<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Northern hemisphere</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japan b, c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Chiba</td>
<td>0.42</td>
<td>2.75</td>
<td>0.37</td>
<td>0.9</td>
<td>1.2</td>
<td>5</td>
<td>32</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Miyagi</td>
<td>0.60</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>United Kingdom b, c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>United States</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sebastian City c</td>
<td>9.3</td>
<td></td>
<td>107</td>
<td></td>
<td>43</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Houston c</td>
<td>3.7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nashville b, c</td>
<td>0.90</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>Southern hemisphere</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bariloche</td>
<td>7.6</td>
<td>1.4</td>
<td>4.6</td>
<td>4.17</td>
<td>4.0</td>
<td>1.7</td>
<td>8.5</td>
<td>310</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Buenos Aires</td>
<td>27</td>
<td>4.3</td>
<td>2.5</td>
<td>4.6</td>
<td>5.0</td>
<td>1.7</td>
<td>8.5</td>
<td>110</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Salta</td>
<td>15</td>
<td>1.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia c</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Malanda (highest) d</td>
<td>11</td>
<td>10.4</td>
<td>4.5</td>
<td>5.8</td>
<td>5.4</td>
<td>0.17</td>
<td>0.05</td>
<td>2.47</td>
<td>127</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hobart-Lauweston c</td>
<td>1.5</td>
<td>0.38</td>
<td>0.79</td>
<td>0.86</td>
<td>0.35</td>
<td>0.04</td>
<td>0.04</td>
<td>0.34</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Country average</td>
<td>0.02</td>
<td>0.07</td>
<td>0.78</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bolivia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>La Paz</td>
<td>11</td>
<td>2.4</td>
<td>5</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brazil</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Guanabara v</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Santiago</td>
<td>4.0</td>
<td></td>
<td>3.0</td>
<td>1.9</td>
<td>0.3</td>
<td>2.1</td>
<td>50</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Colombia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bogota</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.9</td>
<td>0.7</td>
<td>1.5</td>
<td>0.1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Ecuador</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Quito</td>
<td>2.5</td>
<td>0.3</td>
<td></td>
<td></td>
<td></td>
<td>1.3</td>
<td>30</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Fiji</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Suva c</td>
<td>18 f</td>
<td>2.9</td>
<td>4.4</td>
<td>3.7</td>
<td>2.9</td>
<td>0.4</td>
<td>0.4</td>
<td>2.4</td>
<td>210</td>
</tr>
<tr>
<td>Madagascar</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Diego-Suarez</td>
<td>13</td>
<td>1.8</td>
<td>6.5</td>
<td>4.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Caledonia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Noumea</td>
<td>0.4</td>
<td>3.5</td>
<td>2.6</td>
<td>16</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>New Zealand c</td>
<td>1.5</td>
<td>0.4</td>
<td>0.7</td>
<td>0.7</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>0.4</td>
<td>17</td>
</tr>
</tbody>
</table>

TABLE 16. CONCENTRATION OF $^{131}I$ IN MILK AND THYROID DOSI TO INFANTS AT VARIOUS LOCATIONS, 1966-1974
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Peru</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arica</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lima</td>
<td>6</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tacna</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samoa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Apia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Society Islands</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tahiti</td>
<td>4.7</td>
<td>4.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>South Africa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cape Town</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pretoria</td>
<td>8.0</td>
<td>11.1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Southern hemisphere (continued)

* There are 1976 data: France (0.91, 10); Japan: Fukushima (0.95, 11), Chiba (0.36, 4), Fukoku (0.33, 4). The first figure in the parentheses is the integrated milk concentration and the second is the thyroid dose, in the same units as in the table.

* The integrated concentration has been taken to be numerically equal to 10 times the highest observed concentration in nCi l⁻¹.

* The dose is assumed to be the time-integrated concentration multiplied by 11.5 mrad pCi⁻¹ d⁻¹ l⁻¹.

* In 1973, the highest integrated milk concentration was measured at Perth (0.27 nCi d⁻¹ l⁻¹).

* Lowest.

* Value based on an extrapolation.
94. As $^{131}$I concentrates in bovine thyroid, this organ is a suitable biological indicator of the presence of $^{131}$I in the local environment. Beninson (19) measured the concentration of $^{131}$I in bovine milk and thyroid in Argentina during the period 1966-1970. The ratio between the time-integral of the $^{131}$I concentration in thyroid and that in milk was fairly constant for the different years and had a value of about 500. Monitoring of $^{131}$I in bovine thyroid carried out in Czechoslovakia (66) confirms the very high sensitivity of this method of surveillance for $^{131}$I in the environment.

95. Infants receive higher doses in their thyroids than do adults for a given intake of $^{131}$I, the main reason being the smaller thyroid mass. A mass of 2 g was used for estimating doses to infant thyroids. Estimates of the dose in infant thyroids per unit activity of $^{131}$I reaching the organ range from 15.5 to 18.5 mrad nCi$^{-1}$ (179, 189), and a value of 16.5 was used in the 1972 report of the Committee. Assuming that infants consume 0.7 l of fresh milk per day and that all the $^{131}$I ingested is taken up by the thyroid, the $P_{m}=0$ transfer factor (relating thyroid dose in infants to the time-integrated iodine-131 concentration in milk) can be estimated to be about 11.5 mrad per nCi d l$^{-1}$.

96. Table 16 presents estimates of the dose in infant thyroids, as calculated with the assumptions mentioned above. They should be regarded as the highest individual doses in the areas for which the assumed consumption is realistic, and as clear overestimates in areas such as the Society Islands where fresh cow's milk is only a small fraction of the total milk consumed by infants. The dose to adults should be at least an order of magnitude lower, because the mass of their thyroids is about ten times larger, and their milk consumption is smaller.

J. CAESIUM-137

97. Caesium-137 is a beta emitter with a maximum beta energy of 1.17 MeV, which decays with the emission of gamma rays of 0.63 MeV. It has a half-life of 30 y, very close to that of $^{90}$Sr, and since the 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 (245), it is useful to use the more complete data on $^{90}$Sr to estimate the deposition of $^{137}$Cs. In this way also the latitudinal distribution of $^{137}$Cs integrated deposition density can be estimated from the $^{90}$Sr data of table 3.

