	226
Females		1961	140	1,440	320[h]	1,900	A	226
Sweden	~ 55–70°N	1962[g]	95	50	70	215	A	214
		1964[f]	90	75	100	265	A	277
United Kingdom	50–60°N	1961	9	11	11	31	A	280
		1962	26	40	16	82	A	280
		1963	57	70	40	162	A	280
AFRICA								
United Arab Republic (delta region)	< 30°N	1962				~ 34	C	291, 393
FAR EAST								
Japan	30–50°N	1961[i]	12[j]		53	65	C	170, 221
		1962[k]	17[j]		61	78	C	170, 221
		1963[l]	20[j]		67	87	C	170, 221
OCEANIA								
United States, Hawaii (institutional diet sampling)	21°N	1961				32	B	366
		1962				39	B	366
		1963				95	B	366
SOUTH AMERICA								
Argentina	~ 35°S	1961	11.6	20.2	8.6	~ 40	B	301

[a] Depending on the source of drinking water.
[b] November 1963.
[c] October 1963.
[d] December 1963.
[g] Late summer of 1962.
[f] January 1964.
[e] Including 420 pCi/d with fish.
[h] Including 310 pCi/d with fish.
[i] Data for Tokyo, October 1961 only.
[j] Dairy products, eggs, meat, fish and shellfish.
[k] Data for 1962 include 4 series of sampling at 4 locations in Japan.
[l] Data for 1963 include 3 series of sampling at 4 locations during the period January–July.
[m] Widespread dietary survey in 21 boarding schools in the USA, based on composite diets of children and adolescents of 6–18 years of age.
[n] Range of yearly averages reported for individual schools.

TABLE XXV. BIOLOGICAL HALF-LIFE OF CAESIUM IN ADULT MAN AS DETERMINED BY WHOLE BODY COUNTING TECHNIQUES
(*Long-term component of retention*)

Author	*Number of persons studied*	*Half-life in days (range in parentheses)*
Liden[344]	1	74
Richmond[222]	4	135 (110–147)
Rundo[330]	10	89 (58–129)
Rundo[330]	4	~119 (109–149)
McNeil[223]	3	115
Miller[334]	2	110
Miller[335]	2	88 (82, 95)
Oberhausen[336]	1	144
Rowe[337]	1	150
Van Dilla *et al.*[338]	3	~140
Taylor *et al.*[339]	4	109 (79–123)
Colard[216]	2	99
Liden[275]	8	72 (32–92)
Häsänen *et al.*[370]	6	63 (42–93)

TABLE XXVI. CAESIUM-137 IN MAN

All values are group averages in pCi Cs^{137}/gK. Figures in parentheses indicate number of measurements performed

Region, country or area	Latitude	1960 III	1960 IV	1961 I	1961 II	1961 III	1961 IV	1962 I	1962 II	1962 III	1962 IV	1963 I	1963 II	1963 III	1963 IV	1964 I	1964 II	Reference
SUBARCTIC REGIONS																		
United States, Alaska (Eskimoes)	> 65°N								136–3,200[a, y] (532)				240–4,500[a, y]					225, 368
Finland (Lapps)...	> 65°N					470–1,630[a] (140)			750–3,580[a] (89)	800–2,420[a] (40)		1,190–4,420[a] (48)					3,700–7,000[a] (39)	226, 369
Sweden (Lapps)...	> 65°N				820[b] (4)	980–2,140[a] (81)			1,070–2,960[a] (108)				1,380–3,120[a] (218)					226, 243, 244, 371
USSR[x].....	Far North				3,025[a] (2)				1,430–12,860[x, y] (20)				3,570–23,570[x, y] (60)			7,140–25,700[x, y] (30)		398
Greenland.....	> 60°N	45 (1)																311
NORTH AMERICA																		
United States[c].....	30–50°N	46 (147)	46 (164)	31 (170)	32 (75)	22 (61)	24 (80)	28 (104)			45[d] (155)							311, 312
United States, New Mexico....	~35°N	58	58	53	42	29	46	47 (74)	44 (69)	40 (163)	49 (33)	58 (72)	72 (86)	92 (80)	95[a]			220, 313
Canada.....	> 45°N		55 (1)				26 (2)											311
CENTRAL AMERICA and CARIBBEAN[n]...	10–20°N	58 (1)	58 (4)	37 (5)	20 (3)													311
EUROPE																		
Europe[o].....	40–60°N	66 (36)	65 (40)	52 (32)	49 (11)	41 (5)	36 (14)	36 (7)										311
Denmark.....	55–60°N													114 (31)	150[aa] (22)			179
Norway.....	~60°N			180[e] (15) 480[f] (6)								332[f] (11) (11) 784[g] (10) 180[a] (25)			651[v] (169) 341[s] (25) 1,404[g] (9)	353[a] (24)		222, 224, 244
Sweden.....	~60°N				55[a] (87)											183 (67)		243, 244, 372
Finland[h].....	~60°N					44 (11)			50	75 (10)		112 (49)	120 (49)	175 (49)	200 (49)	204 (24)	218 (49)	226, 369, 370
United Kingdom[bb].	50–55°N	49 (14)	42 (15)	37 (15)		36 (12)	31 (14)	28 (10)	25 (25)	35 (12)	50 (15)	54 (10)	64 (12)	89 (11)	115 (13)	135 (13)		314, 340
Federal Republic of Germany.....	47–55°N	64 (982)	57 (1,299)	45 (488)	36 (610)	33 (1,305)	31 (1,634)	28 (1,181)	32 (837)	45 (834)	54 (954)	74[i] (211)	89 (469)	104[i] (187)				311, 315
Poland.....	50–55°N												133[k] (23)		181[r] (23)			233

EUROPE (continued)																	
Belgium.....	~50°N	51 (49)	44 (60)	38 (55)	33 (94)	——31—— (279)		——29—— (303)		——48—— (495)		——73—— (507)		——117—— (529)		143[p] (233)	316
Switzerland[t].....	~47°N											74 (5)	107 (5)	151 (5)	171[u] (5)		300
ASIA																	
Asia[e].....Not specified		32 (1)															311
FAR EAST																	
Far East[e].....Not specified		44 (27)	42 (38)	30 (28)	19 (3)	31 (2)	19 (9)	37 (3)									311
Japan.....	30–45°N			28 (12)	37 (11)		41[m] (21)	61[m] (38)	39[m] (62)	41[m] (57) 30 (15)	55[m] (54)	64[m] (68)	59[m] (68)	66[m] (74)	79[m] (65)	104[m] (66)	239, 241, 242, 311, 385
NEAR EAST[e].....Not specified		33 (1)	62 (2)	49 (2)													311
AFRICA																	
Country unspecified[e].....Not specified			43 (5)	26 (1)		20 (4)											311
AUSTRALIA[e].....Not specified					36 (1)		30 (5)	28 (24)	27 (23)	25 (10)	35 (7)	36 (24)	33 (19)	33 (22)	21 (21)	32 (29)	317

[aa] October only.
[bb] Data from Harwell, Berks., only.
[a] Average values for different groups of local population (Lapps only).
[b] Local farmers.
[c] Pooled data reported by the Walter Reed Army Institute of Research.
[d] This data for 155 persons reported from Los Angeles.
[e] Oslo residents.
[f] Bergen residents.
[g] Masfjorden residents.
[h] Helsinki residents.
[i] March only.
[j] July only.
[k] April only. Residents of Lodz.
[m] Estimated from radio-chemical analysis of muscles according to Yamagata.
[n] Reindeer breeders.
[p] January and February.
[q] October only.
[r] November only. Residents of Lodz.
[s] Stockholm residents.
[t] Residents of Geneva.
[u] January only.
[v] People from western Norway. Average value for Masfjorden was 1404 (778–2147) pCi/gK.
[x] Range of concentrations observed in individual reindeer breeders in regions of Murmansk, Magadan, districts of Nenec, Yamal-Nenec and Taimyr, and autonomous Soviet Socialist Republic of Komi.
[y] Approximate values calculated only for adults from total body burden (nanocurie) assuming 140 g of potassium in the body.
[z] 12–16-year old boys from Oslo.

TABLE XXVII. PROPORTIONALITY FACTORS RELATING Cs^{137}/K RATIO IN THE HUMAN BODY TO THE AVERAGE FALL-OUT OF Cs^{137} IN LATITUDINAL BAND 30°–60°N

P_r —current fall-out rate factor in the 12-month period ending 1 July of given year
P_{2c}—factor for deposition over previous 24 months
Both factors in pCi Cs^{137}/gK per mCi/km²

Country	P_r	P_{2c}
Belgium	2.25	2.42
Federal Republic of Germany	1.94	3.35
United Kingdom, Berkshire	1.54	2.90
United States, New Mexico	1.79	3.47
Average	$1.88 \simeq 1.9$	$3.04 \simeq 3.0$

TABLE XXVIII. I^{131} CONTENT OF HUMAN THYROIDS AS DETERMINED BY *post mortem in vitro* COUNTING
pCi/g fresh tissue
(Number of samples in parentheses)

Location and subject of study	*1961*			*1962*				*Reference*
	October	*November*	*December*	*September*	*October*	*November*	*December*	
New York City, foetal thyroids, prenatal age from 3 months to full term				199[a] 10.5–630.0 (4)	29.0 0–61.0 (7)	4.7 0–13.1 (4)	20.0 0–40.5 (2)	249
New York City, accident cases	~11.5[b] (20)	2.2 (26)		5.8 (82)				248, 249
New York City, adult hospital patients	2.3 (4)				1.6 ± 1.5 (7)			248, 249
New York City, children, hospital and accidental deaths					26 ± 17 (5)			249
Tokyo, hospital patients			5.6 (52)					255

[a] Data starting 20 September. Negative results from preceding period omitted.

[b] Calculated from reported data on total activity in gland, and from average weight of thyroid in adults given in the same reference.

TABLE XXIX. I^{131} IN THYROIDS
In vivo *counting technique*
(Number of subjects in parentheses)

Location and age	*Period of measurements*	*Average milk consumption in litres per day*	*I^{131} in thyroids pCi*	*Reference*
UNITED STATES				
New York City, N. Y.				
Adults	November 1961	0.25–1.0	57 ± 33 (6)	248
New York City, N. Y.				
Adults	November 1961	Very low	4.3 ± 4.9 (3)	248
New York City, N. Y.				
Below 18 years	November 1961	~ 1.0	83 ± 29 (16)	248
UNITED KINGDOM				
London, Sutton				
Adults	November 1961	~ 0.25	250[a] (20)	254
UNITED STATES				
Utah				
Adults	1–6 August 1962	1.3	5,900 3,700–11,000 (14)	250
Utah				
Adults	22–31 August 1962	1.3	3,600 700–10,900 (12)	250
Boston, Mass.				
4–17 years	September 1962	Not specified	30–56[b]	260
Boston, Mass.				
4–17 years	October 1962	Not specified	71–124[b]	260
Boston, Mass.				
4–17 years	November 1962	Not specified	75–175[b]	260
New York City, N. Y.				
Adults	October 1962	0.8	300 ± 130 (11)	249
FEDERAL REPUBLIC OF GERMANY				
Adults				
(municipal water supply system)	September-October 1962	< 0.5	< 50 < 30–170 (16)	256
Adults				
(water supply from cisterns)	September 1962	~ 1.0	~ 300 < 30–700 (18)	256
Infants fed fresh cow's milk	October 1962		64 10–100 (5)	256

[a] Peak level. Integral activity in thyroids from September 1961 to January 1962 = 15 nanocurie days.

[b] Range of means reported from measurements on group of children, performed on different days of the period.

