REPORT OF THE UNITED NATIONS SCIENTIFIC COMMITTEE ON THE EFFECTS OF ATOMIC RADIATION

GENERAL ASSEMBLY

OFFICIAL RECORDS : TWENTY-FIRST SESSION
SUPPLEMENT No. 14 (A/6314)

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UNITED NATIONS
New York, 1966

Annex B

ENVIRONMENTAL CONTAMINATION

CONTENTS

I. Airborne and deposited artificial radio-activity

INTRODUCTION

1. There have been no major weapons tests between the end of 1962 and the date of the present report (June 1966). The atmospheric tests in central Asia in October 1964 and in May 1965 and the several accidental releases from low-yield underground tests that have occurred are known to have contributed negligibly to human exposure. Data on an additional Asian test explosion in May 1966 are still not sufficient to permit complete evaluation.

2. Fall-out, however, still provides the major contribution to radio-active contamination of the environment. The purpose of the present report is to update the evaluations of fall-out from the earlier major series of tests made by the Committee in 1964[1] and of the doses to which man has been thereby committed.

3. The cessation of injections of fission products into the stratosphere since the end of 1962 has facilitated the study of the transport mechanisms of nuclear debris and of the depletion process of the stratospheric reservoir that the Committee had discussed at some length in its 1962 and 1964 reports.[1, 2] The reader is referred to these reports for a general outline of the problems of transfer and distribution of radio-activity injected into the atmosphere.

4. There have been indications that fall-out over the oceans may be greater than on equivalent land surfaces. This is a new subject and is therefore treated in some detail in this report.

5. Space activities can also be a potential source of accidental contamination, as shown by the unplanned re-entry into the atmosphere of a spacecraft carrying a power source containing Pu^{238}. As a consequence of the burning up of this device, Pu^{238} was released into the atmosphere. Its distribution will be dealt with later.

6. Local contamination took place in Spain in January 1966 when, as a result of an air collision between an aircraft carrying nuclear weapons and a refuelling plane, fissionable materials were scattered over a limited area by the unexploded devices.[3]

7. Industrial, medical and research applications of nuclear technology contribute only to a very limited extent to environmental contamination and to the attendant exposure of populations. Some gaseous wastes are discharged in limited amounts directly into the atmosphere from reactors and fuel reprocessing plants, while, as discussed in the 1962 report, some low activity liquid wastes are diluted in sea and rivers during normal operations.

8. Doses to the world population from either accidental or controlled releases of wastes have been negligible so far in comparison with those due to nuclear explosions, particularly those carried out above ground. While it is realized that, if large-scale atmospheric testing is not resumed, other sources of contamination

from the peaceful uses of atomic energy may in the future contribute comparatively more to environmental contamination, the present review will mainly be devoted to contamination from nuclear explosions.

Atmospheric injections

Tropospheric tests

9. Two fission devices were exploded above ground in central Asia on 16 October 1964 and on 14 May 1965. The debris of the first device reached Japan two days after the explosion, was detected in North America and Europe about one week later and persisted in some locations for about three weeks. Most of the debris was limited to the band from 20°N to 80°N by the time it reached 80°W.[4-21]

10. Short-lived fission products such as Sr^{89}, Zr^{95}, I^{131}, Ba-La^{140} and Ce^{141} were identified at several sampling sites and 2-10 mCi/km² of short-lived debris were deposited in the United States of America during October-December 1964.[22] Half removal times from the troposphere of five to over twenty days were reported for barium-140.[4, 17, 23] The first evidence of Ba^{140} at Gracefield, New Zealand (41°S 175°E), was found in the monthly sample of December 1964, six to ten weeks following the detonation.[24]

11. According to preliminary data, debris of the second nuclear device, detonated on 14 May 1965, followed tropospheric pathways similar to those followed by debris from the first test and with comparable activity concentrations. Traces of short-lived activity were detected in the United States and elsewhere eight to twelve days after the shot.[16, 17, 20, 25-30] Relatively high concentrations of Np^{239} and some activity due to U^{237} were observed a few days after each detonation in Japan[19, 31] as well as in high altitude samples collected by Indian aircraft.[16]

12. These two explosions were estimated to have contributed about 2 per cent of the long-lived activity in the troposphere that was measured in the monthly samples immediately following each explosion. The contribution became practically insignificant thereafter.[17]

Underground tests

13. Some accidental releases of fission products into the troposphere occurred from at least three low-yield underground tests since March 1964.[17, 20, 31-38] A relative enrichment of volatile radio-isotopes and their radio-active daughters in surface air was expected.[36, 39, 40] The contribution of these events to the radiation doses received by the world population is negligible. Doses in the proximity of the vented tests are not known with any precision.

Stratospheric injection of plutonium-238

14. The only stratospheric injection of radio-active material since December 1962 has consisted of the 17,000 Ci Pu^{238} (alpha emitter, half-life eighty-six years) from a radio-isotope power source (SNAP-9A) which burned up on 21 April 1964 above the Indian Ocean upon re-entry of a spacecraft into the atmosphere. The nuclide was probably released at an altitude of about 50 km, mainly in the form of submicron particles.[41-44] Pu^{238} from this burn-up was first detected in high altitude balloon samples collected at 33 km and 34°S in August 1964, and was also found at 28 km and 34°S in September 1964.[45, 46] In the northern hemisphere (35°N) Pu^{238} was first identified in samples collected at an altitude of 33 km in January 1965.[47] By June 1965, it was found in samples from altitudes exceeding 28 km, at 35°N and higher northern latitudes.[47]

15. By May 1965, the Pu^{238} attributable to the SNAP-9A power source had descended into the lower stratosphere of the southern hemisphere. None was detectable in the lower stratosphere of the northern hemisphere by June 1965.[47-50]

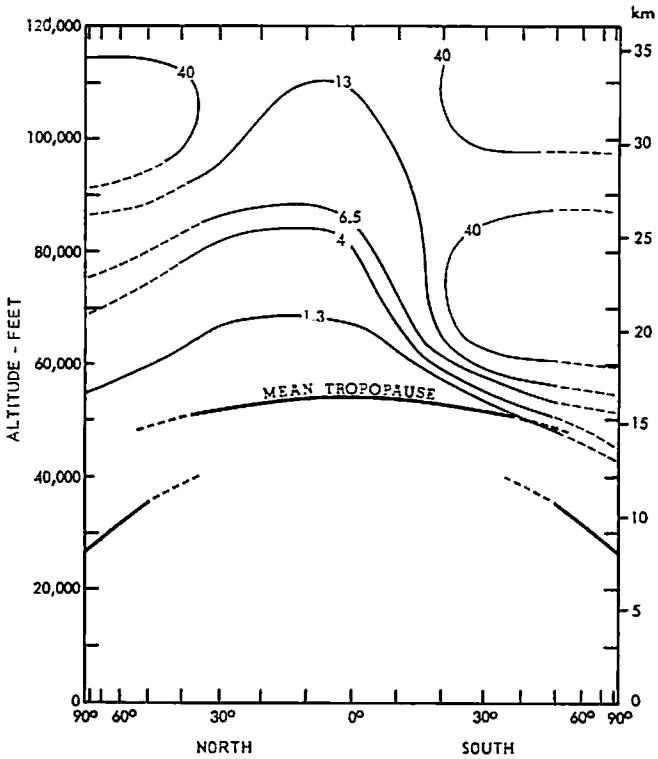


Figure 1. Global atmospheric distribution of Pu^{238}, September-November 1965[64] (pCi/1,000 kg air)

16. Figure 1 shows the global atmospheric distribution of SNAP-9A Pu^{238} a year and a half after its injection, in units of 1×10^{-3} pCi/kg air.[64] Integrating the concentration pattern obtaining one year after the injection indicates that about 10^4 Ci Pu^{238} (approximately 60 per cent of the total) were then present in the stratosphere between 22 and 36 km.[48] Part of the unaccounted for 7×10^3 Ci were probably still above 36 km in the southern hemisphere. Data available so far[44, 47, 48, 50, 51] confirm the general trend predicted by Harley[42] and Machta[43] concerning Pu^{238} concentrations expected in the atmosphere. These predictions were based on the information gathered from the follow-up of the radio-active tracers Rh^{102} and Cd^{109} that were introduced into the stratosphere by high altitude explosions at about 17°N and 43 km in August 1958, and at 17°N and 400 km in July 1962, respectively.[42, 43, 48, 50, 52]

17. Average concentrations of Pu^{238} oxide of the order of 10^{-5} pCi/m³ are expected to persist in surface air during 1965 to 1968.[50] corresponding to about one alpha disintegration due to Pu^{238} per month per m³. This is well below the detection limit of most sampling stations; however, concentrations ten times as great may be reached at some locations. Further predictions should await additional data.

Stratosphere

18. Stratospheric sampling by aircraft between the tropopause and 21 km was continued during 1964 and 1965.[49, 51, 53-56] Higher altitudes up to 35 km were sampled by balloons.[57-60] Because of sampling limitations, the inventories obtained from these data by interpolation and integration may not be better than ± 25 per cent.[61]

19. Recent data refer mainly to C^{14}, Sr^{90} and Cs^{137} which are relevant to population dose estimates, as well as to certain tracer elements such as Cd^{109}, Mn^{54} or Pu^{238}, the movement and distribution of which might contribute to our understanding of stratospheric motions.

20. The distribution of Sr^{90} in the stratosphere during January 1964 and January 1965 is shown in figures 2 and 3. The corresponding distribution of C^{14} is shown in figures 4 and 5. Integration of the distributions show[51, 62] that the stratospheric burden of Sr^{90} decreased from about 4 ± 1 MCi in January 1964 to about 1.6 ± 0.4 MCi by January 1965, while the C^{14} excess in the stratosphere decreased from about 25 ± 5 × 10^{27} atoms to 15 ± 3 × 10^{27} within the same period.

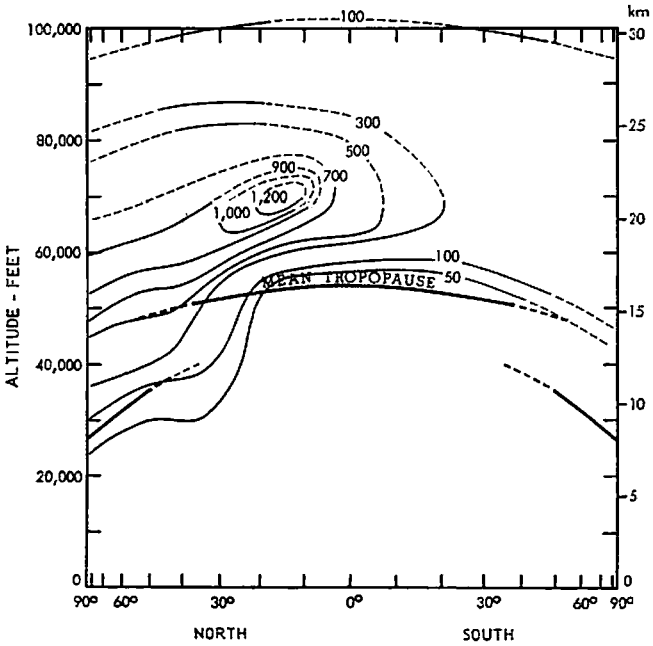


Figure 2. Distribution of Sr^{90} in the stratosphere, January 1964[64] (dpm Sr^{90}/1,000 SCF)[a]

[a] 1 dpm/1,000 SCF = 13 pCi/1,000 kg air.

21. The mean residence time of particulate radioactive debris in the stratosphere, as derived by integration of the results of the stratospheric sampling network for Sr^{90}, was approximately fourteen months during 1963 to 1964.[51, 63] The mean residence time of $C^{14}O_2$ in the stratosphere was about twenty-five months during the same period[51] (about seventeen months for the northern stratosphere alone). These differences in residence times, as well as the different distributions of these two nuclides in the stratosphere, may reflect the facts that some settling of particulates may take place in the atmosphere and that tropospheric air, rich in $C^{14}O_2$ relative to Sr^{90}, re-enters the stratosphere.[64]

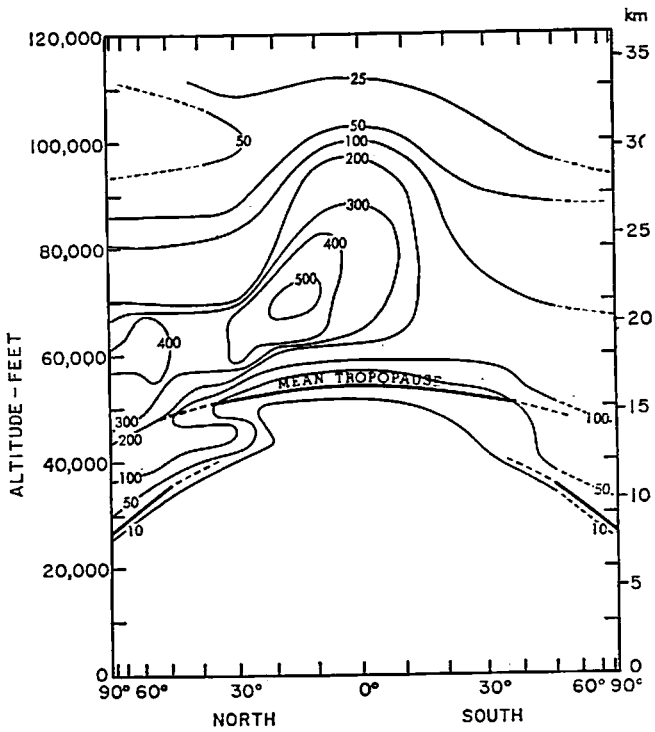


Figure 3. Distribution of Sr^{90} in the stratosphere, January 1965[62] (dpm Sr^{90}/1,000 SCF)[a]

[a] 1 dpm/1,000 SCF = 13 pCi/1,000 kg air.

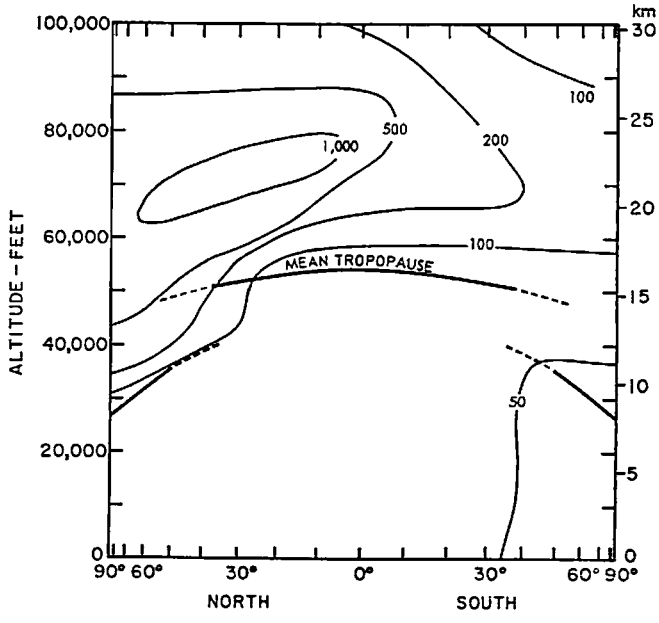


Figure 4. Distribution of C^{14} in the stratosphere, January 1964[64] (10^5 atoms of excess C^{14}/g air)

22. Provisional results since October 1964 of total gamma counts on high altitude samples, when expressed in activity per unit standard volume of air, suggested some accumulation of nuclear debris above 20 km at equatorial latitudes.[57, 58] Balloon samples taken during the period January-April 1965, at 9°N and 20 km also contained activity per unit standard volume of air about two to three times higher than samples collected at 31°, 45° and 65°N at similar altitudes.[60] No final results are available yet from the few samples taken by aircraft in the lower stratosphere at equatorial latitudes during the first half of 1965.

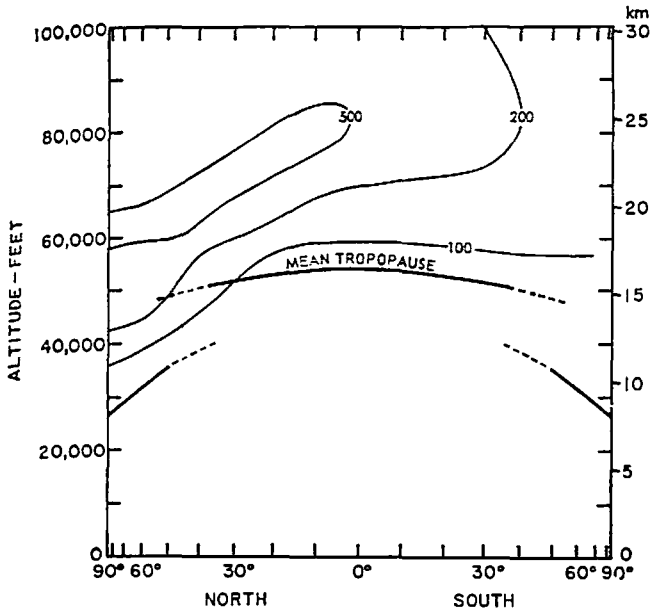


Figure 5. Distribution of C^{14} in the stratosphere, January 1965[62] (10^5 atoms of excess C^{14}/g air)

23. These findings are summarized in figure 3, which reveals two regions of high activity concentrations, one at about 10°N and the other at about 65°N, some 7 km above the tropopause. However, the maximum concentrations above equatorial regions as shown in the figure, rather than reflecting the actual stratospheric distribution of the nuclear debris, are an artifact due to the unit chosen to express concentrations (SCF^{-1}).

24. Figure 6 depicts the same data as figure 3, but expresses concentrations in terms of activity per actual volume of space rather than per unit mass (standard volume) of air.[64] The concentration gradients become steeper above altitudes where the maximum concentrations occur and less steep at lower altitudes. The apparent piling up of activity over the equator is much less pronounced. This type of presentation gives a more direct picture of the activity distribution but does not permit simple calculations of the movement and mixing of air masses. Figure 7 is the corresponding figure for C^{14} concentrations in the stratosphere using the same data as those in figure 5.

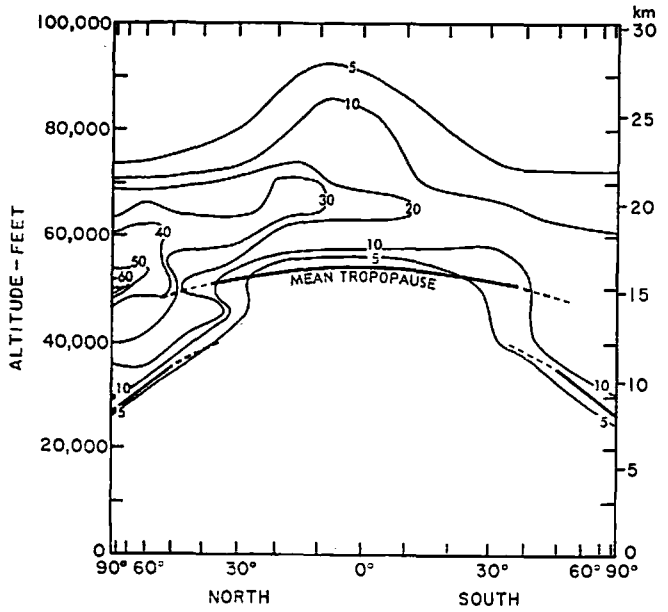


Figure 6. Distribution of Sr^{90} in the stratosphere, January 1965[64] (dpm Sr^{90}/1,000 ambient cubic feet)[a]

[a] 1 dpm/1,000 cubic feet = 15.9 pCi/1,000 m³.

Troposphere

25. *Strontium-90.* Figure 8 shows the average Sr^{90} concentrations in surface air at the United States western hemisphere stations.[1, 62, 65] Average Sr^{90} concentrations for the fourteen stations sampled in the northern hemisphere ranged from about 15 pCi/1,000 m³ to 70 pCi/1,000 m³ in 1963, from about 7 pCi/1,000 m³ to 50 pCi/1,000 m³ in 1964 and continued to decline in 1965. The decrease in Sr^{90} concentrations in the northern hemisphere during 1964 and 1965 is compatible with a fourteen-month mean residence time in the stratosphere.

26. The average concentrations in surface air at seven stations of the southern hemisphere were lower than those encountered in the northern hemisphere by a factor of ten to twenty during 1963 and ranged from about 1.5 to 4 pCi/1,000 m³. They ranged from about 2 pCi/1,000 m³ to 5 pCi/1,000 m³ in 1964 and declined during the first half of 1965. Air concentrations throughout the first half of 1965 were about five times lower than the values for the northern hemisphere.[66]

27. An isopleth representation of Sr^{90} concentrations in surface air as a function of latitude is shown in figure 9, which was derived from results at twenty western hemisphere stations for the years 1963-1965.[67] The data from Chacaltaya, Peru (16°S 68°W), were not included, because the altitude of this station (5,200 m) is such that the results cannot be considered as representative of the surface air concentrations at this latitude. An approach to symmetry between the concentration patterns in each hemisphere is evident when a six-month shift is allowed for between hemispheres.

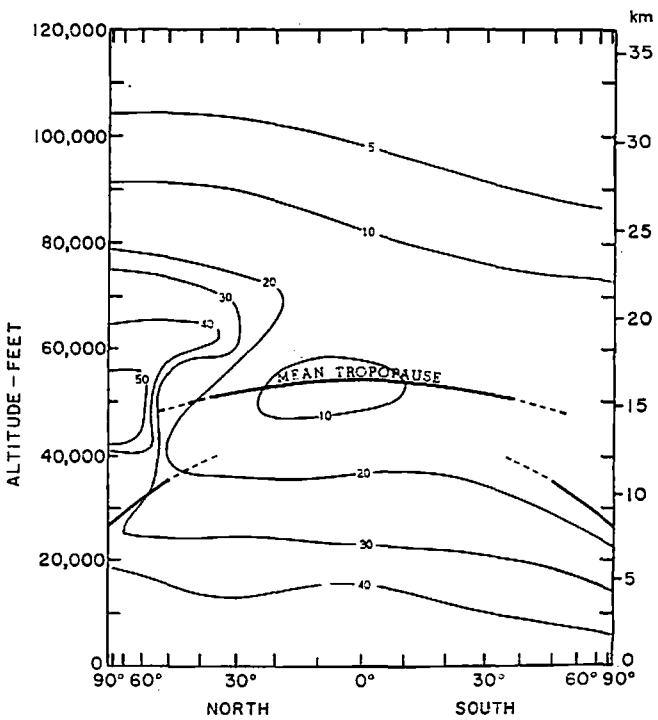


Figure 7. Distribution of excess C^{14} in the stratosphere, January 1965[64] (10^5 atoms C^{14}/0.8 litres ambient air)

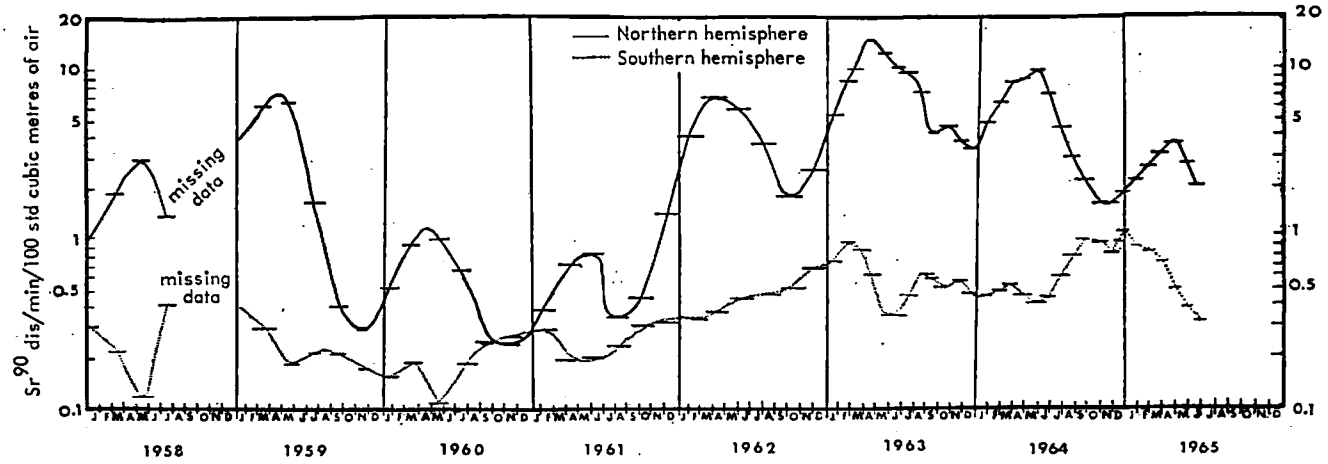


Figure 8. Average Sr^{90} concentrations in surface air (80°W), 1958-1965[65]

28. *Caesium-137.* Figure 10 shows the average monthly Cs^{137} concentrations in surface air in Norway[68, 69] and Sweden[70, 71] since January 1962. Cs^{137} concentrations in the United Kingdom[17, 72] and at Argonne, Illinois, United States,[23, 73, 74] are shown in figure 11. The spring maxima and autumn minima evident in figures 8 and 9 are also obvious in figures 10 and 11. Cs^{137} concentrations were highest at Argonne and of comparable magnitude in Norway, Sweden and the United Kingdom. A decrease in concentrations during 1964 and 1965 as compared to 1963 levels is evident. Measurements in India show similar trends.[75, 76]

29. *Carbon-14.* Excess C^{14} concentrations in the troposphere for each hemisphere are shown in figure 12 for the years 1956-1965.[62] Concentrations in both hemispheres tend to equalize, and they follow closely earlier predictions.[1, 77] Over-all average values of excess C^{14} concentration in the troposphere for 1963 were 60 per cent above the natural level of 74×10^5 atoms C^{14} per gramme of air[78] that obtained before nuclear tests were conducted. The excess of artificial C^{14} continued to increase until mid-1964. Average excess values were about 85 per cent for 1964 and 1965.[62, 78-81]

Deposition on land

30. Samples of deposited activity have been collected in the period under review at more than 200 sites scattered throughout a large part of the land area of the earth's surface.[16-19, 22, 31, 68-70, 72, 76, 82-105] Total beta activities and deposition rates of Sr^{90}, Cs^{137} and other radio-nuclides have been systematically analysed.

