# ANNEX E

## Exposures resulting from nuclear explosions

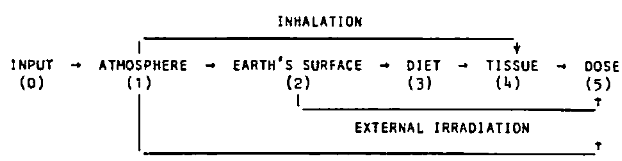
CONTENTS



### *Introduction*

1. Since the publication of the 1977 report of the Committee [U6], a few additional nuclear tests have occurred in the atmosphere of the northern hemisphere. In this Annex, therefore, the total inventory of radionuclides from nuclear tests has been re-assessed and the consequent changes in the dose commitments have been evaluated.

2. The transfer of radionuclides between compartments of the environment linking the input of radionuclides to the dose in man has been modelled in the same way as in the previous reports of the Committee and can be represented schematically as follows:




Transfers between successive steps in the pathway chains are described by transfer coefficients, which relate infinite time integrals of concentration, dose or other quantities in the relevant compartments (see Annex A of this report and Annex C of the 1977 report [U6]). For example, the transfer coefficient from diet to tissue is the ratio of the integral concentration of activity in tissue to that in diet and is designated $P_{34}$. Transfers linking input to dose are determined by sequential multiplication of transfer coefficients. Transfers by parallel pathways are assumed to be independent and are thus additive. For the transfers indicated in the diagram the dose commitment for a specific radionuclide and a given tissue, $D^c$, due to an input $A_0$ into the atmosphere is given by

$$D^c = P_{01} [P_{12} P_{23} P_{34} P_{45} + P_{14} P_{45} + P_{15} + P_{12} P_{25}] A_0 \quad (1)$$

3. In addition to dose commitments, estimates are also made of the collective dose commitments and the collective effective dose equivalent commitments, according to the general methods presented in Annex A. The specific assumptions regarding the global population size are as follows: 3.2 $10^9$ persons in the early 1960s during the maximum exposures from nuclear explosions, applied to inhalation exposures and to exposures to radionuclides with half-lives less than a few years; an average population size of 4 $10^9$ persons applied to exposures from radionuclides with half-lives from 10 to 30 years; 6 $10^9$ persons corresponding to exposures from radionuclides with 50- to 90-year half-lives; and $10^{10}$ persons for exposures from longer-lived radionuclides.

4. This Annex deals essentially with topics for which new information has become available since the publication of the 1977 report [U6]. The reader is referred to Annex C of that report for a more detailed presentation. Since this Annex incorporates the SI units, a brief summary for each radionuclide is given with converted values for the transfer coefficients. The dose calculations are extended to include estimates of exposures to nuclear tests which have occurred prior to 1981.

## I. INPUT AND TRANSPORT OF RADIOACTIVE DEBRIS WITHIN THE ATMOSPHERE

5. Nuclear tests have been conducted in the atmosphere since 1945. Large yield test programmes took place during 1954–1958 and 1961–1962. Continued individual tests have occurred since 1964. Recent deposition of fallout radioactivity has been largely due to the high yield test (4 Mt) which occurred in November 1976. Smaller atmospheric tests (20 kt each) took place in September 1977 and in March and December 1978. No atmospheric tests were conducted during 1979. In October 1980, a test of intermediate yield (0.2 to 1 Mt) occurred.

6. Estimates of the explosive yields of individual nuclear tests have not generally been available. Therefore the estimates of the cumulative amounts of radioactive materials released to the environment have come from measurements of deposition of significant fission nuclides ($^{90}$Sr, $^{137}$Cs). Production of other nuclides can be estimated from observed ratios, taking into account the various radioactive decay times.

7. For some purposes, however, estimates of explosive and fission yields of individual tests or of annual test series are required so that more specific records of concentrations of radionuclides in air or of deposition amounts can be derived. An example is $^{241}$Am, which is not directly produced in nuclear tests, but results from decay of $^{241}$Pu as it disperses in the atmosphere or after it has been deposited on the ground. Estimates of the total and fission yields for each reported test through 1978 have been made by Bennett [B7]. This compilation makes use of previous listings of dates, locations and types of tests [U8, Z1]. The estimates of individual yields are useful for calculations but cannot yet be verified. The cumulative yields over a one- or two-year period agree with the reported total yields [F3], and these are listed in Table 1. The listing does not include underground nuclear tests, which do not normally release radioactive material to the atmosphere or cause exposure of the public.

8. The production of fission nuclides is proportional to the fission yields of the tests, whereas the production of nuclides formed mainly by neutron activation, such as $^3$H and $^{14}$C, can be assumed to be proportional to the fusion yields. From Table 1 it may be seen that only about 10% of the fission production has occurred since 1963 and that about 1% is due to explosions carried out between 1976 and 1980.

9. The radioactive debris from a nuclear test is partitioned between the local ground or water surface and tropospheric and stratospheric regions, depending on the type of test, location and yield. Local fallout, which can comprise as much as 50% of the production for surface tests and includes activity present in large aerosol particles which are deposited within about one hundred km of the test site, has not been considered in the Committee's assessments, as tests have generally been conducted in isolated areas.

10. Tropospheric fallout consists of smaller aerosols which are not carried across the tropopause after the explosion and which deposit with a mean residence time of up to 30 d. During this period the debris becomes dispersed, although not well mixed, in the latitude band of injection, following trajectories governed by wind patterns, as illustrated in Figure I. From the viewpoint of human exposures, tropospheric fallout is important for nuclides of a few days to two months half-life, such as $^{131}$I, $^{140}$Ba or $^{89}$Sr.

11. Stratospheric fallout, which comprises the bulk of the production, is due to those particles which are carried to the stratosphere and later give rise to world-wide fallout, the major part of which is in the hemisphere of injection. Stratospheric fallout accounts for most of the world-wide contamination of long-lived fission products.

12. The estimated stratospheric partitioning of nuclear debris is given in Table 2. In this summary from Bennett [B7], partitioning criteria provided by Ferber [F7] and Peterson [P4] have been used. As shown in Figure II, the atmosphere is divided into equatorial and polar regions from 0° to 30° and 30° to 90° latitude, respectively. The lower stratosphere is assumed to range from 9 to 17 km in the polar region and from 17 to 24 km in the equatorial region. The upper stratosphere extends to 50 km altitude. The region above the stratosphere is designated the high equatorial and high polar atmosphere, which extends to several hundred kilometres to include the remainder of the region from which debris will eventually be deposited on the earth's surface. Only a few tests injected debris into this region of the atmosphere. There have been no injections into the south polar atmosphere.

13. The main features of mixing processes and air movements in the atmosphere, illustrated in Figure II,

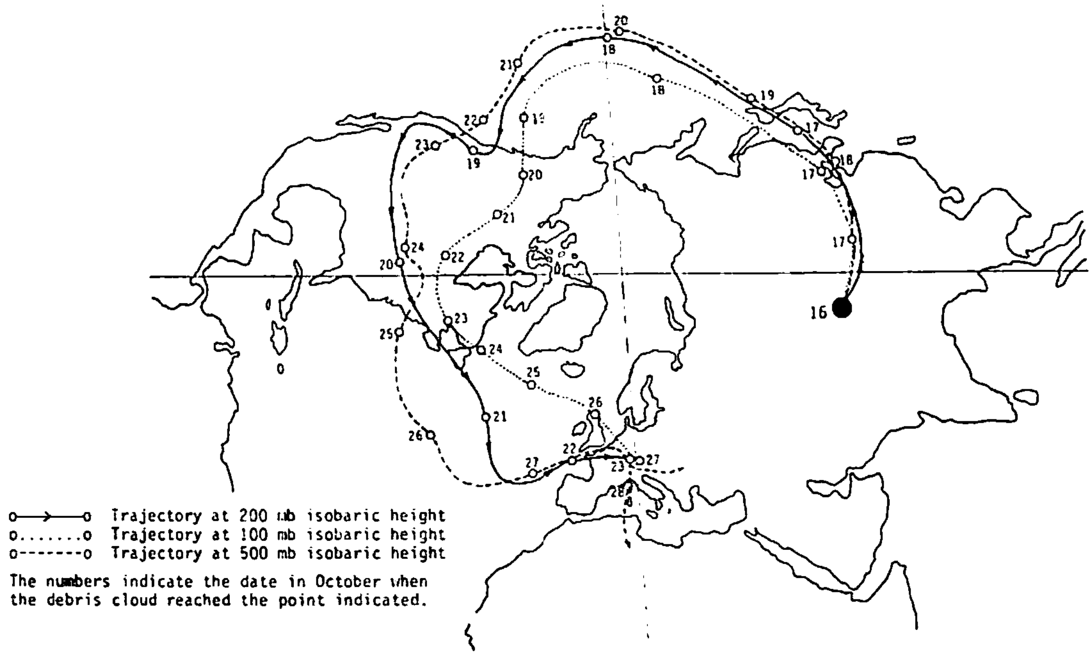



**Figure I. Trajectories derived from meteorological data, generally confirmed by activity measurements in ground-level air, of tropospheric fallout from the atmospheric nuclear explosion of 16 October 1980 [I5]**

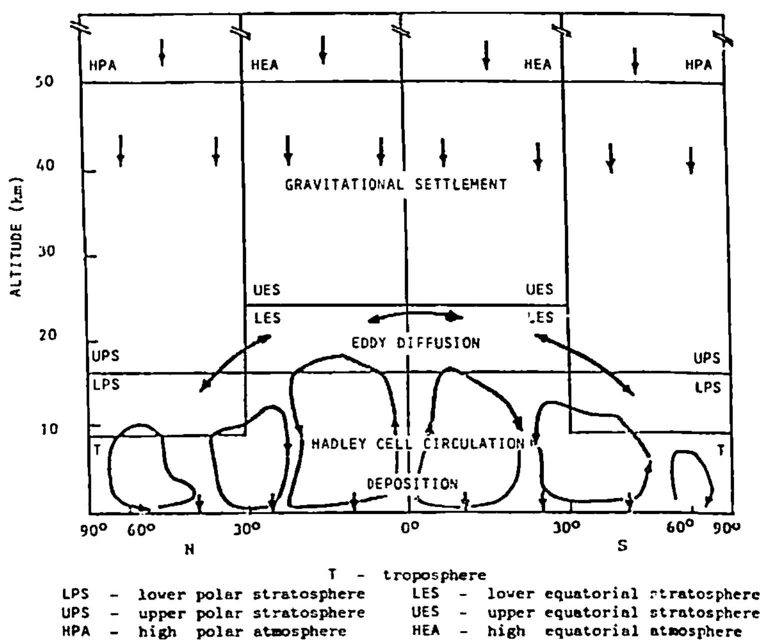



**Figure II. Atmospheric regions and the predominant atmospheric transport processes**

have been determined largely from the measurements of radionuclide concentrations [B7, D3, F1, F3, K1, K10, M1, P2, P4, R1, S3, T2, U3]. Aerosols descend gravitationally at highest altitudes and move with the general air movements of lower levels. Eddy diffusion in the lower stratosphere and upper troposphere is the irregular migration of air masses in the general directions indicated in Figure II. The circular air flow pattern in the troposphere at lower latitudes is termed Hadley cell circulation. These cells increase or decrease in size and shift latitudinally with season [N11]. The mean residence time of aerosols in the lower stratosphere ranges from 3 to 12 months in the polar regions and 8 to 24 months in the equatorial regions, and the most rapid removal occurs during the spring months. Removal half-time to the next lower region of 6 to 9 months in the upper stratosphere and 24 months in the high atmosphere are considered representative [B7].

14. The estimated total stratospheric injection of nuclear debris given in Table 2, when combined with specific fission yields, is in good agreement with measured deposition. For example, $^{90}Sr$ production is estimated to be about 3.9 PBq per Mt of fission energy, giving the total production through 1980 of 660 PBq. The estimate from deposition measurements is 600 PBq (see paragraph 37). Representative fission yields and normalized production for past nuclear testing are listed in Table 3. Large deviations are possible for individual tests. It is assumed that 1 Mt fission energy corresponds to $1.45\ 10^{26}$ fissions [H8]. This figure times the fission yield times the decay constant ($\lambda = \ln 2 / T_{1/2}$) for the specific nuclide gives the activity production per unit Mt fission energy.

15. Exposure of humans to fallout radioactivity consists of internal irradiation (inhalation of activity in

surface air and ingestion of contaminated foodstuffs) and of external irradiation from activity present in surface air or deposited on the ground.

## II. INTERNAL IRRADIATION

### A. TRITIUM

16. Tritium, a radioactive isotope of hydrogen, is a pure beta emitter with average energy of 5.69 keV and a half-life of 12.3 years [K7]. It occurs naturally, being produced in the stratosphere in cosmic ray induced reactions [U6]. Man-made tritium, in amounts substantially larger than the natural inventory, has been injected into the stratosphere by thermonuclear explosions. Most of this tritium is in the form of tritiated water. After entering the troposphere, tritium enters the hydrological cycle. The ocean is the ultimate sink for environmental tritium.

17. In Annex C of the 1977 report, the Committee estimated the tritium production from nuclear tests prior to 1970 to be 1.7 $10^{20}$ Bq [U6], based on an assessment by Michel of tritium inventories in the world oceans in 1970 [M5]. An estimate by Miskel [M7], using average tritium production values and an earlier estimate of total fusion yields of nuclear tests conducted through 1962, was 3.0 $10^{20}$ Bq.

18. Using the representative tritium production values per unit fission and fusion yields, as given by Miskel [M7], and the estimates of yields from Table 1, a revised estimate of total tritium production can be obtained:

Fission 220 Mt × 2.6 $10^{13}$ Bq/Mt = 5.7 $10^{15}$ Bq
Fusion 330 Mt × 7.4 $10^{17}$ Bq/Mt = 2.4 $10^{20}$ Bq
Total 2.4 $10^{20}$ Bq

Production by fusion is far more significant than by fission. About 75% of the production estimate can be associated with stratospheric injection (from Table 2). The tropospheric and local releases can, however, also be expected to have become widely distributed.

19. The United States National Council on Radiation Protection and Measurements [N3], using a seven compartment model to describe the transfer of tritium in the global environment, concluded that the measurements in streams in the United States could be matched closely by approximating the tritium released from weapons testing by a single release of 2.6 $10^{20}$ Bq injected into the atmosphere in 1962 with 90% of this amount, or 2.3 $10^{20}$ Bq, depositing in the northern hemisphere. It was recognized, however, that this overestimates the total injection since levels in the mid-latitude region are enhanced by the general fallout deposition pattern.

20. In this Annex, a value of 2.4 $10^{20}$ Bq is used for the total production of $^3H$ and it is assumed that about 20% of this, that is 0.5 $10^{20}$ Bq, was transferred into or produced in the southern hemisphere, as indicated by the general pattern of fallout deposition measurements (see Table 5).

21. The annual absorbed dose in tissue from natural tritium has been estimated to be $10^{-8}$ Gy, which results from an annual production per hemisphere of 3.7 $10^{16}$ Bq, corresponding to a global inventory of natural origin of 1.3 $10^{18}$ Bq (see Annex B). Assuming the total release to the atmosphere of the northern hemisphere of 1.9 $10^{20}$ Bq and 0.5 $10^{20}$ Bq in the southern hemisphere from nuclear tests and using the estimation procedure applied previously [U6], the absorbed dose commitments in tissue from fallout tritium are:

$$\text{Northern hemisphere: } \frac{10^{-8}\ \text{Gy a}^{-1}}{3.7\ 10^{16}\ \text{Bq a}^{-1}}\ 1.9\ 10^{20}\ \text{Bq} = 5.1\ 10^{-5}\ \text{Gy}$$

$$\text{Southern hemisphere: } \frac{10^{-8}\ \text{Gy a}^{-1}}{3.7\ 10^{16}\ \text{Bq a}^{-1}}\ 0.5\ 10^{20}\ \text{Bq} = 1.4\ 10^{-5}\ \text{Gy}$$

The effective dose equivalent commitments are 51 µSv (northern hemisphere), 14 µSv (southern hemisphere) and 47 µSv (world). The global value is the population-weighted estimate, assuming 89% of the population in the northern and 11% in the southern hemisphere.

22. For the appropriate world population of 4 $10^9$ people, the collective effective dose equivalent commitment is estimated to be 1.9 $10^5$ man Sv. On the basis of the relative intakes of hydrogen in water by the pathway of inhalation, including passage through the skin, and the ingestion pathway [N3], the dose commitments and effective dose equivalent commitments can be apportioned as 7% arising from inhalation and absorption through the skin and 93% from ingestion.

### B. CARBON-14

23. Carbon-14 is a pure beta emitter with average energy of 49.5 keV and a half-life of 5730 years [K7]. It is formed in nuclear explosions from the capture of excess neutrons by atmospheric nitrogen. Present in the atmosphere as carbon dioxide, it is taken up by plants during photosynthesis and is subsequently incorporated into the human body. The specific activity in human tissue has been found to come into equilibrium with that in atmospheric $CO_2$ with a delay time of about 1.4 years [N9].

24. In Annex C of the 1977 report [U6], the Committee estimated that the input of man-made $^{14}C$ into the atmosphere up to 1972 was 215 PBq. Subsequent injections have increased this amount by less than 1%, based primarily on the increase in total fusion yield of nuclear tests. A rounded estimate of 220 PBq will be assumed for tests through 1980.

25. The dose commitments from $^{14}C$ from atmospheric explosions can be assessed, as for the case of tritium, by comparison with the natural $^{14}C$ annual absorbed doses, which are given in Annex B as 5 $10^{-6}$ Gy in the gonads, 5.7 $10^{-6}$ Gy in the lungs, 2.2 $10^{-5}$ Gy in bone lining cells, 2.4 $10^{-5}$ Gy in red bone marrow, 5.9 $10^{-6}$ Gy in the thyroid and 1.3 $10^{-5}$ Gy in other tissues. The natural $^{14}C$ production rate is 1 PBq $a^{-1}$ (see Annex B). The dose commitments from fallout $^{14}C$, assumed to apply uniformly in the world, are thus:

| *Organ or tissue* | *Dose commitment* (mGy) |
|---|---|
| Gonads | 1.1 |
| Lungs | 1.3 |
| Bone lining cells | 4.8 |
| Red bone marrow | 5.3 |
| Thyroid | 1.3 |
| Other tissues | 2.9 |

Using ICRP weighting factors, the effective dose equivalent commitment from $^{14}C$ from atmospheric explosions is thus found to be 2.6 mSv. On the basis of the relative intake and retention of carbon by inhalation and by ingestion, the dose commitments from inhalation are estimated to be about $10^4$ times less than those arising from ingestion [K14].