TABLE XXX. I^{131} IN MILK AND THYROID DOSES

Region, country or area	Latitude	Time integral of I^{131} concentration in milk in pCi d/l (picocurie × days/litre)			Calculated radiation doses in infants consuming 0.7 litre of fresh milk per day (millirads)			Reference
		1961	1962	1963	1961	1962	1963	
NORTH AMERICA								
Canada	~ 40–55°N	~ 6,100[a]	7,350		70	85		302, 303
United States	25–48°N	8,220[b]	10,820[b]	1,700[b]	95	130	20	164
United States, Alaska	62°N	21,500	37,800	1,800	250	440	21	164
EUROPE								
Denmark	55–60°N		3,160			36		97
Federal Republic of Germany	43–55°N	7,350	6,160[k]		85	71		256
France	42–50°N	12,250	9,630		140	110		282, 390
Ireland (northern Dublin zone)	52–55°N		6,070[c]			70		169
Italy	37–47°N	8,600[e]	9,100[d]		100	110		247, 304
Netherlands	52–54°N	9,520	5,180		110	60		274, 391, 392
Norway	58–70°N	20,000[j]			230			276
Sweden	55–70°N		8,600			100		214
United Kingdom	50–60°N	8,100	6,890		94	80		305, 306
FAR EAST								
Japan	30–50°N							
Chiba			13,300[f]			150		185, 255
Tokyo		5,000[h]	10,500[g]		58	120		185, 255
CENTRAL AMERICA								
United States, Puerto Rico	18°N	2,750	4,560	2,950	32	53	34	164
PACIFIC								
United States, Hawaii	21°N	2,130	4,410	2,220	25	51	26	164
SOUTH AMERICA								
Argentina, Buenos Aires	35°S	*	4,450			51		307
OCEANIA								
Australia	10–40°S		950[i]			11		308

* Not detected.
[a] Ontario area only.
[b] Country-wide average for children 0–2 years old weighted by population.
[c] September 17–December 17.
[d] September 1962–February 1963.
[e] October–December.
[f] September 1962–March 1963.
[g] August 1962–February 1963.
[h] Estimated for October–December 1961.
[i] May–November 1962 average weighted by population.
[j] September–November 1961.
[k] January–October 1962.

TABLE XXXI. LATITUDINAL POPULATION AND FALL-OUT DISTRIBUTION [27, 104, 124, 275]

Latitude	Area (10^6 km²)	Population (millions)	Sr^{90} deposition mCi/km²				Sr^{89} deposition mCi/km²		
			Cumulative to 1960	1961	1962	1963	1961	1962	1963
60–70°N	19	10	10	1.4	4.8	10.6	39	90	70
50–60°N	26	270	9.7	1.4	6.6	15	38	105	81
40–50°N	32	400	17	2.0	8.6	16	58	135	103
30–40°N	37	530	23	1.6	6.7	11	44	135	93
20–30°N	40	570	26	1.4	6.1	11	33	107	80
10–20°N	43	190	6.4	0.6	2.4	4.5	15	61	27
0–10°N	44	90	4.3	0.7	2.7	3.7	17	49	28
0–10°S	44	95	5.3	0.6	1.8	1.2		29	12
10–20°S	43	38	2.7	0.5	0.7	0.8		16	1.4
20–30°S	40	34	4.0	0.9	1.2	1.1		15	2.9
30–40°S	37	32	4.8	1.0	0.9	1.5		9	2.7
40–50°S	32	3	5.2	0.7	1.3	1.5		8	1.8

TABLE XXXII. ESTIMATES OF THE Z FACTORS

	Cumulative to 1960	Sr^{90}			Sr^{89}		
		1961	1962	1963	1961	1962	1963
		NORTHERN HEMISPHERE					
Mean deposition $\overline{F}$, mCi/km²..	17.6	1.2	5.3	9.7	33	95	62
$\Sigma N_i F_i$.....	42,540	2,970	12,970	23,700	80,130	231,400	165,900
Z_N.....	1.17	1.17	1.20	1.18	1.18	1.18	1.27
		SOUTHERN HEMISPHERE					
Mean deposition $\overline{F}$, mCi/km²..	4.3	0.8	1.2	1.2		16	4.4
$\Sigma N_i F_i$.....	907	137	270	233		4,180	1,380
Z_S.....	1.07	0.94	1.13	0.97		1.30	1.54
		GLOBAL					
Mean deposition $\overline{F}$, mCi/km²..	11	1.0	3.4	5.6	16	58	37
$\Sigma N_i F_i$.....	43,000	3,240	13,200	24,000	80,130	274,000	167,000
Z_T.....	1.75	1.45	1.74	1.82	2.16	1.78	2.00

TABLE XXXIII. TOTAL INTEGRATED DEPOSITS OF Sr^{90} AND Cs^{137} UP TO DECEMBER 1963, AND PREDICTED FUTURE DEPOSITS
(*Megacuries*)

	0–80°N		0–50°S		50°S–80°N	
	Sr^{90}	Cs^{137}	Sr^{90}	Cs^{137}	Sr^{90}	Cs^{137}
Integrated deposit to December 1963	8.6	14.1	1.7	2.7	10.3	16.8
Expected future deposit, based upon stratospheric inventory, January 1964.....	3.0	4.5	0.9	1.3	3.9	5.8
Expected total integrated deposit....	11.6	18.6	2.6	4.0	14.2	22.6

TABLE XXXIV. MEASURED ANNUAL AIR DOSES (mrad/y) FROM FISSION PRODUCTS [351-355]

Country	1961	1962	1963
Japan			
Tokyo.....	8.2	31	23
Chiba.....		40	40
Yokosuka.....			26
United Kingdom			
Leeds.....	4	19	20
Grove.....	5	27	31
Sweden[a].....	5	17	21
Region A.....	4	12	18
Region B.....	5	17	23
Region C.....	6	16	23
Region D.....	3	24	18
Average dose in northern hemisphere weighted by population[a].....	5.2	26	23

[a] These doses are corrected for the latitudinal distribution of fall-out, using the Sr^{89} deposition data in table XXXI.

TABLE XXXV. RATIOS OF THE ANNUAL DEPOSITS OF SHORT-LIVED FISSION PRODUCTS TO THE ANNUAL DEPOSITS OF Sr^{89} DURING 1962 [27, 45, 75, 76, 91]

Collection station	$\frac{Zr^{95}}{Sr^{89}}$	$\frac{Ru^{103}}{Sr^{89}}$	$\frac{Ru^{106}}{Sr^{89}}$	$\frac{I^{131}}{Sr^{89}}$	$\frac{Ba^{140}}{Sr^{89}}$	$\frac{Ce^{141}}{Sr^{89}}$	$\frac{Ce^{144}}{Sr^{89}}$
United States							
Westwood, N. J.	1.6					0.7	1.3
Pittsburgh, Pa.	1.5		0.72			1.9	1.5
Richmond, Cal.	1.2		0.45			0.6	0.8
Houston, Tex.	1.9				1.8	1.2	1.7
United Kingdom							
Milford Haven	0.78				0.67		1.0
Chilton	1.6			1.1	1.3		1.6
Italy							
Ispra	2.1	1.4	1.4			0.84	2.7
1962 average ratio R_j	1.5	1.4	0.9	1.1	1.3	1.0	1.5

TABLE XXXVI. ESTIMATED AIR DOSE COMMITMENTS FROM SHORT-LIVED RADIO-NUCLIDES [27, 45, 75, 76, 91, 358]

Radio-nuclide	Zr^{95}	Ru^{103}	Ru^{106}	I^{131}	Ba^{140}	Ce^{141}	Ce^{144}	Dose commitments (mrad)
Gamma ray dose constant, $K_j \times B_j$ mrad/y per mCi/km²	0.30[a]	0.062	0.03	0.05	0.39[a]	0.008	0.004	
Mean life years, T_m	0.26	0.16	1.46	0.03	0.05	0.13	1.15	
$T_m \times K_j \times B_j \times G_n$	0.094	0.012	0.053	0.0019	0.024	0.0012	0.0055	
1961								
Annual deposit								
Annual Sr^{89} deposit	1.7	0.8	0.2	0.8	1.8	1.6	0.5	7.4
Dose commitment mrad	5.1	0.32	0.3	0.05	1.4	0.06	0.16	
1962								
Annual deposit								
Annual Sr^{89} deposit	1.5	1.4	0.9	1.1	1.3	1.0	1.5	27.2
Dose commitment mrad	14.4	1.7	4.9	2.1	3.2	0.1	0.8	
1963								
Annual deposit								
Annual Sr^{89} deposit	1.5	0.4	$\frac{Ru^{106}}{Ce^{144}} = 0.7$		$\frac{Ce^{144}}{Sr^{90}} = 18$			15.5
Dose commitment mrad	8.5	0.3	5.8				0.9	

[a] The gamma-ray dose constants include the dose due to daughter radio-nuclides such as Nb^{95} and La^{140}. In the case of $Zr^{95} + Nb^{95}$ transient equilibrium is assumed.

TABLE XXXVII. PROPORTIONALITY FACTORS USED FOR PREDICTING FUTURE Sr^{90}/Ca RATIOS IN TOTAL DIET

Diet type	Area	p_d (pCi/g per mCi/km²)	p_r (pCi/g for one mCi/km² per year)
I	North America Europe Oceania	0.4	1.3
II	Near East India South America Africa	0.6	2.6
III	Asia and Far East	0.7	2.0

TABLE XXXVIII. RADIO-NUCLIDES IN RESPIRATORY TRACT AND ESTIMATES OF DOSES

Author	*Period of observation*	*Isotope*	*Lungs*	*Lymph nodes*	*Dose rate mrad/y*	*Reference*
Krey *et al.*	1958–1959	Pu^{239}	$1.3–11.9 \times 10^{-3}$ dpm/g tissue	$11–65 \times 10^{-3}$ dpm/g tissue	Lungs: 0.06–0.5 Lymph nodes: 1.1–6.4	346
Osborne *et al.*	Spring 1962	Pu^{230}	0.16 pCi/person		0.016	347
		$Zr^{95} + Nb^{95}$	250 pCi/person		2.4	
Rundo	January 1962	$Zr^{95} + Nb^{95}$	300 pCi/person		2.9	348
Schonfeld (quoted)	February 1962	$Zr^{95} + Nb^{95}$	200 pCi/person		2.0	
Liebscher *et al.*	1960	$Ce^{144} + Pr^{144}$	0.03 pCi/g tissue	0.7 pCi/g tissue	Lungs: 0.7 Lymph nodes: 17	349
Wegst *et al.*	March 1963	Ce^{141}				
		$Ce^{144} + Pr^{144}$	156 pCi[a]		1–7	350
		Ru^{103}				
		$Ru^{106} + Rh^{106}$	106 pCi		0.5–3	
		$Zr^{95} + Nb^{95}$	173 pCi		3.4	

[a] In one lung cleared of bronchial lymph nodes.

TABLE XXXIX. DOSE COMMITMENTS FROM NUCLEAR EXPLOSIONS [a]

Tissue	*Source of radiation*	*Dose commitments (mrad)* For period of testing 1954–1960 (estimates from 1962 report)	For period of testing 1954–1962 (new estimates)	*Paragraph*
Gonads	External, short-lived[b]	11	21	163
	Cs^{137}	16	29	165
	Internal, Cs^{137}[b]	8	13	179
	C^{14}	5[c]	13[c]	187
	TOTAL	40	76	
Cells lining bone surfaces	External, short-lived[b]	11	21	163
	Cs^{137}	16	29	165
	Internal, Sr^{90}	67	174	173
	Cs^{137}[b]	14	13	179
	C^{14}	8[c]	20[c]	187
	Sr^{89}	0.15	0.30	176
	TOTAL	116	257	
Bone marrow	External, short-lived[b]	11	21	163
	Cs^{137}	16	29	165
	Internal, Sr^{90}	33	87	174
	Cs^{137}[b]	10	13	179
	C^{14}	5[c]	13[c]	187
	Sr^{89}	0.07	0.15	176
	TOTAL	75	163	

[a] In the 1962 report, these doses were reported in mrems. As explained in paragraph 191, the doses in the present report are all given in mrads.

[b] The dose commitments from short-lived nuclides and from internal Cs^{137} have been calculated on a slightly different basis in this report (paragraphs 162, 178) as compared to the 1962 report.

[c] For C^{14} it seems to be appropriate to include only the dose which is accumulated up to year 2000, at which time the doses from the other nuclides will have essentially been delivered in full. The *total* dose commitments from C^{14} from tests up to 1960 for the gonads, cells lining bone surfaces and bone marrow are 48, 80 and 48 mrads, respectively. For all tests up to the end of 1962, the dose commitments from C^{14} are 180, 290 and 180 mrads, respectively.