1. Caesium-137 in the environment

98. Since the half-life of $^{137}$Cs is relatively long, the assessment of dose commitments requires the understanding of the behaviour of this radionuclide in the environment. A recent review of the literature on this subject has been published by Moiseev et al. (262). The deposition of $^{137}$ Cs occurs over land and over the oceans. As in the case of $^{90}$Sr, it has been found that fallout over land is the more important pathway as far as dose commitments to man are concerned.

99. After deposition over land, caesium-137 enters the dietary pathway, being taken up by plants either through the root system or by direct uptake by the leaves. Caesium-137 seems to become more strongly fixed in the soil than $^{90}$Sr does (14, 114, 159, 267), but its availability to plants depends markedly on the soil type and has been found to decrease in time (256). In a sandy soil in Massachusetts (United States), Hardy (114) found that 84 per cent of the fallout $^{137}$Cs was in the top 4 cm of soil, and 97 per cent was in the top 31 cm. Marei et al. (159) have identified regions in the USSR where the soil is wet, peaty and podzolic, from which the transfer of $^{137}$Cs into the food chain is 10 times higher than for other regions. Other regions of the world where there are soils giving rise to high $^{137}$Cs transfer into diet have also been identified, for example, in the Faroe Islands (3), New Zealand (188) and Sweden (151). The mechanism of such enhanced transfer has also been studied (94). Much smaller amounts of $^{137}$Cs than of $^{90}$Sr are leached out of the soil to enter rivers and lakes.

100. Regarding deposition of $^{137}$Cs on the oceans, measurements made on sediments of the Atlantic Ocean indicate that only about 3 per cent of the fallout $^{137}$Cs has reached the bottom (193). Activity concentrations in surface waters of the open ocean are about 0.2 pCi l$^{-1}$ (46), and in the deep ocean they are lower by a factor of about 30. Hodge et al. (127), from measurements of $^{137}$Cs concentrations in Pacific tuna, estimated the half residence-time of $^{137}$Cs in surface waters to be about 17 y.

101. Marine food chains seem to be of secondary importance in relation to human intakes. The reported concentration factors between sea water and mose biota are about 50 (93, 191, 214, 240). It has been estimated that in Japan, between 1966 and 1971, only about 8 per cent of the dietary intake of $^{137}$Cs came from the consumption of fish products (240).

2. Levels in diet

102. Since $^{137}$Cs is an alkali metal like potassium, and since the concentration of potassium in lean body mass is constant (225), it is convenient to express the $^{137}$Cs activity in food and in the human body as the $^{137}$Cs/K quotient, usually in picocuries per gram. Data on the $^{137}$Cs concentration in milk and on its daily intake from the total diet are shown in tables 4 and 6. Data available for 1973 and 1974 indicate that, generally speaking, levels are still falling. The transfer of $^{137}$Cs from deposition to diet is normally high during the first year after deposition and relatively small subsequently. Concentrations in milk are strongly dependent on deposition in the same year. That explains why in the northern hemisphere the milk concentrations on the average decreased from 1966 to 1969, were relatively stable from 1969 to 1971, and decreased again from 1971 to 1973.

103. The transfer of $^{137}$Cs from deposition to diet can be studied quantitatively using an approach similar to that for $^{90}$Sr (paras. 55-69). The measured $^{137}$Cs/K quotients in the various components of the Danish diet are plotted against time in figure X (2). Evans and
Figure X. Variation of $^{137}$Cs in various diet components in Denmark, 1955-1974. The unit for parameters $b_1$, $b_2$, $b_3$ is pCi (gK)$^{-1}$ per mCi km$^{-2}$. The unit for parameter $\mu$ is s$^{-1}$. The unit for the transfer factor $F_{2,3}$ is pCi y (gK)$^{-1}$ per mCi km$^{-2}$. 
TABLE 17. PARAMETERS OF THE TRANSFER FUNCTION BETWEEN $^{137}$Cs
FALLOUT AND DIET

Obtained by regression analysis from Danish data

<table>
<thead>
<tr>
<th>Parameter$^a$</th>
<th>Milk products</th>
<th>Grain products</th>
<th>Meat, fish, eggs</th>
<th>Vegetables</th>
<th>Fruit</th>
<th>Total composite diet</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_1$</td>
<td>2.17</td>
<td>2.36</td>
<td>4.45</td>
<td>0.63</td>
<td>0.81</td>
<td>1.56</td>
</tr>
<tr>
<td>$b_2$</td>
<td>1.48</td>
<td>17.02</td>
<td>0.0</td>
<td>0.0</td>
<td>0.55</td>
<td>2.21</td>
</tr>
<tr>
<td>$b_3$</td>
<td>0.05</td>
<td>0.02</td>
<td>17.24</td>
<td>0.006</td>
<td>0.08</td>
<td>0.04</td>
</tr>
<tr>
<td>$\mu$</td>
<td>0.07</td>
<td>0.0</td>
<td>1.60</td>
<td>0.02</td>
<td>0.30</td>
<td>0.12</td>
</tr>
<tr>
<td>$P_{23}^m$</td>
<td>4.32</td>
<td>19.38</td>
<td>8.80</td>
<td>0.92</td>
<td>1.59</td>
<td>4.08</td>
</tr>
<tr>
<td>$W_{23}^m$</td>
<td>0.20</td>
<td>0.09</td>
<td>0.17</td>
<td>0.37</td>
<td>0.09</td>
<td>1.00</td>
</tr>
<tr>
<td>Total diet $P_{13}$</td>
<td>0.86</td>
<td>1.74</td>
<td>1.50</td>
<td>0.34</td>
<td>0.14</td>
<td>4.08</td>
</tr>
</tbody>
</table>

$^a$The unit for parameters $b_1$, $b_2$, $b_3$ is pCi (gK)$^{-1}$ per mCi km$^{-2}$. The unit for parameter $\mu$ is y$^{-1}$. The unit for the transfer factor $P_{23}^m$ is pCi y (gK)$^{-1}$ per mCi km$^{-2}$. $W_f$ is the fractional contribution of component $f$ to the total K diet.