26. The dose commitments from $^{14}C$ are delivered over a very long time period. The part accumulated up to the year 2000 is 7% of the total dose commitments, 8% to 2020 and 10% to 2050, based on an environmental compartment model for $^{14}C$ used by the Committee in Annex C of the 1977 report [U6]. The collective dose commitments can be estimated by assuming that the dose commitments apply to an upper limit of the world population, namely $10^{10}$ people. The collective dose commitments from fallout $^{14}C$ are:

| *Organ or tissue* | *Collective dose commitment* ($10^7$ man Gy) |
|---|---|
| Gonads | 1.1 |
| Lungs | 1.3 |
| Bone lining cells | 4.8 |
| Red bone marrow | 5.3 |
| Thyroid | 1.3 |
| Other tissues | 2.9 |

The tissue-weighted result, giving the collective effective dose equivalent commitment, is 2.6 $10^7$ man Sv.

27. This assessment of doses from $^{14}C$ is based on the assumption that the specific activity of natural $^{14}C$ will remain constant in the next hundreds and thousands of years. In fact, the combustion of fossil fuel leads to a decrease of the natural $^{14}C/^{12}C$ isotopic ratio in the biosphere and the dose commitments are therefore somewhat over-estimated.

## C. MANGANESE-54

28. Manganese-54 has a half-life of 312.7 d, decaying by electron capture with the emission of x rays and a gamma ray of energy 834.8 keV [K7]. It is an activation product which was produced in largest quantities during the test series of late 1961, following which stratospheric measurements indicated a $^{54}Mn/^{90}Sr$ activity ratio of 100 [F5]. It was produced in other tests as well, but in much smaller amounts. Calculations which assume an injection of 5.2 EBq of $^{54}Mn$ in late 1961 give good agreement with measured surface air concentrations during 1963-1966 [B7].

29. From measurements during 1962-1966, the time integrated $^{54}Mn$ activity concentrations in surface air were 4.9 $10^{-3}$ Bq a $m^{-3}$ at four sites in the United Kingdom [A7], 5.5 $10^{-3}$ Bq a $m^{-3}$ in Denmark [A8], 6.5 $10^{-3}$ Bq a $m^{-3}$ at three sites in the United States [B7] and 2.8 $10^{-4}$ Bq a $m^{-3}$ at two sites in Chile [B7]. The latter two results were increased by 10% to account for missing data during 1962 [U6]. The average for temperate latitudes of the northern hemisphere is 5.6 $10^{-3}$ Bq a $m^{-3}$. Concentrations in air have been very low since 1966. In Braunschweig, Federal Republic of Germany, the integral concentration of $^{54}Mn$ in air during 1971–1977 was 3.6 $10^{-5}$ Bq a $m^{-3}$ [K8, K9], which is negligible when compared to the values obtained for 1962–1966. Since 1970, the $^{54}Mn$ concentrations measured at Braunschweig and at two other European sites have been about 10 times lower than those of $^{137}Cs$ [K9].

30. Measurements of $^{54}Mn$ in grain in localized areas have been reported [A8], but sufficient general data to estimate dose commitments from $^{54}Mn$ via ingestion are not available. The dose commitments from inhalation of $^{54}Mn$ are given in Table 4. The doses per unit intake are those estimated by ICRP for oxides of manganese (class W) [13]. The inhalation rate is assumed to be 20 $m^3$ $d^{-1}$ and the integral air concentration in the temperate latitudes are as given above. Using the latitudinal distribution of $^{90}Sr$ as a guide (Table 6), it is seen that the temperate latitude levels are a factor of about 1.5 greater than the respective population weighted levels that apply to the entire hemisphere. With this factor, and assuming the population distribution of 89% in the northern hemisphere and 11% in the southern hemisphere, the dose commitments applicable to the global population are derived as in Table 4. The effective dose equivalent commitments, applying the ICRP tissue weighting factors, are 0.07 and 0.0035 µSv in the temperate latitudes of the northern and southern hemisphere, respectively, and 0.042 µSv for the global average. The collective effective dose equivalent commitment for the world population (assumed to be about 3.2 $10^9$ people averaged over the deposition period) is estimated to be 130 man Sv.

## D. IRON-55

31. Iron-55 has a half-life of 2.7 years and decays by electron capture with the emission of several low energy x rays and Auger electrons. It is an activation product and was produced mainly in the nuclear tests of 1961–1962. The concentration of $^{55}Fe$ in air fell rapidly after 1962–1963 and has been essentially undetectable since 1970. The total production is estimated to be 2 EBq [H11].

32. In Annex C of the 1977 report [U6], the Committee, on the basis of the work of Persson [P3], estimated the dose commitments in the northern hemisphere from fallout $^{55}Fe$ to be 10 µGy in the gonads and bone lining cells and 6 µGy in the bone marrow. A reduction of 4 was assumed for the southern hemisphere. The dose commitment in the gonads may be taken as representative of that in other soft tissues. As these estimates are based on very limited data, they can be assumed to be only roughly valid. A summary of dose commitments is:

| | *Dose commitment* (µGy) | | |
|---|---|---|---|
| *Organ or tissue* | *Northern hemisphere* | *Southern hemisphere* | *Global* |
| Gonads | 10 | 2 | 9 |
| Bone lining cells | 10 | 2 | 9 |
| Red bone marrow | 6 | 1 | 5 |
| Other tissues | 10 | 2 | 9 |

The effective dose equivalent commitments are 10 µSv (northern hemisphere), 2 µSv (southern hemisphere) and 9 µSv (global). The collective effective dose equivalent commitment to the world population (about 3.2 $10^9$ persons present at the time of exposure) is estimated to be 3 $10^4$ man Sv.

## E. KRYPTON-85

33. Krypton-85 has a half-life of 10.72 years and is a beta emitter of average energy 250.5 keV [K7]. In 0.4% of the disintegrations a 514 keV photon is emitted. In Annex C of the 1977 report, $^{85}Kr$ production was

estimated from the $^{85}Kr/^{90}Sr$ fission yield ratio of 0.07 [U6]. On the basis of the total fission yield of atmospheric nuclear tests from Table 1 and of the normalized production of $^{90}Sr$ from Table 3, production from nuclear tests through 1980 is estimated to be 160 PBq. Most of the $^{85}Kr$ present in the earth's atmosphere originates in releases from the production and processing of nuclear materials and not from nuclear explosions [R6]. The dose estimates in this Annex refer to $^{85}Kr$ produced in nuclear explosions.

34. Krypton is an inert gas and most of it remains in the atmosphere until decay. Its concentration becomes fairly uniform throughout the earth's atmosphere within a few years after release [F2]. Assuming a uniform and instantaneous distribution of $^{85}Kr$ in the atmosphere, which is adequate for dose estimations, the production of 160 PBq results in a time-integrated air concentration of 0.62 Bq a $m^{-3}$. The dose commitments from 1 Bq a $m^{-3}$ are, in accordance with ICRP [I1], taken to be 4.1 $10^{-7}$ Gy in skin and about 4 $10^{-9}$ Gy in the other tissues (see values below). Therefore the dose commitments to the world population from fallout $^{85}Kr$ are estimated to be

| *Organ or tissue* | *Dose commitment per unit integrated concentration in air* [nGy/(Bq a $m^{-3}$)] | *Dose commitment* (nGy) |
|---|---|---|
| Skin | 410 | 250 |
| Gonads | 4.6 | 2.9 |
| Breast | 3.9 | 2.4 |
| Red bone marrow | 5.0 | 3.1 |
| Lungs | 3.8 | 2.4 |
| Bone lining cells | 5.4 | 3.3 |
| Stomach wall | 3.8 | 2.4 |
| Kidneys | 3.5 | 2.2 |
| Liver | 3.3 | 2.0 |
| Spleen | 4.0 | 2.5 |
| Adrenals | 3.5 | 2.2 |

The collective dose commitments are obtained by multiplying by the world's population (4 $10^9$ people). The effective dose equivalent commitment is 0.005 μSv and the corresponding collective quantity is 20 man Sv.

## F. STRONTIUM-90

### 1. Inventory and deposition

35. Strontium-90, a pure beta emitter with average energy of 195.8 keV, decays with a half-life of 28.6 years to $^{90}Y$, which has a half-life of 64.1 h and is a beta emitter with average energy of 934.8 keV [K7]. Strontium-90 has been extensively monitored over the years in human tissues and in the environment. Many of the results obtained may be used as a guide to the behaviour of other long-lived radionuclides released by atmospheric tests.

36. The annual deposition of $^{90}Sr$ in the northern and southern hemispheres for the period 1958–1980 is shown in Table 5, together with the cumulative deposit in each hemisphere and the estimated total injection to January 1981 [T6, U6]. (Deposition is the activity deposited on a specified area. The cumulative deposit is the activity present in a specified area at a given time; it is the result of past depositions and radioactive decay.) The global depositions in 1979 and 1980 were the smallest recorded since the measurements began. In 1977 and 1978 there were increases in the annual deposition in the northern hemisphere as a result of the large test conducted in November 1976 in that hemisphere.

37. The deposition in 1981 may be expected to be slightly increased due to the test of October 1980. Measured data are not yet available. Since 1971, the annual rate of injection has been less than the annual rate of decay and the cumulative deposit has steadily decreased. Total $^{90}Sr$ production from nuclear tests through 1980 is estimated from these measurements to be 600 PBq. The estimate from cumulative fission yields of $^{90}Sr$ injected into the stratosphere was 660 PBq (paragraph 14). This estimate, which excludes local fallout, is in good agreement with the global deposition measurements. The global inventory of deposited $^{90}Sr$, which is decreasing by radioactive decay, was 400 PBq at the end of 1980 [C1, T6].

38. The distribution of $^{90}Sr$ deposition by latitude bands is given in Table 6 [T6, U6]. The results are obtained by averaging measurements at sampling sites within the band and by extrapolation to latitudes which no longer contain sampling sites (north of 70°N and south of 60°S). Integrated depositions in the latitude bands are determined by addition of all previous deposition without taking account of radioactive decay. The deposition density (activity per unit area) is determined by dividing by the area of the band. Population weighted integrated deposition densities are useful in exposure assessment and these are also indicated in Table 6.

39. The relationship between input of activity from sources in the atmosphere and deposition onto the earth's surface is given by the transfer coefficient $P_{02}$, which is defined

$$P_{02} = \frac{\int_0^\infty \dot{U}(t)\,dt}{\int_0^\infty \dot{A}(t)\,dt} = \frac{U_o}{A_o} \quad (2)$$

where $\dot{U}(t)$ is the deposition density rate and $\dot{A}(t)$ is the input rate. The integral quantities are $U_o$, the integrated deposition density over the entire fallout period, and $A_o$, the total injection of $^{90}Sr$ from all atmospheric tests. Estimates of $P_{02}$ for the past pattern of nuclear tests weighted according to population distribution are, for a total injection of $^{90}Sr$ through 1980 of 600 PBq:

| | $P_{02}$ ($10^{-15}$ Bq $m^{-2}$ per Bq released) |
|---|---|
| World | 3.3 |
| Northern hemisphere | 3.6 |
| Southern hemisphere | 0.9 |
| North temperate zone (40–50°) | 5.4 |
| South temperate zone (40–50°) | 1.5 |

### 2. Transfer from deposition to diet

40. The deposition of $^{90}Sr$ on land and the transfer to humans by ingestion is the most important pathway for human exposure. The annual average $^{90}Sr$ concentrations in milk and whole diet from 1974 onwards are given in Table 7. The practice of expressing results in terms of the $^{90}Sr/Ca$ quotient retains some advantages in minimizing variability in measurements; however, in assuming constant and relatively uniform calcium

levels in diet and humans, there is no need to use the quotients in the assessment models.

41. The relative contributions of different foods to the total $^{90}Sr$ dietary intake have been indicated previously [A1, B8, K3, U6]. The concentrations in milk and grain products decline fairly rapidly following deposition periods, while fruits and vegetables, reflecting uptake of $^{90}Sr$ from the slowly varying cumulative deposit in soil, decline much more gradually. It is expected, therefore, that the long-term variation in the $^{90}Sr$ intake will depend on the composition of the diet.

42. The transfer coefficient from deposition to diet is given by

$$P_{23} = \frac{\int_0^\infty C(t)\,dt}{\int_0^\infty \dot{U}(t)\,dt} \tag{3}$$

where C(t) is the $^{90}Sr$ concentration in the diet at time t and $\dot{U}(t)$ is the deposition density rate. For values of C(t) and $\dot{U}(t)$ assessed on a yearly basis, the integrations can be replaced by summation

$$P_{23} = \frac{\sum_{i=1}^{\infty} C(i)}{\sum_{i=1}^{\infty} \dot{U}(i)} \tag{4}$$

43. In Annex C of the 1977 report, the following model was used to relate $^{90}Sr$ in food groups or in the total diet to the annual deposition densities [U6]

$$C(i) = b_1 \dot{U}(i) + b_2 \dot{U}(i-1) + b_3 \sum_{m=1}^{\infty} e^{-\lambda_s m} \dot{U}(i-m) \tag{5}$$

These are contributions to $^{90}Sr$ concentrations *in diet* from the annual deposition density in the year considered $\dot{U}(i)$, in the previous year $\dot{U}(i-1)$, and from all preceding years, expressed by the summation, with an exponential term describing the combined physical decay of $^{90}Sr$ and any decrease in availability to plants of $^{90}Sr$ in soil. The factors $b_1$, $b_2$, $b_3$, and the effective mean life of available $^{90}Sr$, $\lambda_s^{-1}$, can be derived from reported data by regression analysis.

44. The combination of equations (4) and (5) leads to

$$P_{23} = b_1 + b_2 + b_3 \frac{e^{-\lambda_s n}}{1 - e^{-\lambda_s n}} \tag{6}$$

where n = 1 year, a constant in this case. The units for $\lambda_s$ are $a^{-1}$ and for $P_{23}$, $b_1$, $b_2$ and $b_3$, Bq a $kg^{-1}$/(Bq $m^{-2}$).

45. Equation (5) has been fitted by regression analysis to the total and component diet data and the deposition data for Argentina, Denmark and New York City. The results are given in Table 8. The contribution of dietary components to the total transfer coefficient is obtained by weighting each food group k by its fractional consumption by weight, $w_k$, in total diet

$$P_{23} = \sum_k w_k P_{23}^k \tag{7}$$

The differences in parameter values in Table 8 may be explained by the differences in foods included in the groups, in the amounts of the various foods consumed, and in the actual transfers of $^{90}Sr$ at the particular locations. The value of the transfer coefficient obtained by summing over the food groups should give a better result than the single exponential fit to total diet. The results are fairly close, however, by both methods in all cases. The fits for $^{90}Sr$ in total diet of New York and Argentina are shown in Figure III.

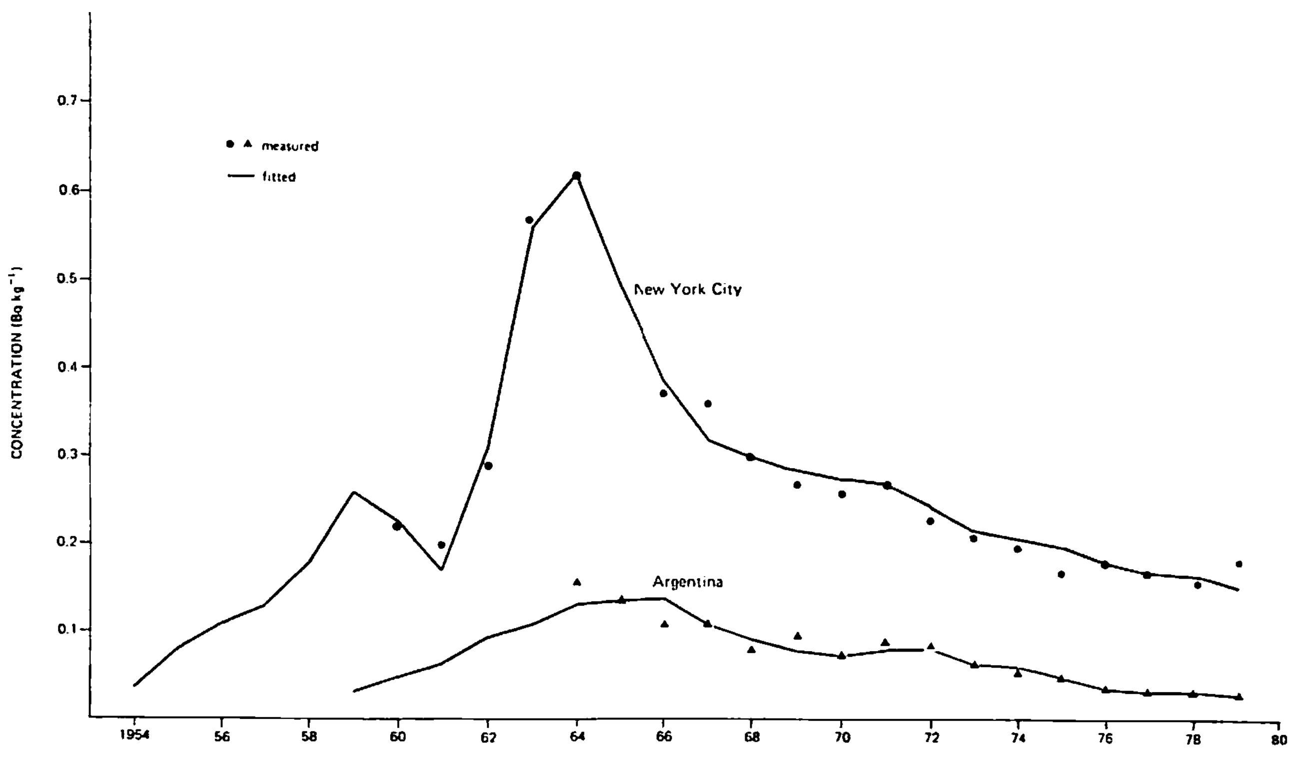



**Figure III. Strontium-90 in total diet of Argentina and New York City, United States**

46. The average value of the transfer factor $P_{23}$ obtained from data of the three countries is about 4 $10^{-3}$ Bq a $kg^{-1}$/(Bq $m^{-2}$). This value is consistent with that in Annex C of the 1977 report of 5 $10^{-3}$ Bq a (g Ca)$^{-1}$/(Bq $m^{-2}$) for a calcium concentration in diet of 0.8 g $kg^{-1}$. The same mean value with less variation is obtained by expressing the results per unit calcium intake, using the actual consumption data given in the footnote of Table 8. This result is typical for the diets considered, however, differences could be obtained for other types of diets. In particular, the transfer coefficient would be an underestimate for diets containing less meat and milk and also in areas for which higher than average transfer of $^{90}$Sr to milk has been noted [M9, U6].