REFERENCES

1. United Nations Scientific Committee on the Effects of Atomic Radiation, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, annex F, part 2, table XX, pp. 329-330. General Assembly document, Suppl. No. 16 (A/5216), 1962.
2. U. S. Weather Bureau, Washington, D.C., Announced nuclear detonations 1945-1962, pp. 219-240 *in* USAEC report HASL-142; *v.e.* United Nations document A/AC.82/G/L.871.
3. Storebø, B., On particle formation in nuclear bomb debris. Paper presented at the XIII Session of UNSCEAR (1964). To be published.
4. Prawitz, J., A fallout model. II. Some quantitative properties. FOA 4 Rapport A 4220-455 (1961); *v.e.* United Nations document A/AC.82/G/L.760.
5. Drevinsky, P. J., E. A. Martell, Preliminary results on the size and vertical distributions of residual nuclear debris in the stratosphere. USAEC report TID-7632, pp. 170-187 (1962); *v.e.* United Nations document A/AC.82/G/L.775.
6. Manson, J. E., The interaction between radioactive and non-radioactive particles in the stratosphere. USAEC report TID-7632, pp. 98-119 (1962); *v.e.* United Nations document A/AC.82/G/L.775.
7. Bolin, B., The general circulation of the atmosphere as deduced with the aid of tracers. Paper presented at the XIII Session of UNSCEAR (1964). To be published.
8. Petterssen, S., Introduction to Meteorology. McGraw-Hill Book Co., Inc., 2nd edition, N.Y., 1958.
9. Junge, C. E., Air Chemistry and Radioactivity. Academic Press, N.Y., 1963.
10. Commission of Atmospheric Chemistry and Radioactivity, International Symposium on Trace Gases and Natural and Artificial Radioactivity in the Atmosphere. J. Geophysical Res. 68 (13): 3745-4016 (1963).
11. Friend, J. P., H. W. Feely, P. W. Krey, *et al.*, The high altitude sampling program. Vol. 3, Discussion of HASP results. Defense Atomic Support Agency report DASA-1300 (1961).
12. Kalkstein, M. I., Movement of material from high altitude deduced from tracer observations. J. Geophysical Res. 68 (13): 3835-3839 (1963).
13. Feely, H. W., Personal communication.
14. Friend, J. P., H. W. Feely, E. L. Fisher, *et al.*, Third quarterly report on Project Star Dust. Defense Atomic Support Agency report DASA-1303 (1962).
15. Lal, D., B. Peters, Cosmic ray produced isotopes and their application to problems in geophysics, chapter I, pp. 3-74 *in* Progress in Elementary Particle and Cosmic Ray Physics, vol. VI. J. G. Wilson and S. A. Wouthuysen, eds., North-Holland Publishing Co., Amsterdam, 1962.
16. Murgatroyd, R. J., Ozone and water vapour in the upper troposphere and lower stratosphere. Paper presented at the XIII Session of UNSCEAR (1964). To be published.
17. Brewer, A. W., The transfer of atmospheric ozone into the troposphere. WMO Technical Note No. 43, pp. 101-106 (1961).
18. Junge, C. E., Global ozone budget and exchange between stratosphere and troposphere. Tellus 14: 363-377 (1962).
19. Feely, H. W., J. Spar, Tungsten-185 from nuclear bomb tests as a tracer for stratospheric meteorology. Nature 188: 1062-1064 (1960).
20. Newell, R. E., The general circulation of the atmosphere and its effects on the movement of trace substances. J. Geophysical Res. 68 (13): 3949-3962 (1963).
21. Telegadas, K., R. List, To be published in J. Geophysical Res.
22. Machta, L., Personal communication.
23. Machta, L., R. J. List, K. Telegadas, Inventories of selected long-lived radioisotopes produced during nuclear testing, pp. 243-260 *in* USAEC report HASL-142; *v.e.* United Nations document A/AC.82/G/L.871.
24. Russell, I. J., R. V. Griffith, The production of Cd^{109} and Cd^{113m} in a space nuclear explosion, pp. 306-322 *in* USAEC report HASL-142; *v.e.* United Nations document A/AC.82/G/L.871.
25. Leo, M. W. M., A. Walton, Rhodium-102 fallout: variations in deposition and concentrations in precipitation. Science 140: 1398-1400 (1963).
26. Machta, L., R. J. List, K. Telegadas, A survey of radioactive fallout from nuclear tests. J. Geophysical Res. 67 (4): 1389-1400 (1962).
27. Collins, Jr., W. R., Sr^{90} deposition on the earth's surface from 1958 through 1962, pp. 240-247 *in* USAEC report HASL-140; *v.e.* United Nations document A/AC.82/G/L.856.
28. Telegadas, K., Global integrals of monthly Sr^{90} fallout, January 1958-May 1962, pp. 215-239 *in* USAEC report HASL-135; *v.e.* United Nations document A/AC.82/G/L.831.
29. Mamuro, T., A. Fujita, T. Matsunami, *et al.*, Microscopic examination of highly radioactive fall-out particles. Nature 529-531 (1962).
30. Staley, D. O., On the mechanism of mass and radioactivity transport from stratosphere to troposphere. J. Atmosph. Sciences 19: 450-467 (1962).
31. Goldsmith, P., F. Brown, World-wide circulation of air within the stratosphere. Nature 191: 1033-1037 (1961).

32. Danielsen, E. F., K. H. Bergman, C. A. Paulson, Radioisotopes, potential temperature and potential vorticity. A study of stratospheric-tropospheric exchange processes. University of Washington, Seattle, 1962.

33. Danielsen, E. F., Radioactivity transport from stratosphere to troposphere. Mineral Industries 33 (6): 1-7 (1964) a publication of the Pennsylvania State University, Pennsylvania.

34. Machta, L., Some aspects of the U.S.A. fallout program. Paper presented at the XIII Session of UNSCEAR, Geneva, 1964. To be published.

35. Mamuro, T., T. Seiyama, T. Matsunami, *et al.*, Electron microscopic examination of highly radioactive fall-out particles. Nature 197: 478-479 (1963).

36. Bhandari, N., Rama, Atmospheric circulation from observations of sodium 22 and other short-lived natural radioactivities. J. Geophysical Res. 68 (7): 1959-1966 (1963).

37. Funk, J. P., G. L. Garnham, Australian ozone observations and a suggested 24-month cycle. Tellus 14: 378-382 (1962).

38. Reed, R. J., D. G. Rogers, The circulation of the tropical stratosphere in the years 1954-1960. J. Atmosph. Sciences 19: 127-135 (1962).

39. Junge, C. E., Studies of global exchange processes in the atmosphere by natural and artificial tracers. J. Geophysical Res. 68 (13): 3849-3859 (1963).

40. Angell, J. K., A climatological analysis of two years of transonde flights from Japan. Monthly Weath. Rev. 87: 427 (1959).

41. Lockhart, Jr., L. B., R. L. Patterson, Jr., A. W. Saunders, Jr., *et al.*, Airborne fission products along the 80th meridian (West) during 1961. Radiological Health Data 4 (2): 71-78 (1963); *v.e.* United Nations document A/AC.82/G/L.825.

42. Comitato Nazionale Energia Nucleare, Data on environmental radioactivity collected in Italy (July-December 1961). BIO/06/62 (1962); *v.e.* United Nations document A/AC.82/G/L.809.

43. Cambray, R. S., E. M. R. Fisher, Radioactive fallout: Short-lived fission products in air and rain, August 1962-April 1963. UKAEA Research Group report AERE-R-4384; *v.e.* United Nations document A/AC.82/G/L.864.

44. Lockhart, Jr., L. B., To be published as an NRL report.

45. Cambray, R. S., E. M. R. Fisher, G. S. Spicer, *et al.*, Radioactive fallout in air and rain, results to the middle of 1963. UKAEA Research Group report AERE-R-4392; *v.e.* United Nations document A/AC.82/G/L.874.

46. Малахов С. Г., Концентрация суммарной радиоактивности продуктов деления, а также Ce^{141}, Ce^{144}, $Zr^{95}+Nb^{95}$ и Cs^{137} в приземном слое воздуха в Подмосковье в 1960-1962 годах. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.906.

47. Краснопевцев Ю. В., Некоторые данные по концентрации радиоактивных продуктов над Индийским и Тихим океанами в 1961-1962 годах. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.908.

48. Walton, A., M. W. M. Leo, Studies of nuclear debris in precipitation. USAEC report NYO-9533 (1962).

49. Machta, L., Fallout forecasting. Paper presented at the XIII Session of UNSCEAR, Geneva, 1964. To be published.

50. Bleichrodt, J. F., Personal communication.

51. United States Department of Health, Education, and Welfare, National air sampling network, fourth quarter and annual summary 1962. Radiological Health Data 4 (4): 167-170 (1963).

52. Lund, L., O. B. Michelsen, B. Ottar, *et al.*, A study of Sr^{90} and Cs^{137} in Norway 1957-1959. Norwegian Defence Research Establishment Intern Rapport K-253 (1962).

53. Brown, W. L., W. N. Hess, J. A. Van Allen, eds., Collected papers on the artificial radiation belt from the July 9, 1962, nuclear detonation. J. Geophys. Res. 68 (3): 605-758 (1963).

54. Bolin, B., C. D. Keeling, Large-scale atmospheric mixing as deduced from the seasonal and meridional variations of carbon dioxide. J. Geophys. Res. 68 (13): 3899-3920 (1963).

55. Labeyrie, J., G. Lambert, Sur l'existence d'une barrière de diffusion entre les troposphères des hémisphères Nord et Sud. C.R. Acad. Sc. 256: 2664-2667 (1963).

56. Fergusson, G. J., Reduction of atmospheric radiocarbon concentration by fossil fuel carbon dioxide and the mean life of the carbon dioxide in the atmosphere. Proc. Roy. Soc. A. 243: 561-574 (1958).

57. Vogel, J. C., K. O. Münnich, Durch Atomexplosionen erzeugter Radiokohlenstoff in der Atmosphäre. Naturwiss. 45: 327-329 (1958).

58. Junge, C. E., Note on the exchange rate between the northern and southern atmosphere. Tellus 14: 242-246 (1962).

59. Stewart, N. G., R. N. Crooks, E. M. R. Fisher, The radiological dose to persons in the U.K. due to debris from nuclear test explosions prior to January 1956. AERE report HP/R.2017 (1956); *v.e.* United Nations document A/AC.82/G/R.20.

60. Burton, W. M., N. G. Stewart, Use of long-lived natural radioactivity as an atmospheric tracer. Nature 186: 584-589 (1960).

61. Miyake, Y., K. Saruhashi, Y. Katsuragi, *et al.*, Seasonal variation of radioactive fallout. J. Geophys. Res. 67: 189-193 (1962).

62. Machta, L., A preliminary model of tropospheric aerosol removal. Paper presented at the Symposium on Air Chemistry and Radioactivity, Helsinki, August 1960.

63. Eriksson, E., Vertical transports and depositions of atmospheric constituents. Paper presented at the XIII Session of UNSCEAR (1964). To be published.

64. Lambert, G., Etude du comportement des aérosols radioactifs artificiels. Applications à quelques problèmes de circulation atmosphérique. Thèses présentées à la faculté des sciences de l'Université de Paris, p. 183, novembre 1963.

65. Kruger, P., A. Miller, C. L. Hosler, Meteorological evaluation of radioactive fallout. Semiannual report. USAEC report TID-17518 (1962).

66. Hardy, Jr., E. P., L. T. Alexander, The relationship between rainfall and strontium-90 deposition in Clallam County, Washington, pp. 287-298 *in* USAEC report TID-7632, Book 2 (1962); *v.e.* United Nations document A/AC.82/G/L.776.

67. Walton, A., R. E. Fried, Studies of nuclear debris in precipitation (summary report). USAEC report NYO-9530 (1961).

68. Hardy, Jr., E. P., R. J. List, L. Machta, *et al.*, Strontium-90 on the Earth's surface. II. Summary and interpretation of a world-wide soil sampling program: 1960-1961 results. USAEC report TID-17090 (1962); *v.e.* United Nations document A/AC.82/G/L.822.

69. Hvinden, F. T., Radioaktivt nedfall. Forsvarets Forskningsinstitutt, Norge.

70. Federal Radiation Council, Estimates and evaluation of fallout in the United States from nuclear weapons testing conducted through 1962. Report No. 4 (1963); *v.e.* United Nations document A/AC.82/G/L.843.