Bennett (86) have carried out a regression analysis using these data and the annual deposition data, with a transfer function of the same form as that shown in paragraph 58 for $^{90}$Sr. The figure also shows the curves fitted to the data with the parameters given in table 17. In Denmark the main contribution to the intake of $^{137}$Cs has been from meat and grain products, with a sizeable contribution from milk. Fruit and vegetables contribute much smaller amounts. The same is true of Chicago (United States). In Japan, however, the main contribution has been from cereals (240). For all foods the transfer seems to be rapid, being essentially completed within the first two years after deposition.

104. The same transfer function was also fitted to the $^{137}$Cs/K quotients in fresh milk in several countries, and the resulting parameters are shown in table 18. The transfer factors $P_{23}^m$ linking deposition density and the time-integrated $^{137}$Cs/K quotient in milk for Argentina, Australia, Faroe Islands, New Zealand, Norway and USSR are significantly greater than those for Denmark and the United States. The value reported for Finland, 15.8 pCi y (gK)$^{-1}$ per mCi km$^{-2}$ (65), is also in this higher range. It should be noted that parameters relating to Denmark in table 18 are for fresh milk, while those in the first column table 17 refer to milk products.

105. The results of the regression analysis for the estimation of $P_{23}$, or its components such as $P_{23}^{milk}$, are consistent with the assessments carried out by the Committee for its 1969 and 1972 reports (244, 245). A value of 4.1 pCi y (gK)$^{-1}$ per mCi km$^{-2}$ was estimated in these reports for the factor $P_{23}$, identical with that shown in table 17, which was derived by regression analysis. The same value, rounded to 4 pCi (gK)$^{-1}$ per mCi km$^{-2}$, will be used in this report for the purpose of assessing dose commitments from $^{137}$Cs for the world population. This value of the transfer factor adequately represents some areas in the northern hemisphere, but on the available evidence discussed above, it would appear to underestimate $P_{23}$ for other areas, especially in the southern hemisphere.

106. The latitudinal distribution of $^{137}$Cs deposition density in 1972 (assessed from the $^{90}$Sr data assuming a constant $^{137}$Cs/$^{90}$Sr activity ratio) is shown as the curve in figure XI. Also shown in figure XI are the $^{137}$Cs concentrations in milk in 1972 at various localities. The $^{137}$Cs milk concentrations for a number of them depart markedly from a general correlation with the deposition data. Since data on $^{137}$Cs concentration in foods are not available for many areas of the world, particularly in the tropical regions, it is not possible to assess what the importance of this effect might be on the global scale.

TABLE 18. PARAMETERS OF THE TRANSFER FUNCTION FROM $^{137}$Cs FALLOUT TO MILK

Obtained by regression analysis of data for various countries and areas

<table>
<thead>
<tr>
<th>Parameter$^a$</th>
<th>Argentina</th>
<th>Australia</th>
<th>Denmark</th>
<th>Faroe Islands</th>
<th>New Zealand</th>
<th>Norway</th>
<th>USSR</th>
<th>United Kingdom</th>
<th>United States</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b_1$</td>
<td>2.21</td>
<td>7.24</td>
<td>2.37</td>
<td>6.80</td>
<td>6.79</td>
<td>3.52</td>
<td>4.43</td>
<td>1.75</td>
<td>2.28</td>
</tr>
<tr>
<td>$b_2$</td>
<td>0.00</td>
<td>4.78</td>
<td>0.69</td>
<td>5.44</td>
<td>0.68</td>
<td>2.26</td>
<td>0.22</td>
<td>1.61</td>
<td>1.34</td>
</tr>
<tr>
<td>$b_3$</td>
<td>1.80</td>
<td>0.30</td>
<td>0.06</td>
<td>2.83</td>
<td>3.62</td>
<td>2.63</td>
<td>0.31</td>
<td>0.03</td>
<td>0.00</td>
</tr>
<tr>
<td>$\mu$</td>
<td>0.27</td>
<td>0.18</td>
<td>0.30</td>
<td>0.17</td>
<td>0.51</td>
<td>0.24</td>
<td>0.18</td>
<td>0.023</td>
<td>0.05</td>
</tr>
<tr>
<td>$p_{milk}$</td>
<td>8.02</td>
<td>13.59</td>
<td>3.23</td>
<td>27.51</td>
<td>12.91</td>
<td>15.48</td>
<td>6.22</td>
<td>4.75</td>
<td>3.63</td>
</tr>
</tbody>
</table>

$^a$The unit for parameters $b_1$, $b_2$, $b_3$, is pCi (gK)$^{-1}$ per mCi km$^{-2}$. The unit for parameter $\mu$ is y$^{-1}$. The unit for the transfer factor $P_{23}^{milk}$ is pCi y (gK)$^{-1}$ per mCi km$^{-2}$.  

143
3. Caesium-137 in the human body

107. Caesium-137 ingested by man is distributed in the body, with about 80 per cent being deposited in muscle and 8 per cent in bone (225). About 10 per cent of the activity taken in is eliminated rapidly, with a biological half-life of about 1 d, while the remaining 90 per cent is excreted at a lower rate (225). The biological half-life of this main fraction varies between less than 50 d to more than 200 d in adults (43, 124, 245) and is shorter in children than in adults (124). Owing to this relatively short biological half-life, the activity of $^{137}\text{Cs}$ in the body tends to follow the fluctuations of the concentration of $^{137}\text{Cs}$ in the diet.

108. Table 19 summarizes the information on $^{137}\text{Cs}/\text{K}$ quotients in the human body in the period 1964-1974. For all localities, the values have continued to decrease since the 1972 report of the Committee. The $^{137}\text{Cs}/\text{K}$ quotients in subarctic populations are between two and three orders of magnitude higher than those in the middle latitudes, as shown by data from Finland, Norway and Sweden and from the northern USSR and United States (Alaska) (123, 200, 210, 238, 250). These high values are due to the lichen-reindeer (or caribou) food chain (245).