### 3. Transfer from diet to bone

47. The annual average $^{90}$Sr concentrations in bone from 1974 are given in Table 9 for the various age groups. As a general rule, only the $^{90}$Sr/Ca quotients are available in the literature. The data may be converted to units of Bq $kg^{-1}$ by assuming $10^3$ g Ca in the 5 kg mineral skeleton. Some caution is required, however, as variations may be noted for particular bone types. The $^{90}$Sr concentrations for adult bone have varied little in recent years. Typical values are around 40 mBq (g Ca)$^{-1}$, corresponding to 8 Bq $kg^{-1}$.

48. The transfer coefficient linking diet and human bone, $P_{34}$, is defined by

$$P_{34} = \frac{\int_0^\infty C_b(t)\,dt}{\int_0^\infty C_d(t)\,dt} \qquad (8)$$

where $C_b(t)$ is the $^{90}$Sr concentration in bone at time t and $C_d(t)$ is the concentration in the diet. For values of $C_b(t)$ and $C_d(t)$ assessed as annual averages, equation (8) becomes

$$P_{34} = \frac{\sum_{i=1}^{\infty} C_b(i)}{\sum_{i=1}^{\infty} C_d(i)} \qquad (9)$$

49. In Annex C of the 1977 report, the following model was used to relate $^{90}$Sr in bone to concentrations in diet [U6]

$$C_b(i) = c\,C_d(i) + g \sum_{m=0}^{\infty} e^{-\lambda_b m}\, C_d(i-m) \qquad (10)$$

The parameters c and g may be related to short- and longer-term components of $^{90}$Sr retention in bone. The exponential factor accounts for radioactive decay and removal from the body. Combining equations (9) and (10) yields

$$P_{34} = c + \frac{g}{1 - e^{-\lambda_b n}} \qquad (11)$$

where n = 1 year, a constant in this expression.

50. The $^{90}$Sr data for diet and adult bone in several countries have been fitted by regression analysis using equation (10). The values of the parameters are given in Table 10, together with the estimates of $P_{34}$ obtained by use of equation (11). The estimates of the transfer coefficient $P_{34}$ vary little from one locality to another, particularly when normalized to dietary calcium intake. The results for Argentina are less certain due to the less specific fit to the data, which show little change from year to year. The results shown in Table 10, along with previously computed estimates of $P_{34}$ [U6], indicate that the most consistent value is 0.15 Bq a (g Ca)$^{-1}$ in bone per Bq a (g Ca)$^{-1}$ in diet, corresponding to 38 Bq a $kg^{-1}$ in bone/(Bq a $kg^{-1}$) in diet, with the assumptions of $10^3$ g Ca in the 5 kg skeleton and 0.8 g Ca per kg diet.

### 4. Transfer coefficient relating $^{90}$Sr concentration in bone to dose

51. The transfer coefficient $P_{45}$ relates the $^{90}$Sr time-integrated concentration in bone to the dose commitment. As in Annex C of the 1977 report [U6], the values of $P_{45}$ can be derived for doses to red bone marrow and bone lining cells on the basis of the work of Spiers [S2, S7]. The dose rate $\dot{D}_o$ per unit $^{90}$Sr activity in a small tissue-filled cavity in bone from decay of $^{90}$Sr–$^{90}$Y is equal to 6.1 μGy $a^{-1}$/(Bq $kg^{-1}$). In order to obtain the dose rates in red bone marrow, $\dot{D}_{RM}$, and in bone lining cells, $\dot{D}_{BLC}$, use is made of the $\dot{D}_{RM}/\dot{D}_o$ and $\dot{D}_{BLC}/\dot{D}_o$ ratios. These values are

| | $\dot{D}_{RM}/\dot{D}_o$ | $\dot{D}_{BLC}/\dot{D}_o$ |
|---|---|---|
| Cortical contribution | 0.05 | 0.45 |
| Trabecular contribution | 0.26 | 0.17 |
| Total | 0.31 | 0.62 |

The value of the latter ratio has been changed in comparison to Annex C of the 1977 report [U6] to account for irradiation of cells on surfaces of both types of bone [I3]. The values of the transfer coefficient obtained in this manner are

$$P_{45}\,(\text{red bone marrow}) = 1.9\ \mu Gy/(Bq\ a\ kg^{-1})$$

$$P_{45}\,(\text{bone lining cells}) = 3.8\ \mu Gy/(Bq\ a\ kg^{-1})$$

52. The dosimetry used by ICRP [I3] for beta emitters uniformly distributed throughout the volume of bone is also based on the work of Spiers [S2, S7]. The absorbed fractions (fractions of energy absorbed in target tissue from radiation originating in a source organ) derived from the $\dot{D}_{RM}/\dot{D}_o$ and $\dot{D}_{BLC}/\dot{D}_o$ ratios given above are:

| | | *Absorbed fraction* | |
|---|---|---|---|
| *Source* | *Target* | *Calculated from the results of Spiers* | *Adopted by ICRP* |
| Cortical bone | Red bone marrow | 0.019 | 0 |
| Trabecular bone | Red bone marrow | 0.42 | 0.35 |
| Cortical bone | Bone lining cells | 0.014 | 0.015 |
| Trabecular bone | Bone lining cells | 0.022 | 0.025 |

Instead of using the calculated values appropriate to each beta emitter uniformly distributed throughout the volume of bone, ICRP decided to apply representative nominal values for any radionuclides of that category. These nominal values are presented above in the right-hand column. The results obtained for $P_{45}$ using the nominal values of the absorbed fractions and the distribution of $^{90}$Sr in bone adopted by ICRP are found to be

$$P_{45}\,(\text{red bone marrow}) = 1.9\ \mu Gy/(Bq\ a\ kg^{-1})$$

$$P_{45}\,(\text{bone lining cells}) = 4.2\ \mu Gy/(Bq\ a\ kg^{-1}).$$

These values, which are in good agreement with those derived in the previous paragraph, have been adopted by the Committee in this report for reasons of consistency with the dose calculations carried out in this and other Annexes.

### 5. Dose commitments from strontium-90

53. The dose commitments from $^{90}Sr$ released by atmospheric nuclear explosions can now be assessed for the ingestion pathway. The relevant part of equation (1) is

$$D^c = P_{02}\, P_{23}\, P_{34}\, P_{45}\, A_o \qquad (12)$$

Using the deposition distribution of $^{90}Sr$ given in Table 6 from the total production of 600 PBq of $^{90}Sr$ from nuclear tests conducted through 1980 and values of the transfer factors given in the previous paragraphs, the dose commitments listed in Table 11 are obtained. The doses to other tissues are negligible. Estimates of the collective dose commitments are also included in Table 11. The applicable world population size has been taken to be 4 $10^9$ persons, distributed as indicated in Table 6. The effective dose equivalent commitments are 110 μSv (world), 170 μSv (North temperate zone), 48 μSv (South temperate zone). The collective effective dose equivalent commitment is 4.4 $10^5$ man Sv (world).

54. The dose commitment from $^{90}Sr$ via the inhalation pathway can also be estimated. The average quotient of the integrated concentration in air to the deposition density is 1.8 $10^{-6}$ Bq a $m^{-3}$/(Bq $m^{-2}$), as determined from $^{90}Sr$ measurements over several years in New York City [B7]. The integrated concentrations in air, derived from the deposition estimates of Table 6, are thus estimated to be 5.8 mBq a $m^{-3}$ in the North temperate zone, 1.6 mBq a $m^{-3}$ in the South temperate zone and 3.5 mBq a $m^{-3}$ in the world (population-weighted). For a breathing rate of 20 $m^3$ $d^{-1}$ and the dose to lungs per unit intake as given by the ICRP [I3] for $^{90}Sr$ (Class Y) of 2.9 $10^{-6}$ Gy $Bq^{-1}$, the dose commitments to the lungs from the inhalation pathway are 7.4 $10^{-5}$ Gy (world), 1.2 $10^{-4}$ Gy (North temperate zone), and 3.4 $10^{-5}$ Gy (South temperate zone). The dose commitments to other tissues are negligible. The effective dose equivalent commitments are 8.9 μSv (world), 14 μSv (North temperate zone), and 4.1 μSv (South temperate zone). Since depletion of activity from air is fairly rapid, the inhalation exposures occurred soon after the explosions. The collective effective dose equivalent commitment to the world population (3.2 $10^9$ persons present at the time of exposure) is estimated to be 2.8 $10^4$ man Sv.

## G. STRONTIUM-89

55. Strontium-89 has a half-life of 50.5 d and decays with the emission of beta particles with average energy of 583.0 keV [K7]. It is one of the main components of fallout activity in the first few months after a nuclear test. As the ratio of activities $^{89}Sr$ /$^{90}Sr$ at the time of fission is approximately 150 (Table 3), the total atmospheric input of $^{89}Sr$ is estimated to have been about 90 EBq.

56. Strontium-89 was measured in milk at some 63 cities in the United States between 1961 and 1965 [P6]. The average time integral of the concentration for the period September 1961 to December 1965 was 3.5 Bq a $l^{-1}$ [O1]. Using the measured deposition of $^{90}Sr$ as a guide (Table 5), it is noted that about 55% of the total deposition in the northern hemisphere occurred during this period. Therefore, the time integral of the $^{89}Sr$ concentration in milk arising from all tests up to 1980 is estimated to be about 6.4 Bq a $l^{-1}$. For average milk consumption of 0.3 l $d^{-1}$, the intake commitment of $^{89}Sr$ is 700 Bq. The committed doses per unit intake of ingested $^{89}Sr$ activity as given by the ICRP [I1], are 3.2 $10^{-9}$ Gy $Bq^{-1}$ (red bone marrow), 4.8 $10^{-9}$ Gy $Bq^{-1}$ (bone lining cells), 7.3 $10^{-9}$ Gy $Bq^{-1}$ (upper large intestine) and 2.1 $10^{-8}$ Gy $Bq^{-1}$ (lower large intestine). The dose commitments from fallout $^{89}Sr$ ingestion are thus

| *Organ or tissue* | *Dose commitment* (μGy) |
|---|---|
| Bone marrow | 2.2 |
| Bone lining cells | 3.4 |
| Upper large intestine | 5.1 |
| Lower large intestine | 15 |

The effective dose equivalent commitment is 1.6 μSv. These values, being derived from measurements in the United States, apply to the population in the temperate zone of the northern hemisphere. They are somewhat underestimated as other components of the diet, such as leafy vegetables, might have contributed significantly to the intake by ingestion.

57. The dose commitments from inhalation of $^{89}Sr$ can be assessed from the estimated deposition density. The measured integrated deposition density of $^{89}Sr$ between 1961 and 1969 in the temperate zone of the northern hemisphere was 1.3 $10^4$ Bq $m^{-2}$ [H2]. Using measurements of $^{90}Sr$ deposition as a guide (Table 5), 62% of total deposition in the northern hemisphere occurred in this period. Therefore, the estimated $^{89}Sr$ deposition in the North temperate zone for the entire fallout period 1951–1980 is about 2.1 $10^4$ Bq $m^{-2}$. Using the average quotient of integrated air concentration to deposition density of 1.8 $10^{-6}$ Bq a $m^{-3}$/(Bq $m^{-2}$), as for $^{90}Sr$ [B7], and assuming that the adult person inhales 20 $m^3$ $d^{-1}$ of air, the intake commitment of $^{89}Sr$ via inhalation is estimated to be 280 Bq.

58. The committed dose to the lungs per unit intake of inhaled $^{89}Sr$ (Class Y), as given by the ICRP [I1], is 8.4 $10^{-8}$ Gy $Bq^{-1}$, the doses to other tissues being negligible. The dose commitment to the lungs from $^{89}Sr$ inhalation in the North temperate zone is, thus, 2.4 $10^{-5}$ Gy. The effective dose equivalent commitment is 2.9 μSv (North temperate zone).

59. From measurements of $^{90}Sr$, it is estimated that the dose commitments which apply to the population of the South temperate latitudes are a factor of about 4 less than the northern hemisphere temperate zone values and that hemispheric values are about 1.5 times less than the temperate zone values (from data in Table 6). Estimates of the effective dose equivalent commitments weighted for the world population are 1.0 μSv from ingestion and 1.8 μSv from inhalation. Most of the dose was delivered in the early 1960s during maximum deposition. Assuming the doses apply to a world population of 3.2 $10^9$ persons at that time, the collective effective dose equivalent commitments are estimated to be 3.2 $10^3$ man Sv (ingestion) and 5.8 $10^3$ man Sv (inhalation).

## H. RUTHENIUM-106

60. Ruthenium-106 has a half-life of 368 days and decays to $^{106}Rh$ by pure beta decay with average energy

of 10 keV. The 29.9 s half-life $^{106}Rh$ decays with average beta energy of 1.41 MeV and also emits several gamma rays. The total stratospheric injection of $^{106}Ru$, assessed from that of $^{90}Sr$ using the activity ratio of 20 at the time of fission, derived from Table 3, has been about 12 EBq.

61. In Annex C of the 1977 report [U6], the time integral of the concentration of $^{106}Ru$ in air was estimated to be 5.6 $10^{-2}$ Bq a m$^{-3}$ in the North temperate zone and 1.3 $10^{-2}$ Bq a m$^{-3}$ in the South temperate zone. Assuming $^{106}Ru$ from fallout to be in the oxide form (Class Y compound), the committed dose per unit inhalation intake is 1.0 $10^{-6}$ Gy Bq$^{-1}$ to the lungs [I4]. For a daily intake of air of 20 m$^3$, the dose commitment to lungs from $^{106}Ru$ is estimated to be

$$D^c(\text{lungs}) \begin{cases} = 4.1\ 10^{-4}\ \text{Gy (North temperate zone)} \\ = 9.5\ 10^{-5}\ \text{Gy (South temperate zone)} \end{cases}$$

The hemispheric values are less by a factor of 1.5. The value weighted for the world population is 2.5 $10^{-4}$ Gy. Doses to other tissues are negligible. The effective dose equivalent commitments are 49 μSv (North temperate zone), 11 μSv (South temperate zone) and 30 μSv (world). The collective effective dose equivalent commitment to the world's population (about 3.2 $10^9$ persons on average during the time of exposure) is estimated to be 9.6 $10^4$ man Sv.

## I. IODINE-131

62. Iodine-131 is a beta emitter with a half-life of 8.04 d. The average beta energy is 181.7 keV, and gamma rays of 0.36 MeV and other energies are also emitted [K7]. The total injection of globally dispersed $^{131}I$ into the atmosphere from nuclear testing is estimated to be about 700 EBq from its yield in test debris (Table 3) and the total explosive yield by fission given in Table 2.

63. Fresh milk dominates as a source of $^{131}I$ intake in areas where it is a major diet component, because of the large areas scavenged by the grazing animals and also because of the short storage period of milk. Data on $^{131}I$ concentrations in milk, which have become available since the 1977 report [U6], are given in Table 12. As there were tests only in the northern hemisphere during 1976–1978, $^{131}I$ in milk has only been detected in that hemisphere.

64. The short half-life of $^{131}I$ means that it is not well mixed in the atmosphere before deposition or decay. Consequently, concentrations in air or deposition at particular sites vary with meteorological conditions and are not necessarily representative of a larger region nor of a latitude band. There were not widespread measurements of $^{131}I$ throughout the major fallout period; however a rough estimate of the total activity density deposited, weighted over the population of the world, may be made from the average ratio of measured $^{131}I/^{140}Ba$ in deposition. The half-life of $^{140}Ba$, 12.8 d, is comparable to that of $^{131}I$.

65. Data from Argentina [B12, C2] for the years 1966–1973 indicate that the $^{131}I/^{140}Ba$ ratio of annual deposition densities varied from 0.4 to 1.3, with a median value of 0.6. Data from the stations of the global network of the United Kingdom Atomic Energy Authority [C1] indicate that the $^{131}I/^{140}Ba$ ratio of annual integrated air activity concentrations at nine stations throughout the world ranged from 0.19 to 3.1, with a median value of 0.46. Since only particulate iodine was sampled, total iodine including the gaseous form in air and deposition would have been higher [P7]. The $^{131}I/^{140}Ba$ ratio is estimated to be 0.9 from these data, comparable to the value from Argentina of 0.6. An intermediate value of 0.8 will be adopted for the dose estimation.

66. Estimates of population-weighted integrated deposition densities of $^{140}Ba$ are given in Table 28, the global value being 1.7 $10^4$ Bq m$^{-2}$. The corresponding value for $^{131}I$ is thus estimated to be 1.3 $10^4$ Bq m$^{-2}$. The relationship between deposition density and the integrated activity concentration of $^{131}I$ in milk derived from measurements in Argentina [B12] is 6.3 $10^{-4}$ Bq a l$^{-1}$/(Bq m$^{-2}$), showing little variation from year to year. This is the transfer factor $P_{23}$.

67. Consumption of milk, uptake and retention of $^{131}I$ in the thyroid and the thyroid size are all age-dependent. Representative values were adopted by the Committee in Annex D of the 1977 report [U6]. A summary of these parameters and the estimated absorbed doses per unit intake is given in Table 13.

68. The product of the milk consumption rate and the dose per unit intake of $^{131}I$ activity gives the transfer factor $P_{35}$ relating integrated activity of $^{131}I$ in milk to absorbed dose in the thyroid. Taking the three groups of children to be representative of the age groups 0–1, 1–9 and 10–19 years and that these groups contain respectively 2, 16 and 20% of the population [U6], the population-weighted value of $P_{35}$ is 0.13 mGy per Bq a l$^{-1}$.