31. *Strontium-90.* The monthly Sr^{90} deposition in New York City since 1954[106] and in Buenos Aires since 1959[102] are given in figures 13 and 14, respectively, as examples of rates of deposition in the northern and southern hemispheres. As the rainfall throughout 1964 and 1965 was exceptionally low in the New York area, deposited Sr^{90} levels after August 1964 were somewhat lower than predicted on the basis of a normal precipitation pattern.[107]

32. An isopleth representation of global Sr^{90} deposition rates per month from 60°S to 80°N for the period 1963-1965 is shown in figure 15, based on the sampling network operated by the United States Atomic Energy Commission.[65, 86] The deposition pattern follows closely the surface air concentrations shown in figure 9. Sr^{90} peak deposition values were encountered in the period April-July 1963 between 40°N and 60°N. Comparable values were encountered during the period April-June 1964 at the same latitudes.

33. A general decrease in the yearly deposition rates for the northern hemisphere has been evident since 1963, total Sr^{90} depositions being 2.32, 1.47 and 0.69

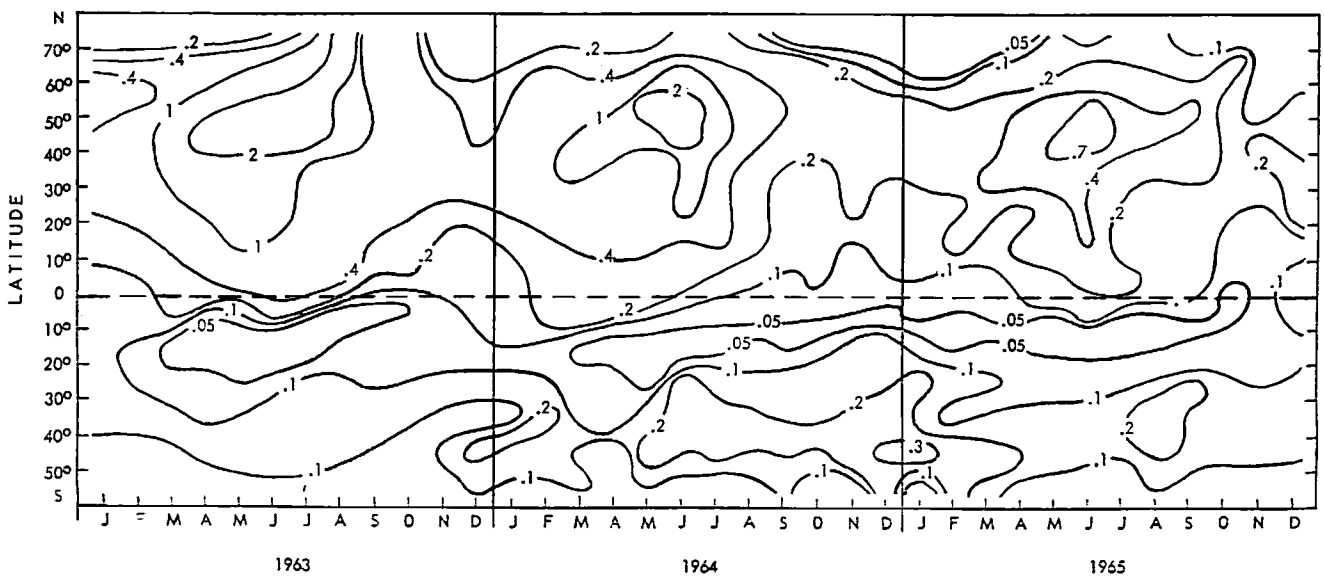


Figure 9. Isopleth representation of Sr^{90} concentrations in surface air, 1963-1965[65, 67] (dpm Sr^{90}/1,000 m^3)

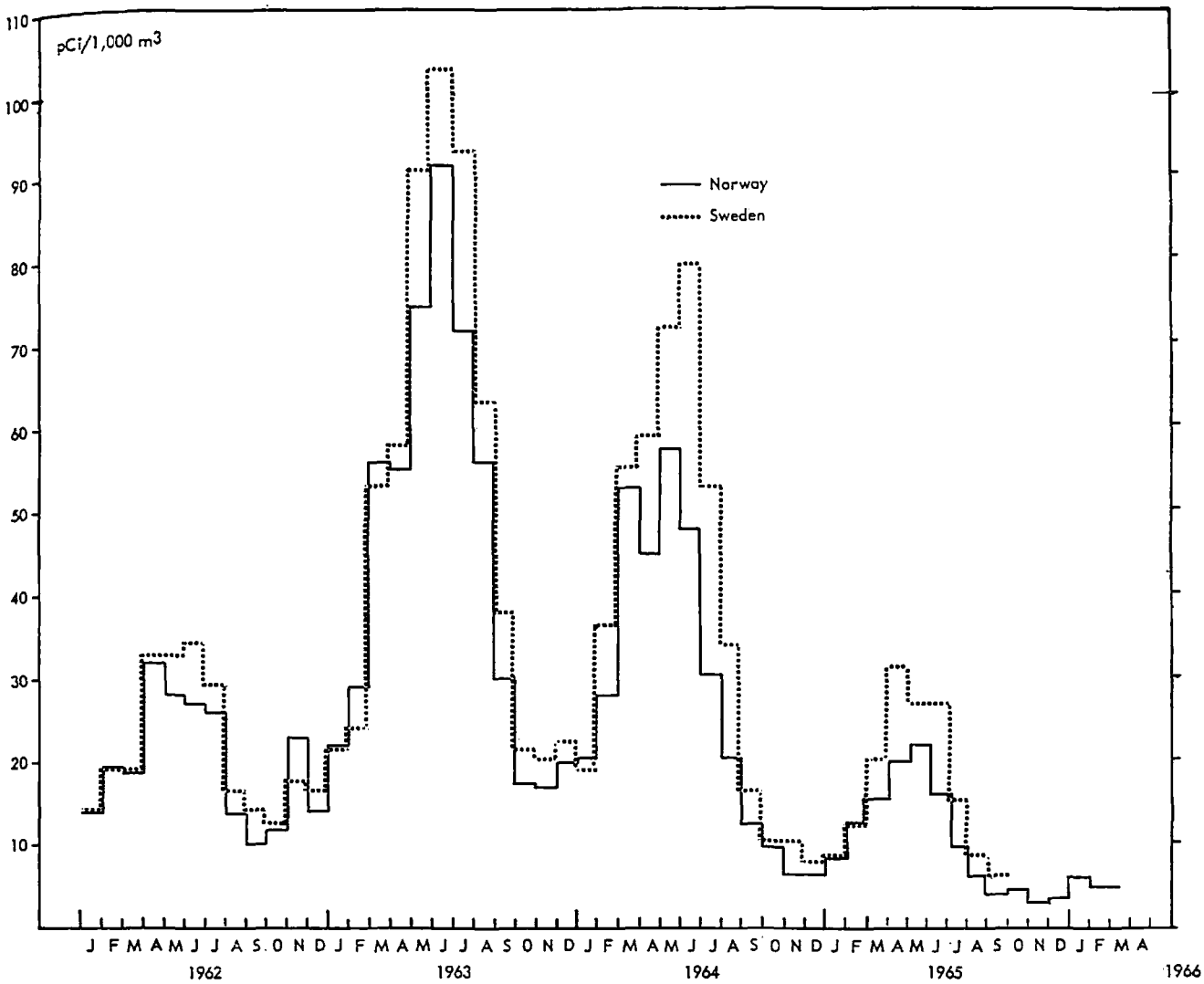


Figure 10. Average monthly Cs^{137} concentrations in surface air for Norway[68, 69] and Sweden,[70, 71] 1962-1966

MCi for 1963, 1964 and 1965, respectively.[65] Corresponding Sr^{90} deposition values for the southern hemisphere were 0.29, 0.38 and 0.31 MCi, respectively.[65] The annual deposition rates in the two hemispheres are expected to be about equal by 1967. Figure 16 shows the world-wide monthly deposition of Sr^{90} since 1958 as derived from the United States Atomic Energy Commission data.[62, 86] The Sr^{90} cumulative deposition, corrected for radio-active decay, is shown in figure 17 for each hemisphere.[86]

34. These global annual deposition rates of Sr^{90} and the cumulative deposition since 1957 as estimated by the United States Atomic Energy Commission are compared to the United Kingdom Atomic Energy Research Establishment estimates[17, 72] in table I. The United States estimates are derived by simple arithmetic averaging of the deposition sites in each 10° latitude band. The United Kingdom estimates, which are based on a smaller number of sampling stations and weighted by regional precipitation,[108] systematically show somewhat higher values. Considering the incomplete coverage of the land surface of the earth by either network, some discrepancy between the two sets of estimates must be expected.

35. The deposited Sr^{90} activity during 1964 and 1965 was close to former predictions based on the application of previously observed deposition patterns to the stratospheric inventory of Sr^{90} as of the end of 1963.[1, 73, 77, 109]

36. *Caesium-137.* No comprehensive information on global Cs^{137} deposition comparable to that on Sr^{90} is available. Some networks include Cs^{137} determinations in their routine as a supplement to Sr^{90} data.[22, 91, 99, 100] Others, applying nominal values of Cs^{137}/Sr^{90} ratios, use Cs^{137} results to estimate Sr^{90} values,[17, 72, 104] thus saving considerable radio-chemical efforts, as Cs^{137} distributions in the atmosphere must parallel Sr^{90} distribution patterns. Figure 18 shows the monthly Cs^{137} deposition at Argonne, Illinois, United States, since 1962[23] and the monthly average Cs^{137} deposition rates for Australia during 1964 and 1965.[104]

37. Some recent estimates of Cs^{137}/Sr^{90} ratios as obtained from deposited activity, rain-water concentrations, ground level air concentrations at various sites and stratospheric samples since 1963 are shown in table II. These ratios are in general higher than 1.5. The variations in Cs^{137}/Sr^{90} values probably reflect inconsistencies in the radio-chemical determination of Cs^{137} at many laboratories.

38. Some evidence suggests that the average Cs^{137}/Sr^{90} ratios for the large scale stratospheric tests during 1961 and 1962 was about 1.45 rather than 1.7.[62, 110] Experimental errors preclude any conclusion

as to a shift in Cs^{137}/Sr^{90} ratios towards lower values since 1963.

Deposition in the oceans

39. Deposition of Sr^{90} in the oceans is mainly of importance in relation to the inventory of Sr^{90}. The dilution of Sr^{90} and other fall-out products by the large volume of the ocean at present suggests minimal doses to man.

40. The oceans cover 70 per cent of the earth's surface, and sampling them presents a different, and,

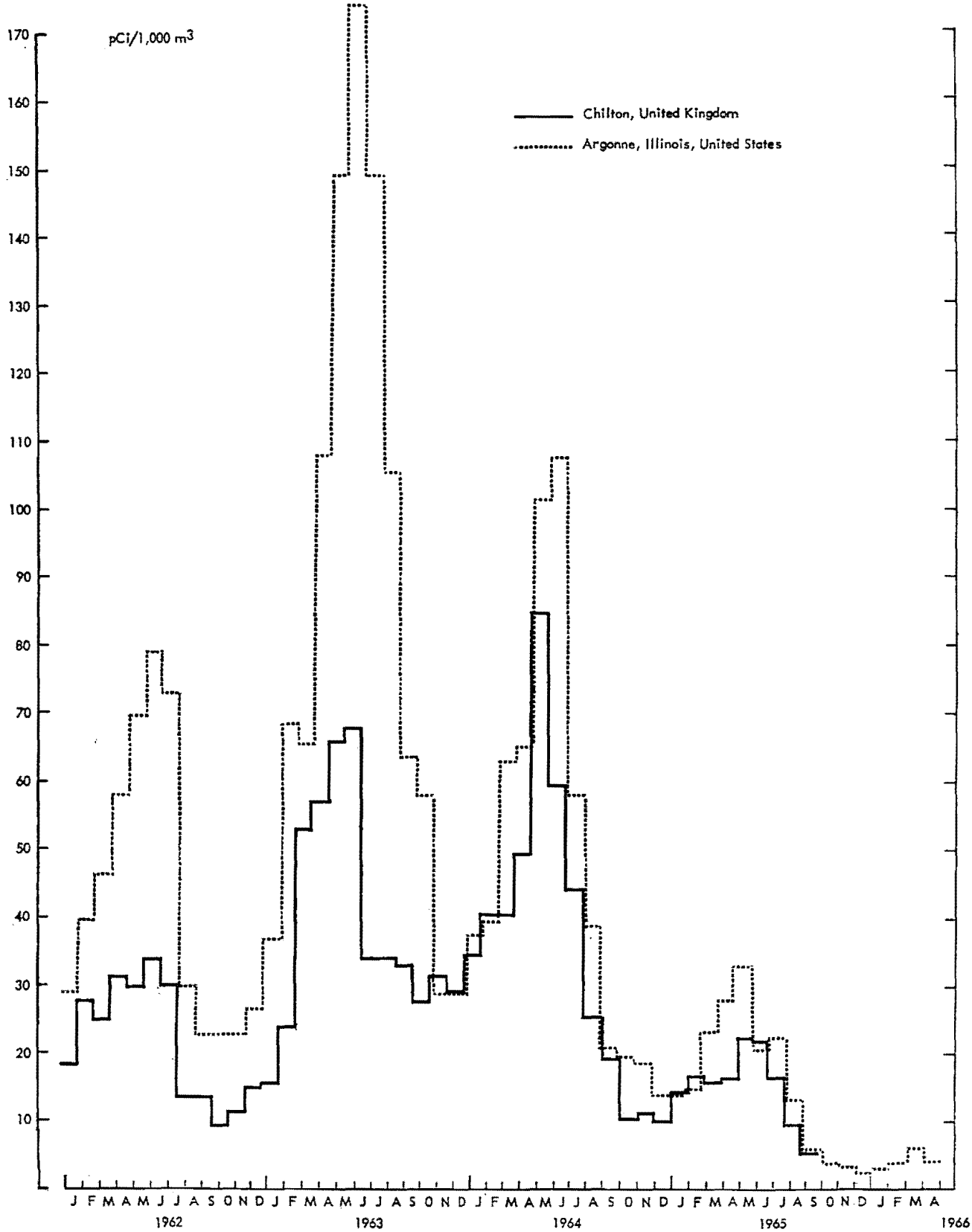
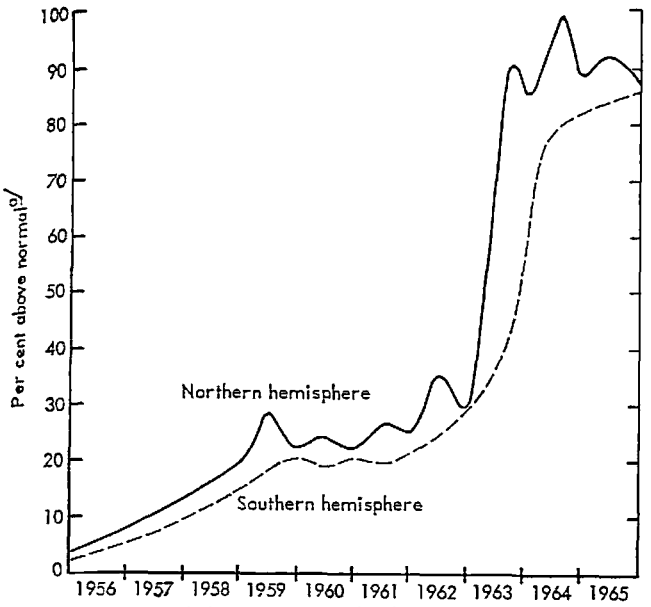


Figure 11. Monthly Cs^{137} concentrations in surface air for Chilton, United Kingdom,[17, 72] and Argonne, Illinois, United States,[23, 73, 74] 1962-1966



[a] Taking as normal the air concentration in 1954 (74×10^5 atoms of C^{14} per gramme of air).[78]

Figure 12. Tropospheric inventory of carbon-14[64]

from some points of view, a more difficult problem than sampling the continents. The depth of the oceans, averaging almost 4,000 metres, and the movement of water are major complicating factors.

41. The radio-chemical analysis of Sr^{90} in ocean water is difficult, particularly the analysis of samples from great depths, since levels are low and large amounts of reagents are required. Blank samples are frequently found to show detectable levels, often of the same order as the measured values.[111-117] This increases the uncertainty of measurement and has cast doubt on some of the results for deep water.

Concentrations of strontium-90 in surface water

42. The Sr^{90} concentration of surface water in the seas and oceans as reported by various investigators has varied greatly as a function of both geography and time. Figures 19 to 22 summarize most of the reported surface water Sr^{90} results through 1961. The variation of Sr^{90} concentrations with latitude in the oceans and certain seas for 1960 and 1961 clearly illustrates that, even under the best circumstances, as in the southern Atlantic and Indian Oceans, the values have a variability of at least a factor of two. Pacific Ocean values have even greater variability, probably reflecting "hot spots"

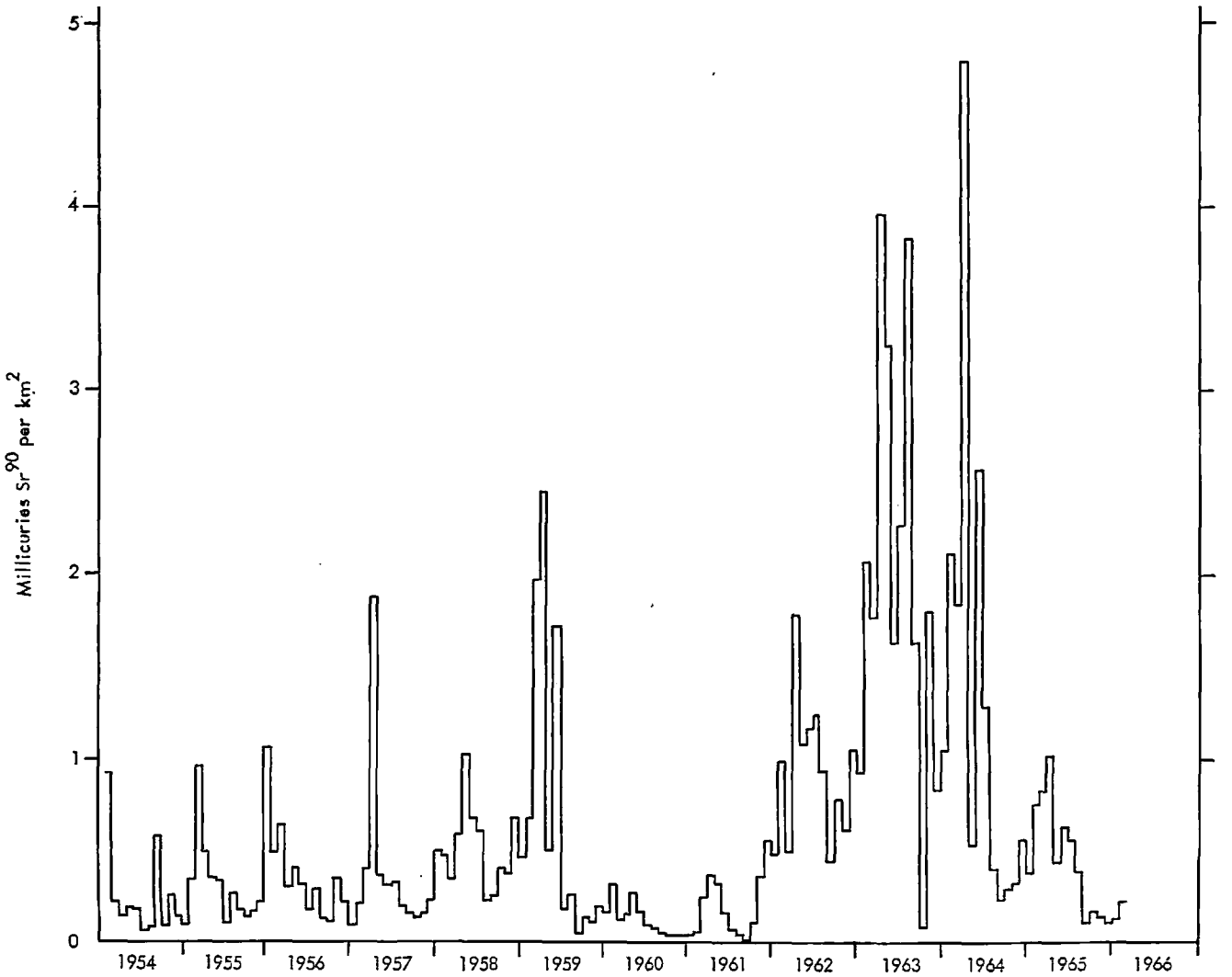


Figure 13. Monthly deposition of Sr^{90} in New York City, 1954-1966[106]