71. Friend, J. P., H. W. Feely, M. W. M. Leo, Sixth quarterly report on Project Star Dust. Defense Atomic Support Agency report DASA-1306 (1962).

72. Friend, J. P., H. W. Feely, M. W. M. Leo, Seventh quarterly report on Project Star Dust. Defense Atomic Support Agency report DASA-1307 (1963); *v.e.* Eighth quarterly report on Project Star Dust, DASA-1308 (1963).

73. Salter, L. P., High altitude balloon sampling program, pp. 166-172 *in* USAEC report HASL-140 and pp. 184-219 *in* HASL-144; *v.e.* United Nations documents A/AC.82/G/L.856 and G/L.-936, respectively.

74. Congress of the United States, Hearings before the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy on "Fallout, Radiation Standards, and Countermeasures", pp. 381-410. 88th Congress, 1st Session, June 3, 4, and 6, 1963; *v.e.* United Nations document A/AC.82/G/L.849.

75. Health and Safety Laboratory, Fallout program quarterly summary report. USAEC reports HASL-135; 138; 140; 142; 144; *v.e.* United Nations documents A/AC.82/G/L.831; 842; 856; 871; 936.

76. Cambray, R. S., E. M. R. Fisher, G. S. Spicer, *et al.*, Radioactive fallout in air and rain, results to the middle of 1962. UKAEA Research Group report AERE-R-4094; *v.e.* United Nations document A/AC.82/G/L.823.

77. Department of National Health and Welfare, Canada, Radiation Protection Division, Data from radiation protection programs, vol. I, Nos. 1-9 (1963).

78. Aarkrog, A., J. Lippert, J. Petersen, Environmental radioactivity in Denmark, 1961. Risö report No. 41 (1962); *v.e.* United Nations document A/AC.82/G/L.802.

79. Boulenger, R., G. Koch, La retombée radioactive à Mol (rapport d'avancement — second semestre 1961). Centre d'étude de l'énergie nucléaire, rapport R-2168 (1962); *v.e.* United Nations document A/AC.82/G/L.815.

80. Беляев Л. И., Гедеонов Л. И., Максимова А. М., Радиоактивные выпадения близ Семеиза в 1960-1961 годах. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.914.

81. Шубко В. М., Еремичева А. М., Выпадение стронция-90 на поверхность территории СССР в четвертом квартале 1961 года и первой половине 1962 года. Государственный комитет по использованию атомной энергии СССР; *v.e.* документ ООН A/AC.82/G/L.916.

82. Department of National Health and Welfare, Canada, Radiation Protection Division, Annual report for 1961 on the radioactive fallout study program. Report CHNW (RP-5), 1962.

83. Малахов С. Г., Давыдов Е. Н., Карагод Н. А., Выпадение Ce^{141}, Ce^{144}, $Zr^{95}+Nb^{95}$ и Sr^{90} на территории СССР во второй половине 1962 года. Государственный комитет по использованию атомной энергии СССР; *v.e.* документ ООН A/AC.82/G/L.902.

84. Gat, J. R., Y. Feige, N. Pazy, *et al.*, Early radioactive fallout in Israel following the 1961 nuclear weapon tests. Israel Atomic Energy Commission report IA-751; *v.e.* United Nations document A/AC.82/G/L.798.

85. McMurray, W. R., L. O. Stander, Radioactive fallout, its dispersion, deposition over South Africa and biological significance. South African J. Science 59 (1): 19-30 (1963); *v.e.* United Nations document A/AC.82/G/L.838.

86. Der Bundesminister für Atomkernenergie Umweltradioaktivität und Strahlenbelastung. Bericht II/62.

87. Petersen, J., Environmental radioactivity at Copenhagen, February 1961-August 1962. Danish Atomic Energy Commission Research Establishment Risö report No. 51 (1962).

88. Hvinden, T., Radioactive fallout in Norway, July 1960 to July 1963. Norwegian Defense Research Establishment Intern rapport F-444 (1963).

89. Miyake, Y., K. Saruhashi, Y. Katsuragi, *et al.*, Deposition of Sr^{90} and Cs^{137} in Tokyo through the end of July 1963. Pap. Met. Geophys., Tokyo, 14 (1): 58-65 (1963).

90. Philippot, J.-Cl., G. Hemon, Retombées radioactives dans l'air et l'eau de pluie. Résultats de 1959 à 1962. Laboratoire "radioactivité de l'air". Extrait du BIST No 75, août 1963.

91. Communauté européenne de l'énergie atomique, Radioactivité ambiante dans les pays de la Communauté, vol. 1, No 2: 1-16 (1964).

92. Bortoli, M., P. Gaglione, A. Malvicini, *et. al.*, Sorveglianza della radioattività del latte a Ispra risultati del periodo 1960-1962. Comunità Europea dell'Energia Atomica rapporto EUR-294.i (1963): *v.e.* Misure di radioattività ambientale Ispra 1962. EUR-481.i (1964).

93. Guthrie, J. E., W. E. Grummitt, Radioactivity in

precipitation collected at CRNL and NPD. Atomic Energy of Canada Ltd. report AECL-1863 (1963).

94. Service central de protection contre les rayonnements ionisants, France. Surveillance de la radioactivité sur le territoire français de 1961 à 1963. Rapport SCPRI No 98 (1964); *v.e.* United Nations document A/AC.82/G/L.877.
95. Khandekar, R. N., K. G. Vohra, Estimation of zirconium-95 deposited by fallout during September 1961 to February 1962. Atomic Energy Establishment Trombay report AEET/AM/31 (1963).
96. Шведов В. П., Широков С. И., Радиоактивное загрязнение внешней среды. Атомиздат, Москва, 1962.
97. Aarkrog, A., J. Lippert, J. Petersen, Environmental radioactivity in Denmark in 1962. Risö report No. 63 (1963).
98. Aarkrog, A., J. Lippert, J. Petersen, Environmental radioactivity in the Faroes in 1962. Risö report No. 64 (1963).
99. Aarkrog, A., J. Lippert, J. Petersen, Environmental radioactivity in Greenland in 1962. Risö report No. 65 (1963).
100. Comitato Nazionale Energia Nucleare, Data on environmental radioactivity collected in Italy (January-June 1962). BIO/26/62 (1962); *v.e.* United Nations document A/AC.82/G/L.831.
101. Comitato Nazionale Energia Nucleare, Data on environmental radioactivity collected in Italy (July-December 1962). BIO/03/63 (1963); *v.e.* United Nations document A/AC.82/G/L.890.
102. Шведов В. П., Росянов С. П., Гритченко З. Г., О загрязнении растительности стронцием-90 и цезием-137 в 1961 году. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.913.
103. Harley, J., Personal communication.
104. Kulp, J. L., A. R. Schulert, Strontium-90 in man and his environment. Vol. I: Summary. USAEC report NYO-9934 (1962); *v.e.* United Nations document A/AC.82/G/L.792.
105. Harley, J., Personal communication.
106. Walton, A., The distribution in soils of radioactivity from weapons tests. J. Geophysical Res. 68 (5): 1485-1496 (1963).
107. Yamagata, N., S. Matsuda, K. Kodaira, Run-off of Cs^{137} and Sr^{90} from rivers. Nature 200: 668-669 (1963).
108. Середа Г. А., Бобовникова Ц. И., Стронций-90 в воде пресных водоемов Советского Союза в 1961-1962 годах. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.896.
109. Страдомский В. Б., Стронций-90 в воде бассейна р. Дон. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.918.
110. Богоров В. Г., Попов Н. И., Вопросы глобального радиоактивного загрязнения вод Мирового океана. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.919.
111. Bowen, V. T., T. T. Sugihara, Strontium-90 in the "mixed layer" of the Atlantic Ocean. Nature 186: 71-72 (1960).
112. Bowen, V. T., T. T. Sugihara, Vertical distribution of fallout radionuclides in the Atlantic Ocean. USAEC report TID-18389 (1963).
113. Шведов В. П., Юзефович А. А., Гедеонов Л. И. и др., Определение стронция-90 в водах Атлантического океана в 1961 году. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.899.
114. Rocco, G. G., W. S. Broeker, The vertical distribution of caesium-137 and strontium-90 in the oceans. J. Geophysical Res. 68 (15): 4501-4512 (1963).
115. Broeker, W. S., G. G. Rocco, M. Ewing, *et al.*, Natural radiocarbon in the Atlantic Ocean. J. Geophysical Res. 65 (9): 2903-2931 (1960).
116. Bien, G. S., N. W. Rakestraw, H. E. Suess, Radiocarbon dating of deep water of the Pacific and Indian Oceans, pp. 159-173 *in* Proceedings of a Symposium on Radiocarbon Dating. IAEA, Vienna, 1963.
117. Попов Н. И., Патин С. А., Пчелкин В. А. и др., Стронций-90 в водах Тихого океана. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.907.
118. Чулков П. М., Горбунов В. Ф., Содержание цезия-137 в поверхностных водах Атлантического океана и его морей в 1961 году. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.-82/G/L.897.
119. Попов Н. И., Орлов В. М., Патин С. А. и др., Стронций-90 в поверхностных водах Индийского океана в 1960-1961 годах. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.-904.
120. Шведов В. П., Патин С. А., Максимова А. М. и др., Содержание стронция-90 в Черном море в 1959-1961 годах. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.909.
121. Katcoff, S., Fission product yields from neutron induced fission. Nucleonics 18: 201-208 (1960).
122. Ehhalt, D., K. O. Münnich, W. Rœther, *et al.*, Artificially produced radioactive noble gases in the atmosphere. J. Geophysical Res. 68 (13): 3817-3821 (1963).
123. Delibrias, S., M. Perquis, J. Labeyrie, Mesure de l'activité de l'air due au krypton-85. Extrait du BIST No 54, septembre 1961.
124. Harley, J., Personal communication.
125. Kerr, V. N., F. N. Hayes, E. Hansbury, *et al.*, Radiocarbon in contemporaneous plant products, pp. 238-259 *in* Biological and Medical Research Group (H-4) of the Health Division, Semiannual Report, January through June 1961. USAEC report LAMS-2627 (1961).
126. Craig, H., The natural distribution of radiocarbon

and the exchange time of carbon dioxide between atmosphere and sea. Tellus 9 (1): 1-17 (1957).

127. Hagemann, F., J. Gray, Jr., L. Machta, *et al.*, Stratospheric carbon-14, carbon dioxide, and tritium. Science 130: 542-552 (1959).

128. Münnich, K. O., Circulation of radiocarbon in nature. Naturwissenschaften 50: 211-218 (1963).

129. Fergusson, G. J., Upper tropospheric carbon-14 levels during spring 1962. J. Geophysical Res. 68 (13): 3933-3941 (1963).

130. Kigoshi, K., Personal communication.

131. Broeker, W. S., Personal communication.

132. Ostlund, H. G., Personal communication.

133. Olsson, I. U., Personal communication.

134. Nydal, R., Increase in radiocarbon from the most recent series of thermonuclear tests. Nature 200: 212-214 (1963).

135. Tauber, H., Personal communication.

136. Rafter, T. A., Personal communication.

137. Kigoshi, K., To be published in J. Rad. Res.

138. Kanwisher, J., Effect of wind on CO_2 exchange across the sea surface. J. Geophysical Res. 68 (13): 3921-3927 (1963).

139. Olsson, I. U., I. Karlén, The half-life of C^{14} and the problems which are encountered in absolute measurements on beta-decaying gases, pp. 3-11 *in* Proceedings of a Symposium on Radioactive Dating. IAEA, Vienna, 1963.

140. Latter, A. L., M. S. Plesset, Carbon-14 production from nuclear explosions. Proc. Nat'l. Acad. Sci. 46: 241-247 (1960).

141. Münnich, K. O., J. C. Vogel, Investigation of meridional transport in the troposphere by means of carbon-14 measurements, pp. 189-197 *in* Proceedings of a Symposium on Radioactive Dating. IAEA, Vienna, 1963.

142. Health and Safety Laboratory, Fallout program quarterly summary report, April 1, 1964, p. 169 only. USAEC report HASL-144; *v.e.* United Nations document A/AC.82/G/L.936.