69. From the formula $D^c = P_{23}\, P_{35}\, U_o$ using the values given above, the thyroid dose commitment for the world population arising from $^{131}I$ fallout is estimated to be 1.1 mGy. Additional estimates, which can be derived in a similar fashion, include for the North temperate zone 1.6 mGy (age-weighted population) and 18 mGy (0–1 year old infants) and in the South temperate zone 0.23 mGy (age-weighted population) and 2.5 mGy (0–1 year old infants). Most of this dose commitment was delivered in the early 1960s. Taking the world population at that time to be 3.2 $10^9$ persons, the thyroid collective dose commitment would be 3.5 $10^6$ man Gy. The effective dose equivalent commitments are obtained by multiplying by the weighting factor for thyroid of 0.03 [I3]. Estimates of the effective dose equivalent commitments are 48 μSv (North temperate zone), 6.9 μSv (South temperate zone) and 33 μSv (world). The collective effective dose equivalent commitment to the population of the world is estimated to be 1.1 $10^5$ man Sv.

## J. CAESIUM-137

### 1. Inventory and deposition

70. Caesium-137 is a beta emitter with average beta energy of 170.8 keV [K7]. Its daughter, $^{137m}Ba$ of half-life 2.55 min, decays with the emission of a gamma ray of energy 661.6 keV. The half-life of $^{137}Cs$ is 30.2 a, very close to that of $^{90}Sr$, and since the average measured activity ratio of $^{137}Cs/^{90}Sr$ in deposition at many sites and over a long time has been fairly constant at about 1.6 [C3, U5], the total injection of $^{137}Cs$ into the stratosphere by past atmospheric tests is about 600 PBq x 1.6 = 960 PBq. The latitudinal distribution of $^{137}Cs$ can also be estimated from the corre-

sponding data for $^{90}Sr$ given in Table 6. The population-weighted integrated deposition densities are given below. Also listed are the population-weighted values of the transfer coefficient from input to deposition density, $P_{02}$, for the past pattern of nuclear testing.

| | *Integrated deposition density* ($10^3$ Bq $m^{-2}$) | *Transfer coefficient* $P_{02}$ ($10^{-15}$ Bq $m^{-2}$ per Bq released) |
|---|---|---|
| World | 3.14 | 3.3 |
| Northern hemisphere | 3.42 | 3.6 |
| Southern hemisphere | 0.86 | 0.9 |
| North temperate zone (40–50°) | 5.17 | 5.4 |
| South temperate zone (40–50°) | 1.42 | 1.5 |

### 2. Transfer from deposition to diet

71. As in the case of $^{90}Sr$, it has been found that fallout over land is the most important pathway as far as dose commitments to man are concerned. Reported annual average $^{137}Cs$ activity concentrations in milk and in total diet are shown in Table 14. The transfer of $^{137}Cs$ from deposition to diet is normally high during the first year and relatively small subsequently.

72. The transfer of $^{137}Cs$ from deposition to diet can be studied quantitatively using the same approach as for $^{90}Sr$. The values of $P_{23}$ obtained in this way for total diet and for milk are summarized in Table 15. Figure IV shows the total diet data for Argentina and Denmark and the fit from regression analysis using equation (5). The parameters of the model and the values for the transfer coefficient also for the component food groups are given in Table 16. The summation of the contributions to the transfer coefficient from the various foods is in agreement with the value obtained from the total diet data. The apparent difference between the two countries in the transfer coefficient $P_{23}$ for total diet disappears when the results are normalized to dietary potassium intake. In both cases the value is 40 mBq a (g K)$^{-1}$ per Bq $m^{-2}$. This is also the value adopted by the Committee in Annex C of the 1977 report [U6]. For average potassium concentration in diet of the two countries of 2.35 g kg$^{-1}$, the value of $P_{23}$ is 9 mBq a kg$^{-1}$/(Bq $m^{-2}$).

73. The estimated transfer coefficient of $^{137}Cs$ from deposition to diet and dietary components cannot yet be said to be widely representative and could be underestimated for areas which have shown greater transfer of $^{137}Cs$ to milk. These are areas where caesium is not strongly adsorbed in soil and, thus, greater uptake by plants from the cumulative deposit in soil occurs.

### 3. Transfer from diet to human tissues

74. Caesium-137 ingested by man is readily absorbed and becomes relatively uniformly distributed in soft tissues. Uptake by mineral bone is slight and the concentrations in fat tissues are low. The biological half-time of caesium is a function of age and sex. For calculational purposes, representative retention assumptions for the adult are that 10% is excreted with a half-time of 2 d and 90% with a half-time of 110 d [I3].

75. Information on $^{137}Cs$ activity concentrations in the human body since 1974 is given in Table 17. The measurements are generally reported as $^{137}Cs$/K quotients. The results may be converted to concentra-

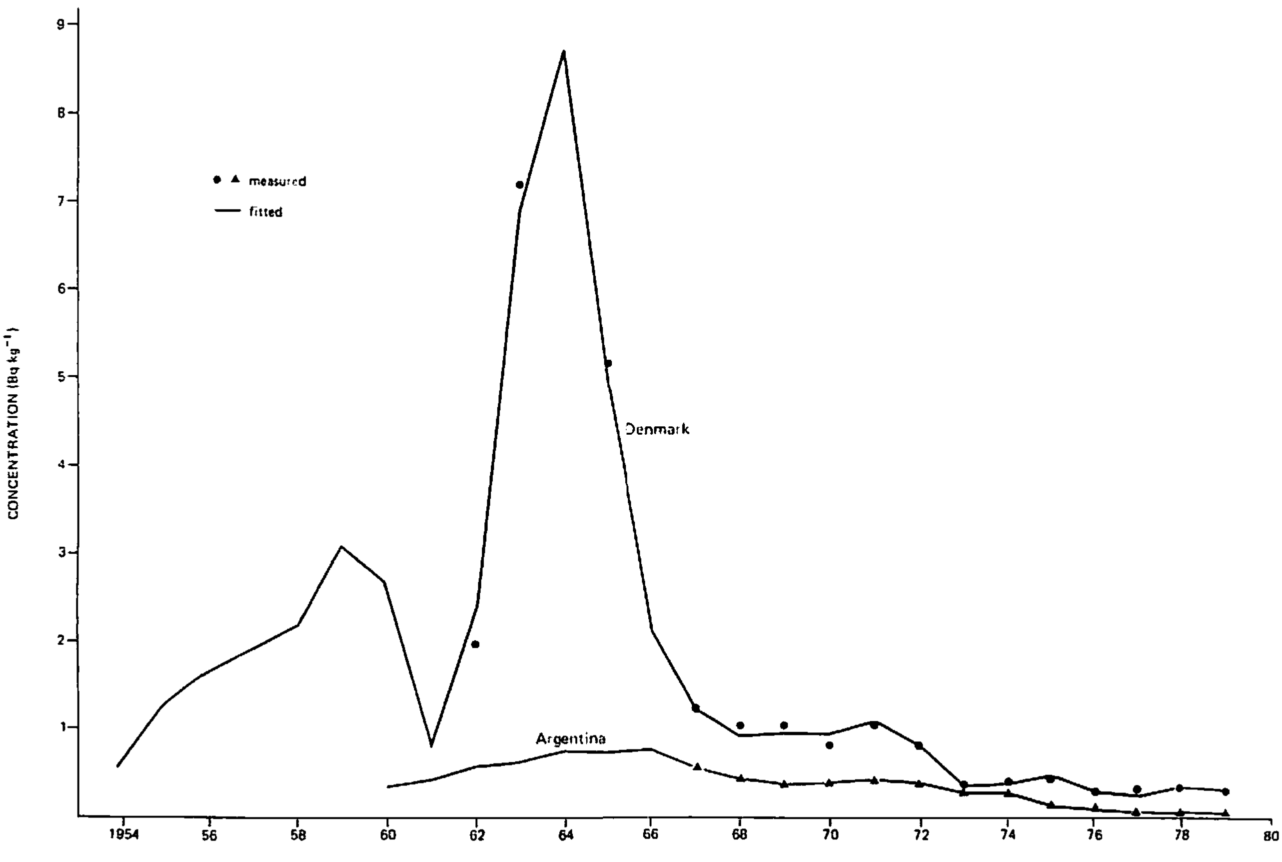



**Figure IV. Caesium-137 in total diet of Argentina and Denmark**

tions by assuming 140 g K in the 70 kg adult body. For most localities, the $^{137}Cs$ concentrations have decreased steadily since 1970. The values in subarctic populations are between two and three orders of magnitude higher than those in the middle latitudes, due to higher transfer of $^{137}Cs$ in the lichen-reindeer (or lichen-caribou) food chain [U5].

76. The short biological half-time of caesium in the body makes it possible to assess the transfer between diet and body, $P_{34}$, from the quotient of respective $^{137}Cs$ concentrations integrated over a few years. Using this procedure, an average value of 3 Bq a (g K)$^{-1}$ per Bq a (g K)$^{-1}$ was derived in Annex C of the 1977 report [U6]. In terms of concentration, the value of the transfer factor becomes 2.6 Bq a kg$^{-1}$ in the body per Bq a kg$^{-1}$ in diet.

### 4. Dose commitments from caesium-137

77. The combined transfer coefficient, $P_{24}$, linking deposition density to the $^{137}Cs$ concentration in the body is the product of $P_{23}$ and $P_{34}$. From the estimated average values for these two coefficients, the value of the combined coefficient is

$$P_{24} = 0.009\,\frac{\text{Bq a kg}^{-1}}{\text{Bq m}^{-2}} \times 2.6\,\frac{\text{Bq a kg}^{-1}}{\text{Bq a kg}^{-1}} = 0.023\,\frac{\text{Bq a kg}^{-1}}{\text{Bq m}^{-2}}$$

78. An alternative procedure for the assessment of $P_{24}$ is the direct use of the time-integrated $^{137}Cs$ concentration in the body and the integrated deposition density, both over the same period of several years. The results obtained using this procedure are shown in Table 18. There is general agreement with the value of the previous paragraph except that in the more northern latitudes the greater transfer of $^{137}Cs$ to diet may contribute to somewhat higher values of $P_{24}$. The dose commitments will be higher in these areas and, indeed, much higher if reindeer or caribou meat is consumed. It may be assumed, however, that these special situations do not make a large contribution to the collective dose commitments.

79. As was shown in Annex A of the 1969 report of the Committee [U4], the transfer coefficient $P_{45}$, linking tissue activity and tissue dose, is approximately independent of age if expressed as dose per unit of the time-integrated $^{137}Cs$/K quotient. The value of $P_{45}$ is 4.9 $10^{-6}$ Gy per Bq a (g K)$^{-1}$. Converting to concentration, the transfer coefficient is

$$P_{45} = 2.4\ 10^{-6}\ \text{Gy/(Bq a kg}^{-1})$$

which is in good agreement with the value derived from ICRP [I1]. It has also been shown directly that this is the appropriate transfer coefficient for the adult [F8, N4]. The transfer coefficient for children is less, due to the partial escape of the photon energy in the smaller body size. For example, Spiers [S2] gave the value for a child weighing 8 kg as 4.1 $10^{-6}$ Gy per Bq a (g K)$^{-1}$.

80. Combining the transfer coefficients $P_{24}$ and $P_{45}$ gives a value of $P_{25}$ of 5.5 $10^{-8}$ Gy/(Bq m$^{-2}$). Values of the transfer coefficient $P_{02}$ between input from the nuclear tests and deposition density were given in paragraph 70. Table 19 summarizes the dose commitments which apply to all tissues in the body and the collective dose commitments from $^{137}Cs$. The applicable world population size has been taken to be 4 $10^9$ persons, distributed as indicated in Table 6.

81. The dose commitments from $^{137}Cs$ via the inhalation pathway can be estimated in a manner similar to $^{90}Sr$. The same relationship between deposition density and integrated air concentration may be expected to apply. The integrated concentrations of $^{137}Cs$ in air, which are 1.6 times the values for $^{90}Sr$, are 9.3 mBq a m$^{-3}$ in the North temperate zone, 2.6 mBq a m$^{-3}$ in the South temperate zone and 5.6 mBq a m$^{-3}$ in the world (population-weighted). For the breathing rate of 20 m$^3$ d$^{-1}$ and dose per unit intake of 8.8 $10^{-9}$ Gy Bq$^{-1}$, which is nearly uniform in the various tissues, the dose commitments are 0.6 μGy (North temperate zone), 0.17 μGy (South temperate zone) and 0.36 μGy (world). The collective effective dose equivalent commitment to the world population at the time of exposure (3.2 $10^9$ persons) is estimated to be 1.2 $10^3$ man Sv. These dose estimates from $^{137}Cs$ inhalation are about 600 times less than those from $^{137}Cs$ ingestion.

## K. CAESIUM-136

82. Caesium-136 is a beta emitter with a half-life of 13.2 d. The average beta energy is 101.1 keV, and several gamma rays with energies up to 1.24 MeV are emitted [K7]. Since it must be produced directly by fission and not by beta decay, because $^{136}Xe$ is stable, the amount produced in nuclear tests is relatively small (less than 1% of $^{137}Cs$ on the basis of number of atoms [H8]). The short half-life of $^{136}Cs$ gives a greater activity, the estimated total production being about 7 $10^{18}$ Bq.

83. The importance of $^{136}Cs$ in fallout had at one time been questioned, but the estimated doses have been shown to be very low [O1]. If only the ingestion of fresh milk is considered as a significant pathway, the estimated dose commitment, derived from O'Brien [O1], is about 0.1 μGy to body tissues in general for the population of the temperate region of the northern hemisphere from all tests through 1980. Using the distributional assumptions of levels as before, the dose commitment which applies to the world population (3.2 $10^9$ persons) is 0.06 μGy and the collective dose commitment is 190 man Gy.

## L. BARIUM-140

84. Barium-140 is a beta emitter with a half-life of 12.8 d and average beta energy of 272 keV [K7]. Several gamma rays are also emitted. Its daughter product, the 40.22 h half-life $^{140}La$, decays with 526.9 keV average beta energy and several gamma rays, with energies up to 2.5 MeV. Barium-140 is measurable in fallout only for a few weeks after a nuclear explosion. The activity of $^{140}Ba$ produced in atmospheric tests is estimated to be 720 EBq, based on globally dispersed $^{90}Sr$ production and the ratio of fission yields in weapons explosions (Table 3).

85. Barium-140 was measured in the pasteurized milk supply networks of the United States by the Public Health Service between 1961 and 1965 [P6]. The time-integrated concentration in milk was 0.6 Bq a l$^{-1}$ for this period, corresponding to a time integral for all tests of about 1.1 Bq a l$^{-1}$. For average milk consumption of 0.3 l d$^{-1}$, the intake commitment of $^{140}Ba$ is 120 Bq.

86. The committed doses per unit ingested activity of $^{140}Ba$ are estimated to be 1.0 $10^{-9}$, 7.7 $10^{-9}$ and 2.6 $10^{-8}$ Gy $Bq^{-1}$ to gonads and walls of the upper large intestine (ULI) and lower large intestine (LLI), respectively [I4]. The dose commitments from ingested fallout $^{140}Ba$ in the North temperate zone are, thus, 1.2 $10^{-7}$ Gy (gonads), 9.2 $10^{-7}$ Gy (ULI) and 3.1 $10^{-6}$ Gy (LLI). Ingestion of $^{140}Ba$ in other diet items, such as leafy vegetables, and also direct intake of $^{140}La$, have not been taken into account.

87. The same relationship as indicated in paragraph 59 between the North and South temperate zone dose commitments (factor of 4) and between the respective temperate and hemispheric values (factor of 1.5) may be assumed to apply to $^{140}Ba$. The dose commitments weighted to the world population are thus estimated to be 7.3 $10^{-8}$ Gy (gonads), 5.6 $10^{-7}$ Gy (ULI) and 1.9 $10^{-6}$ Gy (LLI). The effective dose equivalent commitment to the world population is 0.17 μSv and the collective quantity, applicable to the population of 3.2 $10^9$ persons in 1961–1962, when most of the $^{140}Ba$ was released, is 540 man Sv.

88. The dose commitments from inhalation of $^{140}Ba$ can be calculated using the same method described in paragraph 57 for $^{89}Sr$. The integrated deposition density of $^{140}Ba$ has been evaluated from available measurements and from comparisons with other short-lived radionuclides, as in Annex C of the 1977 report [U6]. The population-weighted values are noted in a subsequent section (Table 28). The estimate for the world population is 1.7 $10^4$ Bq $m^{-2}$. This corresponds to a time-integrated concentration in surface air of about 0.03 Bq a $m^{-3}$ during the entire testing period. The intake commitment by inhalation is thus 220 Bq. The corresponding values for the North and South temperate zone are 330 and 46 Bq, respectively.

89. The dose commitments to tissues from inhalation of $^{140}Ba$ are determined from the product of the intake commitments by the committed doses per unit intake, as given by the ICRP [I4]. The results are listed in Table 20. The effective dose equivalent commitments are 0.32 μSv (North temperate zone), 0.044 μSv (South temperate zone) and 0.21 μSv (world). The collective effective dose equivalent commitment to the applicable world population (3.2 $10^9$ persons) is 670 man Sv.

## M. CERIUM-144

90. Cerium-144 with a half-life of 284 d and its decay product, $^{144}Pr$ with a half-life of 17.3 min, emit beta particles and several gamma rays [N5]. The average beta decay energies are 82.0 keV from $^{144}Ce$ and 1.21 MeV from $^{144}Pr$ [K7]. In comparing with $^{90}Sr$ fission yield and production (Table 3), the estimated $^{144}Ce$ production in nuclear tests is 30 EBq.

91. Cerium-144 has been widely measured in air and deposition [C1]. The estimated population-weighted integrated deposition densities are included in Table 28. The corresponding integrated concentrations of $^{144}Ce$ in air are 8.7 $10^{-2}$ and 2.4 $10^{-2}$ Bq a $m^{-3}$ for the North and the South temperate zones, respectively, and 5.3 $10^{-2}$ Bq a $m^{-3}$ for the global average. Taking the committed dose to the lungs per unit intake of inhaled $^{144}Ce$ oxide (Class Y compound) to be 7.9 $10^{-7}$ Gy $Bq^{-1}$ [I1], the estimated dose commitments to the lungs are 5.0 $10^{-4}$ Gy (North temperate zone), 1.4 $10^{-4}$ Gy (South temperate zone) and 3.1 $10^{-4}$ Gy (world). The doses to other tissues are negligible. The effective dose equivalent commitment weighted for the world population is 37 μSv. Assuming a world population of 3.2 $10^9$ in the early 1960s when most of the $^{144}Ce$ was released in nuclear tests, the estimated collective effective dose equivalent commitment is 1.2 $10^5$ man Sv.