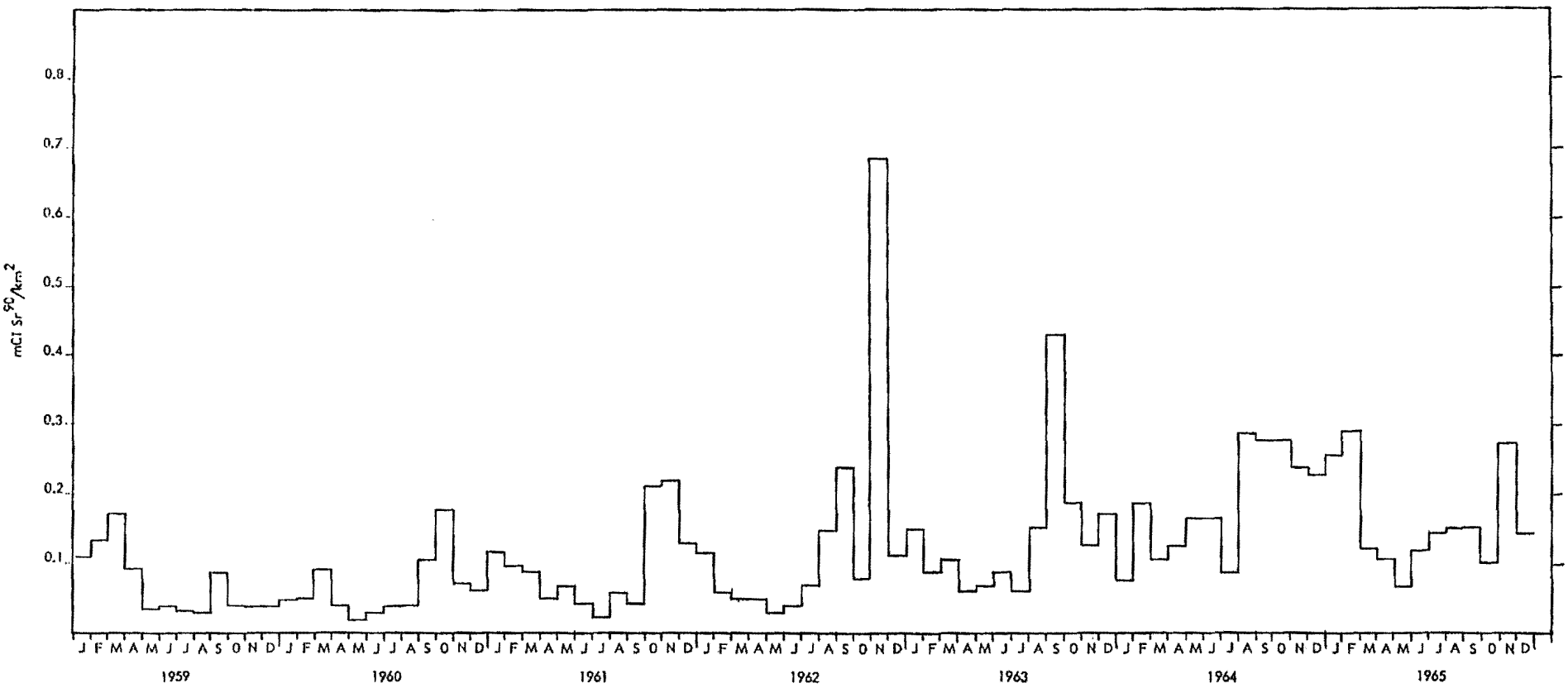


Figure 14. Monthly deposition of Sr^{90} in Buenos Aires, Argentina, 1959-1965[215]

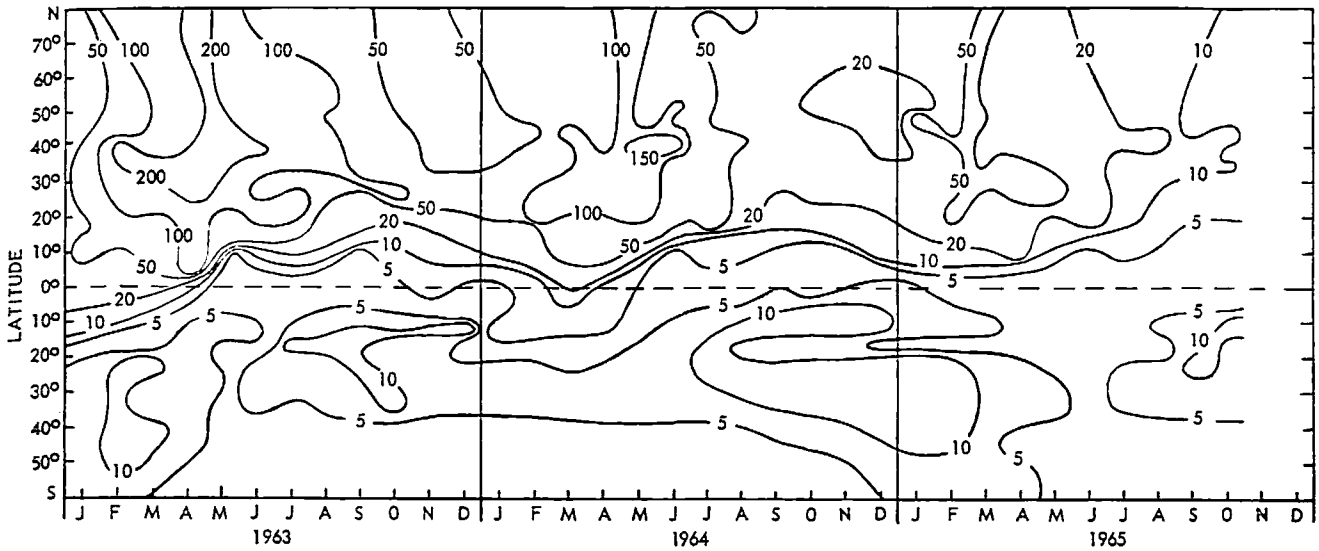


Figure 15. Sr^{90} deposition integrated according to zonal belts as a function of time, 1963-1965[65] (mCi/km² per month)

due to greater local fall-out.[325, 326, 338-341] For inventory purposes, however, only data from the north Atlantic Ocean have been considered.

43. From the data used in these graphs, Popov and Patin tabulated the average concentrations of Sr^{90} for 1960 and 1961 shown in table III. Very few measurements have been reported after 1961 except from the north Atlantic Ocean.[112, 113, 115, 118] These (table IV) indicate an increasing trend of Sr^{90} concentrations in surface water until the end of 1964. The data from the first half of 1965 suggest that the level of Sr^{90} in this region has started to decline.

44. For the western Pacific Ocean in the vicinity of Japan, surface water in the years 1963 and 1964 averaged about 0.43 pCi/litre and ranged from 0.25 to 0.53,[119] while, for the eastern region of the Pacific Ocean, concentrations from about 0.04 pCi/litre[112] in 1963 to 0.5 pCi/litre in 1965[111] were reported.

45. The now well documented latitudinal variation of deposition of Sr^{90} on land (figure 15) is not observable in surface ocean water. However, in table III and figures 19 to 21 the generally higher values for the northern hemisphere presumably reflect the fact that most nuclear tests have so far been carried out in the northern hemisphere.[120-128]

Concentrations in deep water

46. Measurements of fission product concentrations are consistent with more rapid contamination of deeper water with strontium-90[111, 113, 117, 119, 121-123, 129, 130] than some investigators believed possible.[112, 118, 131] Bowen *et al.*[113, 115, 120] found mid-depth (1,000 to 3,000 metres) concentrations of Sr^{90} in the Atlantic Ocean consistent with the flow rates of intermediate depth currents derived from hydrographic considerations. Belyaev *et al.*[130] used observed turbulent diffusion coefficients and mean current velocities to solve the complete transport equation. The calculated distribution of Sr^{90} with depth in the Atlantic Ocean was found to be in agreement with observed data.[325, 327, 338-341]

47. Ozmidov and Popov[122] pointed out the slower increase of Sr^{90} concentration with time in the north Atlantic Ocean surface water compared to that on adjacent land and concluded that these data indicated intense vertical turnover of ocean water above and below the thermocline.

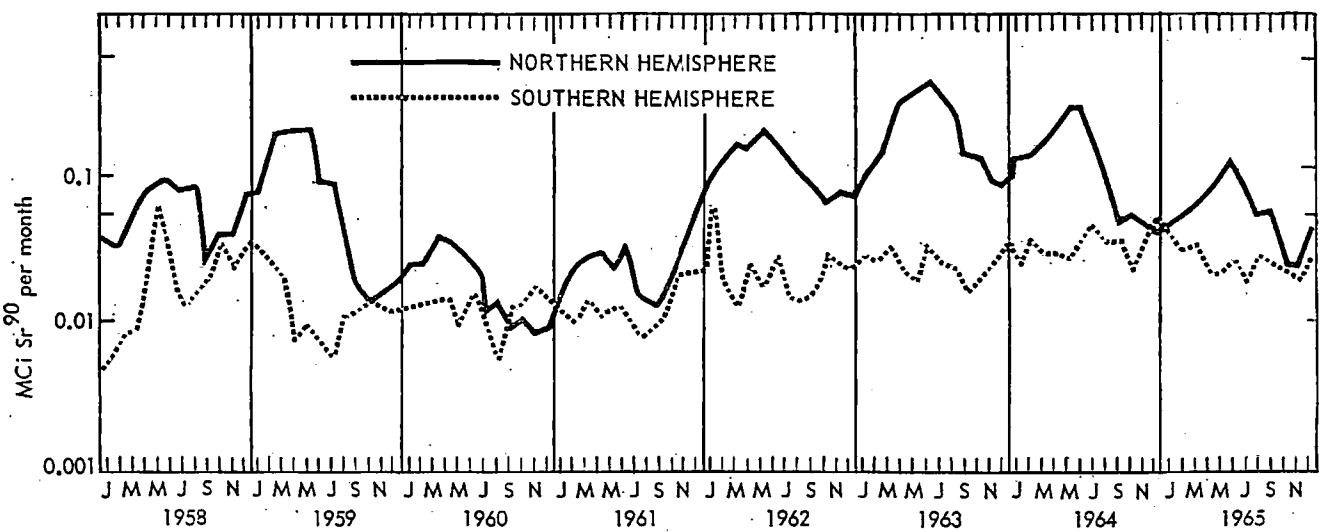


Figure 16. Hemispheric deposition rates of Sr^{90}, 1958-1965[85, 86]

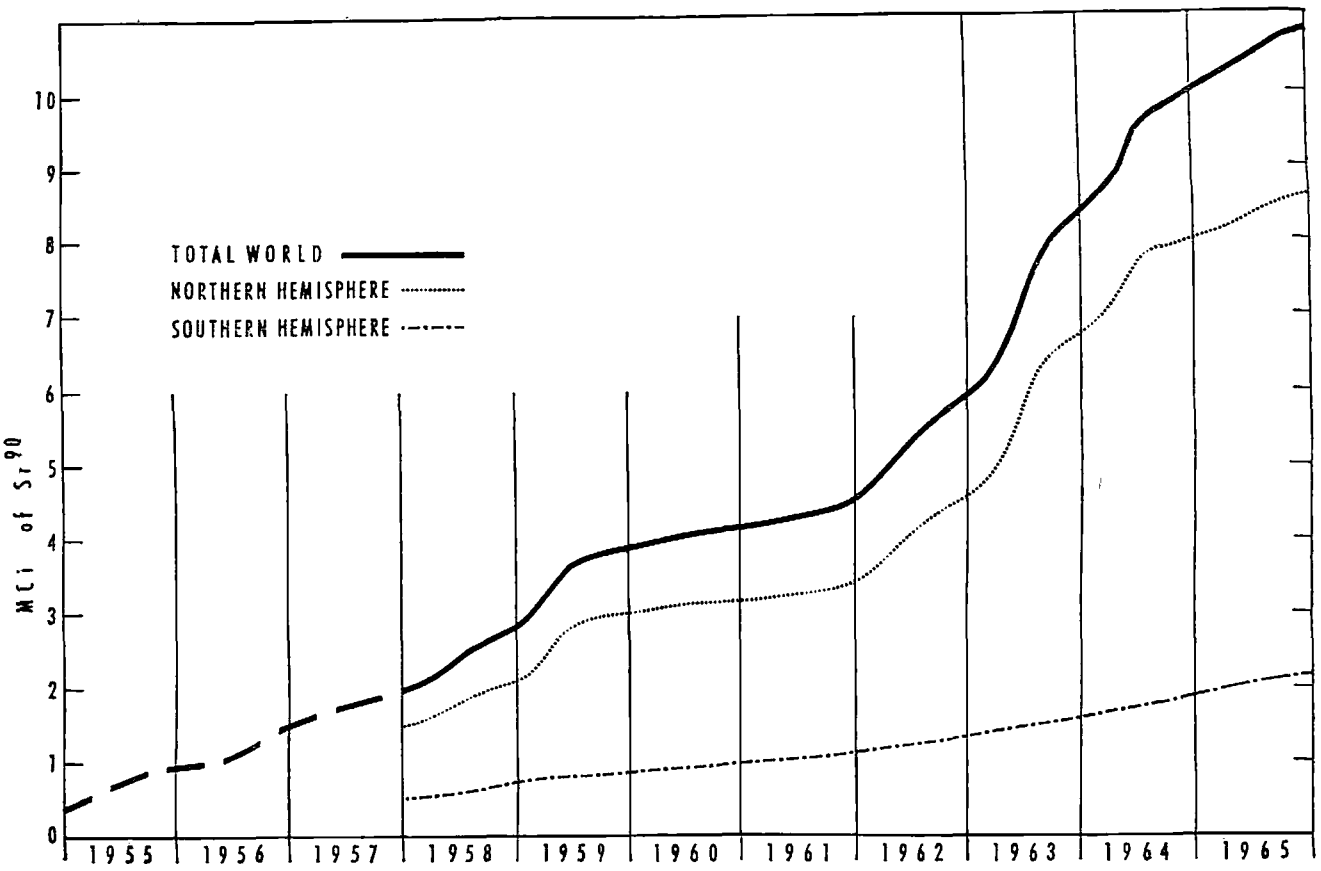


Figure 17. Cumulative Sr^{90} deposit, 1955-1965[85, 86] (corrected for radio-active decay)

48. In 1962, north Atlantic water samples at depths from 1,000 to 3,000 metres or more had Sr^{90} concentrations averaging about 0.03 pCi/litre with values ranging from 0.01 to 0.07.[113] Equatorial Atlantic samples from similar depths averaged about 0.04 pCi/litre in 1963.[113] Figure 23 illustrates average profiles of Cs^{137} and Sr^{90} for the equatorial Atlantic Ocean in 1963 and 1964.

49. Broecker[112] reported much lower values for mid-1963, generally less than 0.01 pCi/litre, for deep water from both the Atlantic and Pacific Oceans. This lack of agreement in deep water samples probably relates to the problem of corrections for blank samples.

50. The dating of deep water samples by natural pre-test radio-carbon shows a very slow rate of exchange between deep and surface water which is incompatible with the appearance of Sr^{90} in the deep ocean. Östlund,[139] moreover, found water with little or no tritium in certain areas of the deep Atlantic Ocean where Bowen detected appreciable amounts of Sr^{90}.

51. Several investigators[111, 119, 120, 132] have also reported measurements of other nuclides from atomic explosions, such as Cs^{137}, Zr^{95}, Nb^{95}, Ce^{144}, Ru^{103}, Ru^{106} and Pm^{147}, at considerable depths in the oceans. It must be recognized, however, that the mechanism of transport of some of these nuclides may be different from that of Sr^{90}.

Comparison of terrestrial and oceanic fall-out

52. Several investigators[111, 115, 120-124, 129, 133-136] found that deposition of Sr^{90} in the oceans was higher than on the adjacent land bodies, generally by a factor of between 1.5 and 5 per unit area. Karol *et al.*,[124] studying 1960-1961 data in 10° latitude bands, found ocean/land deposition ratios ranging from 1 to 8, with the average for the entire 70°N to 30°S region being about 2.

53. Integration of observed Sr^{90} values in the mixed layer down to the thermocline yields a value for accumulated Sr^{90} deposited which is approximately the same as that expected from observations on land. Accordingly, in so far as the presence of Sr^{90} in water below the thermocline can be demonstrated, the fall-out over the oceans must be greater than that measured over land.

54. Enhanced Sr^{90} deposition over the ocean compared with land areas would help to explain the disparity between the change in atmospheric content, and that in land fall-out. The annual reduction in the observed atmospheric content of Sr^{90} is found to be 1.5 times the total world-wide deposition estimated from land-based stations since 1963.[63, 64, 111, 124, 137]

55. Calculation shows that this corresponds to a deposition factor over the oceans, per unit area, of about 1.8 times that which has been estimated over land. It must be remembered that our knowledge of deposition over the entire land surface is far from complete, little information being available, for example, regarding heavily forested areas. Heavier deposition in such regions could partially explain the apparent discrepancy.

56. Chesselet *et al.*[132, 138] measured concentrations of $Zr^{95} + Nb^{95}$, Ru^{103} and Ru^{106} in waters of the western Mediterranean and the Bay of Biscay in late 1963 by *in situ* gamma spectrometry. Comparing the results of these measurements with observations made simultaneously at continental sea shore stations, they concluded that the deposition had been two to seven times greater over the oceans.

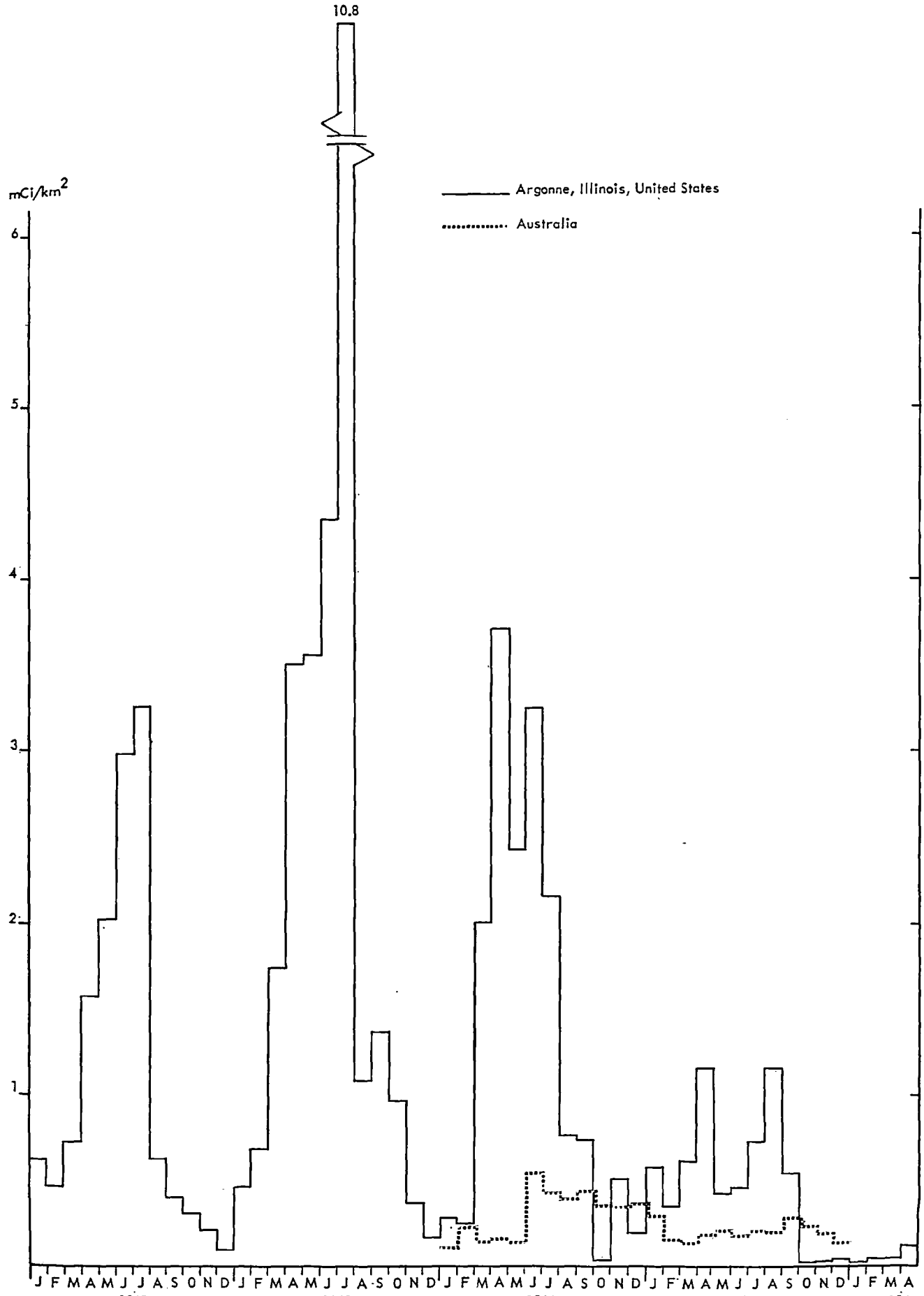


Figure 18. Monthly deposition of Cs^{137} at Argonne, Illinois, United States, for 1962-1966,[23] and the average monthly deposition of Cs^{137} in Australia for 1964-1965[104]

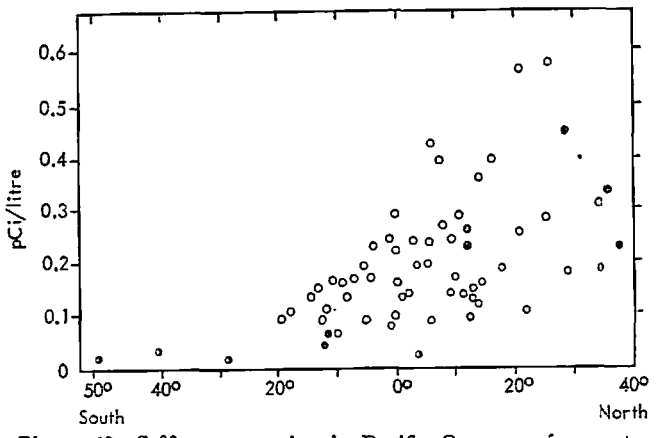


Figure 19. Sr^{90} concentration in Pacific Ocean surface water in 1960 and 1961[125, a]

[a] Different symbols indicate results of different investigators.[118, 325, 326]

showed that, in almost all latitudes tested, the concentration of artificial radioactivity is lower above the sea than above the land.

Conclusions

60. The presence of Sr^{90} in the deep waters of the oceans and seas appears to be confirmed by several investigators, although the low levels of the radioactivity may in some cases preclude the accuracy in the radio-chemical analyses that would be necessary for unambiguous interpretation. Other information, such as C^{14} and H^3 measurements, is in conflict with this.