109. The short biological half-life of caesium in the body makes it possible to assess the transfer factor between diet and body $P_{34}$ from the $^{137}\text{Cs}/\text{K}$ quotients integrated over a few years. Using this procedure, an average value of 3 is derived from the data of tables 6 and 19 converted into $^{137}\text{Cs}/\text{K}$ quotients, which is practically identical to the value used in the 1969 and 1972 reports, namely 2.9.
**TABLE 19. CAESIUM-137/POTASSIUM QUOTIENT IN THE HUMAN BODY**

\( (\text{pCg (gK)\(^{-1}\))} \)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Northern hemisphere</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td></td>
<td>M, F</td>
<td>50</td>
<td>158</td>
<td>135</td>
<td>87</td>
<td>50</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>244</td>
</tr>
<tr>
<td>Canada (Ottawa)</td>
<td></td>
<td>M, F</td>
<td>45</td>
<td>170</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>175</td>
</tr>
<tr>
<td>Denmark</td>
<td></td>
<td>M, F</td>
<td>55-60</td>
<td>185</td>
<td>168</td>
<td>106</td>
<td>65</td>
<td>46</td>
<td>40</td>
<td>23</td>
<td>13</td>
<td>16</td>
<td>11</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>Egypt</td>
<td></td>
<td>M, F</td>
<td>30</td>
<td></td>
<td>23</td>
<td>14</td>
<td>12</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td></td>
<td>M, F</td>
<td>60</td>
<td>182</td>
<td>150</td>
<td>107</td>
<td>72</td>
<td>53</td>
<td>44</td>
<td>34</td>
<td>38</td>
<td>37</td>
<td>28</td>
<td>29</td>
<td>231, 232</td>
</tr>
<tr>
<td>France</td>
<td></td>
<td>M, F</td>
<td>50</td>
<td>227</td>
<td>194</td>
<td>93</td>
<td>64</td>
<td>36</td>
<td>32</td>
<td>26</td>
<td>28</td>
<td>28</td>
<td>21</td>
<td>18</td>
<td>17</td>
</tr>
<tr>
<td>Germany, Fed. Rep. of</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Karlsruhe</td>
<td></td>
<td>M, F</td>
<td>49</td>
<td>151</td>
<td>111</td>
<td>81</td>
<td>49</td>
<td>27</td>
<td>16</td>
<td>15</td>
<td>15</td>
<td>17</td>
<td>11</td>
<td>9</td>
<td>12</td>
</tr>
<tr>
<td>Düsseldorf</td>
<td></td>
<td>M</td>
<td>51</td>
<td>243</td>
<td>186</td>
<td>128</td>
<td>76</td>
<td>41</td>
<td>32</td>
<td>31</td>
<td>22</td>
<td>30</td>
<td>23</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>Israel</td>
<td></td>
<td>M</td>
<td>35</td>
<td>93</td>
<td>77</td>
<td>54</td>
<td>33</td>
<td>20</td>
<td>14</td>
<td>13</td>
<td>16</td>
<td>12</td>
<td>10</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Japan</td>
<td></td>
<td>M, F</td>
<td>30-45</td>
<td>77</td>
<td></td>
<td>54</td>
<td>33</td>
<td>20</td>
<td>14</td>
<td>13</td>
<td>16</td>
<td>12</td>
<td>10</td>
<td>9</td>
<td>8</td>
</tr>
<tr>
<td>Norway</td>
<td></td>
<td>M, F</td>
<td>60</td>
<td>143</td>
<td>186</td>
<td>128</td>
<td>76</td>
<td>41</td>
<td>32</td>
<td>31</td>
<td>22</td>
<td>30</td>
<td>23</td>
<td>19</td>
<td>15</td>
</tr>
<tr>
<td>Poland</td>
<td></td>
<td>M, F</td>
<td>50-55</td>
<td>164</td>
<td>185</td>
<td>71</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweden (Stockholm)</td>
<td></td>
<td>M, F</td>
<td>60</td>
<td>205</td>
<td>187</td>
<td>139</td>
<td>107</td>
<td>74</td>
<td>54</td>
<td>47</td>
<td>46</td>
<td>38</td>
<td>31</td>
<td>22</td>
<td>233</td>
</tr>
<tr>
<td>Switzerland (Geneva)</td>
<td></td>
<td>M</td>
<td>45</td>
<td>206</td>
<td>179</td>
<td>103</td>
<td>54</td>
<td>30</td>
<td>24</td>
<td>21</td>
<td>23</td>
<td>19</td>
<td></td>
<td></td>
<td>129</td>
</tr>
<tr>
<td>USSR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moscow</td>
<td></td>
<td>M</td>
<td>55</td>
<td>258</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leningrad</td>
<td></td>
<td>M, F</td>
<td>60</td>
<td>174</td>
<td>142</td>
<td>92</td>
<td>68</td>
<td>70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>London area</td>
<td></td>
<td>M</td>
<td>50</td>
<td>148</td>
<td>89</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West Cumberland</td>
<td></td>
<td>F</td>
<td>149</td>
<td>60</td>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>United States</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Country average</td>
<td></td>
<td>M, F</td>
<td>25-30</td>
<td>141</td>
<td>109</td>
<td>60</td>
<td>35</td>
<td>17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Florida</td>
<td></td>
<td>M, F</td>
<td>25-30</td>
<td>143</td>
<td>132</td>
<td>120</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>West Berlin</td>
<td></td>
<td>M, F</td>
<td>52</td>
<td>68</td>
<td>49</td>
<td>47</td>
<td>36</td>
<td>29</td>
<td>25</td>
<td>19</td>
<td>10</td>
<td>11</td>
<td>5</td>
<td></td>
<td>52</td>
</tr>
<tr>
<td><strong>Subarctic region</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eastern (Eskimos)</td>
<td></td>
<td>M</td>
<td>60-70</td>
<td>5800</td>
<td>11000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central (Eskimos)</td>
<td></td>
<td>M</td>
<td>60-70</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Finland</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inari (reindeer herders)</td>
<td></td>
<td>M</td>
<td>70</td>
<td>7800</td>
<td>9000</td>
<td>7800</td>
<td>5500</td>
<td>5200</td>
<td>3400</td>
<td>3100</td>
<td>4100</td>
<td>3100</td>
<td>11000</td>
<td></td>
<td>123</td>
</tr>
<tr>
<td>USSR</td>
<td></td>
<td>M</td>
<td>65-70</td>
<td>10000</td>
<td>25500</td>
<td>17500</td>
<td>16500</td>
<td>15500</td>
<td>12500</td>
<td>11500</td>
<td>9000</td>
<td></td>
<td></td>
<td></td>
<td>238</td>
</tr>
<tr>
<td><strong>Southern hemisphere</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Argentina</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Reference**

110. An alternative approach for the derivation of $P_{34}$ is the assessment by regression analysis of the parameters of a postulated transfer function relating diet to body. Applying this procedure to the data from Denmark and the United States, and assuming a single exponential transfer function, the estimated values of $P_{34}$ are 2.6 for Denmark and 3.0 for the United States (86), in good agreement with the value of 3 mentioned in paragraph 109.