## N. PLUTONIUM AND TRANSPLUTONIUM ELEMENTS

92. Isotopes of plutonium and of transplutonium elements are generated in all weapons tests by activation of $^{238}U$ or from unfissioned material. Estimates of the production of several isotopes of plutonium, as well as of $^{242m}Am$ and $^{244}Cm$ can be inferred from environmental measurements of weapons debris and from the total explosive yield by fission. Such estimates are presented in Table 21. The most important plutonium isotopes are $^{239}Pu$, $^{240}Pu$, and $^{241}Pu$. Since $^{239}Pu$ and $^{240}Pu$ are not usually distinguished in environmental measurements, activities reported as $^{239}Pu$ apply generally to a mixture of $^{239}Pu$ and $^{240}Pu$, containing approximately 60% of $^{239}Pu$ in terms of activity. The isotope $^{241}Pu$ is a beta emitter with a half-life of 14.4 a which decays to the alpha emitter $^{241}Am$ with a half-life of 433 a. Although not produced directly in nuclear explosions, $^{241}Am$ activity is increasing as $^{241}Pu$ decays and the total ultimately produced will amount to 5.5 $10^{15}$ Bq of $^{241}Am$. Decays of curium isotopes produce plutonium isotopes but in amounts much less significant than direct production. The decay schemes of several transuranium radionuclides are illustrated in Figure V.

93. Plutonium transfer to human tissues can follow the inhalation of airborne plutonium or the ingestion of contaminated food. The available data indicate that for plutonium released by atmospheric tests, the most important pathway to man is the inhalation of contaminated air. Dose commitments have been estimated for each pathway.

### 1. Dose commitments from inhalation

94. The integrated deposition density of $^{239,240}Pu$ can be inferred from the corresponding values of $^{90}Sr$, as it has been observed that the $^{239,240}Pu/^{90}Sr$ activity ratio in stratospheric air samples has been relatively constant throughout the years with a value of about 0.018 [H3]. The $^{90}Sr$ estimates were given in Table 6. Table 22 gives the results for $^{239,240}Pu$ and for $^{238}Pu$ and $^{241}Pu$ from the production ratios (Table 21) and for $^{241}Am$ from decay of $^{241}Pu$.

95. The time-integrated concentrations of the plutonium isotopes in surface air, also presented in Table 22, were estimated from the corresponding deposition densities using the assumption that the value of the apparent deposition velocity of 1.8 $10^{-2}$ m $s^{-1}$ found in New York for $^{90}Sr$ [B7] can be applied to the plutonium isotopes for large sections of the world. The results agree reasonably well with the values calculated by Bennett [B7] for the New York area, using estimated source terms for each reported nuclear test and a 12-compartment atmospheric model.

96. The time-integrated surface air concentrations of $^{241}Am$ depend in a significant way on the decay of

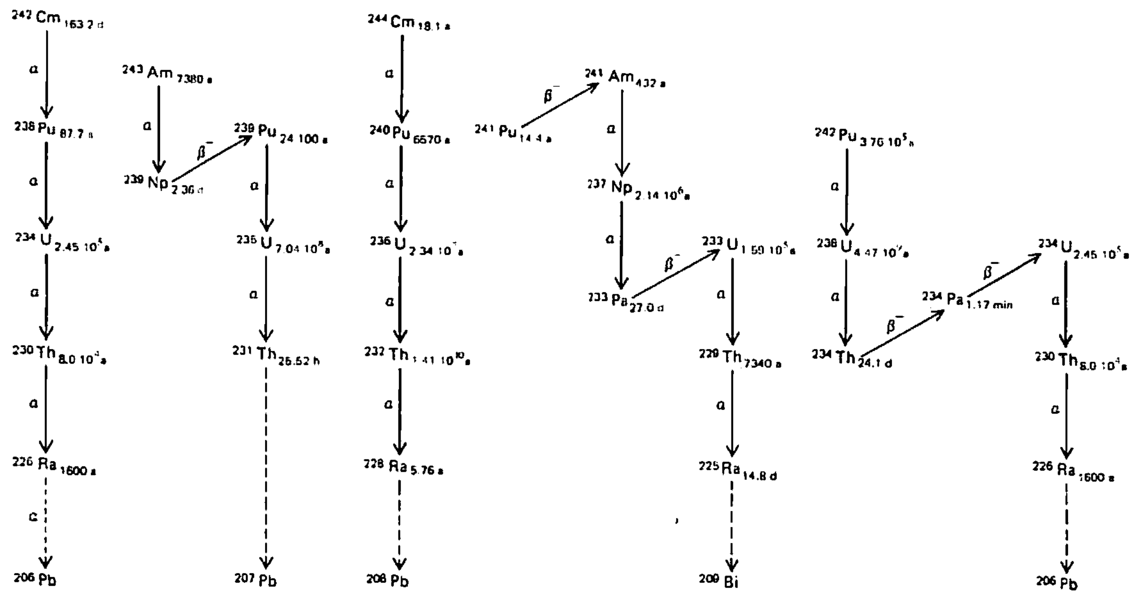



**Figure V. Decay schemes of transuranium radionuclides [K7, L3]**

$^{241}$Pu during its residence time in the stratosphere following each nuclear test, and a straightforward comparison with the behaviour of $^{90}$Sr or the plutonium isotopes cannot be made. The $^{241}$Am surface air concentrations and integrated deposition densities were derived from Bennett's work [B7], using the latitudinal distribution of $^{241}$Pu as a guide.

97. It has previously been shown that use of the ICRP lung model with Class Y parameters (appropriate for insoluble aerosol particles) with estimates of $^{239,240}$Pu concentrations in air to calculate organ burdens in the general public gives good agreement with measured plutonium concentrations in tissues [B6, U6]. From animal experiments, Class W parameters appear appropriate for americium compounds, including oxides [I3]. Estimates are given in Table 23 of the committed doses per unit intake of plutonium isotopes and $^{241}$Am, using the ICRP lung model [I1]. The committed doses per unit intake for $^{239}$Pu also apply to $^{240}$Pu.

98. Estimates of the dose commitments from inhalation of fallout plutonium and americium are given in Table 24. These results are obtained from the integrated concentrations in air of Table 22, the committed doses per unit inhaled activity of Table 23 and the intake rate of air of 20 m$^3$ d$^{-1}$. The effective dose equivalent commitments weighted for the world population are 1.0 µSv ($^{238}$Pu), 41 µSv ($^{239,240}$Pu), 8.8 µSv ($^{241}$Pu) and 1.7 µSv ($^{241}$Am). The collective effective dose equivalent commitments are obtained by multiplying by the relevant population at the time of exposure (3.2 10$^9$ persons globally). The results are 3.2 10$^3$ man Sv ($^{238}$Pu), 1.3 10$^5$ man Sv ($^{239,240}$Pu), 2.8 10$^4$ man Sv ($^{241}$Pu), and 5.4 10$^3$ man Sv ($^{241}$Am).

99. It is to be noted that inhalation of activity resuspended from the soil surface by winds could add to the long-term intake. However, the Committee in Annex C of its 1977 report [U6] considered this to be insignificant based on a realistic estimate for the resuspension factor of 10$^{-9}$ m$^{-1}$, applicable to the activity contained in the top centimetre of soil, and considering that plutonium would penetrate into the soil within a few years and then become unavailable for resuspension.

### 2. Dose commitments from ingestion

100. Information on the dietary intake of $^{239,240}$Pu and of $^{241}$Am is presented in Table 25 [B7]. Food samples from the New York area were measured for $^{239,240}$Pu for 1963, 1964, 1972 and 1974 and for $^{241}$Am for 1974 [B7]. The dietary intake of $^{239,240}$Pu was found to be about ten times higher in 1963 than in 1974, due to the influence of direct deposition. Clemente [C6] has estimated $^{239,\ 240}$Pu intake in Italian diet to be 0.06 Bq a$^{-1}$ during 1975–1978, in good agreement with the New York data.

101. Using an approach similar to that used for $^{90}$Sr and $^{137}$Cs, the relationship between ingestion in the year i, $I_{ig}(i)$, and the deposition density rate $\dot{U}(i)$ has been expressed in the following way for the plutonium isotopes

$$I_{ig}(i) = b_1\,\dot{U}(i) + b_3 \sum_{m=0}^{\infty} e^{-\lambda_s m}\,\dot{U}(i-m) \qquad (13)$$

where $b_1$ and $b_3$ are proportionality constants to be inferred from the measurements and $e^{-\lambda_s m}$ is a factor combining the physical decay and any decrease in the availability to plants of plutonium in soil.

102. The fallout to diet transfer coefficient $P_{23}$ [Bq/(Bq m$^{-2}$)] derived from equation (13) is

$$P_{23} = b_1 + \frac{b_3}{1 - e^{-\lambda_s n}} \approx b_1 + \frac{b_3}{\lambda_s n} \qquad (14)$$

where n = 1 year, a constant in this expression.

103. As the number of measurements of the annual ingestion intake, $I_{ig}$, are very few and cover a time span of only 11 years, the determination of $\lambda_s$ from equation (13) would be very uncertain as large variations in the value of $\lambda_s$ result in small variations in the value of $I_{ig}$. Taking $\lambda_s$ to be very small, Bennett [B7] found the average solutions for $b_1$ and $b_3$ to be 3.3 10$^{-2}$ Bq/(Bq m$^{-2}$) and 3.5 10$^{-4}$ Bq/(Bq m$^{-2}$), respectively, for $^{239,240}$Pu. The estimation of $P_{23}$ depends on the real value of $\lambda_s$. It could be as low as 5 10$^{-2}$ Bq/(Bq m$^{-2}$) if the availability of plutonium decreases with a mean residence time of 50 a ($\lambda_s$ = 0.02 a$^{-1}$) and as high as about 10 Bq/(Bq m$^{-2}$) for $^{239}$Pu and 3 Bq/(Bq m$^{-2}$) for $^{240}$Pu, if the availability

Table 1

Estimated yields of atmospheric nuclear tests

| Year | Country | Number of tests | Estimated yield (Mt) | |
|---|---|---|---|---|
| | | | Fission | Total |
| 1945 | USA | 3 | 0.05 | 0.05 |
| 1946 | USA | 2 | 0.04 | 0.04 |
| 1948 | USA | 3 | 0.10 | 0.10 |
| 1949 | USSR | 1 | 0.02 | 0.02 |
| 1951 | USA | 15 | 0.50 | 0.50 |
| | USSR | 2 | 0.04 | 0.04 |
| 1952 | USA | 10 | 6.6 | 12.6 |
| | UK | 1 | 0.02 | 0.02 |
| 1953 | USA | 11 | 0.25 | 0.25 |
| | UK | 2 | 0.04 | 0.04 |
| 1954 | USA | 6 | 29.6 | 47.1 |
| | USSR | 1 | 0.5 | 0.5 |
| 1955 | USA | 13 | 0.17 | 0.17 |
| | USSR | 4 | 1.5 | 3.0 |
| 1956 | USA | 14 | 9.7 | 22.7 |
| | USSR | 7 | 2.5 | 4.8 |
| | UK | 6 | 0.10 | 0.10 |
| 1957 | USA | 25 | 0.34 | 0.34 |
| | USSR | 13 | 4.7 | 11.3 |
| | UK | 7 | 5.85 | 9.25 |
| 1958 | USA | 53 | 8.2 | 17.6 |
| | USSR | 25 | 16.2 | 35.2 |
| | UK | 5 | 4.54 | 7.24 |
| 1960 | France | 3 | 0.11 | 0.11 |
| 1961 | USSR | 50 | 25.4 | 122.3 |
| | France | 1 | 0.02 | 0.02 |
| 1962 | USSR | 39 | 60.05 | 180.3 |
| | USA | 38 | 16.5 | 37.1 |
| 1964 | China | 1 | 0.02 | 0.02 |
| 1965 | China | 1 | 0.04 | 0.04 |
| 1966 | France | 5 | 0.68 | 0.68 |
| | China | 3 | 0.62 | 0.62 |
| 1967 | France | 3 | 0.20 | 0.20 |
| | China | 2 | 1.72 | 3.02 |
| 1968 | France | 5 | 4.1 | 4.9 |
| | China | 1 | 1.2 | 3.0 |
| 1969 | China | 1 | 2.0 | 3.0 |
| 1970 | France | 8 | 2.55 | 2.75 |
| | China | 1 | 2.0 | 3.0 |
| 1971 | France | 5 | 1.95 | 1.95 |
| | China | 1 | 0.02 | 0.02 |
| 1972 | France | 3 | 0.12 | 0.12 |
| | China | 2 | 0.12 | 0.12 |
| 1973 | France | 5 | 0.05 | 0.05 |
| | China | 1 | 1.6 | 2.5 |
| 1974 | France | 7 | 1.1 | 1.1 |
| | China | 1 | 0.45 | 0.60 |
| 1976 | China | 3 | 2.37 | 4.12 |
| 1977 | China | 1 | 0.02 | 0.02 |
| 1978 | China | 2 | 0.04 | 0.04 |
| 1980 | China | 1 | 0.45 | 0.6 |
| Summary | | | | |
| 1945-1962 | USA | 193 | 72.1 | 138.6 |
| 1949-1962 | USSR | 142 | 110.9 | 357.5 |
| 1952-1953 | UK | 21 | 10.6 | 16.7 |
| 1960-1974 | France | 45 | 10.9 | 11.9 |
| 1964-1980 | China | 22 | 12.7 | 20.7 |
| TOTAL | | 423 | 217.2 | 545.4 |

Table 2

Stratospheric partitioning of nuclear debris
(Mt fission energy)

| Year | Equatorial stratosphere (N) | | | Polar stratosphere (N) | | Equatorial stratosphere (S) | | |
|---|---|---|---|---|---|---|---|---|
| | Lower | Upper | High | Lower | Upper | Lower | Upper | High |
| 1951 | 0.009 | | | | | | | |
| 1952 | 1.3 | 1.8 | | | | | | |
| 1953 | 0.001 | | | 0.12 | | | | |
| 1954 | 7.99 | 6.76 | | 0.003 | | | | |
| 1955 | | | | 1.13 | | | | |
| 1956 | 4.97 | 0.15 | | 2.10 | | | | |
| 1957 | 2.32 | | | 3.09 | | 2.32 | | |
| 1958 | 2.41 | 0.4 | 1.5 | 14.18 | | 1.85 | | 1.51 |
| 1961 | | | | 15.20 | 7.14 | | | |
| 1962 | 6.26 | 0.24 | 1.2 | 28.19 | 30.54 | 3.79 | 0.05 | 0.35 |
| 1965 | | | | 0.003 | | | | |
| 1966 | | | | 0.26 | | 0.17 | | |
| 1967 | 1.7 | | | | | 0.10 | | |
| 1968 | | | | 0.89 | 0.31 | 3.22 | | |
| 1969 | | | | 1.5 | 0.5 | | | |
| 1970 | | | | 1.5 | 0.5 | 2.31 | | |
| 1971 | | | | | | 1.80 | | |
| 1972 | | | | 0.02 | | 0.002 | | |
| 1973 | 1.6 | | | | | | | |
| 1974 | 0.45 | | | | | 0.14 | | |
| 1976 | | | | 1.49 | 0.78 | | | |
| 1980 | | | | 0.45 | | | | |
| Total | 29.0 | 9.3 | 2.7 | 70.1 | 39.8 | 15.7 | 0.05 | 1.9 |

(N) Hemisphere total: 150.9 (S) Hemisphere total: 17.6
Global total: 168.5 (Mt)

Table 3

Fission and production yields of radionuclides in weapons testing

| Nuclide (half-life) [K7] | Representative fission yield (%) [H8] | Normalized production (PBq per Mt fission energy) |
|---|---|---|
| $^{89}Sr$ (50.5 d) | 2.56 | 590 |
| $^{90}Sr$ (28.6 a) | 3.50 | 3.9 |
| $^{95}Zr$ (64.0 d) | 5.07 | 920 |
| $^{103}Ru$ (39.4 d) | 5.20 | 1500 |
| $^{106}Ru$ (368 d) | 2.44 | 78 |
| $^{131}I$ (8.04 d) | 2.90 | 4200 |
| $^{136}Cs$ (13.2 d) | 0.036 | 32 |
| $^{137}Cs$ (30.2 a) | 5.57 | 5.9 |
| $^{140}Ba$ (12.8 d) | 5.18 | 4700 |
| $^{141}Ce$ (32.5 d) | 4.58 | 1600 |
| $^{144}Ce$ (284 d) | 4.69 | 190 |

Table 4

Dose commitments from inhalation of $^{54}Mn$

| Organ or tissue | Committed dose per unit intake ($nGy\ Bq^{-1}$) | Dose commitment ($10^{-8}$ Gy) | | |
|---|---|---|---|---|
| | | Northern temperate zone | Southern temperate zone | Global |
| Lungs | 6.7 | 27 | 1.4 | 16 |
| Liver | 2.5 | 10 | 0.51 | 6.1 |
| Red bone marrow | 1.1 | 4.5 | 0.22 | 2.7 |
| Breast | 0.86 | 3.5 | 0.18 | 2.1 |
| Gonads | 0.71 | 2.9 | 0.15 | 1.7 |
| Other tissues | 1.8 | 7.4 | 0.37 | 4.4 |