143. International Atomic Energy Agency, Tritium concentration in rain, rivers, oceans and other water. List No. 1, 2 and 3, WP/17/1, 2, 3 (1962-1963).

144. Brown, R. M., W. E. Grummitt, The determination of tritium in natural waters. Canadian J. Chem. 34: 220-226 (1956).

145. Brown, R. M., Tritium in rainfall. Atomic Energy of Canada Quarterly Reports, PR-13-46 - PR-13-49 (1961).

146. Bibron, R., G. Delibrias, J. Labeyrie, Accroissement du tritium atmosphérique dû aux explosions thermonucléaires. Extrait du BIST No 54, septembre 1961.

147. Martell, E. A., On the inventory of artificial tritium and its occurrence in atmospheric methane. J. Geophysical Res. 68 (13): 3759-3769 (1963).

148. Begemann, F., The tritium content of atmospheric hydrogen and atmospheric methane. J. Geophysical Res. 68 (13): 3757-3758 (1963).

149. Israel, G., W. Roether, G. Schumann, Seasonal variations of bomb-produced tritium in rain. J. Geophysical Res. 68 (13): 3771-3773 (1963).

150. Bainbridge, A. E., Tritium in the North Pacific surface water. J. Geophysical Res. 68 (13): 3785-3789 (1963).

151. Libby, W. F., Moratorium tritium geophysics. J. Geophysical Res. 68: 4485-4494 (1963).

152. Bainbridge, A. E., B. J. O'Brien, Levels of tritium in a variety of New Zealand waters and some tentative conclusions from these results, pp. 33-39 *in* Proceedings of a Symposium on Tritium in the Physical and Biological Sciences, vol. I. IAEA, Vienna, 1962.

153. Brown, R. M., Hydrology of tritium in the Ottawa valley. Geochim. et Cosmochim. Acta 21: 199-216 (1961).

154. Thatcher, L. L., C. M. Hoffman, Tritium fallout over North America from the Soviet tests in 1961. J. Geophysical Res. 68 (20): 5899-5901 (1963).

155. Taylor, C. B., Tritium content of Antarctic snow. Nature 201: 146-147 (1964).

156. Bolin, B., Report of tritium in atmosphere, rain and sea in the European area. University of Stockholm, Sweden.

157. Bleichrodt, J. F., E. R. van Abkoude, On the deposition of cosmic ray produced beryllium-7. J. Geophysical Res. 68 (18): 5283-5288 (1963).

158. Bleichrodt, J. F., E. R. van Abkoude, Artificial beryllium-7 in the lower stratosphere. J. Geophysical Res. 68 (15): 4629-4631 (1963).

159. Peirson, D. H., Beryllium-7 in air and rain. J. Geophysical Res. 68 (13): 3831-3832 (1963).

160. Schumann, G., M. Stoeppler, Beryllium-7 in the atmosphere. J. Geophysical Res. 68 (13): 3827-3830 (1963).

161. Murayama, N., Meteorological features of cosmic ray produced beryllium-7. J. Meteorological Society of Japan, series II, 42 (1): 43-52 (1964).

162. United States Department of Health, Education, and Welfare, Radiological Health Data, vol. IV, No. 6, pp. 291-296 (1963); *v.e.* United Nations document A/AC.82/G/L.851.

163. Campbell, J. E., G. K. Murthy, Summary of results from the raw milk sampling program, June 1957-April 1963, pp. 511-523 *in* Radiological Health Data, vol. IV, No. 10 (1963); *v.e.* United Nations document A/AC.82/G/L.868.

164. United States Department of Health, Education, and Welfare, Mean values of Sr^{89}, Sr^{90} and Cs^{137} in milk 1961-1963: Estimated dose to infant thyroids from iodine-131 in milk. Unpublished report.

165. Rivera, J., Tri-city diet study. USAEC reports HASL-117, pp. 220-224 (1961); HASL-122, pp. 180-182 (1962); HASL-127, pp. 198-199 (1962); HASL-131, pp. 235-238 (1962); HASL-132, pp. 219-223 (1963); HASL-135, pp. 269-272 (1963); HASL-138, pp. 163-165 (1963); HASL-140, pp. 163-165 (1963); HASL-142, pp. 182-184 (1964); HASL-144, pp. 281-287 (1964); *v.e.* United Nations documents A/AC.82/G/L.737; G/L.766; G/L.793; G/L.803; G/L.814; G/L.831; G/L.842; G/L.856; G/L.871 and G/L.936.

166. International Atomic Energy Agency, Survey of radioactivity in food consumed in Austria. Report on second sampling period—January-June 1961. IAEA report WP/19; *v.e.* United Nations document A/AC.82/G/L.767.

167. Aarkrog, A., J. Lippert, J. Petersen, Environmental radioactivity in Denmark in 1961. Risö report No. 41; *v.e.* United Nations document A/AC.82/G/L.802.

168. Agricultural Research Council Radiobiological Laboratory, Annual report, 1961-1962. ARCRL report No. 8 (1962); *v.e.* United Nations document A/AC.82/G/L.806.

169. Agricultural Research Council Radiobiological Laboratory, Annual report, 1962-1963. ARCRL report No. 10 (1963); *v.e.* United Nations document A/AC.82/G/L.858.

170. Hiyama, Y., H. Hayami, N. Yamagata, *et al.*, Japanese dietary habits and the fallout problem II. To be published in J. Rad. Res.

171. Committee on Protection against Ionizing Radiations, Medical Research Council, The exposure of the population to radiation from fallout. HMSO, London, 1964.

172. Hiyama, Y., H. Hayami, N. Yamagata, *et al.*, Japanese dietary habits and the fallout problem. J. Rad. Res. 3: 61-67 (1961).

173. Mercer, E. R., J. D. Burton, B. O. Bartlett, Relationship between the deposition of strontium-90 and the contamination of milk in the United Kingdom. Nature 198: 662-665 (1963).

174. Harley, J., Prediction of levels of strontium-90 and caesium-137, pp. 210-218 *in* Hearings before the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy. 88th Congress, 1st session, June 3, 4 and 6, 1963; *v.e.* United Nations document A/AC.82/G/L.849.

175. Bartlett, B. O., J. D. Burton, F. B. Ellis, *et al.*, Information on food chain mechanisms obtained by the analysis of survey results. ARCRL report No. 10, pp. 82-85 (1963); *v.e.* United Nations document A/AC.82/G/L.858.

176. Minnesota Department of Health, and University of Minnesota, Factors influencing strontium-90 in milk from the Brainerd, Minn. milkshed. U.S. Department of Health, Education, and Welfare, Public Health Service Publ. No. 999-R-1 (1962); *v.e.* United Nations document A/AC.82/G/L.821.

177. Schulert, A. R., Strontium-90 in Alaska. Science 136: 146-148 (1962).

178. Miettinen, Y. K., Studies of Sr^{90} and Cs^{137} in plants, animals and man in Lapland. Plenary lecture held at the 11th Meeting of Scandinavian Chemists, August 20-25, 1962, Turku, Finland. Personal communication in form of typed manuscript.

179. Aarkrog, A., Preliminary 1963 data on environmental contamination in Denmark and its territories. Danish Atomic Energy Commission, Research Establishment Risö, April 1964. Personal communication.

180. Health and Safety Laboratory, Fallout program quarterly summary report, January 1, 1964, pp. 2-153. USAEC report HASL-142 (1964); *v.e.* United Nations document A/AC.82/G/L.871.

181. Rivera, J., A comparison of strontium-90 and calcium in infants and adult diets, pp. 273-275 *in* USAEC report HASL-135 (1963); *v.e.* United Nations document A/AC.82/G/L.831.

182. United States Department of Health, Education, and Welfare, Radiological Health Data, vol. III, pp. 42-49; 224-242; 471-475 (1962); vol. IV, pp. 177-182; 347-352; 441-446 (1963).

183. Czosnowska, W., Sr^{90} in diet in Poland (August 1961-July 1962). In press.

184. Czosnowska, W., Sr^{90} in diet in Poland in the period from 1 August 1960 to 31 July 1961. In press.

185. National Institute of Radiological Sciences, Chiba, Japan, Radioactivity survey data in Japan, No. 1 (1963); *v.e.* United Nations document A/AC.82-G/L.921.

186. Tsugo, T., H. Nozaki, T. Asari, *et al.*, Radioactive contamination of milk in Japan, 1961-1963. To be published in J. Rad. Res.

187. Bryant, F. J., J. F. Loutit, Human bone metabolism deduced from strontium assays. AERE report R-3718 (1961); *v.e.* United Nations document A/AC.82/G/L.668.

188. Rivera, J., Stable strontium concentrations in three bones of the human skeleton, pp. 303-305 *in* USAEC report HASL-140 (1963); *v.e.* United Nations document A/AC.82/G/L.856.

189. Rivera, J., Calcium discrimination by adults and infants, pp. 235-238 *in* USAEC report HASL-138 (1963); *v.e.* United Nations document A/AC.82/-G/L.842.

190. Grummitt, W. E., Strontium and barium in bone and diet, pp. 376-380 *in* USAEC report TID-7632, Book 2 (1962); *v.e.* United Nations document A/AC.82/G/L.776.

191. Comar, C. L., Over-all considerations of strontium-calcium discrimination, pp. 405-417 *in* The Transfer of Calcium and Strontium Across Biological Membranes. R. H. Wasserman, editor, Academic Press, N.Y., 1963.

192. Kornberg, H. A., The use of element-pair in radiation hazard assessment. Health Physics 6: 46-62 (1961).

193. Bryant, F. J., J. F. Loutit, The entry of strontium-90 into human bone. Proc. Roy. Soc. Series B, 159: 449-465 (1964).

194. Lough, S. A., J. Rivera, C. L. Comar, Retention of strontium, calcium and phosphorus in human infants. Proc. Soc. Exp. Biol. Med. 112: 631-636 (1963).

195. McClelan, R. O., J. R. McKenney, L. K. Bustad, Changes in calcium-strontium-90 discrimination with age in young miniature swine. Life Sci. No. 12: 669-675 (1962); *v.e.* USAEC report HW-SA-2790.

196. Ichikawa, R., Y. Enomoto, Strontium-calcium discrimination in rats feeding on rice, milk and commercial diets. Health Physics 9: 717-720 (1963).

197. McClelan, R. O., Calcium-strontium discrimina-

tion in miniature pigs as related to age. Nature 202: 104-106 (1964).

198. Della Rosa, R. J., F. Gielow, G. Peterson, Skeletal uptake of injected Sr^{90}: Discrimination against strontium in growing beagles continually ingesting Sr^{90}, pp. 45-51 *in* University of California, Davis, report UCD-108 (1963).

199. Loutit, F. J., R. Scott Russell, R. S. Bruce, *et al.*, Ratios of Sr^{90} to calcium in milk and in the bones of infants. Nature 201: 770-772 (1964).

200. Rivera, J., Strontium-90 in human bones collected during 1962, pp. 239-248 *in* USAEC report HASL-138 (1963); *v.e.* United Nations document A/AC.82/G/L.842.

201. Kulp, J. L., A. R. Schulert, Strontium-90 in man. V. Science 136: 619-632 (1962).

202. Liniecki, J., Some aspects of the kinetics of Sr^{90} accumulation in the body under conditions of chronic intake. Pelnomocnik Rzadu d/s Wykorzystania Energii Jadrowej. Warszawa, 1963.

203. Marshall, J. H., Theory of alkaline earth metabolism, pp. 5-29 *in* Argonne National Laboratory report ANL-6646 (1963).

204. Pribilla, O., Der Gehalt menschlicher Knochen und Gewebe an radioaktivem Strontium (90-Sr) in der Bundesrepublik Deutschland in den Jahren 1958-1962. Dtsch. med. Wschr. 88: 1560-1564 (1963).

205. Cohn, S. H., H. Spencer, J. Samachson, *et al.*, The turnover of Sr^{85} in man as determined by whole body counting. Rad. Res. 17: 173-182 (1962).