4. Dose commitment from caesium-137

111. The combined transfer factor $P_{234}$, linking deposition to the $^{137}$Cs/K quotient in the body, is the product of $P_{23}$ and $P_{34}$. From the estimated average values for these two factors (para. 105 and 109), a value of 12 pCi y (gK)$^{-1}$ per mCi km$^{-2}$ is calculated for the combined factor $P_{234}$.

112. An alternative procedure for the assessment of $P_{234}$ is the direct use of the time-integrated $^{137}$Cs/K quotient in the body $Q_{int}$ and the integrated deposition density $F$, both over the same period of several years, the factor being $P_{234} = (Q_{int}/F)$. This procedure, applied to data from Argentina in the period 1966-1974 (16, 21), estimates the factor $P_{234}$ to be 11 pCi y (gK)$^{-1}$ per mCi km$^{-2}$. For Stockholm the time-integrated $^{137}$Cs/K quotient in the body in the period 1962-1972, is 1053 pCi y (gK)$^{-1}$ (244, 245), while for the same period the integrated deposition density of $^{137}$Cs in the region (at Tumba, near Stockholm) is 58 mCi km$^{-2}$. This gives a value of $P_{234}$ of 18 pCi y (gK)$^{-1}$ per mCi km$^{-2}$, about 50 per cent higher than the average estimate given above. Aarkrog estimated $P_{234}$ in Denmark by regression analysis from the body $^{137}$Cs/K quotients and the annual deposition densities, obtaining a value of about 11 pCi y (gK)$^{-1}$ per mCi km$^{-2}$ (2).

113. The transfer factor $P_{234}$ could vary mainly as a result of variations of $P_{23}$ with the local conditions, particularly soil characteristics (para. 99) and the nature of the diet. In the 1972 report (245), the Committee assessed the possible range of $P_{23}$ values, based on USSR data and the conservative assumption that available $^{137}$Cs decreased only by radioactive decay. This range, multiplied by the value of $P_{34}$ given in paragraph 109, implies that $P_{234}$ would be smaller than 22 pCi y (gK)$^{-1}$ per mCi km$^{-2}$. The use of a value of 12 pCi (gK)$^{-1}$ per mCi km$^{-2}$ for $P_{234}$ (para. 112), for the purpose of assessing dose commitments, could therefore not underestimate these commitments by a factor of more than two.

114. As was shown in the 1969 report of the Committee (244), the transfer factor $P_{44}$, 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 $P_{44} = 1.8 \times 10^{-2}$ mrad per pCi y (gK)$^{-1}$, combined with the estimate of $P_{234} = 12$ pCi y (gK)$^{-1}$ per mCi km$^{-2}$, gives a value for the overall transfer factor $P_{234}$ of about 0.2 mrad per mCi km$^{-2}$.

115. The integrated deposition density of $^{137}$Cs can be assessed from that of $^{89}$Sr (para. 47 and 81), using an activity ratio of 1.6 (para. 97). The values are (mCi km$^{-2}$): temperate latitudes of the northern hemisphere, 136; temperate latitudes of the southern hemisphere, 39; global value weighted by the population distribution, 84. The resulting dose commitments are respectively 27 and 8 mrad for the populations in the temperate latitudes of the northern and southern hemisphere and 17 mrad for the world population.

116. It is to be noted that the above dose commitments are based upon information obtained in areas where $^{137}$Cs in the soil becomes unavailable to plants fairly rapidly. For populations consuming food from other types of soil, the dose commitments could be higher (para. 113), and for people in the subarctic regions eating reindeer and caribou meat, the dose commitments are indeed much larger. Assuming, however, that the contribution of such different situations to the total collective dose is not large, it can be estimated that the collective dose commitment from internal exposure, per unit activity of $^{137}$Cs released, is of the order of 3 man rad Cl$^{-1}$ for the past pattern of nuclear explosions.

K. CAESIUM-136

117. Caesium-136 is a beta emitter with a half-life of 13.5 d. The maximum beta energy is 0.66 MeV, and several gamma rays with energies up to 1.25 MeV are emitted. Since it must be produced directly by fission and not by beta decay, because $^{136}$Xe is stable, the activity produced in nuclear tests is fairly small. By using the $^{136}$Cs/$^{140}$Ba fission yield ratio and the deposition-to-milk transfer factors of $^{137}$Cs and $^{140}$Ba, O'Brien (195) has estimated the integrated deposition density of $^{136}$Cs and the time-integrated concentration in milk in the United States between 1961 and 1965. These calculated values agree roughly with the few measurements which have been made of $^{136}$Cs (177). The time-integrated concentration in milk in the United States between 1961 and 1965 was estimated to be 4.2 pCi y l$^{-1}$. Using data on transfer factors for $^{137}$Cs and $^{140}$Ba as a guide, O'Brien estimated $P_{345}$ (milk-to-dose) for $^{136}$Cs to be $1.3 \times 10^{-3}$ mrad per pCi y l$^{-1}$. The estimated dose commitment for the population of the temperate regions of the northern hemisphere from all tests to 1970 is 0.01 mrad.