61. On balance, it appears that more Sr^{90} has been deposited over oceans than over land per unit area. The precise amount of the excess has not yet been determined but the average ratio of ocean deposition per unit area to that measured on land may be between 1.5 and 3. The mechanisms which bring about this

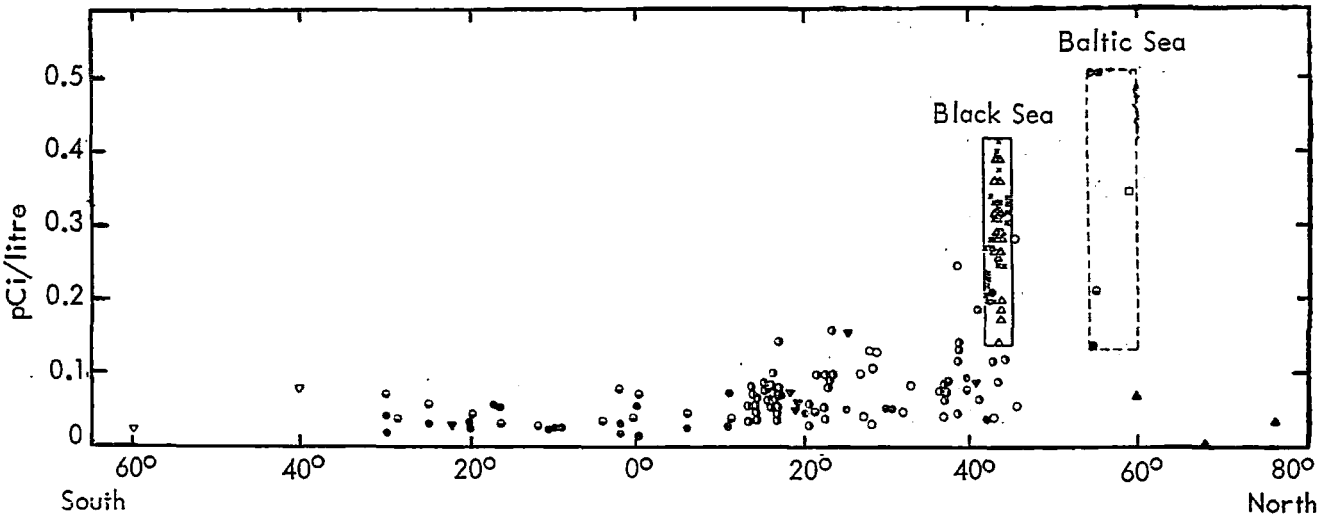


Figure 20. Sr^{90} concentration in Atlantic Ocean surface water in 1960 and 1961[125, a]

[a] Different symbols indicate results of different investigators.[118, 165, 326-334]

57. Broecker *et al.*[134] utilized the Sr^{90} concentration of shallow water on the Bahama Banks which was also dated by its content of artificial C^{14}. These parameters permitted a comparison of fall-out in that region with land sites. The data suggested that fall-out on the Bahama Banks was not systematically higher than that observed on land masses in the same latitude belt. The sensitivity of this experiment, however, could not distinguish differences of less than about a factor of two.

58. Machta *et al.*[140] studied the Sr^{90} distribution in Lake Michigan and found that the deposition over this large lake was not higher than that extrapolated from nearby land stations. The relevance of this observation will depend upon many factors such as absorption by sediments and general similarity to ocean conditions.

59. Karol *et al.*[124] have shown that neither higher concentration of Sr^{90} in oceanic rain[342, 343] nor higher precipitation are likely mechanisms of enhanced deposition over the ocean, since no increased deposition was observed on island stations, confirming the conclusion reported in the 1964 report. They suggest that the major mechanism is related to the air-sea interface, and consists of "scrubbing" of the surface air by sea-water spray and salt particles, and of irreversible absorption of the aerosol by the water surface. These conclusions were tested by comparing Sr^{90} and other radio-nuclides in surface air taken over land and sea areas. The result

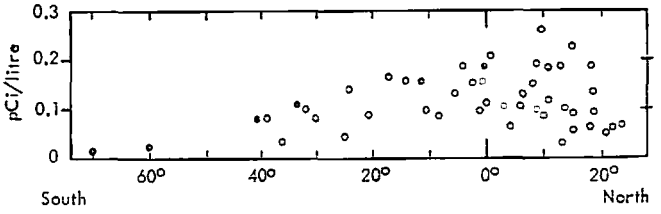


Figure 21. Sr^{90} concentration in Indian Ocean surface water in 1960 and 1961[125, a]

[a] Different symbols indicate results of different investigators.[128, 326]

enhanced oceanic deposition are not clear, but evidence suggests that it is related to phenomena at sea-air interface rather than to precipitation.

Summary

62. Table V shows the changes in the global Sr^{90} inventory since 1960. The estimate of cumulative deposition is based on the assumption that deposition per unit area is the same over oceans as that measured on land.

63. The observed stratospheric mean residence time of fourteen months for particulate radio-activity in the years 1963-1965 is shorter than the assumed value of twenty-four months used in the 1964 report. No single

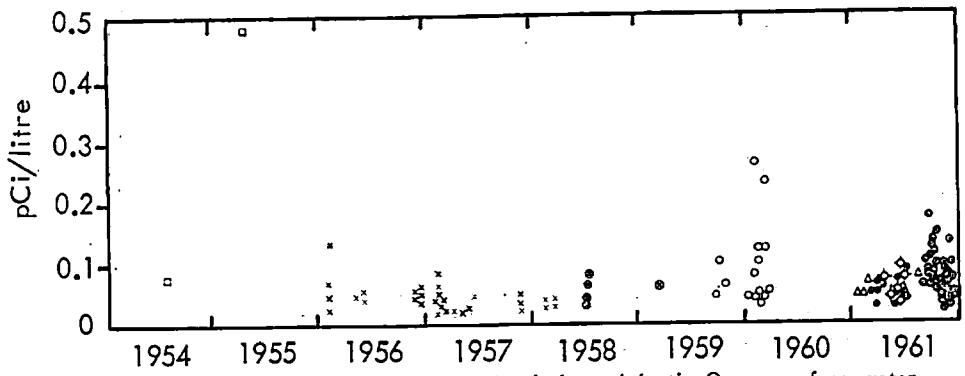


Figure 22. Sr^{90} concentration in northern hemisphere Atlantic Ocean surface water, 1954-1961[125, a]

[a] Different symbols indicate results of different investigators.[118, 125, 127-129, 135-137]

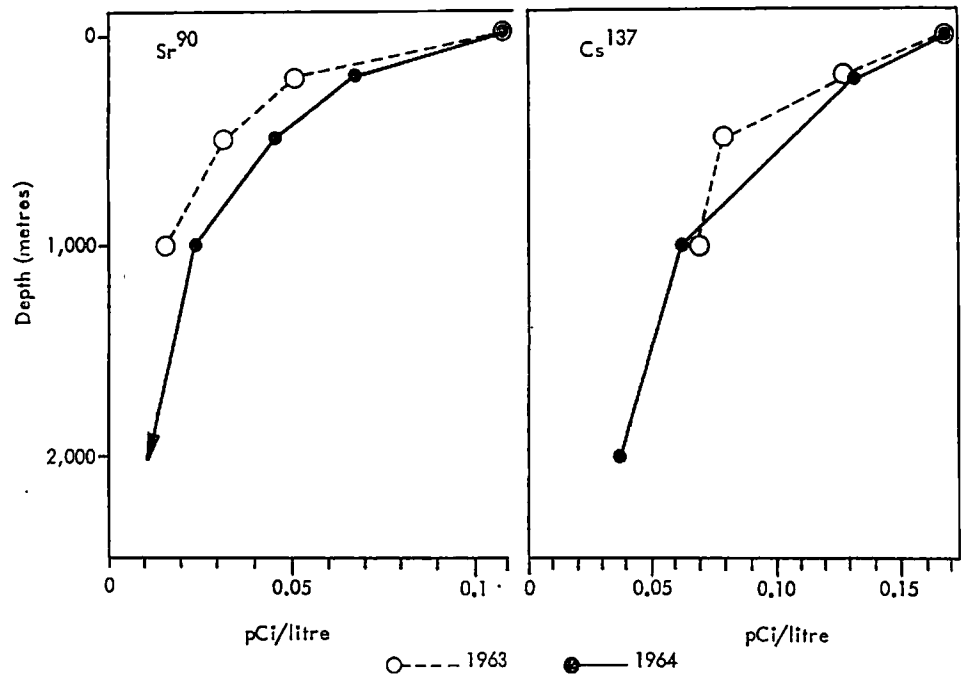


Figure 23. Vertical profiles of concentration of Sr^{90} and Cs^{137} in the equatorial Atlantic Ocean, 1963 and 1964[121]

value for the mean residence time can be applied over long periods to describe the depletion of the stratospheric reservoir. The estimates of the residence time must be adjusted to conform with the temporal changes of the distribution of the nuclear debris in the stratosphere.

64. In the absence of further large scale injections of fresh radio-activity into the atmosphere, the radio-active decay of already deposited Sr^{90} and Cs^{137} will more than offset any subsequent deposition rates starting in the current year, so that the amount present over the whole surface of the globe will begin to decrease. However, some further increases in deposited activity are expected in the southern hemisphere.

65. Strontium-90 observations in deep oceans, though in conflict with C^{14} and H^3 findings, suggest that between 1.5 and three times more Sr^{90} has been deposited per unit area over oceans than measured over land. This enhanced oceanic fall-out helps explain the disparity between changes in atmospheric content and global fall-out derived from land stations.

66. *Carbon-14 and tritium.* Table VI shows the changes in the global inventory of excess C^{14} since July 1963.[62, 64] Values in the northern stratosphere declined gradually, while little change occurred in the southern stratosphere or in the troposphere where peak values of C^{14} concentrations were reached by the end of 1964. Tropospheric C^{14} will decline steadily, since oceanic uptake rates already exceed transfer rates from the stratosphere. No measurements of tritium concentrations in the atmosphere have been reported recently.

II. Artificial radio-activity in food and tissues

Strontium-90 and strontium-89

Food chain mechanisms

67. The principal factors which control the entry of Sr^{90} into human diet were reviewed in the earlier reports of the Committee. More recent information supports the general conclusions advanced therein. However, as is shown in a subsequent section, because of the larger body of survey data which is now available, quantitative relationships between the deposition of Sr^{90}

and dietary levels can now be predicted somewhat more confidently.

Metabolism in man

68. Attempts have been made to explain in kinetic terms the discrimination between strontium and calcium in metabolic processes. The experiments of Walser and Robinson[141] and of Marcus and Wasserman[142] show that the degree of discrimination against strontium during its tubular re-absorption from the glomerular ultra-filtrate is inversely related to the efficiency of calcium re-absorption. A similar relationship holds with regard to absorption of both elements from the gastro-intestinal tract. Quantitative analysis of the data suggests that the ion transfer across the relevant biological membrane is in both cases a first order process and that a constant ratio obtains between the rates of absorption of calcium and strontium.

69. It follows from these experiments and from theoretical considerations that the body/diet OR[a] must vary slightly with the efficiency of calcium absorption in the gastro-intestinal tract and be higher when a greater fraction of calcium is absorbed. In early infancy, however, the limited discrimination between calcium and strontium is due not only to high absorption efficiency but also to the lack of difference in the absorption rates of both elements in the gut.

70. Average values, however, are little affected by individual variations and an average OR of 0.25 will still be used in this report, since:

(*a*) Recent studies,[143, 144] carried out in apparent metabolic steady-state (using stable Sr/Ca ratios in bone and diet) have yielded OR values very close to 0.25;

(*b*) Higher OR values in the first year of life[145] are offset by additional discrimination at the placental barrier during foetal life and by a very rapid turnover of bone mineral in early infancy (1964 report, annex A, paragraphs 94-97).

71. Investigations of the metabolism of strontium in children and adolescents (one to nineteen years old) are in progress. Preliminary results indicate that no changes in the over-all estimate of the bone/diet OR used to calculate dose commitments from Sr^{90} are warranted.

72. Analysis of recent data from various countries on the empirical relationship

$$\frac{Sr^{90}/Ca \text{ infant bone (0-1 year)}}{Sr^{90}/Ca \text{ milk}}$$

shows that the values reported cluster around one-quarter (tables VIII and X).

73. Marei *et al.*[146] on the basis of extensive investigations established a relationship between the Sr^{90}/Ca ratios in human teeth and in the skeleton in all age groups. The

$$\frac{Sr^{90}/Ca \text{ teeth}}{Sr^{90}/Ca \text{ skeleton}}$$

ratio was higher in infancy and childhood than in adults (table VII), and remained relatively constant over a period of two to three years. The authors concluded that teeth may be used for monitoring Sr^{90} levels in man, if the ratios between dental and skeletal values are corrected for age and changes in time.

74. The distribution of Sr^{90} and calcium in skeletons of adults in 1963 was re-examined in a recent study.[147] The

$$\frac{Sr^{90}/Ca \text{ single bone}}{Sr^{90}/Ca \text{ total skeleton}}$$

ratios were as follows: vertebrae/skeleton = 1.7; rib/skeleton = 1.0; femur shaft/skeleton = 0.4. These results are in essential agreement with data reported earlier,[148-150] showing that changes in these ratios over the last three to four years did not exceed some 20 per cent.

Levels of strontium-90 in foods

75. The levels of Sr^{90} in milk in the period 1963-1965 are presented in table VIII. In the northern hemisphere the Sr^{90}/Ca ratios in milk in 1964 remained roughly at the level of 1963, when yearly mean values are compared. In 1965 a significant decline was observed which amounted, on the average, to about 20-30 per cent of the 1964 values (based on results of widespread, systematic studies). Time trends in milk concentrations of Sr^{90} in a few countries are shown in figure 24.

76. In the temperate zone of the southern hemisphere (Argentina, Australia, New Zealand), the absolute levels of Sr^{90} in milk were lower by a factor of three to four than those in the northern temperate zone. They were similar, however, to the levels reported from equatorial regions, reflecting roughly the latitudinal distribution of past fall-out levels in both hemispheres. The time trends in the two hemispheres were somewhat different: the increase in concentrations in the southern hemisphere continued from 1963 to 1964, but the yearly average levels remained unchanged in 1965.

77. In some areas, such as the Faroe Islands, Iceland, western Norway and the mountainous regions of many countries, the levels of Sr^{90} in milk were significantly higher than the average values typical for most of the northern temperate zone. As already indicated in previous reports, these elevated concentrations of Sr^{90} in milk are mainly due to high rainfall and poor pastures.

78. The levels of Sr^{89} in milk declined in 1964 below detection limits. In the summer of 1965, transient levels of this nuclide in milk were reported[151, 152] from some countries of the northern hemisphere following the atmospheric nuclear test conducted in May of that year. As the levels declined again below detection limits within three to four months, Sr^{89} will not be further considered in this report.

79. Information on the average Sr^{90}/Ca ratios of total diets is more limited than for milk, but seems to disclose similar time trends and geographical distribution. The available information is presented in table IX.

80. New information on Sr^{90} levels in total diet and in milk shows that the

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

ratio has remained at about 1.5 in the United States, western Europe, Argentina and Australia (tables VIII and IX). Information now available from the USSR indicates that this ratio ranged from 2 to 3 in 1963 and 1964; this result is similar to that found in Poland from 1961 to 1963. These higher ratios found in the USSR and in Poland are due to greater consumption of whole-meal cereal products.

[a] $OR = \text{observed ratio} = \frac{Sr/Ca \text{ sample}}{Sr/Ca \text{ precursor}}$

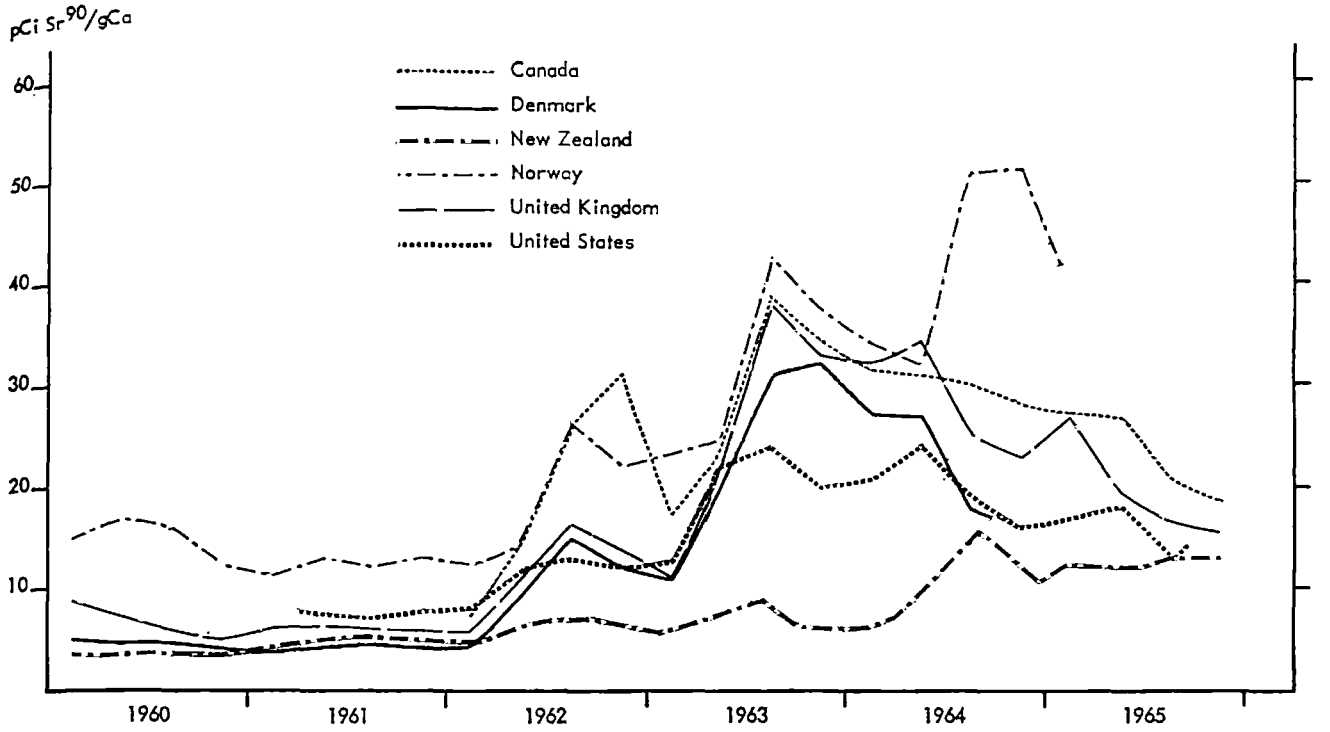


Figure 24. Sr^{90} in milk (time trends). Quarterly averages from country-wide surveys, 1960-1965

81. The relative constancy of the ratio

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

at least for a few years, supports the conclusion reached in the 1962 report that in many areas the Sr^{90}/Ca ratio in total diet can be reasonably inferred from analyses of milk.

82. Studies in Argentina,[145] Austria,[153] the United States[154] and the United Kingdom[155] have shown that the Sr^{90}/Ca ratio in the diets of infants who were not breast-fed in the first year of life falls between the values determined for milk and those for a typical adult's diet. As the ratio of Sr^{90}/Ca in human milk equals about one-tenth of the adult diet, the effective contamination of infant food depends very much on the extent of breast feeding.

Strontium-90 in human bone

83. Levels of Sr^{90} in human bone in 1963, 1964 and 1965 are presented in table X.

84. The age distribution of the Sr^{90}/Ca ratios in human bone remained essentially unaltered from that previously reviewed. The highest levels are still encountered in the zero to one or in the one-year-old age group (figure 25).

85. The data for adults are reported in table X, both in original values and as normalized skeletal averages, calculated by applying the normalization factors given in paragraph 74. In the years of high fall-out rate, the average skeletal levels in adults were lower by a factor of four to ten than the highest values in young infants. This difference is expected to diminish with decreasing dietary levels of Sr^{90}, because the skeletal contaminations in infants will change faster than in adults, and trends in these two age categories may be in opposite directions.

Geographical distribution and time trends

86. In the northern hemisphere, bone levels were higher by a factor of two to four than those reported from Argentina and Australia. There was a tendency for a marked increase in bone levels in all age groups from 1963 to 1964, the highest relative increase being in youngest infants. In the zero to one-year-old age group, the increase amounted on the average to some 30 per cent over the 1963 values, as compared to the factor of two or three by which the latter rose above the 1962 values. Although only limited results are available for 1965, it may be provisionally concluded that, in the zero to one-year-old age group, levels may have reached their peak in 1964 and started decreasing in 1965. In the one-year-old age group, bone levels in 1965 seemed either the same as or slightly higher than in 1964. As expected, levels in adults are still increasing.

87. On the basis of available data, it seems that in the southern hemisphere, in the period under review, the time trends of Sr^{90} levels in human bone were not markedly different from those in the northern temperate zone.

88. The frequency distribution of the Sr^{90}/Ca ratios in adult bone—where levels are age-independent—has been repeatedly studied and recent data[156, 157] confirmed earlier findings,[158, 159] indicating that the distribution was positively skewed and might be described as log-normal. If data from individual locations are considered, the probability that the Sr^{90}/Ca ratio in a single sample will exceed the mean value by a factor of three is of the order of 1 per cent.

Quantitative relationships between deposition of strontium-90 and dietary levels

89. In earlier reports of the Committee, fall-out rates and accumulated soil deposits of Sr^{90} were related to the concentrations of this nuclide in foodstuffs to

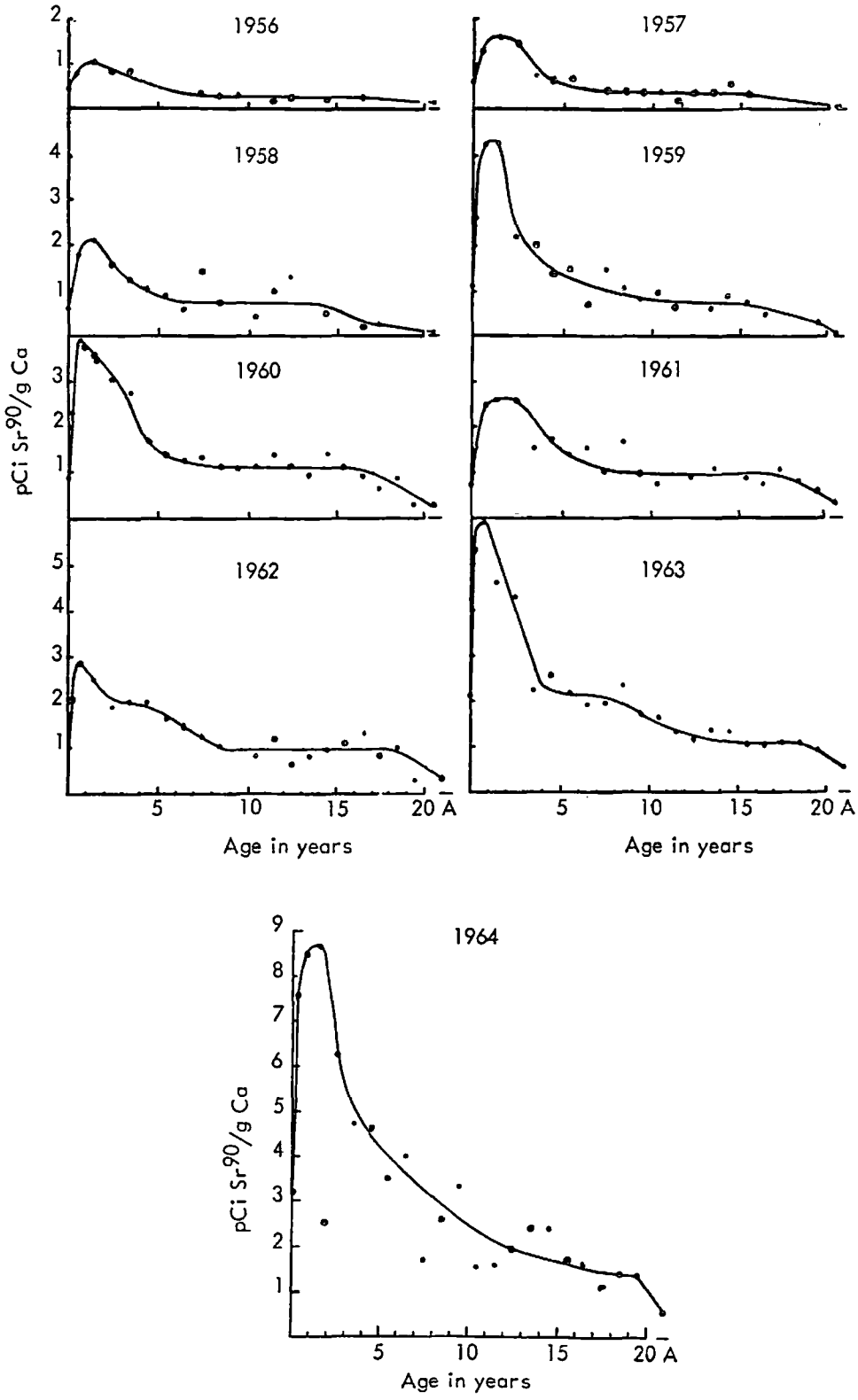


Figure 25. Sr^{90} concentrations in bone, plotted according to age (A = adult): United Kingdom results, 1956-1964[272]

predict future levels of contamination. The basic equation applied with respect to milk was:

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

where

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

F_d = total accumulated deposit of Sr^{90} in soil in mCi/km²,

F_r = yearly fall-out rate of Sr^{90} in mCi/km² in giv year,

p_d and p_r = proportionality factors also called "soi and "rate" factors.