206. Kulp, J. L., A. R. Schulert, E. J. Hodges, Strontium-90 in man. IV. Science 132: 448-454 (1960).

207. Onstead, C. O., E. Oberhausen, F. V. Keavy, Cesium-137 in man. Science 137: 508-510 (1962).

208. Fredriksson, L., B. Eriksson, A. Eriksson, *et al.*, Personal communication.

209. Yamagata, N., S. Matsuda, The environmental increase of cesium-137 since 1957 to 1960; *v.* United Nations document A/AC.82/G/L.479.

210. Liniecki, J., Personal communication.

211. Agricultural Research Council, Strontium-90 in milk and agricultural materials in the United Kingdom 1959-1960. Report ARCRL-4 (1961); *v.e.* United Nations document A/AC.82/G/L.587.

212. Lillegraven, A., L. Lund, O. L. Michelsen, Quoted by D. A. Barber and W. A. Mitchell, pp. 57-58 *in* Agricultural Research Council Radiobiological Laboratory Annual Report 1962-63. Report ARCRL-10 (1963); *v.e.* United Nations document A/AC.82/G/L.858.

213. Agricultural Research Council, Surveys of radioactivity in human diet and experimental studies. Report for 1960. Report ARCRL-5 (1961): *v.e.* United Nations document A/AC.82/G/L.701.

214. Lindell, B., B. Aberg, L. Fredriksson, *et al.*, Collected data on radioactivity in Swedish food. Swedish Radiation Council, 1962.

215. Comar, C., R. H. Wassermann, F. W. Langemann, *et al.*, Fallout and the food-chain: A status review, pp. 426-456 *in* USAEC report TID-7632, Book 2 (1962); *v.e.* United Nations document A/AC.82/G/L.776.

216. United States Department of Health, Education and Welfare, National food consumption survey: Fresh whole milk consumption in the U.S.—July 1962. Radiological Health Data, vol. IV, No. 1: 15-17 (1963); *v.e.* United Nations document A/AC.82/G/L.820.

217. Fredriksson, L., Personal communication.

218. Barber, D. A., W. A. Mitchell, Influence of soil organic matter on the uptake of caesium-137 by perennial rye-grass, pp. 57-58 *in* Agricultural Research Council Radiobiological Laboratory Annual Report 1962-63. Report ARCRL-10 (1963); *v.e.* United Nations document A/AC.82/G/L.858.

219. Bartlett, O., R. Scott Russell, Personal communication.

220. Anderson, E. C., G. M. Ward, J. Z. Holland, *et al.*, Cesium-137 in United States powdered milk and in the population, pp. 477-516 *in* USAEC report TID-7632, Book 2 (1962); *v.e.* United Nations document A/AC.82/G/L.776.

221. Abe, M., K. Kitahara, Y. Hiyama, *et al.*, Annual reports of scientific research grants 1963. Radiation Effects, Ministry of Education, Japan 1964.

222. Madshus, K., A. Strømme, K. Koren, Caesium-137 body burden in persons chosen at random from selected areas in Norway. Nature 200: 278-279 (1963).

223. Madshus, K., A. Strømme, K. Koren, Rapport om innholdet av Cesium-137 i melk fra varen 1962 og 1963. Private communication in the form of typed manuscript.

224. Madshus, K., A. Strømme, K. Koren, Redegjørelse for stralebelastningen fra Cs^{137} "in vivo" hos befolkningen i Vest-Norge 1963. Personal communication in the form of typed report.

225. Hanson, W. C., H. E. Palmer, B. E. Griffin, Radioactivity in Northern Alaskan Eskimos and their foods. Summer 1962. Health Physics 10: 421-429 (1964).

226. Miettinen, J. K., A. Jokelainen, P. Roine, *et al.*, Cs^{137} and potassium in people and diet—a study of Finnish Lapps. Ann. Ac. Sci. Fennicae. II. Chemica issue 120, Helsinki 1963.

227. Salo, A., J. K. Miettinen, Strontium-90 and caesium-137 in Arctic vegetation during 1961. Nature 201: 1177-1179 (1964).

228. Häsänen, E., J. K. Miettinen, Cs^{137} content of fresh-water fish in Finland. Nature 200: 1018-1019 (1963).

229. Paakkola, O., J. K. Miettinen, Strontium-90 and caesium-137 in plants and animals in Finnish Lapland during 1960. Ann. Ac. Sci. Fennicae. Series A, II. Chemica issue 125, Helsinki 1963.

230. Rundo, J., J. I. Mason, D. Newton, *et al.*, Biological half-life of caesium in man in acute and chronic exposure. Nature 200: 188-189 (1963).

231. Cohn, S. H., B. Rosoff, E. A. Gusmano, *et al.*, Long-term Cs^{137} turnover in man as measured by a whole body counter. Rad. Res. 19: 655-658 (1963).

232. Richmond, C. R., J. E. Furchner, W. H. Lang-

ham, Long-term retention of radiocaesium by man. Health Physics 8: 201-205 (1962).

233. Karniewicz, W., J. Liniecki, A. Kosterkiewicz, Personal communication.

234. Rundo, J., Personal communication.

235. Oberhausen, E., Die Altersabhängigkeit des Kalium- und Cäsium-137-Gehaltes des Menschen. Biophysik 1: 135-142 (1963).

236. Harrison, G. E., A. Sutton, K. B. Edwards, *et al.*, Concentrations of radioactive and stable caesium in bone and soft tissue. Brit. J. Radiol. 36: 745-748 (1963).

237. Rosoff, B., S. H. Cohn, H. Spencer, Cesium-137 metabolism in man. Rad. Res. 19: 643-654 (1963).

238. Yamagata, N., Cesium-137 levels in human body. August 1958-August 1960. Bull. Inst. Public Health 10: (1961); *v.e.* United Nations document A/AC.82/G/L.691.

239. Yamagata, N., Estimation of the total-body load of caesium-137 in Japanese people. Nature 196: 284-285 (1962).

240. Anderson, R. W., P. F. Gustafson, Concentration of Cs^{137} in human rib bone. Science 137: 668 only (1962).

241. Suguri, S., Cs^{137} in man in Japan in 1961 and 1962. Personal communication.

242. Saiki, M., T. Unuma, M. Uchiyama, Body burden of Cs^{137} determined with human counter in November-December 1963. Summary book on 1964 Annual Meeting of the Atomic Energy Society of Japan.

243. Andersson, J. O., J. Nilsson, Radioactivity in people living in the North of Sweden: *v.* United Nations document A/AC.82/G/L.650.

244. Liden, K., Cs^{137} burdens in Swedish Laplanders and reindeer; *v.* United Nations document A/AC.82/G/L.652.

245. United States Department of Health, Education, and Welfare, Radiological Health Data, vol. II, pp. 484: 522-523 (1961); vol. III, pp. 13-17; 48-49; 86-87; 122-123; 150-151; 189-191; 224-242; 285-289; 336-342; 397-401; 437-441; 482-487 (1962); vol. IV, pp. 23-25; 31-34; 86-89; 96-99; 138-141; 147-149; 183-187; 196-199; 233-242; 291-295; 298-302 (1963).

246. Ministerie van Landbouw en Visserij, The Netherlands. Unpublished report.

247. Cigna, A. A., F. G. Giorcelli, Iodine-131 thyroid dose from milk in Italy during the period September 1962 to February 1963. Science 143: 379-380 (1964).

248. Eisenbud, M., Y. Mochizuki, A. S. Goldin, *et al.*, Iodine-131 dose from Soviet nuclear tests. Science 136: 370-374 (1962).

249. Eisenbud, M., Y. Mochizuki, G. R. Laurer, Iodine-131 dose to human thyroids in New York City from nuclear tests in 1962, pp. 1146-1157 *in* Hearings before the Subcommittee on Research, Development, and Radiation of the Joint Committee on Atomic Energy, 88th Congress, August 20, 21, 22 and 27, 1963; *v.e.* United Nations document A/AC.82/G/L.888.

250. Mays, C. W., Iodine-131 in Utah during July and August 1962. Science 141: 640-642 (1963).

251. Mays, C. W., Iodine-131 in Utah from Nuclear tests in Nevada, pp. 559-563 *in* Hearings before the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy, 88th Congress, August 20, 21, 22 and 27, 1963; *v.e.* United Nations document A/AC.82/G/L.888.

252. Knapp, H. A., Iodine-131 in fresh milk and human thyroids following a single deposition of nuclear test fallout. USAEC report TID-19266 (1963); *v.e.* United Nations document A/AC.82/G/L.872.

253. Martell, E. A., Iodine-131 fallout from nuclear underground tests. Science 143: 126-129 (1964).

254. Vennart, J., Measurements of iodine-131 in human thyroids following nuclear tests in 1961. Nature 196: 740-743 (1962).

255. Yamagata, N., K. Iwashima, Environmental contamination with short-lived radionuclides in Japan in 1961. J. Rad. Res. 3: 1-15 (1963); *v.e.* United Nations document A/AC.82/G/L.764.

256. Der Bundesminister für Atomkernenergie, Umweltradioaktivität und Strahlenbelastung, pp. 152-157. Bericht III/62.

257. Eisenbud, M., B. Pasternack, G. Laurer, *et al.*, Estimation of the distribution of thyroid doses in a population exposed to I^{131} from weapon tests, pp. 1158-1172 *in* Hearings before the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy, 88th Congress, August 20, 21, 22 and 27, 1963; *v.e.* United Nations document A/AC.82/G/L.888.

258. Comar, C. L., Factors influencing the biological availability of fallout radionuclides for animals and man. Federation Proceedings 22: 1402-1409 (1963).

259. Laurer, G. R., M. Eisenbud, Low-level *in vivo* measurement of I^{131} in humans. Health Physics 9: 401-406 (1963).

260. Visalli, F. J., *In vivo* measurements of I^{131} in children's thyroids, pp. 475-477 *in* Radiological Health Data, vol. IV, No. 8 (1963); *v.e.* United Nations document A/AC.82/G/L.853.

261. Eisenbud, M., B. Pasternack, G. Laurer, *et al.*, Variability of I^{131} concentrations in the milk distribution system of a large city, pp. 1173-1175 *in* Hearings before the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy, 88th Congress, August 20, 21, 22 and 27, 1963; *v.e.* United Nations document A/AC.82/G/L.888.

262. United States Department of Health, Education and Welfare, Radiological Health Data, vol. II, p. 528 only (1961); vol. III, pp. 45-50, 151-152, 342-343, 403-404 (1962); vol. IV, pp. 30-31, 94-96, 144-146, 192-194, 249-251, 297-298, 364-365, 411-412, 463-464, 505-506, 560-562, 601-603 (1963); vol. V, pp. 26-28, 65-67 (1964).

263. Department of National Health and Welfare, Canada, Radiation Protection Division, Data from radiation protection programs, vol. I, No. 12, pp. 25-30 (1963); vol. II, No. 1, pp. 27-31 (1964).

264. Comar, C. L., R. H. Wasserman, Radioisotope

absorption and methods of elimination: Differential behavior of substances in metabolic pathways, pp. 526-540 *in* Symposium on Radioisotopes in the Biosphere, Univ. of Minnesota, Minneapolis, 1960.

265. Beninson, D., Radioestroncio y estroncio estable en la dieta y el hueso humano. Comisión Nacional de Energía Atómica de República Argentina, 1964.

266. Lindell, B., Correlations between Cs^{137} fallout rates, food levels and body burdens. The Radiation Protection Board, Institute of Radiophysics, Stockholm, June, 1964.

267. Martínez, A. M., S. Bulbulian, T. A. Brody, Determinación del estroncio 90 en leches y aguas de lluvia. Instituto de Física, Universidad Nacional Autónoma de México, 1964.

268. Suschny, O., Uberblick über die Radioaktivität der in Osterreich im Jahre 1961 konsumierten Lebensmittel. Mitteilungen Osterr. Sanitätsverw. 64: 15-24 (1963).

269. Drasil, V., Z. Papezova, Milk contamination by Sr^{90} in Czechoslovakia. Institute of Biophysics, Czechoslovak Academy of Sciences, Brno. Unpublished report to the UNSCEAR.

270. Paakkola, O., Strontium-90 in Finnish milk during 1960-63. Personal communication.

271. Saiki, M., N. Mochizuki, To be published in Radioactivity Survey Data in Japan, No. 3 (1964). National Institute of Radiobiological Sciences, Japan.