L. BARIUM-140

118. Barium-140 is a beta emitter with a half-life of 12.8 d and a maximum beta energy of 1.02 MeV. It emits several gamma rays. Its daughter product, the 40.2-h half-life $^{140}$La, decays with a 2.18-MeV maximum-energy beta emission and several gamma rays, with energies up to 1.6 MeV. Barium-140 is measurable in fallout only for a few weeks after a nuclear explosion. This radionuclide was measured in the pasteurized milk supply networks of the United States by the Public Health Service between 1961 and 1966 (204). The time-integrated concentration in milk was 0.26 pCi y l$^{-1}$ for this period. O'Brien (195) estimated the factor $P_{34}$ for $^{140}$Ba to be around 3.0 mrad per pCi y (gBa)$^{-1}$ in bone. In addition, using the $P_{34}$ value for $^{90}$Sr together with the ICRP model for alkaline-earth metabolism (160), the factor $P_{34}$ for $^{140}$Ba was estimated to be
5.5 \times 10^{-5}. With these values, in the United States the mean dose to bone marrow for the period 1961-1965 is estimated to be 2.6 \times 10^{-3} mrad. The dose commitment in the temperate zone of the northern hemisphere is estimated to be 6 \times 10^{-3} mrad, assuming an average consumption of 0.6 l of milk per day.

M. CERIUM-144

119. Cerium-144 has been widely measured in air and in fallout (61, 249). It has a half-life of 285 d and together with its daughter decay product, the 1.7-min \textsuperscript{144}Pr, emits beta particles of 2.99-MeV maximum energy and several gamma rays. Table 20 shows for a number of sites in each hemisphere, the ratio of the integrated deposition density of \textsuperscript{144}Ce to that of \textsuperscript{90}Sr, together with similar ratios of the time-integrated activity concentrations in air (obtained by the sum of the average monthly activity concentrations over the specified period of time). These ratios are indicated in the table as $\Sigma^{144}\text{Ce}/\Sigma^{90}\text{Sr}$. Using a value of 15 as representative for the ratio for all tests up to 1974, the mean integrated deposition density of \textsuperscript{144}Ce is estimated to be (mCi km\(^{-2}\))

TABLE 20. RATIO OF THE INTEGRATED DEPOSITION DENSITIES OR OF THE TIME-
INTEGRATED AIR CONCENTRATIONS OF \textsuperscript{144}Ce and \textsuperscript{90}Sr AT VARIOUS LOCATIONS

<table>
<thead>
<tr>
<th>Location</th>
<th>Period</th>
<th>Type of ratio</th>
<th>$\Sigma^{144}\text{Ce}/\Sigma^{90}\text{Sr}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buenos Aires, Argentina</td>
<td>1966-1974</td>
<td>Deposition density</td>
<td>18.9</td>
</tr>
<tr>
<td>Moosonee, Canada</td>
<td>1963-1974</td>
<td>Air concentration</td>
<td>13.5</td>
</tr>
<tr>
<td>Antofagasta, Chile</td>
<td>1963-1974</td>
<td>Air concentration</td>
<td>12.8</td>
</tr>
<tr>
<td>Santiago, Chile</td>
<td>1963-1974</td>
<td>Air concentration</td>
<td>15.0</td>
</tr>
<tr>
<td>Puerto Mont, Chile</td>
<td>1963-1974</td>
<td>Air concentration</td>
<td>12.3</td>
</tr>
<tr>
<td>Lower Hutt, New Zealand</td>
<td>1968-1972</td>
<td>Deposition density</td>
<td>16.0</td>
</tr>
<tr>
<td>Chilton, United Kingdom</td>
<td>1961-1965</td>
<td>Deposition density</td>
<td>20.2</td>
</tr>
<tr>
<td>Chilton, United Kingdom</td>
<td>1967-1970</td>
<td>Deposition density</td>
<td>14.7</td>
</tr>
<tr>
<td>Sterling, United States</td>
<td>1963-1974</td>
<td>Air concentration</td>
<td>13.5</td>
</tr>
<tr>
<td>Miami, United States</td>
<td>1963-1974</td>
<td>Air concentration</td>
<td>14.2</td>
</tr>
</tbody>
</table>

120. The inhalation of \textsuperscript{144}Ce gives rise to lung irradiation. At Moosonee (Canada) and Sterling and Miami (United States), the time-integrated concentrations of \textsuperscript{144}Ce in air from 1963 to 1974 were 1.33, 1.78 and 1.66 pCi y m\(^{-3}\), respectively, giving a mean of 1.6 pCi y m\(^{-3}\) (117). The time-integrated activity concentrations in air at Antofagasta and Santiago (Chile) for the same period were 0.36 and 0.39 pCi y m\(^{-3}\), respectively, giving a mean of 0.38 pCi y m\(^{-3}\). Assuming that these two means are representative of the northern and southern hemisphere, and using the \textsuperscript{90}Sr integrated deposition data of table 2 to extrapolate the integrated air concentrations to cover the period 1954-1974, the resulting estimates for that period are respectively 3.0 and 0.7 pCi y m\(^{-3}\) for the northern and southern hemispheres.

121. Using the ICRP lung model (135, 136) with parameters of class Y, and assuming a mean particle size of 0.5 \mu m, which results in a 20-per-cent deposition in the pulmonary region of the lung, the transfer factor $P_{15}$ (time-integrated air concentration-to-dose) is estimated to be 22 mrad per pCi y m\(^{-3}\).

122. Applying this value of $P_{15}$ to the time-integrated air concentrations given in paragraph 120 results in dose commitments to the lung of 65 and 15 mrad for the populations of the northern and southern temperate regions, respectively. The lung dose commitment to the world population is estimated to be about 38 mrad. Assuming a $^{144}\text{Ce}/^{90}\text{Sr}$ activity ratio of 48 at the time of fission, it can be estimated that the collective dose commitment to the lung per unit activity released is of the order of 0.3 man rad Cl\(^{-1}\), for the past pattern of nuclear testing.

N. PLUTONIUM

1. Plutonium in the environment

123. Several isotopes of plutonium have been released into the environment by nuclear tests carried out in the atmosphere between 1945 and 1976. The most important, with half-lives shown in parentheses, are $^{239}\text{Pu}$ (24,000 y), $^{240}\text{Pu}$ (6600 y), $^{238}\text{Pu}$ (87 y) and $^{241}\text{Pu}$ (14 y). The last radionuclide is mainly a beta emitter and decays to the alpha emitter $^{241}\text{Am}$ (430 y). Since $^{239}\text{Pu}$ and $^{240}\text{Pu}$ are not usually distinguished in environmental activity measurements, reported $^{239}\text{Pu}$ activities should be assumed to apply to a mixture of $^{239}\text{Pu}$ and $^{240}\text{Pu}$ (116). Measurements have indicated that this mixture contains approximately 60 per cent of $^{239}\text{Pu}$ on an activity basis.