Although data from many parts of the world rema meagre, it is now possible in a number of countries derive soil and rate factors for milk by appropria regression analysis.

90. In some extensive regions, factors such as stored fodder for cattle justify the introduction of a third term in the equation which takes into account the contribution to milk levels of Sr^{90} which was deposited when crops and grass were growing in the second half of the previous year. The inclusion of this "lag-rate factor" may lead to a significant improvement in the prediction of year to year trends, especially when the rate of fall-out is changing markedly.[112, 160] However, the separate evaluation of rate and lag-rate factors is not necessary for the calculation of dose-commitment.

91. An analysis of survey results from Argentina, Australia, Canada, Denmark, Germany, Japan, New Zealand, the United Kingdom and the United States indicates that the averages of the rate and soil factors for milk fall within the range of 0.8 to 1.0 and 0.2 to 0.3, respectively. These values do not differ sufficiently from those formerly estimated (0.8 and 0.3) to necessitate a revision of the proportionality factors previously adopted for milk nor for the three major types of total diets consumed by the world's population (1962 report, annex F, paragraphs 108-119).

92. In a number of countries, the annual average levels of Sr^{90} in diet, and especially in milk, have hitherto agreed satisfactorily with those predicted from the proportionality factors. While this encourages confidence in the use of this procedure, it must be borne in mind that assessments of the situation many years hence is subject to considerable uncertainty. This is so largely because absorption by plant roots is usually greater from the upper layers of soil where so far the levels of Sr^{90} have been highest. When downward penetration of Sr^{90} leads to its more uniform distribution throughout the rooting zone, lower values of the soil factors are to be expected. However, there is at present no basis for predicting how the soil factors will change with time in the majority of areas.

93. Because at the present time Sr^{90} is more concentrated in the upper layers of soil in permanent pastures than in the ploughed land on which other crops are grown, the decrease in the soil factor for milk is expected to be larger than for other foodstuffs. This should lead to a gradual increase in the ratio of

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

which will approach the relationship obtaining for stable strontium and calcium.

94. A further problem in predicting absorption from the soil in the distant future arises from uncertainties as to the fraction of the total Sr^{90} in the soil which will be removed annually by crops or lost from the rooting zone by leaching. The Committee previously assumed that those processes might decrease the content of the soil by about 2 per cent per annum, leading to a total decrease of 4.5 per cent per year when radioactive decay is taken into account. It is recognized that this figure will lead to an under-estimate of the losses in many countries, but the data are insufficient to justify its revision.

95. Because it is expected that the soil factor for total diet will decrease with time and that the rate of loss of Sr^{90} from the soil may be greater than 2 per cent per year, estimates of the integrated quantities of Sr^{90} which will enter diet over long periods, based upon the methods adopted here, should be regarded as upper limits.

Caesium-137

Food chain mechanisms

96. Cs^{137} which is deposited from the atmosphere is retained on vegetation in a manner similar to Sr^{90}, but the two nuclides contrast markedly in their behaviour in soil. In mineral soils which contain appreciable quantities of clay and moderate or low quantities of organic matter, the entrapment of Cs^{137} in the clay lattice structure causes it to be little absorbed by plants.[161] The process of fixation may not be complete until several years have passed; thereafter, Cs^{137} may be absorbed to not more than about one-fortieth of the extent of Sr^{90}.[162] In contrast, when soils contain much organic matter, and especially when their clay content is low, Cs^{137} enters plants considerably more freely.[163-165]

97. Soils in which organic matter is present in large concentrations throughout the entire rooting depth are mainly important in moist, temperate regions; this circumstance appears to explain, at least partially, why the average levels of Cs^{137} in diet from northern regions, e.g. Scandinavia, exceed those in lower latitudes.[161] A more transient effect of organic matters occurs commonly in the permanent pastures of temperate regions. Appreciable quantities of organic matter form in the superficial soil layers, and, until Cs^{137} has penetrated into the underlying mineral soil, it is readily absorbed by plants; enhanced uptake due to this cause has been shown to continue for one to two years in these circumstances.[161, 163] In the 1964 report, it was noted that Cs^{137} may also readily enter plants when soils are lateritic in type.

98. In its 1964 report, the Committee discussed a special food chain mechanism, whereby in some populations living in subarctic regions unusually high activities of Cs^{137} are transferred to man from lichens through reindeer or caribou meat. Results of a detailed dietary study of Finnish Lapps which became available recently[166] show that about 75 per cent of their total intake of Cs^{137} comes from reindeer meat and meat products, while fish and milk contribute about 11-12 per cent each. It has since become evident that other nuclides in fall-out, such as Na^{22} and Fe^{55}, or of natural origin (Pb^{210} and Po^{210}), also show unusually high levels because of similar mechanisms of transfer.[167-172]

99. Lichens constitute the main fodder of reindeer and caribou during the winter season. In the summer, however, almost only grass and herbaceous plants are consumed. The Cs^{137} body burden of the animals therefore shows a marked seasonal variation, particularly some years after the peak deposition, when Cs^{137} levels in the grass have decreased while the levels in the lichens remain high.

100. Lichens on which these animals graze entrap almost all the Cs^{137} deposited per unit area of ground. It has been shown that the levels in grazing animals have increased up to 1965 in proportion to the lichen levels which are closely related to accumulated deposit of Cs^{137} (table XI). The levels are expected to decrease during the coming years when the fall-out rate will not be sufficient to compensate for the Cs^{137} loss due to grazing and possible wash-out. A number of estimates of the total elimination rate have been published,[173-175] and although there is a wide divergence between these estimates, it seems likely that at least some 5-10 per cent of the Cs^{137} is eliminated annually.

101. Other mechanisms have also been shown to cause elevated levels of Cs^{137} in foodstuffs in northern

latitudes. Unusually high levels (10 or more nCi Cs^{137}/kg) have been reported in fresh water fish from some Scandinavian lakes.[176-178] This has been attributed to the low mineral content of the water which enhances the absorption of Cs^{137} and other fission products. Similarly, aquatic plants which are sometimes important in the diet of cattle in these areas contain higher levels of Cs^{137} than normal pasture species.[179]

Metabolism in man

102. Investigations of the metabolism of caesium in pregnant women and in new-born children[180] have shown that the turnover of this element becomes accelerated in the course of pregnancy, with a resulting biological half-life of the order of about thirty to seventy days as contrasted with the usual value in adults of seventy to 140 days. There seems to be no placental barrier for Cs^{137} in its movement to the foetus, for new-born children revealed practically the same Cs^{137}/weight ratio as their mothers.

103. That the Cs^{137} turnover is generally faster in infants than in adults has been further confirmed, suggesting a biological half-life in the first month of life of only seven to ten days (Wilson and Spiers, quoted by Vennart[181]), or twenty-one to twenty-five days.[180] Both the lower intake and the faster turnover of Cs^{137} in children explain that they show lower levels than adults, as has already been indicated in the 1964 report. This observation was recently confirmed by radiochemical analysis of skeletal muscles obtained from human beings of all age groups.[182] The levels of Cs^{137} per gramme of potassium were lowest in still-born and rose with age, reaching the highest values in adults.

104. Newly reported data on the biological half-life, characterizing the long-term retention of caesium in adults,[183-188] fall in line with the information already reviewed in the 1964 report (table XII). The remarkably shorter average half-life in the inhabitants of some Scandinavian countries has been tentatively explained by elevated potassium intakes[189] which may lead to faster turnover of both caesium and potassium in the body.

105. The distribution of Cs^{137} in human tissues was studied by Nay *et al.*[190] who showed that concentrations in compact bone and bone marrow were lower by a factor of twenty than in skeletal muscle. This implies a dose rate from internal Cs^{137} to bone marrow, to osteocytes and to cells lining the marrow cavities, two to three times lower than to muscular tissue. Although the data are preliminary, refer only to compact bone and may reflect a non-steady-state situation, they suggest that the dose commitment to bone marrow and bone-lining cells due to internal Cs^{137} radiation may have been somewhat over-estimated in the 1964 report. However, the evidence is not convincing enough to warrant a re-evaluation of the dose-rate factors in estimating dose commitments. The changes would in any case have a trivial effect on the total dose commitment because of the relatively low contribution of internal Cs^{137} irradiation.

106. The frequency distribution of the Cs^{137} concentration in human tissues (muscles) was studied by Ellett and Brownell[191] and appeared to be non-normal with positive skewness. By fitting a particular form of gamma function to their data, the authors estimated that the probability that an individual might exceed the population average in a given locality by a factor of three was 1.5×10^{-3}.

107. Static and dynamic distribution studies were conducted by Yamagata *et al.*[192] on caesium in human blood. When the dietary Cs^{137} levels changed slowly with time, the concentrations in blood reflected the total body contents of Cs^{137}. Whole blood samples collected from urban areas in the Far East and the Pacific region gave estimates of body burden ranging from 56 pCi/g K in Rangoon, Burma, to 110 pCi/g K in Manila, the Philippines, in April 1966.[193]

Levels of caesium-137 in food

108. Concentrations of Cs^{137} in milk in the northern hemisphere (table XIII) in 1964 were essentially the same or only slightly higher than in 1963. In 1965, average values were—with only a few exceptions—markedly lower. Time trends are presented in figure 26. In the southern hemisphere, the 1964 yearly average levels rose over those observed in 1963 and remained unchanged in 1965. However, quarterly values in New Zealand and Australia (figure 26) showed a clear decrease in concentrations at the end of 1965.

109. Time trends in the total dietary content of Cs^{137} were basically similar to those for milk, but the data are more limited, especially with regard to the 1965 levels (table XIV). There is, however, a well-established correlation between the Cs^{137} contents in beef and milk, the ratio of the concentrations

$$\frac{\text{pCi/kg meat}}{\text{pCi/l milk}}$$

averaging ~ 4[194-196] (figure 27). Since meat and milk together are the main dietary sources of Cs^{137}, it is evident that trends in dietary contamination can be adequately inferred from the monitoring of milk alone.

110. Cs^{137} levels of up to about 100 nCi/kg were measured in reindeer meat during the winter of 1964 and 1965. According to Lidén,[174] the proportionality factor of Cs^{137} in fresh lichen to that in fresh reindeer meat in northern Sweden averaged 4.9 ± 0.4.

Levels of caesium-137 in man

111. Levels of Cs^{137} in man continued to increase in the northern hemisphere until mid- or late 1964, and declined thereafter. In early 1966 the levels were reduced by about 30-40 per cent as compared to the peak values in 1964. As shown in table XV and figure 28, the ratio between the lowest (Japan) and the highest (France) values reported from the northern temperate zone was between 1 : 2 and 1 : 3 (with the exception of Norway where unusually high levels of rainfall and particular grazing conditions prevail).

112. In the southern hemisphere (southern Australia), the levels rose until late 1965 and appear to have been declining since. The highest levels reached in Australia were lower by about a factor of three when compared with the average 1964 peak levels in normal areas of the northern temperate zone (figure 28).

113. As already discussed in the 1964 report (owing to the factors mentioned in paragraph 111), the levels in Norway, in particular on the western coast, were much higher than those usually encountered in these latitudes.

114. The levels of Cs^{137} in man also rose until 1965 in the majority of those areas where this nuclide follows the lichen-reindeer-man food chain, e.g. Finnish Lapland, Swedish Lapland and the far north of the USSR. Some decrease was, however, reported in Alaska. For reasons explained in paragraph 100 it was ex-

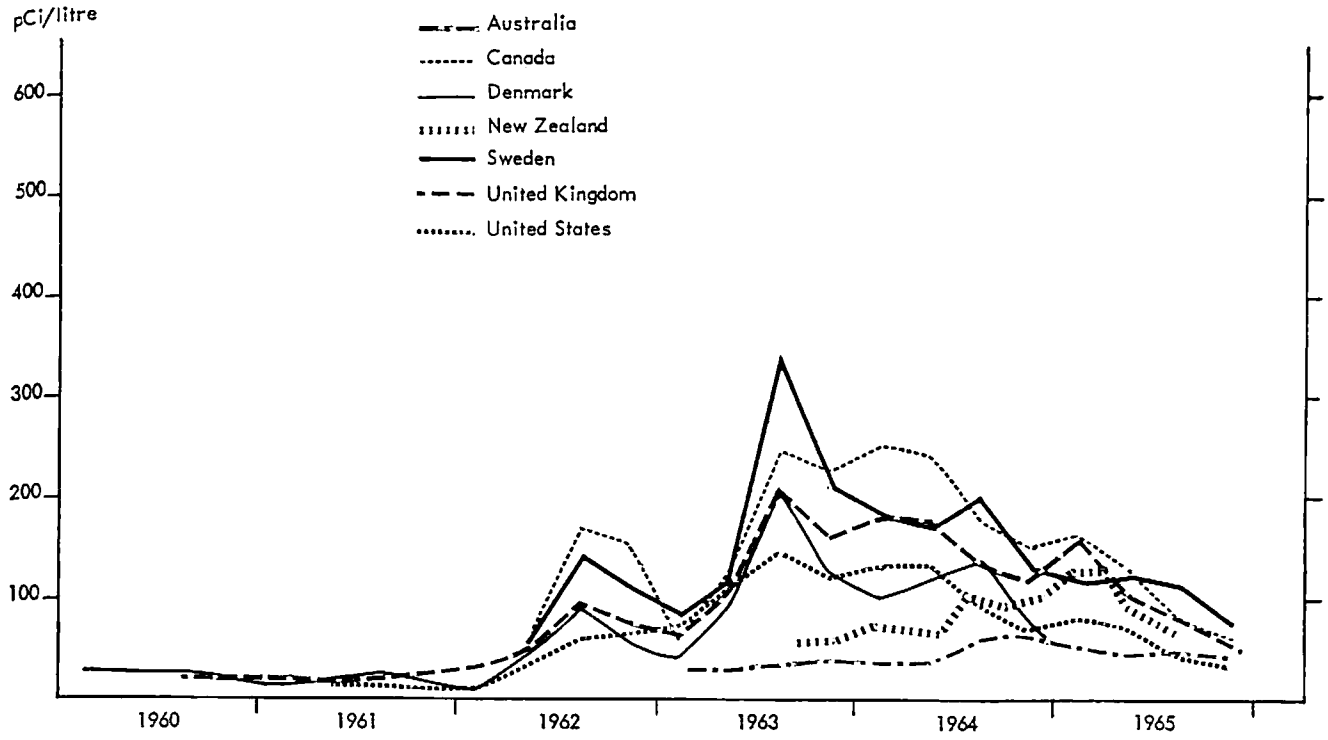


Figure 26. Cs^{137} in milk (time trends). Quarterly average values from country-wide surveys, 1960-1965

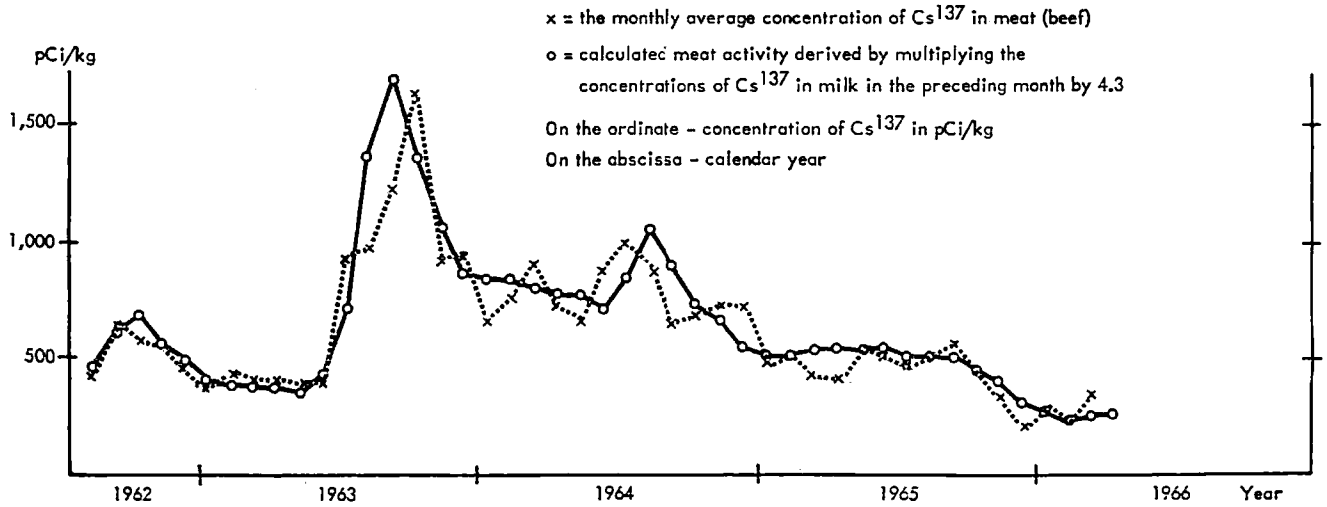


Figure 27. Relationship between concentration of Cs^{137} in beef and milk in Sweden, 1962-1966[344]

pected[173, 174] that levels in man in those areas in 1966 would be the same as, or slightly lower than, in 1965. This is supported by the data for Finnish Lapps (table XV), which show a slight decrease in Cs^{137} body levels (by 5-10 per cent) from April 1965 to March and April 1966.

Quantitative relationships between deposition of caesium-137 and contamination of milk

115. The relationships between fall-out rates and the cumulative total of Cs^{137} in soil, on the one hand, and the contamination of milk on the other, have been further studied in the United Kingdom[160] and in Sweden.[194] In the United Kingdom, it has been shown that levels of Cs^{137} in milk hitherto have depended predominantly on the current rate of deposition and on that observed in the last half of the previous year. Estimates based on tracer experiments indicate that the cumulative deposit in soil has not so far contributed more than about 1 per cent of the total Cs^{137} in milk. Thus, under conditions which have prevailed hitherto, absorption from the cumulative deposit can be ignored. In Sweden, it appears that the transfer of Cs^{137} to milk from the deposit in the current and previous years is about twice[194] that estimated in the United Kingdom.[160]

Quantitative relationships between deposition of caesium-137 and human body burden

116. In the 1964 report, an empirical relationship between rates of deposition of fall-out and Cs^{137} in man was used in calculating dose commitments. The Cs^{137}/K ratio (Q) in human beings was related to the current yearly fall-out and to the deposition over the preceding two years by a 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.

117. The proportionality factors have been revised, using the survey results now available from Belgium, Germany, Sweden, the United Kingdom and the United States. The resulting values $P_r = 2.5$ and $P_{2c} = 4.0$ are larger than those used in the 1964 report; this is due in part to inclusion of data from Sweden,[194] where the factors are approximately twice as high as for the other countries. Since present evidence suggests that factors similar to those in Scandinavia may affect only a small fraction of the world population the above value of the factors may well lead to an over-estimate of the world situation. No allowance has been made for the expected small contribution of the cumulative deposit of Cs^{137} in the soil, as its effect should be very slight in comparison with other sources of uncertainty.

IODINE-131

118. I^{131} was detected in rain and in the air in Japan[197, 198] following the atmospheric tests carried out in central Asia in 1964 and 1965. Average levels of the I^{131} detected in milk in Japan[199, 200] between 18 October and 12 November 1964 were of the order of 100 pCi/litre and nearly the same during one week of May 1965. Only traces of I^{131} were found in milk, at the end of 1964 in Canada[151] and in the United Arab Republic,[201] and at the end of May and in early June 1965 in the United States[152] and in Israel.[26, 202] I^{131} was also observed in human thyroids (0.02-1.3 pCi/g fresh tissue)[202] and in urine[203] in October and November 1964 in Japan.

OTHER NUCLIDES

119. Fe^{55} has been detected in foodstuffs, in cattle and in human beings.[167, 172] Fe^{55} is an emitter of low energy x rays due to electron capture, and at present levels of contamination the radiation dose from this nuclide to man is insignificant.

120. Na^{22} has been measured in rain, in grass and in foodstuffs.[168, 204, 205] This nuclide was also detected by means of whole body counting in Alaskan Eskimos.[168] The sources of Na^{22} and Cs^{137} in human diet are similar. So far, the activities of the first nuclide do not exceed a few per cent of the latter.

121. Mn^{54} was detected in human food[206, 207] but no observation was reported on its presence in human beings, except for possible traces detected in liver at *post mortem*.[208] The radiation dose from both Na^{22} and Mn^{54} may be neglected at present.

122. Three recent studies[209-211] have confirmed that, as expected, the C^{14} specific activity of plant foodstuffs and milk follows with a slight delay that of tropospheric air. With the exception of adult cartilage, in which the C^{14} specific activity remained essentially unaltered since the pre-test period, the specific activity of human tissues follows the specific activity of air with a delay of the order of one to two years. Until 1964, individuals from the southern hemisphere showed little increase in C^{14} content as compared with the pre-test levels (before 1952), consistent with the small rise of C^{14} specific activity in the air in that hemisphere. Results of C^{14} measurements in biological materials have been presented in table XVI and figure 29.

RADIO-NUCLIDES IN THE RESPIRATORY TRACT

123. Data subsequent to those reviewed in the 1964 report on the contamination of the human respiratory tract by fission products from nuclear tests have been published. Thus, Rundo and Newton[212] reported levels of $Zr^{95} + Nb^{95}$ in the range 79-161 pCi in 1962 and 1963 in England, while Wrenn *et al.*[213] reported values of 210-460 pCi in the respiratory system of people deceased in the United States in the first half of 1963. Assuming a homogeneous distribution of the nuclide, these levels would lead to an annual dose rate of a few millirads at a constant level of contamination. However, the levels of $Zr^{95} + Nb^{95}$ in the air decreased in the period 1963-1965 by two orders of magnitude.