272. Republic of Ireland, Department of Agriculture, Report on estimated levels of radionuclides in foodstuff during 1961, 1962 and 1963. Personal communication to the FAO.

273. Comitato Nazionale Energia Nucleare, Data on environmental radioactivity collected in Italy (January-June 1961). BIO/12/61 (1961); *v.e.* United Nations document A/AC.82/G/L.770.

274. Strackee, L., F. C. U. Mattern, Iodine-131 in milk and vegetables during the second part of 1961. Rijks Institut voor de Volksgezondheid, Utrecht. Rep. RA-15 (1962).

275. Strackee, L., F. C. U. Mattern, Sr^{90} and Cs^{137} in the human diet in the Netherlands during 1962. Rijks Institut voor de Volksgezondheid, Utrecht. Rep. RA-21 (1964).

276. Hvinden, T., L. Lund, P. Thorensen, Fallout in Norwegian milk in 1961. Interim rapport S-15. Forsvarets Forskninginstitut, Norway, 1962.

277. Lindell, B., A review of measurements of radioactivity in food, especially dairy milk, and a presentation of the 1963 data on Cs^{137} and Sr^{90}. The Radiation Protection Board, Institute of Radiophysics, Stockholm, 1964.

278. Huber, P., 5. Bericht der Eidgenössischen Kommission zur Uberwachung der Radioaktivität zuhanden des Bundesrates für das Jahr 1961. Bulletin des Eidg. Gesundheitsamtes Nr. 4 (1962); *v.e.* United Nations document A/AC.82/G/L.801.

279. Huber, P., 6. Bericht der Eidg. Kommission zur Uberwachung der Radioaktivität, zuhanden des Bundesrates für das Jahr 1962. Bulletin des Eidg. Gesundheitsamtes Nr. 4 (1963); *v.e.* United Nations document A/AC.82/G/L.894.

280. Agricultural Research Council, Annual report for 1963-1964. Report ARCRL-12.

281. Чулков П. М., Содержание стронция-90 в молоке отдельных районов СССР в 1960-1961 годах и в первой половине 1962 года. Государственный комитет по использованию атомной энергии СССР, Москва, 1963; *v.e.* документ ООН A/AC.82/G/L.910.

282. Ministère de la santé publique, Service central de protection contre les rayonnements ionisants, Surveillance de la radioactivité sur le territoire français de 1961 à 1963. Rapport SCPRI No 98, p. 18-19 (1963); *v.e.* United Nations document A/AC.82/G/L.877.

283. Pazy, N., Y. Feige, Radioactivity in milk in Israel for the period October 1961-June 1963. Israel Atomic Energy Commission report IA-882 (1964).

284. Vohra, K. G., V. V. Shirvaikar, V. S. Bhatnagar, *et al.*, Measurements on the environmental radioactivity in India from nuclear weapon tests data collected during 1956-1961. Atomic Energy Establishment Trombay report AEET/AM/26 (1962).

285. Vohra, K. G., C. Rangarajan, V. S. Bhatnagar, *et al.*, Measurements on the environmental radioactivity in India from nuclear weapon tests data collected during 1962-1963. Atomic Energy Establishment Trombay report AEET/AM/39 (1963).

286. Asari, T., M. Chiba, M. Kuroda, Strontium-90 and cesium-137 in milk, pp. 9-13 *in* Radioactivity survey data in Japan, No. 1 (1963); *v.e.* United Nations document A/AC.82/G/L.921.

287. Danbara, H., T. Mitsuhashi, Strontium-90 and cesium-137 in milk, pp. 13-16 *in* Radioactivity survey data in Japan, No. 1 (1963); *v.e.* United Nations document A/AC.82/G/L.921.

288. Danbara, H., T. Mitsuhashi, Strontium-90 and cesium-137 in milk. To be published *in* Radioactivity survey data in Japan, No. 3, 1964.

289. Asari, T., M. Chiba, M. Kuroda, Strontium-90 and cesium-137 in milk. To be published *in* Radioactivity survey data in Japan, No. 3, 1964.

290. United Arab Republic Scientific Committee on the Effects of Atomic Radiation, Wide survey of Sr^{90} in soil, food items and diet of the Delta region of UAR during the period July to December 1961. UARSCEAR report, vol. 4, No. 3 (1962).

291. Mahmoud, K. A., F. H. Abd-el Said, A. T. Abd-el Fatah, Report on fallout and radioactive content of the food chain in UAR during the year 1962. UARSCEAR report, vol. 5, No. 1 (1963); *v.e.* United Nations document A/AC.82/G/L.932.

292. Mahmoud, K. A., M. K. Moloukhia, S. A. Abde-Latif, *et al.*, Fallout and radioactive content of food chain in U.A.R. during the year 1963. UARSCEAR report, vol. 6-1, June 1964; *v.e.* United Nations document A/AC.82/G/L.948.

293. Bryant, F. J., J. R. Moroney, D. J. Stevens, *et al.*, Strontium-90 in the Australian environment during 1961. Australian J. Sci. 26: 69-74 (1963); *v.e.* United Nations document A/AC.82/G/L.875.

294. Bryant, F. J., W. J. Gibbs, J. R. Moroney, *et al.*,

Strontium-90 in the Australian environment during 1962. To be published.

295. Health and Safety Laboratory, Fallout program quarterly summary report, p. 229. USAEC report HASL-138 (1963); *v.e.* United Nations document A/AC.82/G/L.842.

296. Health and Safety Laboratory, Fallout program quarterly summary report, p. 231. USAEC report HASL-140 and p. 208 *in* USAEC report HASL-142; *v.e.* United Nations documents A/AC.82/G/L.856 and A/AC.82/G/L.871.

297. Mirna, A., Sr^{90} in Austrian diet in 1960-62. Personal communication.

298. Der Bundesminister für Atomkernenergie, Umweltradioaktivität und Strahlenbelastung. Bericht III/62, p. 144 und Bericht IV/62, p. 155 (1962).

299. Moisio, T., J. K. Miettinen, Caesium-137 and iodine-131 in Finnish milk from September 1962 to August 1963. Suomen Kemistileht, B 36: 125-176 (1963).

300. Wenger, P., K. Soucas, Radioactive fallout in Geneva during 1963. Personal communication.

301. Beninson, D., J. Kramer, Radiocesio en la dieta humana. Comisión Nacional de Energía Atómica, Informe No. 67; *v.e.* United Nations document A/AC.82/G/L.746.

302. United States Department of Health, Education and Welfare, Radiological Health Data, vol. IV, pp. 94-96, 144-146, 192-194 (1963).

303. Grummitt, W. E., P. R. Kamath, Iodine-131 content of Canadian milk during 1961. AECL report AECL-1797 (1963); *v.e.* United Nations document A/AC.82/G/L.854.

304. Cigna, A., C. Polvani, Intake of iodine-131 from milk in Italy during the period October-December 1961. Nature 194: 1123-1124 (1962).

305. Agricultural Research Council, Interim report on radioactivity in diet. Report ARCRL-7 (1962); *v.e.* United Nations document A/AC.82/G/L.771.

306. Agricultural Research Council, Interim report on radioactivity in milk. Report ARCRL-9 (1963); *v.e.* United Nations document A/AC.82/G/L.829.

307. Beninson, D., E. Ramos, Contaminación por I^{131} debida al fallout. Comisión Nacional de Energía Atómica, Informe No. 75 (1962); *v.e.* United Nations document A/AC.82/G/L.808.

308. Bonnyman, J., D. W. Keam, Iodine-131 levels in milk in Australia during the period May-November 1962. Australian J. Sci. 26: 74-76 (1963); *v.e.* United Nations document A/AC.82/G/L.866.

309. United States Department of Health, Education and Welfare, Radiological Health Data, vol. III, pp. 189-191, 246-249, 285-288, 336-341, 397-401, 482-486 (1962).

310. United States Department of Health, Education and Welfare, Radiological Health Data, vol. IV, pp. 23-25, 86-89, 138-142, 183-187, 233-242, 291-295, 359-362, 405-409, 455-459, 499-503, 551-557, 589-595 (1963).

311. United States Department of Health, Education and Welfare, Radiological Health Data, vol. IV, No. 4, pp. 214-215 (1963); *v.e.* United Nations document A/AC.82/G/L.839.

312. McDonald, N. S., D. L. Hutchinson, D. L. Moyer, *et al.*, Gamma-emitting radionuclides in newborn infants and children. Science 141: 1033-1035 (1963).

313. Dean, P. N., Personal communication.

314. Rundo, J., D. Newton, Some recent measurements of caesium-137 and zirconium-95 in human beings. Nature 195: 851-852 (1962).

315. United States Department of Health, Education and Welfare, Radiological Health Data, vol. IV, p. 427 only and 573-574 (1963).

316. Colard, J., Personal communication.

317. Worthley, B., Personal communication.

318. Mar, P. G., Strontium-90 content of human bone specimens, pp. 12-17 *in* Annual report for 1961 on the radioactive fallout study—CHNW (RP-5). Department of National Health and Welfare, Ottawa, Canada (1962).

319. Department of National Health and Welfare, Canada, Radiation Protection Division, Data from radiation protection programs, vol. 1, No. 8, pp. 22-24 (1963).

320. Rivera, J., Strontium-90 in human bones collected during 1961, pp. 203-212 *in* USAEC report HASL-127 (1962); *v.e.* United Nations document A/AC.82/G/L.793.

321. Rivera, J., Strontium-90 in human bones collected during 1962, pp. 239-248 *in* USAEC report HASL-138 (1963); *v.e.* United Nations document A/AC.82/G/L.842.

322. Rivera, J., Personal communication.

323. Drasil, V., Z. Papezova, Personal communication.

324. Pribilla, O., Personal communication.

325. Kvale, E., A. F. Olsen, A. C. Pappas, *et al.*, Assay of Sr^{90} in human bone in Norway, 1961-1963. Personal communication.

326. Liniecki, J., W. Karniewicz, Sr^{90} in human bones in Poland. Results for 1960 and 1961. Nukleonika 8: 401-410 (1963).

327. Karniewicz, W., J. Liniecki, Personal communication.

328. Medical Research Council, Assay of strontium-90 in human bone in the United Kingdom. Results for 1961, part I. MRC Monitoring report No. 4: *v.e.* United Nations document A/AC.82/G/L.779.

329. Medical Research Council, Assay of strontium-90 in human bone in the United Kingdom. Results for 1961, part II. MRC Monitoring report No. 5; *v.e.* United Nations document A/AC.82/G/L.819.

330. Medical Research Council, Assay of strontium-90 in human bone in the United Kingdom. Results for 1962, with some further results for 1961. MRC Monitoring report No. 6: *v.e.* United Nations document A/AC.82/G/L.844.

331. Medical Research Council, Assay of strontium-90 in human bone in the United Kingdom. Results for 1962, part II. MRC Monitoring report No. 7; *v.e.* United Nations document A/AC.82/G/L.865.

332. Saiki, M., T. Koyanagi, G. Tanaka, *et al.*, Assay of Sr^{90} in human bone in Japan 1961-1963. To be published in J. Rad. Res.

333. McNeill, K. G., R. M. Green, The effective half-lives of caesium and iodine in the body. Canadian J. Phys. 37: 528-529 (1959).

334. Miller, C. E., Half-life of Cs^{137} in two men, p. 31 *in* Argonne National Laboratory report ANL-5596 (1956).

335. Miller, C. E., Distribution and retention of Cs^{137} after accidental inhalation. ANL report UAC-8383; *v.e.* United Nations document A/AC.82/-G/L.892.

336. Oberhausen, E., Measurement of contaminated individuals, pp. 286-292 *in* USAEC report TID-7612 (1960).

337. Rowe, M. W., M. A. Van Dilla, Cesium-137 retention by one human subject, pp. 149-153 *in* Los Alamos Scientific Laboratory report LAMS-2780 (1962).

338. Van Dilla, M. A., M. J. Fulwyler, Retention of cesium-137 by adults. Los Alamos Scientific Laboratory report LAMS-3034.

339. Taylor, M. A., J. Vennart, D. M. Taylor, Retention and excretion of caesium-137 by man. Phys. Med. Biol. 7: 157-165 (1962).