124. Plutonium released to the atmosphere during atmospheric tests is subsequently deposited on land and on the oceans as insoluble aerosol particles of the oxide. Profile measurements in sandy soil have shown that about 70 per cent is in the first 4-cm layer and virtually all in the top 30 cm (114). The profile depends on local climate and the physico-chemical properties of the soil. Other measurements (38) indicate that about 40 per cent of the plutonium is in the top 5 cm of soil.

125. The uptake of plutonium from soil by plants can be expressed as a concentration factor, usually defined as the ratio of the activity concentration in fresh plants to that in dry soil. Reported values for the plutonium concentration factor vary widely over the range 4 \times 10^{-8} to 3 \times 10^{-2}, but representative values are on the average
of the order of $10^{-4}$ (38). From measurements of the $^{239}$Pu intake and of the activity in the bone, muscle, and liver of cows that had grazed on a contaminated range of the Nevada test site, a gastro-intestinal uptake factor of 3.4 $10^{-5}$ was obtained (224). In similar study on the uptake of plutonium by reindeer that had fed on lichen, the uptake factor was found to be about 2.4 $10^{-5}$ (128).

126. In the ocean, plutonium has moved to greater depths than has $^{90}$Sr and $^{137}$Cs. Noshkin et al. (193) found that 2-36 per cent of oceanic plutonium in the Atlantic Ocean was in the sediments. In the water, they found that about 50 per cent of the activity was below the thermocline. In 1964 the activity concentration of plutonium in the Pacific Ocean was about $10^{-11}$ pCi l$^{-1}$ (202). Plutonium is taken up by marine biota, and the concentration factors for algae, plankton, crustacea are 1000-3000; for fish (muscle), 1-10 (192).

2. Levels in the environment

127. Most of the plutonium now dispersed around the world came from tests carried out prior to 1963: subsequent tests have contributed an additional 10 per cent to the global inventory (118). The deposition density rate and the integrated deposition density of $^{239,240}$Pu can be inferred from the corresponding values for $^{90}$Sr, as it has been observed that the Pu/$^{90}$Sr activity ratio in stratospheric- and surface-air samples has remained fairly constant in time with a value of about 0.017 (28, 116). A comparison of the cumulative deposit of Pu in soil with that of $^{90}$Sr can also be used to estimate the global deposition of plutonium. From such measurements the global deposition of $^{239,240}$Pu up to the end of 1973 is estimated to be 320 kCi, of which 250 kCi were in the northern hemisphere and 70 kCi in the southern hemisphere (116). This global deposition amounts to about 3 t of the $^{239}$Pu isotope. In 1975 the stratospheric inventory in the northern hemisphere was less than 1 kCi (149).

128. Nuclear tests have contributed 9 kCi of $^{238}$Pu to global fallout (116), while the re-entry of a satellite into the earth's atmosphere in 1964 contributed some 17 kCi, 70 per cent of which has deposited in the southern hemisphere, as discussed in the 1972 report of the Committee (245).

129. Although $^{239,240}$Pu concentrations in ground-level air have been measured on a wide scale only since 1965, previous $^{239,240}$Pu activity concentrations in

---

**TABLE 21. CONCENTRATION OF PLUTONIUM IN BODY TISSUES OF NON-OCCUPATIONALLY EXPOSED PERSONS IN THE UNITED STATES, 1972-1973**

(The number in parenthesis is the number of samples)

<table>
<thead>
<tr>
<th></th>
<th>Lung</th>
<th>Liver</th>
<th>Lymph node</th>
<th>Kidney</th>
<th>Vertebrae</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Alamos</td>
<td>0.36 (8)</td>
<td>0.72 (5)</td>
<td>16.0 (4)</td>
<td>0.09 (5)</td>
<td>0.72 (5)</td>
</tr>
<tr>
<td>Non-residents of Los Alamos</td>
<td>0.18 (17)</td>
<td>0.31 (10)</td>
<td>9.0 (15)</td>
<td>0.54 (10)</td>
<td>0.19 (16)</td>
</tr>
<tr>
<td>Colorado</td>
<td>0.31 (29)</td>
<td>0.81 (25)</td>
<td>6.8 (22)</td>
<td>1.4 (25)</td>
<td>0.30 (25)</td>
</tr>
<tr>
<td>Savannah River</td>
<td>0.18 (20)</td>
<td>0.54 (14)</td>
<td>18.0 (6)</td>
<td>1.0 (11)</td>
<td>0.31 (12)</td>
</tr>
<tr>
<td>Mean</td>
<td>0.27 (74)</td>
<td>0.68 (54)</td>
<td>11.0 (47)</td>
<td>0.68 (51)</td>
<td>0.31 (59)</td>
</tr>
<tr>
<td>Computed from fallout plutonium (1972)$^a$</td>
<td>0.19</td>
<td>0.52</td>
<td>32.0</td>
<td>0.07</td>
<td>0.19</td>
</tr>
</tbody>
</table>

---

*a Assuming organ weights for the lung, liver, lymph node and bone of 1.0, 1.7, 0.015 and 5.0 kg, respectively.*
Bennett based upon the New York data (28). The agreement is quite reasonable, considering the difficulties involved. It should be noted that, to get these results, Bennett used the ICRP lung model with class Y parameters (appropriate for insoluble aerosol particles), while the results with other classes of parameters were at variance with the measured values (28).

134. Inhalation of radioactivity resuspended from the soil surface by winds could add to the long-term intake due to airborne plutonium. Bennett (32), on the basis of natural $^{238}\text{U}$ concentrations in air and soil, considered that $10^{-9}$ m$^{-1}$ would be a realistic estimate for the resuspension factor, applicable to activity in the top 1 cm of soil. This is in agreement with that estimated from normal dust loading of the atmosphere (6). This estimate is also in agreement with values determined using an artificial tracer in a lightly vegetated area (221). Using such a factor, resuspension would only contribute 0.5 percent to the total integral activity of $^{239}\text{Pu}$-$^{240}\text{Pu}$ in air between 1954 and 2000 (29, 34). Since plutonium penetrates into the soil and thus becomes unavailable for resuspension, this effect is not expected therefore to contribute significantly to the dose commitment from plutonium.