Table 5

Annual deposition and cumulative deposit of strontium-90

| | Annual deposition ($10^{16}$ Bq) | | | Cumulative deposit ($10^{16}$ Bq) | | |
|---|---|---|---|---|---|---|
| | Northern hemisphere | Southern hemisphere | Global | Northern hemisphere | Southern hemisphere | Global |
| Pre-1958 | 6.68 a/ | 2.37 a/ | 9.05 a/ | 6.29 | 2.22 | 8.51 |
| 1958 | 2.33 | 0.95 | 3.28 | 8.44 | 3.11 | 11.55 |
| 1959 | 3.89 | 0.68 | 4.57 | 12.06 | 3.70 | 15.76 |
| 1960 | 0.97 | 0.62 | 1.59 | 12.73 | 4.22 | 16.95 |
| 1961 | 1.30 | 0.64 | 1.94 | 13.69 | 4.77 | 18.46 |
| 1962 | 5.34 | 0.98 | 6.32 | 18.65 | 5.59 | 24.24 |
| 1963 | 9.70 | 1.14 | 10.84 | 27.79 | 6.59 | 34.38 |
| 1964 | 6.13 | 1.56 | 7.69 | 33.96 | 7.99 | 41.95 |
| 1965 | 2.86 | 1.32 | 4.18 | 35.15 | 9.10 | 44.25 |
| 1966 | 1.21 | 0.77 | 1.98 | 35.48 | 9.62 | 45.10 |
| 1967 | 0.62 | 0.41 | 1.03 | 35.22 | 9.81 | 45.03 |
| 1968 | 0.72 | 0.38 | 1.10 | 35.08 | 9.92 | 45.00 |
| 1969 | 0.54 | 0.52 | 1.06 | 34.78 | 10.21 | 44.99 |
| 1970 | 0.76 | 0.47 | 1.23 | 34.67 | 10.43 | 45.10 |
| 1971 | 0.70 | 0.56 | 1.26 | 34.52 | 10.73 | 45.25 |
| 1972 | 0.32 | 0.35 | 0.67 | 33.97 | 10.80 | 44.77 |
| 1973 | 0.12 | 0.11 | 0.23 | 33.23 | 10.66 | 43.89 |
| 1974 | 0.45 | 0.14 | 0.59 | 32.89 | 10.55 | 43.44 |
| 1975 | 0.22 | 0.13 | 0.35 | 32.30 | 10.40 | 42.70 |
| 1976 | 0.10 | 0.08 | 0.18 | 31.64 | 10.25 | 41.89 |
| 1977 | 0.30 | 0.08 | 0.38 | 31.15 | 10.06 | 41.21 |
| 1978 | 0.37 | 0.07 | 0.44 | 30.78 | 9.88 | 40.66 |
| 1979 | 0.12 | 0.04 | 0.16 | 30.16 | 9.70 | 39.86 |
| 1980 | 0.11 | 0.04 | 0.15 | 29.54 | 9.51 | 39.05 |
| Integrated deposition ($10^{16}$ Bq) | 45.86 | 14.41 | 60.27 | | | |
| Stratospheric inventory b/ ($10^{16}$ Bq) | 0.18 | < 0.01 | 0.18 | | | |
| Total injection through 1980 ($10^{16}$ Bq) | 46.0 | 14.4 | 60.4 | | | |

a/ Estimated from the cumulative deposit.
b/ Measured July 1979 in the northern hemisphere [L1], reduced with a half-time of 10 months to the end of 1980, plus estimated injection in 1980. Estimate only for the southern hemisphere.

## Table 6

**Latitudinal distribution of strontium-90 deposition[a/]**

| Latitude band (degrees) | Integrated deposition ($10^{16}$ Bq) | Area of band ($10^{12}$ $m^2$) | Integrated deposition density ($10^3$ Bq $m^{-2}$) | Population distribution (%) | Population weighted integrated deposition density ($10^3$ Bq $m^{-2}$) |
|---|---|---|---|---|---|
| NORTHERN HEMISPHERE | | | | | |
| 80-90 | 0.10 | 3.9 | 0.26 | 0 | |
| 70-80 | 0.79 | 11.6 | 0.68 | 0 | |
| 60-70 | 3.29 | 18.9 | 1.74 | 0.4 | |
| 50-60 | 7.39 | 25.6 | 2.89 | 13.7 | |
| 40-50 | 10.16 | 31.5 | 3.23 | 15.5 | |
| 30-40 | 8.53 | 36.4 | 2.34 | 20.4 | |
| 20-30 | 7.12 | 40.2 | 1.77 | 32.7 | |
| 10-20 | 5.09 | 42.8 | 1.19 | 11.0 | |
| 0-10 | 3.57 | 44.1 | 0.81 | 6.3 | |
| Total | 46.0 | | | 100.0 | 2.14 |
| SOUTHERN HEMISPHERE | | | | | |
| 0-10 | 2.10 | 44.1 | 0.48 | 54.0 | |
| 10-20 | 1.78 | 42.8 | 0.42 | 16.7 | |
| 20-30 | 2.81 | 40.2 | 0.70 | 14.9 | |
| 30-40 | 2.76 | 36.4 | 0.76 | 13.0 | |
| 40-50 | 2.81 | 31.5 | 0.89 | 0.9 | |
| 50-60 | 1.21 | 25.6 | 0.47 | 0.5 | |
| 60-70 | 0.67 | 18.9 | 0.35 | 0 | |
| 70-80 | 0.25 | 11.6 | 0.22 | 0 | |
| 80-90 | 0.03 | 3.9 | 0.08 | 0 | |
| Total | 14.4 | | | 100.0 | 0.54 |
| GLOBAL | 60.4 | | | 89 (N)<br>11 (S) | 1.96 |

a/ Through 1980, including projected deposition of stratospheric burden.

Table 7

Strontium-90 concentration in milk and intake rate in total diet

| Location | Milk[a/] (Bq $l^{-1}$) | | | | | | | Total diet (Bq $d^{-1}$) | | | | | | | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | |
| **NORTHERN HEMISPHERE** | | | | | | | | | | | | | | | |
| Canada | 0.2 | 0.2 | 0.1 | 0.2 | 0.1 | 0.1 | 0.08 | 0.3 | 0.2 | 0.2 | 0.3 | 0.2 | | | [M4,H10,I2] |
| Denmark | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.3 | 0.2 | [A1] |
| Faroe Islands | 0.9 | 0.8 | 0.7 | 0.4 | | | | 0.6 | 0.6 | 0.5 | 0.4 | 0.4 | | | [A2] |
| Finland | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | | | | | | | | | | [C4, R3] |
| France (1) | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.3 | [P1, I2] |
| France (2) | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.4 | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | [C10, M10] |
| German Dem.Rep. (Berlin area) | 0.2 | 0.1 | 0.1 | | | | | 0.2 | 0.2 | 0.2 | | | | | [K11] |
| Germany, Fed. Rep. | 0.3 | 0.1 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | 0.4 | 0.3 | 0.3 | 0.2 | 0.3 | 0.4 | 0.3 | [B11] |
| Greenland | | | | | | | | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | | | [A3] |
| India | 0.1 | 0.09 | 0.06 | | | | | 0.2 | 0.2 | 0.1 | | | | | [L2] |
| Italy | 0.3 | | | | | | | | | | | | | | [C9] |
| Japan | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.09 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.1 | [N10, I2] |
| Netherlands | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 | 0.06 | 0.06 | | | | | | | | [M6] |
| Norway | 0.3 | 0.4 | 0.3 | 0.4 | | | | | | | | | | | [H14] |
| Poland | 0.3 | 0.2 | | | | | | | | | | | | | [J1] |
| Senegal | | | 0.1 | | | | | | | | | | | | [R2] |
| Sweden | 0.2 | 0.2 | 0.1 | 0.1 | 0.2 | 0.2 | 0.1 | | | | | | | | [I2] |
| Switzerland | 0.2 | 0.2 | 0.2 | 0.2 | | | | | | | | | | | [H13] |
| USSR | 0.3 | 0.3 | 0.2 | 0.1 | 0.07 | 0.08 | 0.07 | 0.5 | 0.5 | | | | | | [K6, I2, P8] |
| United Kingdom | 0.1 | 0.1 | 0.1 | 0.1 | 0.09 | 0.1 | 0.08 | | | | | | | | [B10, G3, F6] |
| United States | | | | | | | | | | | | | | | |
| New York City | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | 0.4 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.2 | [B8, K3] |
| San Francisco | 0.05 | 0.07 | 0.05 | 0.04 | 0.05 | 0.04 | 0.04 | 0.1 | 0.1 | 0.1 | 0.09 | 0.1 | 0.1 | 0.09 | [B8, K3] |
| **SOUTHERN HEMISPHERE** | | | | | | | | | | | | | | | |
| Argentina | 0.11 | 0.09 | 0.08 | 0.07 | 0.06 | 0.06 | 0.06 | 0.08 | 0.07 | 0.06 | 0.05 | 0.04 | 0.05 | 0.04 | [C7] |
| Australia | 0.2 | 0.2 | | | | | | 0.1 | 0.1 | | | | | | [A6] |
| Bolivia | 0.04 | 0.04 | 0.04 | 0.04 | 0.07 | 0.1 | 0.1 | | | | | | | | [R2] |
| Chile | 0.09 | 0.04 | 0.1 | 0.1 | 0.09 | 0.09 | 0.08 | | | | | | | | [C8, R2] |
| New Caledonia | 0.09 | 0.04 | 0.2 | 0.06 | 0.04 | 0.03 | | | | | | | | | [R2] |
| New Zealand | 0.2 | 0.2 | 0.1 | 0.1 | 0.09 | 0.09 | 0.09 | | | | | | | | [N6, I2] |
| Peru | 0.04 | 0.09 | | 0.1 | 0.08 | 0.06 | 0.05 | | | | | | | | [R2] |
| Réunion | 0.1 | 0.04 | 0.09 | 0.1 | 0.07 | 0.1 | 0.07 | | | | | | | | [R2] |
| Tahiti | 0.2 | 0.2 | 0.09 | 0.1 | 0.1 | 0.09 | 0.08 | | | | | | | | [R2] |

a/ Assumes 1.2 gCa $l^{-1}$.

## Table 8

Parameters of the transfer coefficient for strontium-90 between deposition density and diet

| Parameter[a/] | Milk products | | | Grain products | | | Vegetables | | |
|---|---|---|---|---|---|---|---|---|---|
| | Argentina | Denmark | New York[b/] | Argentina | Denmark | New York | Argentina[c/] | Denmark | New York |
| $b_1$ | 1.2 | 1.5 | 0.7 | 1.6 | 3.3 | 0.7 | 0.02 | 0.4 | 0.3 |
| $b_2$ | 1.1 | 0.7 | 0.3 | 1.5 | 8.9 | 1.5 | 0 | 0 | 0.06 |
| $b_3$ | 0.1 | 0.3 | 0.2 | 0.06 | 0.1 | 0.2 | 0.1 | 0.2 | 0.3 |
| $\lambda_s$ | 0.10 | 0.12 | 0.112 | 0.02 | 0.02 | 0.11 | 0.26 | 0.07 | 0.08 |
| $P_{23}^k$ | 3.7 | 4.8 | 2.5 | 6.0 | 17.4 | 3.9 | 0.4 | 2.5 | 3.9 |
| $w_k$ | 0.26 | 0.35 | 0.31 | 0.20 | 0.16 | 0.15 | 0.24 | 0.24 | 0.19 |
| $w_k P_{23}^k$ | 1.0 | 1.7 | 0.8 | 1.2 | 2.8 | 0.6 | 0.09 | 0.6 | 0.8 |

| Parameter[a/] | Fruit | | | Meat, etc. | | | Total diet | | |
|---|---|---|---|---|---|---|---|---|---|
| | Argentina[d/] | Denmark | New York | Argentina | Denmark | New York | Argentina | Denmark | New York |
| $b_1$ | 0.3 | 1.0 | 0.2 | 0.7 | 0.4 | 0.002 | 1.1 | 1.3 | 0.5 |
| $b_2$ | 0.2 | 0.04 | 0 | 0.8 | 0.1 | 0.09 | 0.6 | 1.8 | 0.4 |
| $b_3$ | 0.04 | 0.04 | 0.1 | 0.03 | 0.04 | 0.05 | 0.04 | 0.1 | 0.2 |
| $\lambda_s$ | 0.09 | 0.02 | 0.03 | 0.02 | 0.09 | 0.17 | 0.03 | 0.05 | 0.08 |
| $P_{23}^k$ | 1.0 | 2.9 | 4.1 | 3.0 | 0.9 | 0.4 | 3.0 | 5.5 | 3.0 |
| $w_k$ | 0.23 | 0.10 | 0.15 | 0.08 | 0.15 | 0.19 | 1.0 | 1.0 | 1.0 |
| $w_k P_{23}^k$ | 0.2 | 0.3 | 0.6 | 0.2 | 0.1 | 0.07 | 3.0 | 5.5 | 3.0 |
| | | | | | | Components total | 2.7 | 5.5 | 2.9 |

a/ The units of parameters $b_1$, $b_2$, $b_3$ and $P_{23}^k$ for diet group k are $10^{-3}$ Bq a $kg^{-1}$ / (Bq $m^{-2}$). The units for $\lambda_s$ are $a^{-1}$. The constant $w_k$ is the fractional amount by weight of food group k in the total diet.

b/ New York City.

c/ Root vegetables.

d/ Fruit and leafy vegetables.

NOTE: Data span for regression analysis: Argentina 1964-1979, Denmark 1959-1979, New York 1960-1979 (New York milk 1954-1979). Comsumption data in model diets: Food 558, 498 and 637 kg $a^{-1}$ in Argentina, Denmark and New York, respectively; calcium 256, 620 and 370 g $a^{-1}$ in Argentina, Denmark and New York, respectively.

Table 9

Strontium-90 to calcium quotients in human bone a/
[mBq (g Ca)$^{-1}$]

| Location | Year | Age (years): Newborn or stillborn | < 1 | 1-4 | 5-19 | > 19 | Ref. |
|---|---|---|---|---|---|---|---|
| NORTHERN HEMISPHERE | | | | | | | |
| Canada | 1974 | | 55 | (75) | 70 | 60 | [M4] |
| | 1975 | | 110 | (100) | 85 | 80 | [M4] |
| | 1976 | | 110 | (120) | 65 | | [M4] |
| | 1977 | | 60 | (150) | (65) | | [M4] |
| | 1978 | | 95 | (200) | 65 | | [M4] |
| Denmark | 1974 | (48) | | 67 | 52 | 52 | [A1] |
| | 1975 | (48) | | 74 | 56 | 56 | [A1] |
| | 1976 | (33) | 41 | (37) | 37 | 37 | [A1] |
| | 1977 | (26) | (52) | (28) | 33 | 33 | [A1] |
| | 1978 | | | | | 41 | [A1] |
| | 1979 | | | | | 37 | [A1] |
| | 1980 | | (37) | | 24 | 30 | [A1] |
| Fiji | 1974 | | | | | 37 | [H4] |
| Germany, Fed. | 1977 | | | (48) | 52 | 30 | [D2] |
| Rep. of b/ | 1978 | | | 37 | 52 | 59 | [D3] |
| India | 1975 | | | | | 85 | [H5] |
| | 1980 | | | | | 32 | [E1] |
| Japan | 1974 | | 49 | 68 | 57 | 41 | [T1] |
| | 1975 | 24 | 35 | 48 | 45 | 44 | [T1] |
| | 1976 | 24 | | (20) | 45 | 36 | [T1] |
| | 1977 | 19 | 30 | | 40 | 34 | [T1] |
| | 1978 | 19 | | 41 | 39 | 38 | [T1] |
| | 1979 | 18 | | 37 | 37 | 34 | [T1] |
| | 1980 | 17 | | 34 | 30 | 35 | [T1] |
| Nepal | 1974 | | | | | 110 | [H4] |
| | 1975 | (70) | | (100) | 150 | 130 | [H4] |
| | 1976 | (160) | (150) | | 130 | 140 | [F6] |
| | 1977 | | (85) | (83) | 200 | 150 | [H6,H7] |
| | 1978 | (67) | | (740) | 180 | 110 | [H7] |
| | 1979 | | | 70 | 100 | 100 | [E1] |
| | 1980 | | | (44) | 150 | 56 | [E1] |
| New Guinea | 1974 | | | | | 19 | [H4] |
| Norway | 1974 | 63 | 100 | 120 | 110 | 89 | [J2] |
| | 1975 | 56 | 96 | 78 | 89 | 100 | [J2] |
| | 1976 | 48 | 63 | 70 | 63 | 67 | [J2] |
| | 1977 | 48 | 59 | (110) | 70 | 74 | [J2] |
| USSR c/ | 1974 | 34 | 52 | (89) | 110 | 53 | [M3,B13] |
| | 1975 | 39 | 48 | (57) | 91 | 56 | [M3,B13] |
| | 1976 | 35 | 40 | (73) | 95 | 56 | [B13] |
| | 1977 | 36 | 38 | (78) | 92 | 56 | [B13] |
| | 1978 | 34 | 45 | 57 | 74 | 56 | [B13] |
| United States | | | | | | | |
| New York | 1974 | | 63 | (56) | 63 | 44 | [B2] |
| | 1975 | | 52 | (62) | 52 | 41 | [B3] |
| | 1976 | | | | (59) | 41 | [B4] |
| | 1977 | | | | | 37 | [B5] |
| | 1978 | | | | | 41 | [K4] |
| | 1980 | | | | | 33 | [K13] |
| San Francisco | 1974 | | 22 | (32) | 26 | 26 | [B2] |
| | 1975 | | 19 | 27 | 30 | | [B3] |
| | 1976 | | 19 | (28) | 30 | 26 | [B4] |
| | 1977 | | 19 | (32) | 22 | 26 | [B5] |
| | 1978 | | 33 | 34 | 30 | 22 | [K4] |
| | 1979 | | 15 | 39 | (35) | 23 | [K12] |
| | 1980 | | 17 | (25) | 18 | 21 | [K13] |
| SOUTHERN HEMISPHERE | | | | | | | |
| Argentina | 1974 | ——— | ——— | 35 | ——— | ——— | [C7] |
| | 1975 | 31 | 33 | 36 | 36 | 36 | [C7] |
| | 1976 | 34 | 33 | 35 | 32 | 36 | [C7] |
| | 1977 | 33 | 33 | 34 | 34 | 32 | [C7] |
| | 1978 | 34 | 32 | 33 | 33 | 31 | [C7] |
| | 1979 | 19 | 31 | 31 | 34 | 31 | [C7] |
| | 1980 | 22 | 30 | 30 | 27 | 30 | [C7] |
| Australia | 1974 | 22 | 37 | 46 | 37 | 37 | [A6] |
| | 1975 | 22 | 37 | 62 | 37 | 37 | [A6] |

a/ Samples are vertebrae, unless otherwise indicated. Parentheses indicate averages from sample size less than 5 individuals.
b/ Tibia.
c/ Normalized to whole skeleton.