124. A study of the contamination of the human respiratory tract by Ce^{144} revealed[214] average yearly lung burdens of 105, 160, 268 and 182 pCi of this nuclide in 1961, 1962, 1963 and 1964, respectively. The authors calculated the average annual dose rate to the whole lung tissue from Ce^{144} and all other fission products over the period of investigation to be 24 mrad/year, with 10 per cent of the population exceeding the

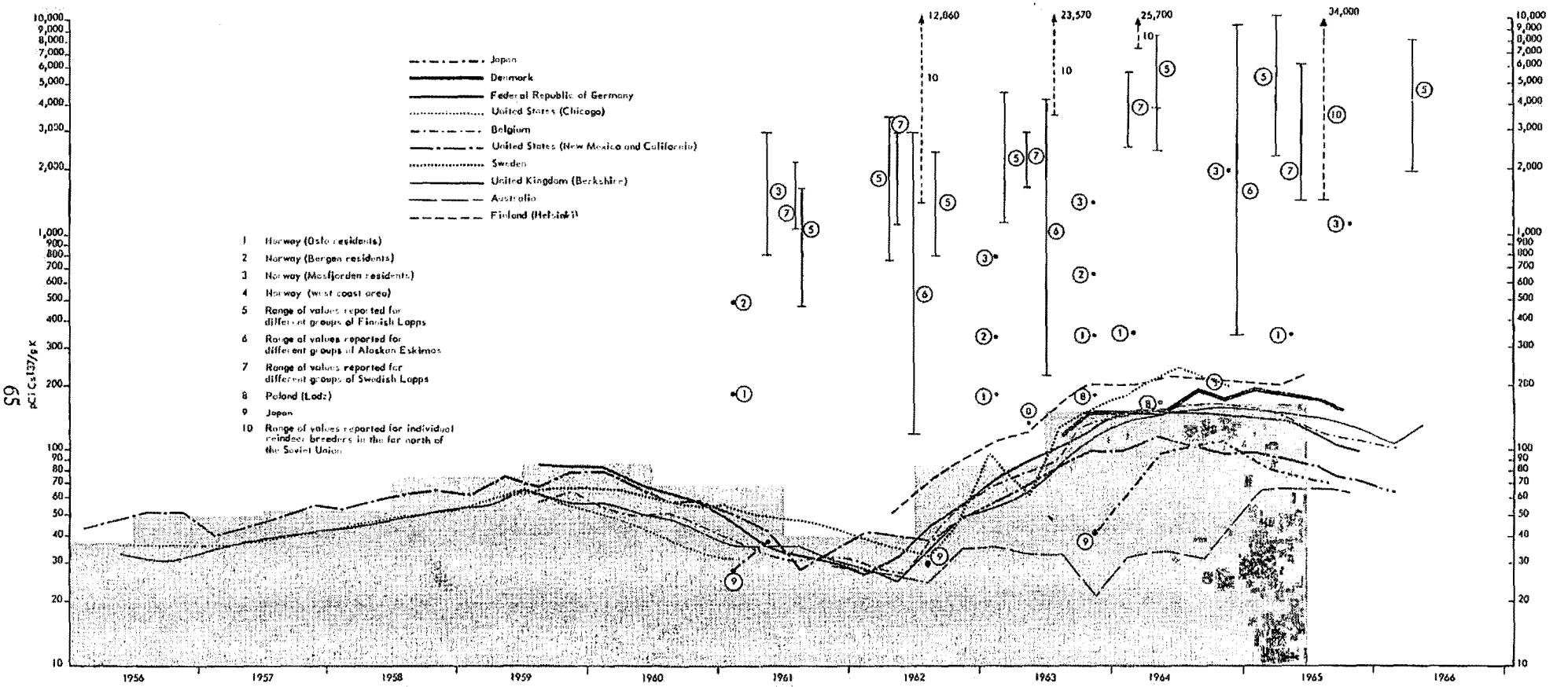


Figure 28. Cs^{137} levels in man during the period 1956 to early 1966 (shaded area indicates the yearly average values calculated according to the formula given in paragraphs 116-117, using average proportionality factors P_r and P_{sr} of 2.5 and 4.0, respectively).

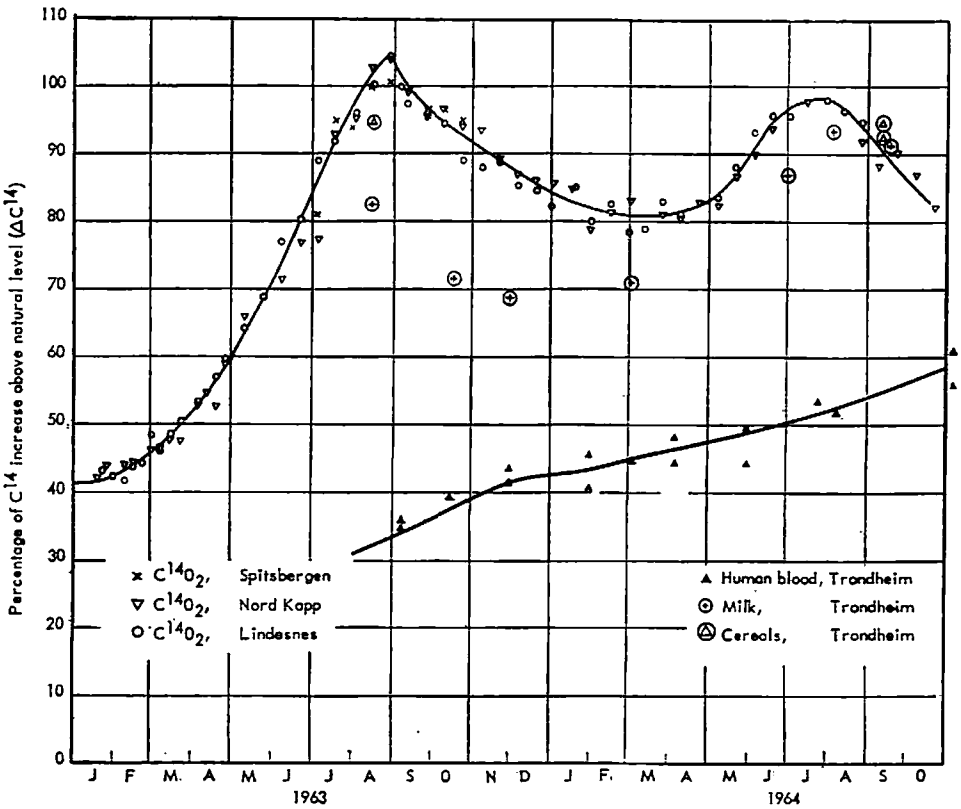


Figure 29. Time trends in C^{14} in Scandinavia, 1963 and 1964[210]

value of 43 mrad/year. In view of the author's assumptions, the dose-rate estimate may be accepted as a possible upper limit.

125. The concentrations and the doses from Ce^{144} in bronchial lymph nodes appear to be higher by one order of magnitude than those in the respiratory system as a whole.[214] The same proportionality has been obtained for the concentrations, and therefore for the doses, from other nuclides that are retained in the respiratory tract and that show similar affinity for the lymphatic tissue (e.g. Pu^{239}).

III. Doses from external and internal contamination

Introduction

126. In this annex, most of the doses are expressed as dose commitments. For the purpose of this report, the dose commitment to a given tissue is defined as the integral over infinite time of the average dose rates delivered to the world's population as a result of a specific practice, e.g. a given series of nuclear explosions. The actual exposures may occur over many years after the explosions have taken place and may be received by individuals not yet born at the time of the explosions (1964 report, annex A, paragraph 147).

127. This concept has been used because it would permit the calculation of the total expected number of individuals eventually showing certain radiation effects as a result of any given test series, if the size of the population to which the dose commitment applied and the appropriate proportionality factors characterizing a linear dose-effect relationship with no threshold were valid and known. The number of affected individuals would then simply be the product of population size, proportionality factor and dose commitment. For further details regarding the general method of computation, see paragraphs 147-155 of annex A of the 1964 report.

128. To estimate dose commitments, the world-wide cumulative deposition of Sr^{90} uncorrected for decay is obtained from the annual deposition figures up to the end of 1965 given in table I and from the cumulative deposition before 1958 assumed to be 2 MCi. The results from the United States and from the United Kingdom networks are weighted according to the number of sampling stations in each network and yield a total figure of 12 MCi. Estimates of future deposition are based on the stratospheric inventory of 0.8 MCi Sr^{90} as of January 1966 (table V) and a mean residence time of fourteen months. Taking into account, as in earlier reports of the Committee, the area of the earth

between 80°N and 50°S (448×10^6 km^2), in which over 97 per cent of the deposition takes place,[65] gives an average expected deposit of

$$\frac{12.8}{0.448} = 28.6 \text{ mCi/km}^2.$$

This figure will be used for the purpose of estimating the Sr^{90} dose commitment. The figure differs slightly from that obtained in the 1964 report (31.7 mCi/km^2), as a consequence of a revision in the estimate of the global inventory of Sr^{90}.

129. Cs^{137} deposition is derived from the deposition of Sr^{90} by means of a Cs^{137}/Sr^{90} ratio of 1.6. This ratio is representative of measurements carried out at various sites, as shown in table II. The total integrated expected deposit of Cs^{137} is therefore 20.5 MCi. The expected deposit in each hemisphere is derived from this figure by using the ratio of the estimated cumulative deposits in either hemisphere as of January 1966 (table V). This gives integrated Cs^{137} deposits of 16.3 MCi in the northern hemisphere (0°-80°N) and 4.2 MCi in the southern hemisphere (0°-50°S), corresponding to 64.5 mCi/km^2 and 21.4 mCi/km^2, respecively.

External dose rates

130. External dose rates from all deposited fission products may be determined by means of ionization chamber measurements, by converting to dose rates directly from results of gamma-ray spectroscopy obtained in the field, or by calculating the rates from radio-activity measurements in soil cores.[18, 346, 349-364] Reasonable agreement is found when results obtained by these different methods are compared.

131. Figure 30 shows the external gamma air dose as measured outdoors 1 m above ground at Grove, Berkshire, United Kingdom[346] and Chiba, Japan.[31] These doses are obtained by subtracting a constant natural background from the measured dose rates. Thus, the net fall-out dose rates include an error due to fluctuations in background. Such fluctuations may be considerable, particularly where snow cover reduces the radiation from the ground during the winter. This is illustrated by figure 31, which shows the total external exposure rate in central Sweden during the years 1962-1965.[348]

132. At Argonne, Illinois, United States, the fall-out doses have been calculated from gamma spectrometric analyses of soil cores.[23, 74, 353] In 1963, the dose rate from fall-out was as high as 30 per cent of the external natural radiation.[351, 353, 356] Its contribution decreased in 1964, owing to the decay of Zr^{95}, Ce^{144} and Ru^{106}. Dose rates during 1965, due mainly to deposited Cs^{137}, were somewhat lower than the 1964 levels.

133. Beck,[364] comparing actual field measurements of dose rates to calculations based on deposition data at Westwood, New Jersey, United States, concluded that the best agreement with regard to Cs^{137} was obtained by assuming an exponential decrease of activity with depth having a 3 cm relaxation length. Measured soil profiles always reveal some penetration of deposited fall-out depending on the type of soil, on climatic conditions and on the fall-out history.[365-369] This exponential distribution in soil would imply a gamma-ray dose-conversion factor of 0.034 mrad/year per mCi/km^2 deposited Cs^{137}. A similar study in Japan gave 0.050 mrad/year per mCi/km^2.[370] For calculation, a value of 0.040 mrad/year per mCi/km^2 will be used in this report.

134. A higher dose-conversion factor (0.12 mrad/year per mCi/km^2) was used in the 1962 and 1964 reports. Such a value was obtained on the assumption that Cs^{137} was deposited on an infinite plane. In estimating dose commitments, the effect of this higher dose-conversion factor was offset by assuming that Cs^{137} disappeared from the ground with an effective mean life of fourteen years, whereas calculations based on the exponential distribution assume disappearance by radio-active decay alone (mean life forty-three years). These two approaches, therefore, lead to about the same numerical estimate of the external dose commitment from Cs^{137}, but that discussed in the previous paragraph is probably more realistic at present and is followed here.

135. From the expected integrated deposits per unit area in each hemisphere as given in paragraph 129, a dose-rate factor of 0.04 mrad/year per mCi Cs^{137}/km^2, a physical mean life of forty-three years, and geographical factors 1.2, and 1.0 (1964 report, annex A, paragraphs 147-155) the external dose commitments from Cs^{137} in the northern and southern hemisphere are 133 and 36.8 mrads, respectively. Weighting these figures by the relative size of the populations involved (91 per cent in the northern hemisphere) gives a world-wide external dose commitment of 124 mrads. By applying the same combined reduction factor of 0.2 that was used in previous reports to allow for shielding by buildings and screening by body tissues, a final estimate of the external dose commitment from Cs^{137} of 25 mrads is obtained, as compared to 29 mrads estimated in the 1964 report.

136. In the case of short-lived radio-nuclides such as Zr^{95}, Ru^{106} and Ce^{144}, accounting for the roughness of the ground would involve reducing by a factor of about two the dose rate estimated from deposition figures on the assumption that the nuclides constitute an infinite plane source.[371] The factor of about three suggested for Cs^{137} for the reduction in dose rate over a long period of time would be too high for short-lived radio-nuclides, since these may decay before substantial redistribution to deeper layers of soil can occur.

137. In the 1962 report, dose commitments due to short-lived nuclides were estimated from actual measurements of external doses after deduction of an estimated contribution of Cs^{137}. The same approach was followed in 1964, except for that fraction of the dose commitment from short-lived nuclides that had not yet been delivered and which was estimated from deposition figures. The correction factor discussed in the previous paragraph can be applied to this fraction which amounts, therefore, to 5 instead of 10 mrads. On the other hand, the measured values of external dose rates from short-lived nuclides must now be somewhat increased in the light of the new estimates of Cs^{137} deposition, thus leading to values of 109 instead of 92 mrads. Adding the 5 mrads estimated above gives a total dose commitment of 114 mrads instead of 104 as obtained in the 1964 report. Applying the combined correction factor for shielding and screening (0.2) leads to an estimated dose commitment from short-lived radioactive nuclides of 23 mrads that has now been essentially delivered in full.

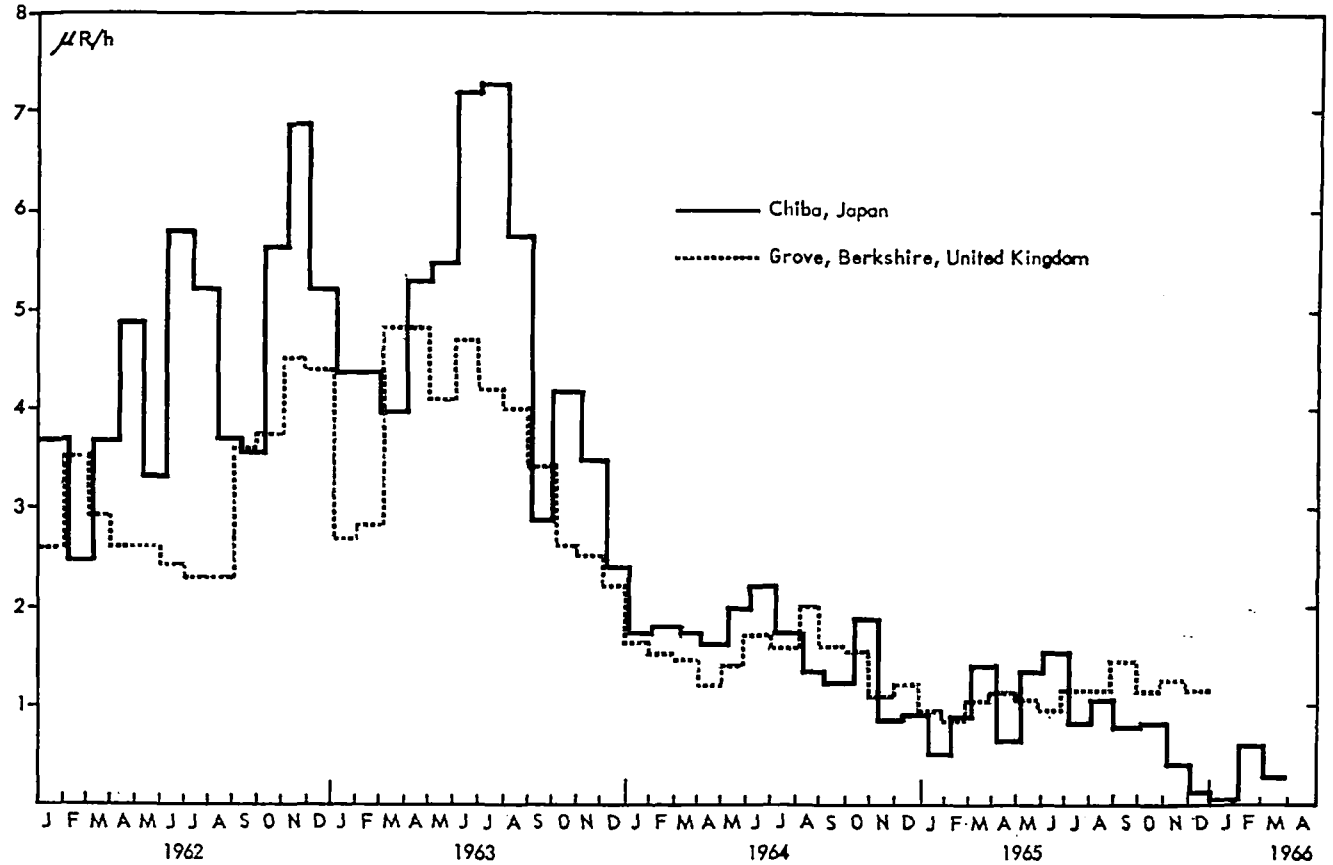


Figure 30. External gamma exposure rates due to fall-out, 1962-1966[31, 346, 347]

Internal doses

Strontium-90

138. The dose commitment $\overline{D}$ to the world's population from Sr^{90} will be calculated by using the formula as derived by Lindell[345] and used in the 1964 report (annex A, paragraph 171):

$$\overline{D} = \theta \overline{F}_m \int_{-\infty}^{+\infty} c(t)dt \qquad (1)$$

where $\overline{D}$ = dose commitment in mrads; $\overline{F}_m$ = dose increment factor; 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).

139. As in previous reports, the integrated dietary Sr^{90}/Ca ratio is calculated by taking into account differences in the contamination patterns for three broad diet categories. Diet type I is that diet for which the predominant sources of calcium are milk or other dairy products. This diet type is generally consumed by peoples of North and South America, Europe and Oceania. Diet type II applies to the Middle East and to India where milk provides less than half of the total calcium intake. In diet type III, which is consumed predominantly in Japan and the Far East, milk provides only a minor source of the total calcium intake.

140. The estimates of mean Sr^{90}/Ca ratios in diets are obtained from the relationship,

$$C(t) = p_d F_d(t) + p_r F_r(t), \text{ pCi } Sr^{90}/\text{g Ca} \qquad (2)$$

where $F_d(t)$ = cumulative mean deposit of Sr^{90} (mCi/km^2); $F_r(t)$ = mean annual deposition rate (mCi/km^2 × y) at time t; p_d and p_r = proportionality factors discussed in paragraphs 89-91. It can be shown (1964 report, annex A, paragraph 167) that the infinite integral of the Sr^{90}/Ca ratio in the total diet can be expressed in terms of the effective mean life of Sr^{90} in the soil in years (T_m), of the proportionality factors p_d and p_r and of the integrated deposition of Sr^{90} per unit area, F, as follows:

$$\int_0^\infty C(t)dt = (p_d T_m + p_r)F, \text{ pCi years of } Sr^{90} \text{ per g Ca} \qquad (3)$$

141. The integrated Sr^{90}/Ca ratios in each diet as calculated from equation (3) must be combined by means of appropriate weighting factors to take into account differences in the size of the populations represented in each diet category and differences in fall-out deposit over the regions where the different types of diet are consumed. These weighting factors (Z) were calculated in the 1962 report (annex F III, table VIII) and are tabulated below together with the corresponding p_d and p_r factors used in equation (3).

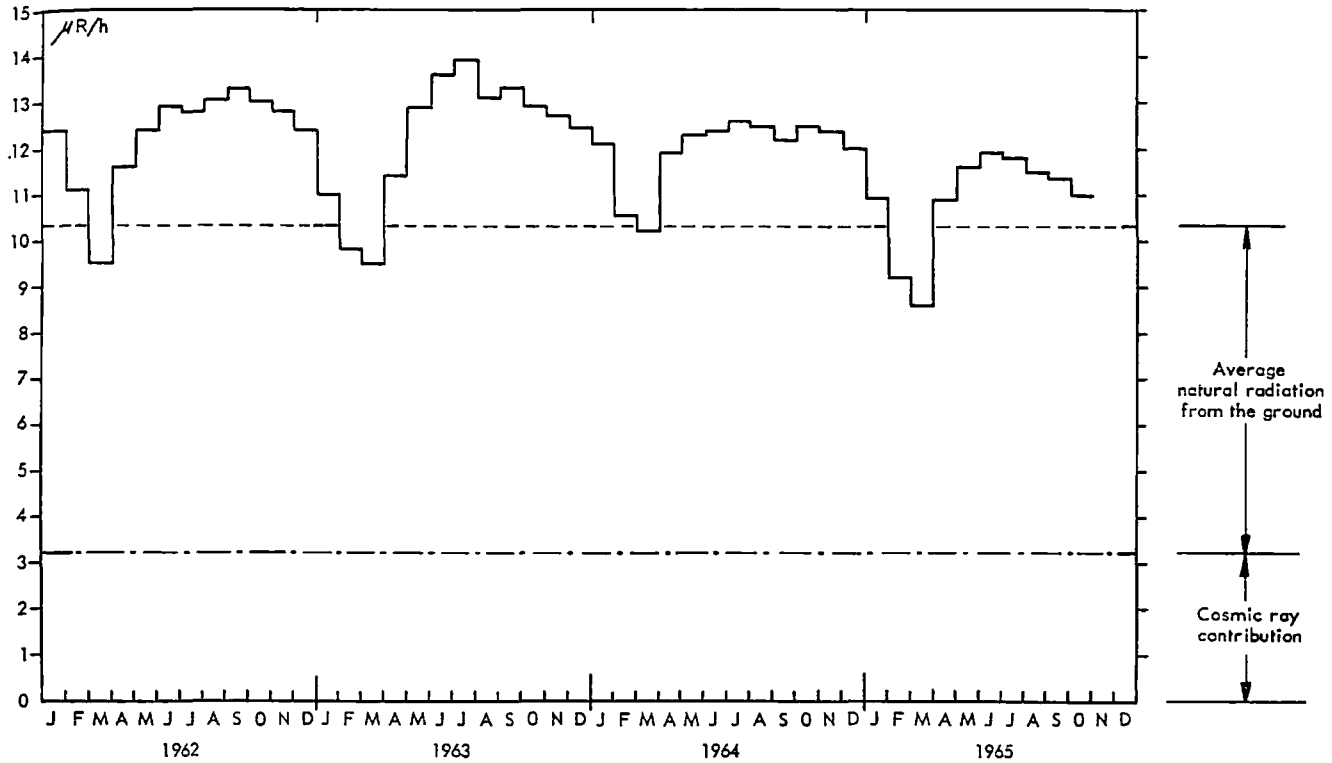


Figure 31. External exposure rates in central Sweden, 1962-1965[348]

Diet type	p_d	p_r	Z
I	0.4	1.3	0.7
II	0.6	2.6	0.5
III	0.7	2.0	0.7

142. Assuming losses of Sr^{90} from the soil of 2 per cent per year due to leaching etc. (paragraph 94), the effective mean life of Sr^{90} in the soil (T_m) is taken to be (as in the 1964 report) twenty-one years. The integrated deposition of Sr^{90} per unit area (F) is now estimated to be 28.6 mCi/km² (paragraph 128). By substituting successively in equation (3) the values of p_d and p_r for each diet type and the integrated Sr^{90} deposition, and by adding the contributions from individual diet types weighted by the Z factors, the world's average integrated dietary intake is estimated to be

$$(21 \times 0.4 + 1.3) \times 28.6 \times 0.7 + (21 \times 0.6 + 2.6) \times 28.6 \times 0.5 + (21 \times 0.7 + 2.0) \times 28.6 \times 0.7 = 746 \text{ pCi}$$

years of Sr^{90} per g Ca.