340. Rundo, J., Measurements of fallout Cs^{137} in human beings within the UKAEA. To be published.

341. International Commission on Radiological Protection, Recommendations of the International Commission on Radiological Protection. Report of Committee II on permissible dose for internal radiation. Pergamon Press, N.Y., 1959.

342. Mochizuki, Y., R. Mowafy, B. Pasternack, The weight of human thyroids in New York City, pp. 1189-1194 *in* Hearings before the Subcommittee on Research, Development and Radiation of the Joint Committee on Atomic Energy, 88th Congress, August 20, 21, 22 and 27, 1963; *v.e.* United Nations document A/AC.82/G/L.888.

343. Pendleton, R. C., C. W. Mays, R. D. Lloyd, *et al.*, Differential accumulation of I^{131} from local fallout in people and milk. Health Physics 9: 1253-1262 (1963).

344. Comar, C. L., R. A. Wentworth, J. R. Georgi, Thyroidal deposition in man, rat and dog of radioiodine from milk and non-milk sources. Health Physics 9: 1249-1252 (1963).

345. Van Dilla, M. A., M. J. Fulwyler, Thyroid metabolism in children and adults using very small (nanocurie) doses of iodine-125 and iodine-131. Health Physics 9: 1325-1331 (1963).

346. Krey, P. W., D. Bogen, E. French, Plutonium in man and his environment. Nature 195: 263-265 (1962).

347. Osborne, R. V., Plutonium-239 and other nuclides in ground-level air and human beings during spring 1962. Nature 199: 143-146 (1963).

348. Rundo, J., D. Newton, Some recent measurements of caesium-137 and zirconium-95 in human beings. Nature 195: 851-852 (1962).

349. Liebscher, K., T. Schönfeld, A. Schaller, Concentration of inhaled cerium-144 in pulmonary lymph nodes of human beings. Nature 192: 1308 only (1961).

350. Wegst, A. K., C. A. Peilletier, G. H. Whipple, Detection and quantitation of fallout particles in a human lung. Science 143: 957-959 (1964).

351. Yamasaki, F., Personal communication.

352. Swedjemark, G. A., Personal communication.

353. Gibson, J. A. B., The gamma radiation background at Grove, Berkshire. Report AERE-HP-Gen-39.

354. Burch, P. R. J., J. C. Duggleby, D. B. Oldroy, *et al.*, Studies of environmental radiation at a particular site with a static gamma-ray monitor *in* Proceedings of the International Symposium on Natural Radiation Environment, Rice University, Houston, Texas, 1963. In press.

355. Chamberlain, A. C., Relation between measurements of deposited activity after the Windscale accident of October 1957. UKAEA report AERE-HP/R-2606 (1958).

356. Holme, D. A., K. Stewart, The gamma dose-rate above an infinite plane source. Report AWRE-E-6/63.

357. Gustafson, P. F., Assessment of the radiation dose due to fallout. Radiology 75: 282-288 (1960).

358. Gustafson, P. F., S. S. Brar, Gamma-ray doses from short-lived fission products from nuclear weapon tests. Health Physics 9: 629-634 (1963).

359. Gustafson, P. F., Personal communication.

360. Collins, W. R. Jr., G. A. Welford, R. S. Morse, Fallout from 1957 and 1958 nuclear test series. Science 134: 980-984 (1961).

361. Collins, W. R. Jr., Measured and predicted contribution from fallout to environmental radiation levels, pp. 271-278 *in* USAEC report TID-7632; *v.e.* United Nations document A/AC.82/G/L.776.

362. Collins, W. R. Jr., Personal communication.

363. Gale, H. J., D. L. O. Humphreys, E. M. R. Fisher, The weathering of caesium-137 in soil. UKAEA report AERE-4241; *v.e.* United Nations document A/AC.82/G/L.860.

364. Ministry of Agriculture, Fisheries and Food, National Food Survey Committee, Annual report for 1960. H.M.S.O., London, 1961.

365. Lindell, B., An approach to the question of computing doses and effects from fallout. Health Physics 2: 341-365 (1960).

366. United States Department of Health, Education and Welfare. Radionuclide concentration in daily diet of children 6-18 years old. Institution averages, 1961-1963. Unpublished report.

367. Koren, K., Personal communication.

368. Palmer, H. E., W. C. Hanson, B. J. Griffin, *et al.*, Radioactivity measurements in Alaskan Eskimos in 1963. Science 144: 859-860 (1964).

369. Miettinen, J. K., Measurements of Cs^{137} in Finnish Lapps in 1962-63 by a mobile whole body counter. Proceedings of a Symposium on Assessment of Radioactive Body Burdens in Man, May 10-16, 1964, Heidelberg. IAEA, to be published.

370. Häsänen, E., J. K. Miettinen, The body burden of Cs^{137} in people of Southern Finland, 1961-1963. *Ibid.*

371. Liden, K., Y. Naversten, The enhanced radiocesium levels of people in Northern Sweden. *Ibid.*

372. Bengtson, G., K. Liden, The Cs^{137} and potassium

level of the population at Lund, February 1964. Personal communication.

373. Medical Research Council, Assay of Sr^{90} in human bone in the United Kingdom. Results for 1963, part I. Monitoring report series No. 8, 1964; *v.e.* United Nations document A/AC.82/G/L.938.

374. Michon, G., Personal communication.

375. Liden, K., Personal communication.

376. Hardy, E., W. Collins, Health and Safety Laboratory fallout program quarterly summary report, p. 221. USAEC report HASL-131; *v.e.* United Nations document A/AC.82/G/L.803.

377. Feely, H. W., J. E. Hardaway, R. J. Lagomarsino, An estimate of the stratospheric burden of strontium-90 on 1 January 1964. A report of work performed under contract DA-49-146-XZ-079. Defence Atomic Support Agency, Washington, D.C.

378. Telegadas, K., Personal communication.

379. Collins, W., Personal communication.

380. Salter, L. P., Personal communication.

381. Kalstein, M. I., Rhodium-102 high-altitude tracer experiment. Science 137: 645-652 (1962).

382. United Nations Scientific Committee on the Effects of Atomic Radiation, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, annex F, part 3, paragraph 23. General Assembly document Suppl. No. 16 (A/5216), 1962.

383. Ministry of Housing and Local Government, Scottish Development Department and Ministry of Health and Local Government of Northern Ireland, Radioactivity in drinking water in the United Kingdom—1962 results.

384. Takahashi, T., T. Hamada, F. Yamasaki, Personal communication.

385. Saiki, M., Personal communication.

386. International Atomic Energy Agency, Division of Research and Laboratories, Überblick über die Radioaktivität der in Österreich konsumierten Lebensmittel. Mitteilungen der Österreichischen Sanitätsverwaltung 62, Heft 12: 365-376 (1961).

387. Donth, H., Personal communication.

388. Strackee, L., Personal communication.

389. New Zealand Department of Health, National Radiation Laboratory, Fallout in New Zealand. Annual report for 1963, No. NRL/F-11 (1964).

390. Jammet, H., Personal communication.

391. Strackee, L., Iodine-137 in milk in the first quarter of 1962. Rijks Institut voor de Volksgezondheid, Utrecht. Rep. F1/62 RA (1962).

392. Mattern, F. C. U., Iodine-137 in the last part of 1962. Rijks Institut voor de Volksgezondheid, Utrecht. Rep. 34/63 RA (1963).

393. Mahmoud, K. A., Personal communication.

394. Beninson, D., E. Van der Elst, E. Ramos, Studies on fission products in the environment. In press.

395. Bryant, F. J., Personal communication.

396. Kulp, J. L., A. R. Schulert, E. S. Hodges, Strontium-90 in man. Science 132: 448-457 (1960).

397. Alsop, R. J. L., J. Bonnyman, D. W. Keam, *et al.*, Personal communication.

398. Невструева М. А., Моисеев А. А., Попов Д. К. и др., Характеристика радиоактивного загрязнения биологической цепочки мох-олень-человек на крайнем севере СССР в период с 1961 года до начала 1964 года. Личная передача.

399. Марей А. Н., Книжников В. А., Ярцев Е. И. и др., Содержание стронция-90 в костной ткани населения Советского Союза в 1959-1963 годах. Личная передача.

400. O'Brien, B. J., Personal communication.

401. Stebbins, A. K., Second special report on the high altitude sampling programme. Technical Analysis Report DASA-539B (1961).

402. United Nations Scientific Committee on the Effects of Atomic Radiation, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, annex F, part II, paragraph 120. General Assembly document Suppl. No. 16 (A/5216), 1962.

403. Miyake, Y., H. Tsubota, Estimation of the direct contribution of meteoric water to river waters by means of fall-out radiocaesium and radiostrontium, pp. 425-431 *in* Radioisotopes in Hydrology. IAEA, Vienna, 1963.

404. Miyake, Y., K. Saruhashi, Y. Katsuragi, *et al.*, Penetration of Sr^{90} and Cs^{137} in deep layers of the Pacific and vertical diffusion rate of deep water. J. Rad. Res. 3 (3): 141-147 (1962).

405. Kigoshi, K., Krypton-85 in the atmosphere. Bull. Chem. Soc. of Japan 35 (6): 1014-1016 (1962).

406. Machta, L., Personal communication based upon analysis of stratospheric samples of CO for C^{14} by F. Hagermann.

407. Telegadas, K., Personal communication.

408. Machta, L., Personal communication.

409. Keeling, C. D., The concentration and isotopic abundances of carbon dioxide in the atmosphere. Tellus 12 (2): 200-203 (1960).

410. Bishop, K. F., H. J. Delafield, A. E. J. Eggleton, *et al.*, The tritium content of atmospheric methane, pp. 55-62 *in* Tritium in the Physical and Biological Sciences. IAEA, Vienna, 1962.

411. Miyake, Y., K. Saruhashi, Y. Katsuragi, *et al.*, Cesium-137 and strontium-90 in sea water. J. Rad. Res. 2 (1): 25-28 (1961).

412. Friend, J. P., H. W. Feely, P. W. Krey, *et al.*, The high altitude sampling program. Discussion of HASP results, pp. 201-247 *in* Defense Atomic Support Agency report DASA-1300, vol. 3 (1961).

413. United States Atomic Energy Commission, Press release No. F-250, Dec. 6 (1963).

414. United States Atomic Energy Commission, Press release No. 110, May 11 (1964).

415. Grummitt, W. E., J. E. Guthrie, Assessment of the radiation dose to Canadians from fallout. Canadian J. Phys. 42: 287-291 (1964).

416. Menker, H. E., Isotopic composition of uranium and plutonium in Richmond, California, fallout.

USAEC report HASL-131, p. 200; *v.e.* United Nations document A/AC.82/G/L.803.

417. Peterson, K. R., B^{57} air sampling in Southwestern United States—February and March 1961. USAEC report HASL-142, pp. 277-292; *v.e.* United Nations document A/AC.82/G/L.871.

418. Малахов С. Г., Середа Г. А., Брендаков В. Ф. и др., Радиоактивные выпадения на территории СССР в 1963 году. Личная передача.

419. Collins, Jr., W. R., Sr^{90} deposition on the Earth's surface from 1958 through 1963. USAEC report HASL-146, pp. 241-248 (1964).

420. Harley, J., Personal communication.

421. Chesselet, R., G. Lambert, B. C. Nguyen, *et al.*, Paper presented to International Symposium of the French Health Physics Society, Saclay, November 1963.

422. Lingenfelter, R. E., Production of carbon-14 by cosmic ray neutrons. Rev. Geophys. 1: 35-55 (1963).

423. Machta, L., Personal communication.

424. Brown, R. M., Personal communication; *v.e.* IAEA lists WP/17/1, 2 and 3 (January 1962, October 1962 and November 1963).

425. Kigoshi, K., Natural concentration of krypton-85, carbon-14 and tritium in recent years; *v.* United Nations document A/AC.82/G/L.693.

426. Beninson, D., Personal communication.

427. Hiyama, Y., Personal communication.

428. Commissariat à l'énergie atomique, Département de la protection sanitaire, Pollution radioactive des denrées alimentaires. Tableaux récapitulatifs. Document destiné à l'enquête de l'OAA, octobre 1963.

429. Tajima, E., Personal communication.

430. United States Department of Defense, Defense Atomic Support Agency, Project Star Dust, Personal communication.

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