Table 10

Parameters of the transfer coefficient for $^{90}Sr$ between diet and bone

| Parameter a/ | Argentina 1965-1979 | Denmark 1960-1979 | New York City 1954-1979 | San Francisco 1961-1978 |
|---|---|---|---|---|
| c | 0.16 | 0.04 | 0.02 | 0.06 |
| g | 0.01 | 0.01 | 0.02 | 0.02 |
| $\lambda_b$ | 0.10 | 0.12 | 0.27 | 0.17 |
| $P_{34}$ | 0.32 | 0.16 | 0.11 | 0.18 |

a/ The units for the parameters c, g, and $P_{34}$ are Bq a $(gCa)^{-1}$ in bone per Bq a $(gCa)^{-1}$ and $a^{-1}$ for $\lambda_b$.

Table 11

Dose commitments from ingestion of strontium-90

| Location | Dose commitment ($10^{-4}$ Gy) | | Collective dose commitment ($10^5$ man Gy) | |
|---|---|---|---|---|
| | Bone marrow | Bone lining cells | Bone marrow | Bone lining cells |
| World | 5.7 | 13 | 23 | 50 |
| Northern hemisphere | 6.2 | 14 | 22 | 49 |
| Southern hemisphere | 1.6 | 3.4 | 0.7 | 1.5 |
| North temperate zone (40-50°) | 9.4 | 21 | 5.2 | 11 |
| South temperate zone (40-50°) | 2.6 | 5.7 | 0.01 | 0.02 |

Table 12

Iodine-131 in milk

| Location | Integrated concentration in milk (Bq d $l^{-1}$) 1976 | 1977 | 1978 | Ref. |
|---|---|---|---|---|
| Denmark (Risø) | 7.4 | | | [A1] |
| Finland | 13 | 10 | | [B15] |
| France | 34 | 7.4 | | [P1] |
| Germany, Fed.Rep.of (Kiel) | 16 | 5 | | [B11] |
| Japan (Chiba) | 13 | | 11 | [N10] |
| United Kingdom (Berkshire) | 35 | 7.4 | | [B9] |
| United States (Baltimore) a/ | 59 | | | [S1] |

a/ Inferred from infant thyroid dose, assuming 3 μGy per Bq d $l^{-1}$.

Table 13

Age-dependent parameters for obtaining absorbed doses in the thyroid gland from ingestion of $^{131}I$ in milk

| Parameter | Age: 6 months | 4 years | 14 years | Adult |
|---|---|---|---|---|
| Mass of thyroid gland (g) | 2 | 4 | 14 | 20 |
| Effective half-time in thyroid (d) | 6.0 | 6.3 | 6.9 | 7.6 |
| Milk consumption rate (l $a^{-1}$) | 330 | 180 | 150 | 90 |
| Absorbed energy per disintegration (MeV) | 0.18 | 0.18 | 0.19 | 0.19 |
| Dose per unit intake (μGy $Bq^{-1}$) | 4.3 | 2.0 | 0.65 | 0.51 |
| Transfer coefficient $P_{35}$ [mGy/(Bq a $l^{-1}$)] | 1.4 | 0.36 | 0.098 | 0.046 |

## Table 14

### Caesium-137 concentration in milk and intake in total diet

| Location | Milk ($Bq\ l^{-1}$) | | | | | | | Total diet ($Bq\ d^{-1}$) | | | | | | | References |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | |
| NORTHERN HEMISPHERE | | | | | | | | | | | | | | | |
| Canada | 0.3 | 0.3 | 0.2 | 0.3 | 0.3 | 0.2 | 0.1 | | | | | | | | [H10, I2] |
| Denmark | 0.3 | 0.2 | 0.2 | 0.2 | 0.3 | 0.2 | 0.1 | 0.6 | 0.6 | 0.4 | 0.5 | 0.7 | 0.5 | 0.3 | [A1] |
| Finland | 1.0 | 0.9 | 0.7 | 0.6 | 0.6 | | | | | | | | | | [C4, R3] |
| France (1) | 0.4 | 0.3 | 0.2 | 0.2 | 0.3 | 0.2 | <0.2 | 0.6 | 0.5 | 0.3 | 0.5 | 0.6 | 0.6 | <0.3 | [P1, I2] |
| France (2) | 0.4 | 0.4 | | | 0.3 | 0.1 | 0.1 | | | | | | | | [C10, M10] |
| German Dem.Rep. (Berlin area) | 0.3 | 0.4 | 0.3 | | | | | 0.6 | 1.0 | 0.6 | | | | | [K11] |
| Germany, Fed. Rep. of | 0.7 | 0.2 | 0.4 | 0.3 | 0.3 | <0.3 | <0.2 | 0.6 | 0.6 | 0.4 | 0.5 | 0.4 | 0.4 | 0.3 | [B11] |
| Japan | 0.3 | 0.4 | 0.3 | 0.3 | 0.4 | 0.3 | 0.2 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | [N10, I2] |
| Netherlands | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.1 | | | | | | | | [M6] |
| Norway | 2.2 | 1.8 | 1.9 | 1.9 | | | | | | | | | | | [H14] |
| Poland | 0.8 | 0.8 | | | | | | | | | | | | | [J1] |
| Sweden | 0.4 | 0.4 | 0.3 | 0.4 | 0.4 | 0.3 | 0.3 | | | | | | | | [H1, I2] |
| Switzerland | 0.4 | | | | | | | | | | | | | | [H13] |
| USSR | 0.7 | 0.6 | 0.3 | 0.3 | 0.2 | 0.2 | 0.1 | 0.6 | 0.6 | | | | | | [K6, I2, P8] |
| United Kingdom | 0.3 | 0.3 | 0.1 | 0.2 | 0.3 | 0.2 | 0.1 | | | | | | | | [B10, G3, F6] |
| United States | 0.1 | 0.3 | 0.2 | 0.2 | 0.3 | 0.2 | | 0.5 | 0.5 | 0.3 | 0.3 | 0.2 | 0.2 | 0.2 | [H9, K2, I2] |
| Faroe Islands | 9.4 | 7.3 | 7.0 | 6.6 | 6.6 | | | 8.8 | 10.4 | 5.4 | 4.0 | 5.7 | | | [A2] |
| Greenland | | | | | | | | 2.0 | 1.1 | 1.0 | 2.0 | 2.7 | | | [A3] |
| SOUTHERN HEMISPHERE | | | | | | | | | | | | | | | |
| Argentina | 0.4 | 0.2 | 0.1 | 0.06 | 0.05 | 0.06 | 0.06 | 0.4 | 0.2 | 0.1 | 0.06 | 0.05 | 0.05 | 0.05 | [C7] |
| Australia | 0.3 | 0.2 | | | | | | | | | | | | | [A6] |
| Chile | | | 0.4 | 0.6 | 0.4 | 0.2 | | | | | | | | | [C8, R2] |
| New Zealand | 0.5 | 0.4 | 0.3 | 0.4 | 0.2 | 0.3 | 0.1 | | | | | | | | [N6, I2] |
| Peru | | 0.1 | 0.1 | 0.2 | 0.2 | 0.2 | 0.1 | | | | | | | | [R2] |
| New Caledonia | | 0.2 | | | | | | | | | | | | | [R2] |
| Society Islands Tahiti | 3.9 | 3.7 | 2.6 | 2.6 | 2.2 | 2.0 | 2.1 | | | | | | | | [R2] |

## Table 15

### Transfer coefficient for caesium-137 between deposition density and diet or milk

| Location | $P_{23}$ (milk) ($mBq\ a\ kg^{-1}$ per $Bq\ m^{-2}$) | $P_{23}$ (diet) ($mBq\ a\ kg^{-1}$ per $Bq\ m^{-2}$) | Ref. |
|---|---|---|---|
| NORTHERN HEMISPHERE | | | |
| Denmark (1962-1979) | 5.9 | 12 | [K5] |
| Finland | 24 | - | [C5] |
| France | 11 | - | [M2] |
| Germany, Fed. Rep. of | 12 | - | [H15] |
| Norway (1957-1977) | 23 | - | [K5] |
| United States (1960-1973) | 5.4 | - | [U6] |
| United Kingdom (1961-1978) | 6.5 | - | [K5] |
| USSR | 9.3 | - | [U6] |
| Faroe Islands (1962-1977) | 34 | - | [K5] |
| SOUTHERN HEMISPHERE | | | |
| Argentina a/ | 12 | 8.1 | [K5] |
| Australia (1963-1973) | 20 | - | [U6] |
| New Zealand (1964-1979) | 18 | - | [K5] |

a/ Milk 1964-1979; diet 1967-1979.

Table 16

Parameters of the transfer coefficient for caesium-137 between deposition density and diet

| Parameter a/ | Milk products | | Grain products | | Vegetables | |
|---|---|---|---|---|---|---|
| | Argentina | Denmark | Argentina | Denmark | Argentina | Denmark |
| $b_1$ | 7.7 | 3.0 | 2.0 | 3.3 | 2.1 | 2.4 |
| $b_2$ | 0 | 2.0 | 6.9 | 23.3 | 2.3 | 0 |
| $b_3$ | 0.2 | 0.07 | 0 | 0 | 0 | 0.02 |
| $\lambda_s$ | 0.14 | 0.08 | - | - | - | 0.02 |
| $P^k_{23}$ | 8.8 | 5.9 | 8.9 | 26.6 | 4.4 | 3.5 |
| $w_k$ | 0.26 | 0.35 | 0.20 | 0.16 | 0.31 | 0.24 |
| $w_k P^k_{23}$ | 2.3 | 2.1 | 1.8 | 4.3 | 1.4 | 0.8 |

| Parameter a/ | Fruit | | Meat, etc. | | Total diet | |
|---|---|---|---|---|---|---|
| | Argentina | Denmark | Argentina | Denmark | Argentina | Denmark |
| $b_1$ | 0.5 | 1.8 | 22.1 | 11.9 | 6.3 | 4.0 |
| $b_2$ | 2.6 | 1.2 | 0 | 0 | 1.8 | 6.4 |
| $b_3$ | 0 | 0.2 | 3.7 | 46.9 | 0 | 0.03 |
| $\lambda_s$ | - | 0.29 | 0.65 | 1.6 | - | 0.02 |
| $P^k_{23}$ | 3.1 | 3.5 | 26.2 | 23.6 | 8.1 | 12.0 |
| $w_k$ | 0.16 | 0.10 | 0.08 | 0.15 | 1.0 | 1.0 |
| $w_k P^k_{23}$ | 0.5 | 0.4 | 2.1 | 3.5 | 8.1 | 12.0 |
| | | | Components total | | 8.1 | 11.1 |

a/ The units of parameters $b_1$, $b_2$, $b_3$ and $P^k_{23}$ for diet group k are mBq a $kg^{-1}/(Bq\ m^{-2})$. The units for $\lambda_s$ are $a^{-1}$. The constant $w_k$ is the fractional amount by weight of food group k in the total diet.

NOTE: Data span for regression analysis: Argentina 1967-1979; Denmark 1962-1979.
Consumption data in model diets: Food 558, 498 kg $a^{-1}$; potassium 1.12, 1.37 kg $a^{-1}$ in Argentina and Denmark, respectively.

Table 17

Caesium-137 concentration in the human body

[Bq (g K)$^{-1}$]

| Location | Sex | 1974 | 1975 | 1976 | 1977 | 1978 | 1979 | 1980 | Ref. |
|---|---|---|---|---|---|---|---|---|---|
| NORTHERN HEMISPHERE | | | | | | | | | |
| Denmark | M,F | 0.36 | 0.42 | 0.35 | 0.31 | | | | [A1] |
| Finland | M,F | 1.0 | 1.1 | 0.85 | 0.78 | | 0.96 | | [S5,R4, R5] |
| France | M,F | 0.67 | 0.63 | 0.41 | 0.41 | 0.48 | 0.56 | 0.48 | [P1] |
| Germany, Fed.Rep. | | | | | | | | | |
| Karlsruhe | M,F | 0.35 | 0.43 | 0.38 | | | | | [B11] |
| Düsseldorf | M | 0.61 | 0.58 | 1.2 | 0.29 | | | | [B11] |
| West Berlin | M,F | 0.36 | 0.42 | 0.25 | 0.22 | 0.22 | | | [B11] |
| Japan | M | 0.4 | 0.3 | 0.27 | 0.23 | 0.22 | 0.22 | | [U1,U9] |
| Sweden | | | | | | | | | |
| Stockholm | M,F | 0.82 | 0.88 | 0.60 | 0.45 | 0.31 | 0.43 | 0.37 | [E2] |
| Switzerland | | | | | | | | | |
| Geneva | M | 0.3 | 0.4 | 0.4 | 0.4 | | | | [H13] |
| Geneva | F | 0.3 | 0.4 | 0.5 | 0.4 | | | | [H13] |
| United Kingdom | | | | | | | | | |
| Oxfordshire | M | 0.33 | 0.43 | 0.35 | 0.30 | 0.37 | 0.42 | 0.35 | [N7,N8, F6] |
| United States | | | | | | | | | |
| New Mexico | M,F | | | 0.38 | 0.31 | | | | [T3] |
| Subarctic region (Reindeer herders) | | | | | | | | | |
| Finland (Inari) | M | 80 | 65 | 60 | 50 | | | | [T4] |
| USSR (Murmansk) | M | 260 | | | | | | | [T5] |
| SOUTHERN HEMISPHERE | | | | | | | | | |
| Argentina | | 0.34 | 0.13 | 0.11 | 0.052 | 0.037 | 0.040 | 0.040 | [C7] |

Table 18

Values of $P_{24}$ obtained as the quotient of the time-integrated $^{137}Cs$ concentration in the body and the integrated deposition density

| Location | Period | $P_{24}$ (Bq a kg$^{-1}$ per Bq m$^{-2}$) | Ref. |
|---|---|---|---|
| Argentina | 1966-1974 | 0.022 | [U6] |
| Denmark | | 0.022 | [U6] |
| Finland | 1962-1973 | 0.062 | [C5] |
| Sweden (Stockholm) | 1962-1972 | 0.036 | [U6] |
| United Kingdom (Southern England) | 1957-1976 | 0.015 | [N7] |

Table 19

Dose commitments from ingestion of caesium-137

| Location | Dose commitment (µGy) | Collective dose commitment ($10^5$ man Gy) |
|---|---|---|
| World | 170 | 6.9 |
| Northern hemisphere | 190 | 6.7 |
| Southern hemisphere | 47 | 0.2 |
| North temperate zone (40-50°) | 280 | 1.6 |
| South temperate zone (40-50°) | 78 | 0.003 |

Table 20

Dose commitments from inhalation of $^{140}Ba$

| Organ or tissue | Dose per unit intake ($10^{-9}$ Gy $Bq^{-1}$) | Dose commitment ($10^{-7}$ Gy) | | |
|---|---|---|---|---|
| | | North temperate zone | South temperate zone | Global |
| Lower large intestine | 4.4 | 15 | 2.0 | 9.7 |
| Bone lining cells | 2.4 | 7.9 | 1.1 | 5.3 |
| Lungs | 1.7 | 5.6 | 0.8 | 3.7 |
| Upper large intestine | 1.5 | 5.0 | 0.7 | 3.3 |
| Red bone marrow | 1.3 | 4.3 | 0.6 | 2.9 |
| Small intestine | 0.53 | 1.7 | 0.2 | 1.2 |
| Gonads | 0.43 | 1.4 | 0.2 | 1.0 |
| Breast | 0.29 | 1.0 | 0.1 | 0.6 |

Table 21

Production of plutonium and transplutonium isotopes by atmospheric nuclear tests

| Isotope | Half-life (a) [K7] | Mass ratio relative to $^{239}Pu$ corresponding to production by nuclear tests [B7, G1, H12] | Production by past nuclear tests (PBq) |
|---|---|---|---|
| $^{238}Pu$ | 87.7 | 0.00016 | 0.33 |
| $^{239}Pu$ | 24100 | 1 | 7.8 |
| $^{240}Pu$ | 6570 | 0.18 | 5.2 |
| $^{241}Pu$ | 14.4 | 0.013 | 170 |
| $^{242}Pu$ | 376000 | 0.0034 | 0.016 |
| $^{242m}Am$ | 152 | 0.00000031 | 0.00037 |
| $^{244}Cm$ | 18.1 | 0.000000025 | 0.00026 |

Table 22

Integrated deposition density and concentration in air of $^{238}Pu$, $^{239,240}Pu$, $^{241}Pu$ and $^{241}Am$ a/

| Location | Integrated deposition density ($Bq\ m^{-2}$) | | | | Integrated concentration in air ($10^{-6}$ Bq a $m^{-3}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | $^{238}Pu$ | $^{239,240}Pu$ | $^{241}Pu$ b/ | $^{241}Am$ c/ | $^{238}Pu$ | $^{239,240}Pu$ | $^{241}Pu$ | $^{241}Am$ |
| World | 0.90 | 35 | 440 | 15 | 1.6 | 62 | 770 | 1.7 |
| Northern hemisphere | 0.98 | 39 | 480 | 17 | 1.7 | 69 | 840 | 1.8 |
| Southern hemisphere | 0.25 | 9.7 | 120 | 4.2 | 0.4 | 17 | 210 | 0.5 |
| North temperate zone (40-50°) | 1.5 | 58 | 730 | 25 | 2.6 | 100 | 1300 | 2.8 |
| South temperate zone (40-50°) | 0.41 | 16 | 200 | 7.0 | 0.7 | 28 | 350 | 0.8 |

a/ Through 1979 from nuclear explosions only. A satellite reentry in 1964 in the southern hemisphere caused additional widespread deposition of $^{238}Pu$.

b/ Taking into account a delay of 10 months between production and deposition.

c/ From $^{241}Am$ deposition plus $^{241}Pu$ decay.