The average integrated dietary intake multiplied by the observed ratio (0.25) gives the average integrated bone level

$$\int_{-\infty}^{+\infty} c(t)di = 186 \text{ pCi years of } Sr^{90} \text{ per g Ca.}$$

143. The evidence produced since the last report does not warrant changes in the parameters $\overline{F}_m$ and θ used in equation (1) relating the integrated dietary Sr^{90}/Ca level to dose commitments. The factors applied in the previous report will therefore be used again ($\overline{F}_m = 0.6$; $\theta = 1.4$ and 0.7 mrad/year per pCi Sr^{90}/g Ca for bone-lining cells and bone marrow, respectively). The dose commitments from Sr^{90} are thus

$\overline{D} = 1.4 \times 0.6 \times 186 = 156$ mrads to cells lining bone surfaces

$\overline{D} = 0.7 \times 0.6 \times 186 = 78$ mrads to bone marrow

Caesium-137

144. The method of calculation of the dose commitment from internal irradiation due to Cs^{137} is the same as used in the 1964 report of the Committee. It is assumed that the yearly average Cs^{137}/K ratios in the body (Q_i) can be related to the deposition of Cs^{137} by the formula given in paragraph 116, with proportionality factors $P_r = 2.5$ and $P_{2c} = 4.0$. The total integrated body burden for the northern hemisphere (Q_n) will therefore 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/km²) in the northern hemisphere. The total integrated body burden for the southern hemisphere, Q_s, is computed in a similar manner. The estimates of total expected deposition of Cs^{137} per unit area as obtained in paragraph 129 were 64.5 and 21.4 mCi/km² in the northern and in the southern hemisphere, respectively, giving $Q_n = 677$ and $Q_s = 225$ pCi years of Cs^{137} per g K.

145. The world-wide average integrated body burden (Q) is obtained by weighting the values for the northern and southern hemispheres by population (91 and 9 per cent, respectively) and correcting for the fall-out deposition pattern by means of the geographical factors of 1.2 and 1.0

$Q = (677 \times 0.91 \times 1.2) + (225 \times 0.09 \times 1.0) = 760$ pCi years of Cs^{137} per g K.

Using the same dose-rate factors as in the 1964 report (0.02 mrad/year per pCi Cs^{137}/g K) and assuming

approximately uniform tissue distribution of Cs^{137}, this burden corresponds to 15 mrads to gonads, bone marrow and cells lining the internal surfaces of bone.

Strontium-89, barium-140 and iodine-131

146. As there has been no appreciable deposition of Sr^{89}, Ba^{140} and I^{131} since the Committee prepared its report in 1964, there is no need to increase the estimates of doses from these nuclides which were made at that time.

Carbon-14

147. C^{14} data have so far followed quite closely the 1964 report predictions, and no re-evaluation of the corresponding dose commitment is necessary. By the year 2000, the doses delivered to bone marrow and gonads will each be 13 mrads and the dose delivered to cells lining the internal surfaces of bone will be 20 mrads, some 7 per cent of the total dose commitment due to C^{14}.

CONCLUSIONS

148. The dose commitments to be received by the world population by the year 2000 from the radio-activity released into the atmosphere as a consequence of nuclear explosions carried out to the end of 1965 are summarized in table XVII. They are given for specific tissues for the most important of the radio-active substances released into the environment through nuclear tests.

149. Differences between the present figures and the 1964 estimates are due to minor modifications in the numerical factors used in the computations. They do not reflect any basic change in approach. External radiation accounts for about two-thirds of the total dose to gonads and for only one-fifth of that to cells lining bone surfaces; in this respect, bone marrow is intermediate. The contribution of the 1964 and 1965 tests and of the burn-up of the Pu^{238} power source to the over-all dose commitments of the world population has been negligible. No information is available to assess the exposure of populations living in the proximity of the test sites.

150. The dose commitments, based as they are on a series of assumptions and on measurements which may not be entirely representative of the whole world situation, are subject to uncertainties discussed in the preceding sections of this annex. The values given in table XVII are considered more likely to be an over- rather than an under-estimate of the actual dose commitments.

151. An alternative to presenting dose commitments as such is to express them, as in the 1964 report, in terms of the periods of time during which natural radiation would have to be doubled to give a dose increase equal to the dose commitment. For all tests carried out up to the end of 1965, these periods are approximately three-quarters of a year for the gonads, two and a half years for the cells lining bone surfaces and one year and a half for the bone marrow.

TABLE I. WORLD-WIDE DEPOSITION OF Sr^{90} IN MEGACURIES[17, 63, 65, 68]

Year	*Annual deposition*		*Cumulative deposition*[a]	
	United States network	*United Kingdom network*	*United States network*	*United Kingdom network*
1957		0.66	2.0	2.1
1958	0.90	0.84	2.84	2.89
1959	1.13	1.46	3.89	4.28
1960	0.38	0.40	4.17	4.58
1961	0.46	0.56	4.52	5.02
1962	1.53	2.01	5.93	6.90
1963	2.59	2.87	8.35	9.61
1964	1.84	2.20	9.95	11.58
1965	1.0	1.1	10.7	12.4

[a] Corrected for radio-active decay.

TABLE II. SOME AVERAGE Cs^{137}/Sr^{90} RATIOS[a]

Type of sample	*1963*	*1964*	*1965*
DEPOSITION			
Argentina[215]		1.7 (12)	1.7 (12)
Australia[103, 104]		1.7	
Canada[91, 99]	1.8 (144)	1.7 (288)	1.6 (288)
Finland[216]		1.6 (204)	1.6 (204)
Japan[31, 100]		1.4 (144)	1.6 (144)
New Zealand[24]		1.7 (14)	1.8 (17)
Union of Soviet Socialist Republics[217]	1.9	1.5	
United Arab Republic[105]		1.5	
United Kingdom[17, 72]		1.5 (28)	1.5 (14)
United States[22, b]		1.6 (23)	1.3 (12)

TABLE II. SOME AVERAGE Cs^{137}/Sr^{90} RATIOS[a] (*continued*)

Type of sample	*1963*	*1964*	*1965*
SURFACE AIR			
Union of Soviet Socialist Republics[217]	1.4	1.4	
United Kingdom[17, 72] Chilton, Berkshire	1.7 (12)	1.7 (12)	1.7 (6)
United States network[59, 62, 66, 218, 219]			
Northern hemisphere	1.3 (98)	1.4 (107)	1.4 (75)
Southern hemisphere	1.5 (78)	1.4 (83)	1.4 (40)
STRATOSPHERE			
Northern hemisphere (15-21 km)[59, 60, 62, 218]	1.7 (38)	1.6 (14)	1.4 (8)
Southern hemisphere (15-21 km)	1.5 (11)	1.5 (8)	1.3 (4)
Northern hemisphere (22-34 km)[49, 62, 218, 220]	1.5 (48)	1.5 (47)	1.5 (50)
64°S (22-34 km)	1.5 (35)	1.4 (37)	1.4 (23)

[a] Figures in parentheses indicate the number of samples.
[b] Based on New York City, New York and Westwood, New Jersey data only.

TABLE III. Sr^{90} IN SURFACE WATERS OF THE WORLD'S OCEANS AND SEAS, 1960-1961

(Based on reference 125)

	Average concentrations (pCi/litre)	*Number of samples*		*Average concentrations (pCi/litre)*	*Number of samples*
South China Sea	0.26	2	Baltic Sea	0.30	5
Sea of Japan	0.20	1	Red Sea	0.11	3
Sulu Sea	0.20	2	Indian Ocean	0.11	38
Pacific Ocean			Atlantic Ocean		
Northern hemisphere	0.23	42	Northern hemisphere	0.07	81
Southern hemisphere	0.08	24	Southern hemisphere	0.01	24
Black Sea	0.26	41			

TABLE IV. Sr^{90} IN NORTH ATLANTIC SURFACE WATER, 1960-1965

Sampling year	*Average value (pCi/litre)*	*Range (pCi/litre)*	*Number of samples*	*References*
1960-1961	0.07	0.03–0.14	81	125
1962	0.10	0.05–0.15	6	113, 118
1963	0.15	0.06–0.30	27	112, 115
1964	0.18	0.09–0.26	19	115
1965 (January-June)	0.14	0.07–0.19	20	115

TABLE V. GLOBAL INVENTORY OF Sr^{90} (IN MEGACURIES)[61, 62, 65, 86]

	May 1960	*May 1961*	*April 1962*	*January 1963*	*September 1963*	*January 1964*	*January 1965*	*January 1966 (estimated)*
STRATOSPHERE								
Northern hemisphere	0.50	0.34	2.1	6.2	4.1	3.1	1.10	0.45
Southern hemisphere	0.44	0.38	0.7	0.8	1.0	0.9	0.54	0.35
TOTAL stratosphere	0.94	0.72	2.8	7.0	5.1	4.0	1.64	0.80
TROPOSPHERE								
Northern hemisphere	0.05	0.04	0.03	0.24	0.19	0.24	0.08	0.06
Southern hemisphere	0.01	0.01	0.02	0.03	0.03	0.02	0.04	0.04
TOTAL troposphere	0.06	0.05	0.05	0.27	0.22	0.26	0.12	0.10
CUMULATIVE WORLD-WIDE DEPOSITION[a, b, c]								
Northern hemisphere	3.13	3.25	3.85	4.57	6.39	6.74	8.01	8.48
Southern hemisphere	0.92	1.04	1.23	1.36	1.54	1.61	1.94	2.20
TOTAL deposition	4.05	4.29	5.08	5.93	7.93	8.35	9.95	10.68
TOTAL ACCOUNTED FOR	5.05	5.06	7.93	13.20	13.25	12.61	11.71	11.58

[a] Based on continental sampling.
[b] Corrected for decay.
[c] Does not include local fall-out, estimated as 2.6 MCi in 1960.[61]

TABLE VI. GLOBAL EXCESS C^{14} INVENTORY[62, 64]

(10^{27} atoms)

	July 1963	*January 1964*	*July 1964*	*January 1965*	*July 1965*	*January 1966 (estimated)*
STRATOSPHERE						
Northern hemisphere	24.2	20.3	13.4	10.2	8.8	8.5
Southern hemisphere	5.9	5.3	5.8	5.4	5.5	5.0
TROPOSPHERE	25.3	27.1	29.9	25.9	28.1	28.5
OCEANIC UPTAKE						
Assuming 20 per cent of tropospheric content per year	13.5	17.0	18.9	21.7	24.4	27.2
Assuming 25 per cent of tropospheric content per year	16.0	19.3	24.9	26.4	29.8	33.3
TOTAL	68.9–71.4	69.7–72.0	68.0–72.0	63.2–67.9	66.8–72.2	69.2–75.3

TABLE VII. RATIOS BETWEEN CONCENTRATIONS OF Sr^{90} (Sr^{90}/Ca) IN TEETH AND IN THE SKELETON (WHOLE SKELETON AVERAGES) IN HUMANS OF DIFFERENT AGE IN 1962 AND 1964[146]

Year	*Age group*	
	5-13 years	*> 30 years*[a]
1962	0.60	0.34[b]
1964	0.47	0.30

[a] Values above thirty years were found to be independent of age.
[b] The values estimated for seven urban areas of the USSR vary between 0.33 and 0.37. They are based on 124 bone samples and 2,390 teeth samples pooled in fifty-four analyses.

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

The values are given in pCi/g Ca 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*	*1963*	*1964*	*1965*	*Type of study*	*References*
		NORTHERN HEMISPHERE				
North America						
Canada	40–55°N	28[a]	31[a]	23[a]	A	151
United States						
conterminous	25–48°N	19[b]	19[b]	14[b]	A	221
Alaska	~ 62°N	17	13	14	B	221
Chicago, Ill.	~ 40°N	14	16	13	C	222, 223
New York City, N.Y.	~ 40°N	26	23	19	B	222, 223
San Francisco, Cal.	~ 40°N	10	9	9	C	222, 223
Europe						
Austria	47–49°N	25–42[d]			A	153
Belgium	~ 50°N	20[e]	27		A	224, 225
Czechoslovakia	48–51°N	21[c]	20[c]	18[c]	B	226
Denmark	55–60°N	24[f, g]	24[f, g]	17[f, g]	A	206, 207, 227
Faroes	60–70°N	131	154	115	A	227–229
Federal Republic of Germany	43–55°N	28[f]	28[f]	21[f]	A	230
Finland	60–67°N	22[g]	23[g]	18[g]	A	231
France	42–50°N	27[h]	35	29	A	232–234
Iceland	66–73°N	80[a]	65[a]	80[a]	A	235
Ireland	50–55°N	41	43		A	155
Norway	58–70°N	38[a]	50[a]	40[a]	A	69, 236
Switzerland	46–47°N	55[a]	55[a]		A	237, 238
USSR	32–70°N	30[a]	31[a]		A	239
United Kingdom	50–60°N	26[g]	28[g]	19[g]	A	155, 240

TABLE VIII. Sr^{90} TO CALCIUM RATIO IN MILK (*continued*)

The values are given in pCi/g Ca 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*	*1963*	*1964*	*1965*	*Type of study*	*References*
Near East						
Israel	~ 32°N	9		3.3	C	241, 242
Asia						
India	8–35°N	10[a]	8[a]	6[a]	A	243
Far East						
Japan	30–50°N	15	15	13	A	244–248
Middle America and Caribbean						
Jamaica	~ 13°N		16[l]	13[k]	B	221
Panama	~ 7°N			6[k]	B	221
United States						
Puerto Rico	18°N	12	10	8	B	221
Venezuela	5–12°N	4	6[m]	4[k]	B	221
Africa						
United Arab Republic	20–30°N	16[j]	17[l]		A	201
Oceania						
United States						
Hawaii	21°N	8	10	7	B	221
		SOUTHERN HEMISPHERE				
Oceania						
Australia	10–40°S	6[a]	8.9[a]	9.2[a]	A	103, 249
New Zealand	35–47°S	7[a]	11[a]	12[a]	A	87, 98, 250, 251
South America						
Argentina (littoral area)	35–55°S	3.7	6.2	6.5	B	215, 252

[a] Unweighted mean for all stations.
[b] Country-wide mean weighted by population.
[c] Dried milk from several factories, unweighted mean.
[d] Range of average values reported for three zones of different rainfall, covering the country.
[e] Annual average for three farms and three dairies.
[f] Dried milk country-wide mean weighted by production.
[g] Fresh milk country-wide mean weighted by production.
[h] January-August, unweighted mean for seven collecting stations.
[i] Cairo area only.
[j] Average for Delta region and Upper Egypt.
[k] January-August.
[l] April-December.
[m] January-November.
[n] Means for the European and Asian parts of the USSR.

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

Calcium in grammes per day in parentheses; Sr^{90} in pCi per day; Sr^{90}/Ca ratio in total diet in pCi/g Ca in column 10 (all values have been rounded out to two significant figures)

Types of study: A — Survey of individual foodstuffs
B — Total diet analyses
C — Widespread regular sampling
D — Local regular sampling
E — 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*	*References*
			NORTHERN HEMISPHERE							
North America										
Greenland	> 60°N	1963	7.5	23	0.9	0.4	8.0	AC	26	253
		1964	7.8	69	0.7	0.4	8.0	AC	56	254
		1965								
United States	25–62°N									
Alaska (institutional diet sampling)		1963						BD	24	221
		1964						BD	37	221
		1965						BD	21[e]	221

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

Calcium in grammes per day in parentheses; Sr^{90} in pCi per day; Sr^{90}/Ca ratio in total diet in pCi/g Ca in column 10 (all values have been rounded out to two significant figures)

Types of study: A — Survey of individual foodstuffs
B — Total diet analyses
C — Widespread regular sampling
D — Local regular sampling
E — 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*	*References*
Chicago, Ill.			(0.64)	(0.16)	(0.10)	(0.04)	(0.11)			
		1963	8.4	6.4	2.0	1.1	1.5	AD	19	222
		1964	9.7	8.4	3.9	1.7	0.9	AD	25	223
		1965	7.9	5.7	3.7	1.3	0.9	AD	19	223
New York City, N. Y.		1963	18	6.6	2.6	1.3	2.8	AD	30	222
		1964	15	8.5	5.2	1.8	1.0	AD	32	223
		1965	11	6.2	4.6	1.7	1.3	AD	24	223
San Francisco, Cal.		1963	6.9	3.9	0.9	0.7	1.6	AD	13	222
		1964	5.5	4.7	1.8	0.9	0.7		14	223
		1965	5.5	2.6	1.6	1.3	0.6		11	223
United States (institutional diet sampling)		1963						BC	22 8–41	221
		1964						BC	26 14–54	221
		1965						BC	22[e] 11–43[e]	221
Europe	> 30°N									
Austria	47–49°N		(0.75)	(0.06)	(0.05)	(0.01)	(0.21)			
		1963	26	16	4.5	0.7	1.0	AC	45	153
		1964								
		1965								
Denmark	55–60°N	1963	18	28	4.4	0.9	2.0	AC	31	206
								BC	31	206
		1964	19	48	3.8	0.9	1.8	AC	43	207
								BC	39	207
		1965	13	22	2.3	0.8	1.1	AC	23	227
								BC	23	227
Faroes	60–70°N	1963	54	28	2.2	5.0	7.1	AC	58	228
		1964	63	48	1.7	5.0	8.9	AC	77	229
		1965	46	22	1.0	9.0	13.4	AC	56	227
Federal Republic of Germany	43–55°N	1963	14	9.9	3.0	1.8	0.9	AC		255
		1964	12	11	5.4	2.4		AC		255
		1965								
France	42–50°N		(0.54)	(0.07)	(0.08)	(0.05)				
		1965	15	7.2	1.8	1.3		AC	34	234
USSR (rural population)	35–70°N	1963						AC	62 46–99[d]	239
		1964							88 73–140[d]	239
		1965								
USSR (urban population)	35–70°N	1963						AC	67	239
		1964						AC	94	239
		1965								
United Kingdom	50–60°N		(0.63)	(0.04)	(0.05)	(0.03)	(0.35)[a]			
		1963	15	3.4	2.2	1.3	3.2	AC	23	256
		1964	17	4.3	1.6	1.2	4.0	AC	26	155
		1965	12	2.8	1.4	1.4	1.8	AC	18	257
Near East										
Israel			(0.37)	(0.23)	(——0.11——)		(0.17)		(0.88)	
		1965	11	15.5	0.5	0.5	4.5	AE	25	241, 242
Caribbean										
United States	18°N									
San Juan, P. R.		1963						AD	30	143
Far East										
Japan	30–50°N			(0.05)	(0.31)[b]	(0.07)	(0.20)[c]			
		1963		1.7	9.4	3.5	0.8	BE	28	258
		1964	0.9	2.1	7.2	3.0	2.5	BE	33	258
		1965	1.0	1.8	3.0	2.3	2.9	BE	25	258

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

Calcium in grammes per day in parentheses; Sr^{90} in pCi per day; Sr^{90}/Ca ratio in total diet in pCi/g Ca in column 10 (all values have been rounded out to two significant figures)

Types of study: A — Survey of individual foodstuffs
B — Total diet analyses
C — Widespread regular sampling
D — Local regular sampling
E — 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*	*References*
Oceania										
United States										
Hawaii (institutional diet sampling)	21°N	1963						BD	14	221
		1964						BD	22	221
		1965						BD	29[e]	221
			SOUTHERN HEMISPHERE							
Oceania										
Australia	10–40°S		(0.64)	(0.05)	(0.07)	(0.01)	(0.05)			
		1963	3.9	0.5	0.5	0.1	~0.3	AC	6.4	249
		1964							9.0	103
		1965								
South America										
Argentina (littoral area)	~35–55°S	1963	(0.45)	(0.02)	(0.11)	(0.02)	(0.06)			
			1.7	0.5	1.2	0.4	0.5	AD	6.5	252
		1964	(0.4)	(0.07)	(0.09)	(0.09)	(0.05)			
			2.3	2.1	0.9	0.8	0.4	AD	9.2	215
		1965	2.8	2.1	0.6	0.2	0.4	AD	8.7	215

[a] Including *creta praeparata*.
[b] Including seaweeds.
[c] Including fish and shellfish, dairy products, eggs and meat.
[d] Range of average values reported for sixteen republics of the USSR.
[e] First half of the year 1965.

TABLE X. Sr^{90} IN HUMAN BONE

pCi Sr^{90} per gramme of calcium[a]
(Number of samples in parentheses)

Region, country or area	*Year*	*New-born and/ or still-born*[t]	*0-1 year*[s]	*1 year*	*2 years*	*3 years*	*4 years*	*5-19 years*	*> 19 years*	*Bone type studied (adults)*	*Average Sr/Ca ratio for adult skeleton*[c]	*References*
					NORTHERN HEMISPHERE							
North America (30-60°N)												
Canada	1963	2.3 (15)	6.0 (40)	5.4 (12)	4.8 (9)	3.4 (5)	3.1 (9)	2.6 (48)	1.7 (34)	V	1.0	259
	1964	4.3 (35)	8.4 (46)	9.5 (27)	———	5.8 (47)	———	3.8 (94)	3.1 (59)	V	1.8	260
	1965											
United States												
Chicago, Ill.	1963		3.5 (2)		3.7 (2)	2.8 (3)		2.4 (2)	1.1 (12)	V	0.65	261
	1964					2.0 (1)		3.1 (5)	1.4 (43)	V	0.85	223, 262
	1965								1.3 (16)	V	0.76	263
New York City, N. Y.	1963		6.8 (10)	6.9 (2)	3.7 (6)	2.8 (3)	2.2 (1)	2.1 (26)	1.6 (23)	V	0.94	261
	1964	6.9 (3)	7.9 (7)	4.9 (4)	6.0 (4)	3.2 (3)	4.4 (2)	3.2 (30)	2.0 (28)	V	1.2	223, 262
	1965	2.8 (6)	5.0 (5)	7.0 (3)	7.2 (2)	6.7 (6)	4.1 (2)	3.5 (39)	2.1 (16)	V	1.2	263
San Francisco, Cal.	1963		2.1 (32)	2.7 (2)	1.7 (7)	1.1 (5)	1.7 (5)	1.4 (27)	0.9 (22)	V	0.53	261
	1964	2.2 (13)	2.9 (1.5)	3.2 (8)	2.4 (4)	1.8 (2)		1.6 (24)	1.4 (14)	V	0.82	223, 262
	1965	1.6 (13)	3.3 (13)	3.8 (6)	3.1 (1)	3.0 (3)	1.8 (5)	1.7 (19)	1.2 (30)	V	0.68	263
All regions	1963		1.7 (4)	4.8 (3)	5.7 (8)	5.3 (11)	4.2 (14)	3.0 (141)	2.2 (55)	V	1.3	221
	1964		4.3 (4)	5.4 (7)	5.7 (10)	4.6 (16)	4.1 (15)	3.2 (160)	2.2 (46)	V	1.3	221
	1965		5.5 (6)	3.6 (3)	5.5 (6)	4.2 (6)	3.2 (10)	2.8 (66)	1.9 (19)	V	1.1	221
Caribbean (10-20°N)												
United States												
San Juan, P. R.	1963							2.2 (69)	1.7 (26)	V	1.0	143
Europe (45-70°N)												
Czechoslovakia	1964	4.6 (15)	7.1 (42)	8.3 (6)	3.0 (4)	3.9 (4)	4.0 (3)	3.3 (36)	1.8 (64)	V	1.1	226

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

pCi Sr^{90} per gramme of calcium[a]
(Number of samples in parentheses)