Table 23

Committed dose per unit intake of Pu and Am radionuclides
Committed dose per unit intake of plutonium and americium radionuclides
($\mu$Gy Bq$^{-1}$)
[I1]

| | $^{238}Pu$ | | $^{239}Pu$ | | $^{241}Pu$ | | $^{241}Am$ | |
|---|---|---|---|---|---|---|---|---|
| | Inhalation (Class Y) | Ingestion (Soluble) | Inhalation (Class Y) | Ingestion (Soluble) | Inhalation (Class Y) | Ingestion (Soluble) | Inhalation (Class W) | Ingestion (Soluble) |
| Lungs | 16 | - | 16 | - | 3.2 | - | - | - |
| Red bone marrow | 3.3 | 0.008 | 3.8 | 0.008 | 1.7 | 0.003 | 10 | 0.04 |
| Bone lining cells | 42 | 0.09 | 48 | 0.1 | 21 | 0.04 | 130 | 0.6 |
| Liver | 9 | 0.02 | 11 | 0.02 | 4.4 | 0.009 | 28 | 0.1 |
| Gonads | - | 0.001 | | 0.001 | 0.3 | 0.0006 | 1.6 | 0.007 |

Table 24

Dose commitments from inhalation of fallout plutonium and americium
($\mu$Gy)

| | Lungs | Red bone marrow | Bone lining cells | Liver | Gonads |
|---|---|---|---|---|---|
| $^{238}Pu$ | | | | | |
| World | 0.2 | 0.04 | 0.5 | 0.1 | - |
| Northern hemisphere | 0.2 | 0.04 | 0.5 | 0.1 | - |
| Southern hemisphere | 0.05 | 0.01 | 0.1 | 0.03 | - |
| North temperate zone | 0.3 | 0.06 | 0.8 | 0.2 | - |
| South temperate zone | 0.08 | 0.02 | 0.2 | 0.05 | - |
| $^{239,240}Pu$ | | | | | |
| World | 7.2 | 1.7 | 22 | 5.0 | - |
| Northern hemisphere | 8.1 | 1.9 | 24 | 5.5 | - |
| Southern hemisphere | 2.0 | 0.5 | 6.0 | 1.4 | - |
| North temperate zone | 12 | 2.8 | 35 | 8.0 | - |
| South temperate zone | 3.3 | 0.8 | 9.8 | 2.2 | - |
| $^{241}Pu$ | | | | | |
| World | 18 | 9.6 | 120 | 25 | 1.7 |
| Northern hemisphere | 20 | 10 | 130 | 27 | 1.8 |
| Southern hemisphere | 4.9 | 2.6 | 32 | 6.7 | 0.5 |
| North temperate zone | 30 | 16 | 200 | 42 | 2.8 |
| South temperate zone | 8.2 | 4.3 | 54 | 11 | 0.8 |
| $^{241}Am$ | | | | | |
| World | - | 0.1 | 1.6 | 0.3 | 0.02 |
| Northern hemisphere | - | 0.1 | 1.7 | 0.4 | 0.02 |
| Southern hemisphere | - | 0.04 | 0.5 | 0.1 | 0.006 |
| North temperate zone | - | 0.2 | 2.7 | 0.6 | 0.03 |
| South temperate zone | - | 0.06 | 0.8 | 0.2 | 0.009 |

Table 25

Dietary intake of fallout
$^{239,240}Pu$ and $^{241}Am$
in the New York region

| Year | Annual dietary intake (Bq) | |
|---|---|---|
| | $^{239,240}Pu$ | $^{241}Am$ |
| 1963 | 0.55 | |
| 1964 | 0.34 | |
| 1972 | 0.056 | |
| 1974 | 0.048 | 0.015 |

Table 26

Dose commitments from ingestion of fallout plutonium and americium
($10^{-8}$ Gy)

| | Red bone marrow | Done lining cells | Liver | Gonads |
|---|---|---|---|---|
| $^{238}Pu$ | | | | |
| World | 0.04 | 0.4 | 0.09 | 0.005 |
| Northern hemisphere | 0.04 | 0.4 | 0.1 | 0.005 |
| Southern hemisphere | 0.01 | 0.1 | 0.03 | 0.001 |
| North temperate zone | 0.06 | 0.7 | 0.15 | 0.008 |
| South temperate zone | 0.02 | 0.2 | 0.04 | 0.002 |
| $^{239,240}Pu$ | | | | |
| World | 20 | 250 | 49 | 2.5 |
| Northern hemisphere | 22 | 270 | 55 | 2.7 |
| Southern hemisphere | 5.4 | 68 | 14 | 0.7 |
| North temperate zone | 32 | 410 | 81 | 4.1 |
| South temperate zone | 9.0 | 110 | 22 | 1.1 |
| $^{241}Pu$ | | | | |
| World | 5.3 | 70 | 16 | 1.1 |
| Northern hemisphere | 5.8 | 77 | 17 | 1.2 |
| Southern hemisphere | 1.4 | 19 | 4.3 | 0.3 |
| North temperate zone | 8.8 | 120 | 26 | 1.8 |
| South temperate zone | 2.4 | 32 | 7.2 | 0.5 |
| $^{241}Am$ | | | | |
| World | 12 | 180 | 30 | 2.1 |
| Northern hemisphere | 14 | 200 | 34 | 2.4 |
| Southern hemisphere | 3.4 | 50 | 8.4 | 0.6 |
| North temperate zone | 20 | 300 | 50 | 3.5 |
| South temperate zone | 5.6 | 84 | 14 | 1.0 |

Table 27

Conversion factors for the assessment of the effective equivalent dose commitments due to external irradiation

| | $^{95}Zr$ a/ | $^{103}Ru$ | $^{106}Ru$ a/ | $^{137}Cs$ | $^{140}Ba$ a/ | $^{141}Ce$ | $^{144}Ce$ a/ |
|---|---|---|---|---|---|---|---|
| Quotient of absorbed dose rate in air to deposition density [$10^{-8}$ Gy $a^{-1}$/(Bq $m^{-2}$)] | 9.5 | 1.8 | 0.79 | 0.89 | 9.8 | 0.25 | 0.17 |
| Mean life (a) | 0.253 | 0.156 | 1.46 | 43.6 | 0.051 | 0.128 | 1.12 |
| Quotient of absorbed dose in air to deposition density [$10^{-8}$ Gy/(Bq $m^{-2}$)] | 2.4 | 0.28 | 1.2 | 39 | 0.50 | 0.032 | 0.19 |
| $P_{25}$ b/ [($10^{-10}$ Gy/(Bq $m^{-2}$)] | 72 | 8.4 | 36 | 1170 | 15 | 0.96 | 5.7 |

a/ Including contributions from the daughter radionuclides, assumed in transient equilibrium.
b/ The air-to-tissue conversion factor, taking into account indoor occupancy and shielding by buildings, is assumed to be 0.3 (see Annex A).

Table 28

Integrated deposition densities of the main contributors to external irradiation

($10^3$ Bq $m^{-2}$)

| Location | $^{95}Zr$ | $^{103}Ru$ | $^{106}Ru$ | $^{137}Cs$ | $^{140}Ba$ | $^{141}Ce$ | $^{144}Ce$ |
|---|---|---|---|---|---|---|---|
| World | 27.2 | 20.4 | 14.7 | 3.14 | 16.7 | 15.0 | 29.4 |
| Northern hemisphere | 29.1 | 21.8 | 16.0 | 3.42 | 18.0 | 16.0 | 32.1 |
| Southern hemisphere | 12.1 | 9.1 | 4.1 | 0.86 | 7.5 | 6.7 | 8.1 |
| North temperate zone | 40.1 | 30.1 | 24.2 | 5.17 | 24.9 | 22.1 | 48.4 |
| South temperate zone | 5.6 | 4.2 | 6.7 | 1.42 | 3.5 | 3.1 | 13.4 |

Table 29

Dose commitments due to external irradiation from radionuclides deposited on the ground

(μGy)

| Location | $^{95}Zr$ | $^{103}Ru$ | $^{106}Ru$ | $^{137}Cs$ | $^{140}Ba$ | $^{141}Ce$ | $^{144}Ce$ | Total |
|---|---|---|---|---|---|---|---|---|
| World | 200 | 17 | 53 | 370 | 25 | 1.4 | 17 | 680 |
| Northern hemisphere | 210 | 18 | 58 | 400 | 27 | 1.5 | 18 | 730 |
| Southern hemisphere | 87 | 7.6 | 15 | 100 | 11 | 0.6 | 4.6 | 230 |
| North temperate zone | 290 | 25 | 87 | 600 | 37 | 2.1 | 28 | 1070 |
| South temperate zone | 40 | 3.5 | 24 | 170 | 5.3 | 0.3 | 7.6 | 250 |

Table 30

Summary of dose commitments from radionuclides produced in atmospheric nuclear tests carried out to the end of 1980

(μGy)

| Source of radiation | North temperate zone | | | | South temperate zone | | | | World population | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gonads | Red bone marrow | Bone lining cells | Lungs | Gonads | Red bone marrow | Bone lining cells | Lungs | Gonads | Red bone marrow | Bone lining cells | Lungs |
| External | | | | | | | | | | | | |
| Short-lived nuclides | 470 | 470 | 470 | 470 | 80 | 80 | 80 | 80 | 310 | 310 | 310 | 310 |
| $^{137}Cs$ | 600 | 600 | 600 | 600 | 170 | 170 | 170 | 170 | 370 | 370 | 370 | 370 |
| Internal | | | | | | | | | | | | |
| $^{3}H$ | 51 | 51 | 51 | 51 | 14 | 14 | 14 | 14 | 47 | 47 | 47 | 47 |
| $^{14}C$ a/ | 77 | 370 | 340 | 91 | 77 | 370 | 340 | 91 | 77 | 370 | 340 | 91 |
| $^{55}Fe$ | 10 | 6 | 10 | 10 | 2 | 1 | 2 | 2 | 9 | 5 | 9 | 9 |
| $^{89}Sr$ | | 2 | 3 | 24 | | 0.6 | 0.9 | 6 | | 1 | 2 | 15 |
| $^{90}Sr$ | | 940 | 2100 | 120 | | 260 | 570 | 34 | | 570 | 1300 | 74 |
| $^{106}Ru$ | | | | 410 | | | | 95 | | | | 250 |
| $^{137}Cs$ | 280 | 280 | 280 | 280 | 78 | 78 | 78 | 78 | 170 | 170 | 170 | 170 |
| $^{144}Ce$ | | | | 500 | | | | 140 | | | | 250 |
| $^{239}Pu$ b/ | 0.04 | 3 | 39 | 12 | 0.01 | 0.9 | 11 | 3 | 0.03 | 2 | 25 | 7 |
| $^{241}Pu$ | 3 | 16 | 20 | 30 | 0.8 | 4 | 54 | 8 | 2 | 10 | 120 | 18 |
| $^{241}Am$ | 0.07 | 0.4 | 5 | | 0.02 | 0.1 | 1 | | 0.04 | 0.2 | 3 | |
| TOTAL (rounded) | 1500 | 2700 | 3900 | 2600 | 420 | 980 | 1300 | 720 | 990 | 1900 | 2700 | 1700 |

a/ Doses accumulated to the year 2000. The total dose commitments will be delivered over thousands of years; they are estimated in paragraph 25.

b/ Includes dose commitments from plutonium-240.

NOTE: The dose commitments from $^{54}Mn$, $^{85}Kr$, $^{136}Cs$, $^{140}Ba$ and $^{238}Pu$, although discussed in the text, are not shown in this table because they are negligible compared to the values included.
Estimates of age-weighted absorbed doses to the thyroid gland from iodine-131 are: 1.6 mGy (North temperate zone), 0.2 mGy (South temperate zone) and 1.1 mGy (World).
Absorbed doses from alpha particles: plutonium-239, americium-241.

Table 31

Summary of effective dose equivalent commitments from radionuclides produced in atmospheric tests carried out to the end of 1980

(μSv)

| Radio-nuclide | North temperate zone | | | | South temperate zone | | | | World population | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | External irra-diation | Inha-lation | Inge-stion | Total | External irra-diation | Inha-lation | Inge-stion | Total | External irra-diation | Inha-lation | Inge-stion | Total |
| $^{3}H$ | | 4 | 47 | 51 | | 1 | 13 | 14 | | 3 | 44 | 47 |
| $^{14}C$ | | 0.3 | 2600 | 2600 | | 0.3 | 2600 | 2600 | | 0.3 | 2600 | 2600 |
| $^{54}Mn$ | | 0.07 | | 0.07 | | 0.004 | | 0.004 | | 0.04 | | 0.04 |
| $^{55}Fe$ | | | 10 | 10 | | | 2 | 2 | | | 9 | 9 |
| $^{85}Kr$ | 0.005 | | | 0.005 | 0.005 | | | 0.005 | 0.005 | | | 0.005 |
| $^{89}Sr$ | | 3 | 2 | 5 | | 0.7 | 0.4 | 1 | | 2 | 1 | 3 |
| $^{90}Sr$ | | 14 | 170 | 180 | | 4 | 48 | 52 | | 9 | 110 | 120 |
| $^{95}Zr$ | 290 | | | 290 | 40 | | | 40 | 200 | | | 200 |
| $^{103}Ru$ | 25 | | | 25 | 4 | | | 4 | 17 | | | 17 |
| $^{106}Ru$ | 87 | 49 | | 140 | 24 | 11 | | 35 | 53 | 30 | | 83 |
| $^{131}I$ | | | 48 | 48 | | | 7 | 7 | | | 33 | 33 |
| $^{136}Cs$ | | | 0.1 | 0.1 | | | 0.03 | 0.03 | | | 0.06 | 0.06 |
| $^{137}Cs$ | 600 | 0.6 | 280 | 880 | 170 | 0.2 | 78 | 250 | 370 | 0.4 | 170 | 540 |
| $^{140}Ba$ | 37 | 0.3 | 0.3 | 38 | 5 | 0.04 | 0.07 | 5 | 25 | 0.2 | 0.2 | 25 |
| $^{141}Ce$ | 2 | | | 2 | 0.3 | | | 0.3 | 1 | | | 1 |
| $^{144}Ce$ | 28 | 60 | | 88 | 8 | 17 | | 25 | 17 | 37 | | 54 |
| $^{238}Pu$ | | 2 | 0.008 | 2 | | 0.4 | 0.002 | 0.4 | | 1 | 0.005 | 1 |
| $^{239}Pu$ | | 40 | 3 | 43 | | 11 | 0.7 | 12 | | 25 | 2 | 27 |
| $^{240}Pu$ | | 26 | 2 | 28 | | 7 | 0.5 | 8 | | 16 | 1 | 17 |
| $^{241}Pu$ | | 14 | 0.07 | 14 | | 4 | 0.02 | 4 | | 9 | 0.04 | 9 |
| $^{241}Am$ | | 3 | 3 | 6 | | 0.7 | 0.7 | 1 | | 2 | 2 | 4 |
| Total (rounded) | 1100 | 220 | 3200 | 4500 | 250 | 60 | 2750 | 3100 | 680 | 130 | 3000 | 3800 |

Table 32

Contributions to total effective dose equivalent commitment to the world population from nuclear tests

| Radionuclide | Effective dose equivalent commitment (μSv) | Contribution to total (%) |
|---|---|---|
| $^{14}C$ a/ | 2600 | 69 |
| $^{137}Cs$ | 540 | 14 |
| $^{95}Zr$ | 200 | 5.3 |
| $^{90}Sr$ | 120 | 3.2 |
| $^{106}Ru$ | 83 | 2.2 |
| $^{144}Ce$ | 54 | 1.4 |
| $^{3}H$ | 47 | 1.2 |
| $^{131}I$ | 33 | 0.9 |
| $^{239}Pu$ | 27 | 0.7 |
| $^{140}Ba$ | 25 | 0.7 |
| $^{103}Ru$ | 17 | 0.4 |
| $^{240}Pu$ | 17 | 0.4 |
| $^{241}Pu$ | 9 | 0.2 |
| $^{55}Fe$ | 9 | 0.2 |
| $^{241}Am$ | 4 | 0.1 |
| $^{89}Sr$ | 3 | 0.08 |
| $^{141}Ce$ | 1 | 0.03 |
| $^{238}Pu$ | 1 | 0.03 |
| $^{136}Cs$ | 0.06 | 0.002 |
| $^{54}Mn$ | 0.04 | 0.001 |
| $^{85}Kr$ | 0.005 | 0.0001 |
| Total (rounded) | 3800 | 100 |

a/ The dose commitment from $^{14}C$ will be delivered over thousands of years. That part delivered up to the year 2000 is 7.7 % of the value listed (see paragraph 26).

Table 33

Summary of global collective effective dose equivalent commitments from atmospheric tests carried out to the end of 1980 a/

($10^4$ man Sv)

| Radionuclide | External irradiation | Inhalation | Ingestion | Total |
|---|---|---|---|---|
| $^{14}C$ | | 0.3 b/ | 2600 b/ | 2600 |
| $^{137}Cs$ | 150 c/ | 0.1 | 69 c/ | 220 |
| $^{95}Zr$ | 64 | | | 64 |
| $^{90}Sr$ | | 3 | 44 c/ | 47 |
| $^{106}Ru$ | 17 | 10 | | 27 |
| $^{3}H$ | | 1 c/ | 18 c/ | 19 |
| $^{144}Ce$ | 5 | 12 | | 17 |
| $^{131}I$ | | | 11 | 11 |
| $^{239}Pu$ | | 8 | 2 b/ | 10 |
| $^{140}Ba$ | 8 | 0.07 | 0.05 | 8 |
| $^{103}Ru$ | 5 | | | 5 |
| $^{240}Pu$ | | 5 | 1 b/ | 6 |
| $^{241}Pu$ | | 3 | 0.02 c/ | 3 |
| $^{55}Fe$ | | | 3 | 3 |
| $^{241}Am$ | | 0.5 | 2 b/ | 2 |
| $^{89}Sr$ | | 0.6 | 0.3 | 0.9 |
| $^{141}Ce$ | 0.4 | | | 0.4 |
| $^{238}Pu$ | | 0.3 | 0.003 d/ | 0.3 |
| $^{136}Cs$ | | | 0.02 | 0.02 |
| $^{54}Mn$ | | 0.01 | | 0.01 |
| $^{85}Kr$ | 0.002 c/ | | | 0.002 |
| Total (rounded) | 250 | 44 | 2750 | 3000 |

a/ World population size assumed to be 3.2 $10^9$ persons unless otherwise specified by a footnote.

b/ Population size 1 $10^{10}$ persons.

c/ Population size 4 $10^9$ persons.

d/ Population size 6 $10^9$ persons.

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