Region, country or area	*Year*	*New-born and/ or still-born*[f]	*0-1 year*[g]	*1 year*	*2 years*	*3 years*	*4 years*	*5-19 years*	*> 19 years*	*Bone type studied (adults)*	*Average Sr/Ca ratio for adult skeleton*[r]	*References*
Denmark	1963	2.8 (12)	4.2 (13)	4.9 (2)		2.3 (1)	5.1 (2)	2.2 (13)	1.2 (44)	V	0.71	206
	1964	3.8 (11)	6.5 (44)	5.9 (2)	3.9 (1)	5.1 (3)	9.1 (5)	3.9 (46)	2.4 (77)	V	1.4	207
	1965	2.7 (14)	6.1 (17)	8.5 (3)	6.5 (2)	8.4 (2)		4.1 (31)	2.7 (23)	V	1.6	227
Federal Republic of Germany	1963	2.3 (166)	4.0 (21)			2.9 (9)		1.4 (27)	0.5 (46)	T	—[d]	264, 265
	1964	3.1 (172)	4.9 (20)			6.0 (16)		2.8 (28)	0.8 (47)	T	—[d]	264, 265
	1965	2.5 (92)	6.2 (10)			5.5 (9)		2.7 (13)	1.1 (43)	T	—[d]	264
Norway	1963	2.5 (14)	6.9 (2)			5.3 (1)		3.2 (5)	1.7 (1)	V	1.0	266
	1964	4.8 (7)	8.9 (6)			9.2 (4)		4.2 (8)				266
	1965	5.7 (13)	15.0 (6)			12.0 (1)		5.3 (4)				266
Poland	1963	5.0[h] (53)	5.6[i] (55)	6.1 (3)		4.8 (2)	3.3 (2)	3.2 (23)	1.6 (66)	V	0.94	267
	1964	4.8[h] (44)	5.6[i] (49)	3.9 (3)		6.0 (4)	3.1 (1)	3.8 (10)	2.5 (56)	V	1.5	267
	1965											
Switzerland	1963								1.0 (47)	V	0.59	237, 238
	1963								0.70 (40)	R	0.70	237, 238
	1964								2.5 (15)	V	1.5	238
	1964								1.4 (4)	R	1.4	238
	1965											
USSR[b]	1963		5.0 (6)			4.2 (7)		1.9 (1,567)	1.0[e] (4,142)		1.0	156
	1964	3.5 (68)	5.9 (33)			6.9 (9)		2.9 (5,425)	1.4 (18,694)		1.4	157
	1965											
United Kingdom	1963[k]	2.4 (167)	5.2 (104)	5.1 (24)	4.1 (12)	2.2 (11)	2.3 (14)	1.6 (74)	0.6 (22)	F	—[e]	268, 269
	1963[l]	1.8 (20)	4.5 (17)				2.6[m] (11)	1.3[n] (15)	0.86 (47)	V	0.51	270
	1964[k]	3.0 (92)	8.6 (80)	9.2 (21)	6.4 (7)	4.9 (9)	4.6 (13)	2.2[n] (46)	0.5 (9)	F	—[e]	271, 272

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

pCi Sr^{90} per gramme of calcium[a]
(Number of samples in parentheses)

Region, country or area	*Year*	*New-born and/ or still-born*[f]	*0-1 year*[g]	*1 year*	*2 years*	*3 years*	*4 years*	*5-19 years*	*> 19 years*	*Bone type studied (adults)*	*Average Sr/Ca ratio for adult skeleton*[e]	*References*
	1964[l]	3.3	8.1	———	———	———	4.9[m]	——2.4——	1.5	V	0.88	270
		(15)	(12)				(14)	(13)	(44)			
	1965[k]	3.0	7.2	11.0	8.4	7.1	5.3	2.8	1.3	Diff.	—	270
	Jan.-June	(102)	(53)	(16)	(8)	(3)	(4)	(41)	(5)			
Far East (30–50°N)												
Japan	1963	1.4	———	———	2.0	———	———	1.4	0.4	R	0.4	273
		(17)			(38)			(44)	(47)			
	1964	2.0	———	———	5.1	———	———	2.8	0.9	R	0.9	274
		(36)			(14)			(58)	(39)			
	1965	2.2	3.6	8.5	11	6.0	3.6	2.5	1.0	R	1.0	275
		(12)	(8)	(2)	(1)	(1)	(1)	(27)	(20)			
					SOUTHERN HEMISPHERE							
South America (~ 35°S)												
Argentina (littoral area)	1963	0.8										145
		(23)										
	1964											
	1965	1.6	2.0	2.3	2.0	——1.7——		1.5[j]				215
		(12)	(39)	(8)	(5)	(4)		(12)				
Oceania (10–40°S)												
Australia	1963	0.78	1.2	2.1	1.7	1.2	1.3	1.0	0.61	V	0.36	249
		(80)	(315)	(22)	(9)	(15)	(5)	(247)	(577)			
	1964	0.86	1.9	2.2	2.0	1.8	1.3	1.0	0.69	V	0.41	103
		(60)	(153)	(35)	(25)	(20)	(13)	(119)	(494)			
	1965	1.2	2.9	3.0	2.7	2.0	2.8	1.3	0.76	V	0.45	103
	January-June	(21)	(68)	(12)	(8)	(9)	(6)	(48)	(225)			

Note:
V—Vertebrae.
R—Ribs.
T—Tibiae.
F—Femora.

[a] All values have been rounded out to two significant figures.

[b] Average values for all areas investigated in the European and Asian territory of the USSR. Values in parentheses indicate number of individual samples collected, composed mainly of teeth in 5-19 and > 19 year groups (usually analyzed as pooled samples).

[c] Skeletal average for adults obtained by applying normalization factors determined in 1963 by Marei *et al.*, the ratios vertebrae/skeleton, ribs/skeleton, femur shaft/skeleton and teeth/skeleton being 1.7, 1.0, 0.4 and 0.3, respectively.

[d] No direct normalization factor determined; skeletal averages may be assumed to be higher by a factor of ~ 2.

[e] Vertical hemisections of femora analyzed; no recent normalization factors available.

[f] Still-born children and children of the age between zero and fourteen or zero and thirty days.

[g] Age between two weeks and one year or one month and one year.

[h] Age between zero and two months.

[i] Age between two and twelve months.

[j] Age between five and ten years.

[k] Country-wide survey, including England, Wales and Scotland.

[l] Limited survey in West London area.

[m] One to nine years of age.

[n] Ten to nineteen years of age.

TABLE XI. DEPOSITION OF Cs^{137} IN FINLAND AND Cs^{137} CONTENTS OF LICHEN AND REINDEER MEAT, 1961-65[178]

Year	Deposition Cs^{137} mCi/km²		Lichen			Reindeer meat		
	Annual	Cumulative[a]	Date	nCi/kg dry weight (mean ± σ)	Number of samples	Date	nCi/kg fresh weight (mean ± σ)	Number of samples
1960		24.0[b, c]						
1961	1.3[c]	24.7	8/61	16 ± 3.5	(5)	10/61	15.8	(2)
1962	10.6[c]	34.7	7/62	22 ± 3	(15)	2/62	17.2	(2)
1963	19.4[c]	53.3	7/63	37 ± 0.5	(3)	3/63	48.0	(12)
1964						3/64	50.0 ± 4	(60)
	10.2	63.3	7/64	64 ± 8	(3)	12/64	60.1 ± 5	(6)
1965						4/65	72.3 ± 9	(4)
	4.3	66.1	8/65	56 ± 3	(3)	12/65	55.3 ± 9	(4)

[a] Corrected for decay to the end of each year.
[b] For the 1960 value (end of year) that of Sr^{90} for Leningrad (15 mCi/km²) is used.
[c] Calculated from Sr^{90} data using Cs^{137}/Sr^{90} ratio of 1.6.

TABLE XII. THE VALUES OF BIOLOGICAL HALF-LIFE OF CAESIUM IN ADULT MAN

Author	Locality	Number of cases studied	Average half-life in days (range in parentheses)	References
Melandri	Bologna, Italy	1	165	183
Oberhausen	Landstuhl, Germany	1	144	276
Van Dilla	Los Alamos, N. Mex., U.S.A.	4	128 (113–150)	184
Richmond	Los Alamos, N. Mex., U.S.A.	4	126 (110–146)	277
McNeill	Chalk River, Canada	3	115 (110–119)	278
Taylor	London, U.K.	4	109 (79–123)	279
Jeanmaire	Paris, France	1	100	188
Jordan	Bethesda, Md., U.S.A.	3	99 (76–126)	187
Colard	Mol, Belgium	2	99	280
Rundo	Harwell, Berks., U.K.	14	98 (58–149)	281
Miller	Chicago, Ill., U.S.A.	4	94 (82–100)	282, 283
Hesp	Windscale, West Cumberland, U.K.	2	92 (68–116)	185
Naversten	Lund, Sweden	6	77 (63–89)	186
Häsänen	Helsinki, Finland	6	63 (42–93)	284

TABLE XIII. Cs^{137} IN MILK

Values are given in pCi/litre and represent yearly averages unless otherwise indicated

Type of study: A—Widespread systematic survey
B—Local systematic survey
C—Irregular sampling

Region, area or country	1963	1964	1965	Type of study	References
NORTHERN HEMISPHERE					
North America					
Canada (40–55°N)	170[a]	210[a]	110[a]	A	151
United States (25–48°N) (conterminous)	110[b]	110[b]	57[b]	A	221
United States Alaska (62°N)	120	120	57	B	221
Europe					
Austria (47–49°N)	160–290[c]			A	153
Belgium (~50°N)	300[g]	110[a]		B	224, 225
Denmark (55–60°N)	110[d]	110[d]	56[d]	A	206, 207, 227

TABLE XIII. Cs^{137} IN MILK (*continued*)

Values are given in pCi/litre and represent yearly averages unless otherwise indicated

Type of study: A — Widespread systematic survey
B — Local systematic survey
C — Irregular sampling

Region, area or country	*1963*	*1964*	*1965*	*Type of study*	*References*
Faroes (60–70°N)	790[h, r]	1,400[h, r]	1,100[h, r]	A	227–229
Federal Republic of Germany (43–55°N)	130[d]	110[d]	110[d]	A	230
Finland (60–67°N)	240[i]	250[i]	190[i]	A	285
France (42–50°N)	240[j]	220[j]	130[j]	A	232–234
Iceland (66–73°N)	580[r]	870[r]	750[r]	A	235
Ireland (50–55°N)	190	170		A	155
Italy (37–47°N)	160[b]	200		A	286, 287
Norway (58–70°N)	540[a, e, r]	600[a, e, r]	520[a, e, r]	A	288
	330[a, f, r]	430[a, f, r]	360[a, f, r]	A	69, 236
Sweden (55–70°N)	180[l]	172[l]	110[l]	A	289
Switzerland Geneva (~46°N)	210[m]	180		B	237, 238
United Kingdom (50–60°N)	130[d]	150[d]	98[d]	A	155, 240, 256
USSR (35–70°N)	210[a]	160[a]		C	239
Middle America, South America and Caribbean					
Jamaica (~13°N)		350[p]	280[k]	B	152
Panama (~7°N)			40[k]	C	152
United States Puerto Rico (18°N)	88	70	42	B	221
Venezuela (5–12°N)	22[p]	26	21[k]	B	152
Asia					
India (8–35°N)	29[a]	15[a]	11[a]	A(C)	243
Near East					
Israel (~32°N)	35[a]		25[a]	C	241, 242
Far East					
Japan (30-50°N)	120	95	59[k]	C[o]	244–248, 290
Oceania					
United States Hawaii (21°N)	73	77	51	B	221
SOUTHERN HEMISPHERE					
Oceania					
Australia (10-40°S)	33[a]	49[a]	47[a]	A	291, 292
New Zealand (35–47°S)	56[a, n]	90[a]	96[a]	A	98, 250
South America					
Argentina (littoral area, 35-55°S)	13	20	20	B	102, 215

[a] Unweighted mean for all milksheds surveyed.
[b] Country-wide mean weighted by population.
[c] Average values for three zones of different yearly rainfall, covering the whole country.
[d] Country-wide mean weighted by production.
[e] Unweighted mean from the survey of thirty milksheds.
[f] Unweighted mean from the survey of ten milksheds.
[g] Simple average of values obtained from three farms and three dairies.
[h] Locally produced.
[i] Non-weighted average of three milksheds for the period October 1962-July 1963.
[j] Unweighted mean of representative samples from all departments of France.
[k] January-August only.
[l] Country-wide mean weighted by consumption.
[m] June-December only.
[n] July-December only.
[o] Non-systematic widespread sampling.
[p] April-December only.
[r] Unusually high levels due to heavy rainfall and particular grazing conditions.

TABLE XIV. Cs^{137} IN TOTAL DIET

Yearly average values are given in pCi/day unless otherwise indicated (all values have been rounded out to two significant figures)

Type of study: A—Survey of individual foodstuffs
B—Total diet analyses
C—Widespread sampling
D—Local sampling
E—Irregular sampling

Region, area or country	*Year*	*Milk and milk products*	*Meat*	*Miscellaneous*	*Total*	*Type of study*	*Remarks*	*References*
North America								
Greenland (> 60°N)	1963	24	180[a]	95	300	AC	Area of poor grazing conditions and high rainfall	253
	1964	24	310[a]	230	560	AC		254
	1965							
United States								
Chicago, Ill. (42°N)	1963[b]	58	34	58	150	AD		293
	1963[c]	88	5	6	99	AD		294
	1964[b]	69	43	90	200	AD		293
	1964[c]	120	9	13	140	AD		294
	1965[b, d]	51	38	64	150	AD		294, 295
	1965[c, d]	82	5	12	99	AD		294, 295
United States conterminous (25–48°N) (institutional diet sampling)	1963				140 (14–270)[f]	BC		221
	1964				150 (70–300)[f]	BC		221
	1965				100 (40–220)[f, k]	BC		221
Alaska (62°N) (local institutional diet sampling)..	1963				140	BD		221
	1964				160	BD		221
	1965				65[k]	BD		221
Europe								
Denmark (50–60°N)	1963	50	94	130	270	AC		206
					(250)	BC		206
	1964	53	91	180	320	AC		207
					(320)	BC		207
	1965	26	64	100	190	AC		227
					(240)	BC		227
Faroes (60–70°N)	1963	280	570	170	1,000	AC	Area of high rainfall and poor grazing conditions	228
	1964	430	210	250	890	AC		229
	1965	340	290	250	880	AC		227
Federal Republic of Germany (43–55°N)	1963	50	60	90	200	AC		255
	1964	62	110	88	260	AC		255
	1965				150	AC		296
Sweden (55–70°N)	1964	90	75	100	260[g]	AC		194
USSR (rural population) (35–70°N)	1963				250 (130–450)[j]	AC		239
	1964				330 (190–550)[j]	AC		239
	1965							
USSR (urban population)	1963				210	AC		239
	1964				290	AC		239
	1965							
United Kingdom (50–60°N) ..	1963	57	70	51	180	AC		256
	1964	66	59	36	160	AC		155
Near East								
Israel (~ 32°N)	1965				92	AE		242

TABLE XIV. Cs^{137} IN TOTAL DIET (*continued*)

Yearly average values are given in pCi/day unless otherwise indicated (all values have been rounded out to two significant figures)

Type of study: A—Survey of individual foodstuffs
B—Total diet analyses
C—Widespread sampling
D—Local sampling
E—Irregular sampling

Region, area or country	*Year*	*Milk and milk products*	*Meat*	*Miscellaneous*	*Total*	*Type of study*	*Remarks*	*References*
Far East								
Japan	1963				65	BC		297, 298
	1964				64	BC		299, 300
	1965				41	BC		299, 300
Oceania								
United States								
Hawaii (institutional diet sampling) (21°N)	1963				97	BD		221
	1964				120	BD		221
	1965				120[k]	BD		221

[a] Including eggs and fish.
[b] Average adults' diet.
[c] Infants' diet during the first year of life.
[d] January and April sampling only.
[e] Widespread dietary survey in twenty-one boarding schools in the United States, based on composite diets of children and adolescents of six to eighteen years of age.
[f] Range of yearly averages reported for individual schools.
[g] January 1964 sampling.
[h] Dairy products, eggs, meat, fish and shellfish.
[i] Data for 1963 include three series of sampling at four locations in the period January-July.
[j] Range of values calculated for daily average intake by the rural population of sixteen republics of the Soviet Union.
[k] January-June only.

TABLE XV. CAESIUM-137 IN MAN

All values are group averages in pCi Cs^{137}/g K unless otherwise indicated

(Figures in parentheses indicate the number of measurements performed)

Region, country or area of residence	1963 I	1963 II	1963 III	1963 IV	1964 I	1964 II	1964 III	1964 IV	1965 I	1965 II	1965 III	1965 IV	1966 I	References
NORTHERN HEMISPHERE														
North America														
Canada (northern) (H) ..	~ 1,000[b, c]				~ 1,400–2,800[b, c]				~ 2,800–9,000[b, c]					301, 302
Canada														
Ottawa										170 (63)				303
United States														
Alaska (Eskimos) (H)	240–4,500[a, b]				360–9,100[a, b]				310–7,500[a, b]					304–306
Alaska (Eskimos)					3,400[b]		8,200[b]	5,600[b]	4,600[b]	4,600[b]				307
Anaktuvuk Pass (H)					(50)		(51)	(30)	(25)	(25)				
Brookhaven, N.Y.	~ 60 (10)	70 (10)	95 (10)	120 (10)	130 (10)	140 (10)	180 (10)							308
Los Alamos, N. Mex...		72 (86)	92 (80)	95										309
Los Angeles, Cal.			59 (14)	95 (36)	93 (36)	114 (25)	99 (15)	91 (34)	91 (50)	86 (40)	84 (51)	76 (50)	63 (23)	310
Europe and Asia														
Belgium	73 (507)		117 (529)		146 (552)		169 (623)		144 (407)		125 (381)		105 (167)	280
Denmark														
Riso			89 (14)	132 (14)		143 (10)	195 (10)	176 (10)	191 (20)		170 (15)	153 (20)		206, 207, 227
Federal Republic of Germany	47 (42)	54 (42)	83 (40)	120 (40)	141 (40)	163 (40)	152 (40)	148 (40)	131 (40)	119 (40)	104 (40)	101 (40)		311
Finland														
Helsinki	112 (49)	120 (49)	175 (49)	200 (49)	204 (24)	218 (49)				205[h]	200 (78)	160 (27)		173, 284, 312, 313
Lapland (H)	1,430–4,420[a]				2,260–8,360[a]				2,370–10,640[a]				2,000–8,200[a] (121)	173, 312, 314
France (northern)	70 (~ 60)	103 (~ 60)	132 (~ 60)	168 (~ 60)	197 (~ 60)	240 (~ 60)	273 (~ 60)	198 (~ 60)	242 (~ 60)	220 (~ 60)	159 (~ 60)	155 (~ 60)	103 (~ 60)	315, 316
Italy														
Bologna	74 (13)	81 (13)	124 (13)	150 (13)										183
Norway (western) (R)..	332[f] (11)			651 (169)										288, 317
Oslo[e]	178 (23)			338 (23)	357 (23)					337 (25)				288, 317
Masfjorden (R)	870 (11)			1,430 (10)				2,000 (10)				1,230 (10)		288, 317
Poland														
Lodz		133 (23)		181 (23)		128 (22)		200 (22)						318

TABLE XV. CAESIUM-137 IN MAN (*continued*)

All values are group averages in pCi Cs^{137}/g K unless otherwise indicated

(Figures in parentheses indicate the number of measurements performed)

Region, country or area of residence	*1963*				*1964*				*1965*				*1966*	*References*
	I	*II*	*III*	*IV*	*I*	*II*	*III*	*IV*	*I*	*II*	*III*	*IV*	*I*	
Sweden														
Stockholm	60 (13)	72 (9)	122 (8)	151 (22)	182 (20)	235 (10)		191 (13)						194
Lapland (H)	1,700-2,900[a] (105)				2,600-5,400 (94)				3,000-6,400 (96)					174
Switzerland														
Geneva		74 (~ 15)	107 (~ 15)	151 (~ 15)	180 (15)	188 (17)	196 (14)	184 (22)						237, 238
USSR (far north) (H)	3,570-23,600[b, d] (60)				7,140-25,700[b, d] (30)				1,400-34,000[b, d]					175, 319
United Kingdom														
Berkshire	54 (10)	64 (12)	90 (11)	115 (13)	138 (13)	150 (13)	162 (15)	170 (17)	166 (18)	160 (21)	149 (19)	124 (21)	104 (24)	320, 321
West Cumberland	107 (14)	138 (14)	198 (14)	249 (14)	255 (14)	256 (14)	272 (14)							322
Far East														
Japan	64[g] (68)	59[g] (68)	66[g] (74)	40 (23)		96 (20)	101 (42)	107 (41)	90 (29)	82 (54)	71 (16)			275, 323
					SOUTHERN HEMISPHERE									
Oceania														
Australia														
Adelaide	36 (24)	33 (19)	33 (22)	21 (21)	32 (29)	36 (6)	31 (4)	45 (4)	67 (7)	66 (29)	67 (11)	62 (11)		324

Note:

(H) = High levels of Cs^{137} due to operation of the lichen-reindeer (caribou) food chain mechanism (paragraphs 98–101).

(R) = High levels of Cs^{137} due to very high average rainfall in the area and poor grazing conditions for cattle.

[a] Average values for different groups of local population (Lapps or Eskimos only).

[b] Approximate values calculated only for adults from reported total body burden assuming 140 g of potassium in the body, or from data on caesium-137 body weight ratio assuming approximately 1.9 g K/kg in females and 2.3 g K/kg in males.

[c] Approximate values calculated from excretion of Cs^{137} in urine in groups of population subsisting to a varying degree on reindeer meat in their diet.

[d] Range of concentrations observed in individual reindeer breeders.

[e] Group of schoolboys sixteen to eighteen years old in 1963 and eighteen to twenty years old in 1965.

[f] Masfjorden residents.

[g] Estimated from radio-chemical analysis of muscles.

[h] Calculated from total body burden assuming 140 g K in an average adult male.

TABLE XVI. C^{14} CONTENT OF SOME FOODSTUFFS AND HUMAN TISSUES COLLECTED IN VARIOUS PLACES[209-211]

The values are expressed in per cent increase of C^{14} specific activity above pre-test levels

(Number of samples in parentheses)

Area or locality	*Year:*	*1962*		*1963*				*1964*			
	Quarter:	*III*	*IV*	*I*	*II*	*III*	*IV*	*I*	*II*	*III*	*IV*
Foodstuffs											
Cereals, Norway	64°N									94 (3)	
Milk, Norway	64°N					84 (1)	71 (2)	71 (1)		91 (3)	
Milk, United States	30–50°N				40 (1)						
Meat, poultry and eggs, United States	30–50°N			28 (4)		16 (2)					
Fruits, United States	30–50°N		12 (1)	18 (3)							
Potatoes, United States ..	30–50°N					48 (2)					
Total diet, United States	30–50°N					26 (7)	33 (6)	34 (1)			
Human tissues											
Soft tissues and blood											
Norway	64°N					34 (2)	41 (3)	43 (3)	46 (4)	53 (2)	53 (2)
United States	30–50°N	24 (2)				33 (1)	16 (3)	38 (14)	54 (1)		
Australia, Melbourne ..	38°S								57[a'] 14[a'']		

[a] Data for a subject from Melbourne, Australia, who stayed in the United States for two weeks prior to death (a' — plasma; a'' — erythrocytes).

TABLE XVII. DOSE COMMITMENTS FROM NUCLEAR EXPLOSIONS

Tissue	*Source of radiation*	*Dose commitments (mrad) for period of testing 1954-1965*	*Paragraphs*
Gonads	External, short-lived	23	137
	Cs^{137}	25	135
	Internal, Cs^{137}	15	145
	C^{14} [a]	13	147
	TOTAL[b]	76	
Cells lining bone surfaces	External, short-lived	23	137
	Cs^{137}	25	135
	Internal, Sr^{90}	156	143
	Cs^{137}	15	145
	C^{14} [a]	20	147
	Sr^{89}	0.3	146
	TOTAL[b]	240	
Bone marrow	External, short-lived	23	137
	Cs^{137}	25	135
	Internal, Sr^{90}	78	143
	Cs^{137}	15	145
	C^{14} [a]	13	147
	Sr^{89}	0.15	146
	TOTAL[b]	150	

[a] As in the 1964 report, only the doses accumulated up to year 2000 are given for C^{14}; at that time, the doses from the other nuclides will have essentially been delivered in full. The *total* dose commitment to the gonads due to C^{14} from tests up to the end of 1965 is about 180 mrads.

[b] Totals have been rounded off to two significant figures.

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