135. By using estimates for the $^{239}\text{Pu}$ concentration in New York air between 1954 and 1972, assessed from $^{90}\text{Sr}$ deposition density data together with $^{90}\text{Sr}$ and $^{239}\text{Pu}$ concentration in air measured between 1965 and 1972, and utilizing the ICRP lung model (135, 136), Bennett has estimated the dose to man from inhalation of fallout $^{239}\text{Pu}$ through 2000 (28). The estimated $^{239}\text{Pu}$ annual intake and activity content in body tissues are shown in figure XII. The cumulative doses to 2000 are (mrad): lungs, 1.6; liver, 1.7; bone lining cells, 1.5. As the atmospheric inventory of $^{239}\text{Pu}$ decreases rapidly, the contribution from inhalation after 2000 is very small, and these cumulative doses are therefore good approximations of the dose commitments. The present estimate for the dose commitment to bone differs significantly from that given by the Committee in its 1972 report, which was based upon concentrations in surface air at Ispra, Italy, and on earlier values of parameters for the ICRP lung model (135, 136). It is also to be noted that the lung doses have been calculated on the basis of a uniform distribution of $^{239}\text{Pu}$ over the whole organ (28, 245). As plutonium particles are assumed to be insoluble, the actual distribution of doses in the lung is probably non-homogeneous, but the calculated value can be taken to represent the mean dose to the lung.

136. Assuming that the $^{239}\text{Pu}$ concentrations in New York air are representative of the whole 40°-50° latitude band, that the global distribution of $^{239}\text{Pu}$ deposition is the same as that for $^{90}\text{Sr}$, and that the latitudinal distribution of the population remains unchanged, the
population-weighted dose through 2000 to the bone lining cells would be 1.0 mrad in the northern hemisphere and 0.3 mrad in the southern hemisphere.

137. For the purpose of estimating dose commitments from the ingestion of the plutonium mixture, two extreme cases will be considered, assuming in the first that the amount of plutonium transferred to food depends on the deposition density rate and in the second, that it depends on the cumulative deposition density.

138. Under the first assumption, \( P_{23} \) is estimated from the quotient 1.6 mCi y\(^{-1} \times 0.017 \text{ mCi km}^{-2} \times y\(^{-1} \) to be 94 mCi per mCi km\(^{-2} \). The total individual intake from plutonium deposited from all tests up to 1974 would be 94 mCi per mCi km\(^{-2} \) \( \times 2.68 \text{ mCi km}^{-2} = 252 \text{ pCi} \). Under the second assumption, on the other hand, the lifetime intake is estimated to be 1.6 mCi y\(^{-1} \times 70 \text{ y} = 112 \text{ pCi} \).

139. Of the ingested plutonium it is assumed that a fraction 3 \( \times 10^{-5} \) is absorbed through the GI tract and that 45 per cent of this goes to the bone (136). For the two assumed cases of intake of 252 pCi and 112 pCi, the activity deposited in bone is \( 3.4 \times 10^{-3} \) and \( 1.5 \times 10^{-3} \) pCi, respectively.

140. The dose rate in bone per unit activity of plutonium is 0.098 mrad y\(^{-1} \) pCi\(^{-1} \) (28). Under the first assumed case, the activity in bone is \( 3.4 \times 10^{-3} \) pCi, and the average exposure period in the population is 35 y. The dose commitment is therefore assessed to be 1.2 \( \times 10^{-2} \) mrad.

141. Under the second assumed case the bone activity increases linearly with age with an average in the population of 1.5 \( \times 10^{-5} \) pCi \( \times 0.5 = 0.75 \times 10^{-5} \) pCi. The factor of 0.5 takes account of the fact that the \textit{per caput} bone activity is approximately 0.5 times that at death. The annual dose, averaged over all ages, is therefore 7.5 \( \times 10^{-5} \) mrad. If it is assumed that the \( ^{239}\text{Pu} \) in the soil becomes unavailable only by decay, the dose commitment is estimated to be 2.6 mrad.

142. Taking into account population distribution and using the procedures outlined in Annex A, the collective dose commitments to the lung and to bone lining cells, per unit activity released by past nuclear explosions, are of the order of 10 man rad GI\(^{-1} \).

III. EXTERNAL IRRADIATION

143. Many radionuclides present in fallout emit gamma rays and contribute to the dose from external irradiation. The most important from this point of view are a number of short-lived radionuclides, the most significant of which are \( ^{95}\text{Zr} \) and its daughter \( ^{95}\text{Nb} \), and the long-lived \( ^{137}\text{Cs} \).

144. In principle, it is possible to calculate the external doses from the integrated deposition density of each radionuclide. Table 22 shows the conversion factors for estimating absorbed dose in air, 1 m above ground, that were used in the 1972 report and which are based largely on the work of Beck et al. (13). For short-lived radionuclides, a plane source on the surface of the ground is postulated, but for \( ^{137}\text{Cs} \) an exponential profile is assumed with a mean depth of 3 cm.

| TABLE 22. CONVERSION FACTORS FOR THE ASSESSMENT OF ABSORBED DOSES IN AIR 1 m ABOVE GROUND |
|-----------------------------------------------|-------|-------|-------|-------|-------|-------|-------|
| \( ^{95}\text{Zr} \)                         | 0.341 | 0.072 | 0.042 | 0.033 | 0.316 | 0.011 | 0.004 |
| Mean life (y)                                 | 0.257 | 0.157 | 1.44  | 43.7  | 0.051 | 0.129 | 1.13  |
| Dose conversion factor (mrad per mCi km\(^{-2} \)) | 0.087 | 0.011 | 0.060 | 1.44  | 0.016 | 0.0014| 0.0045|
| \( ^{103}\text{Ru} \)                        |       |       |       |       |       |       |       |
| \( ^{106}\text{Ru} \)                        |       |       |       |       |       |       |       |
| \( ^{137}\text{Cs} \)                        |       |       |       |       |       |       |       |
| \( ^{148}\text{Ba} \)                        |       |       |       |       |       |       |       |
| \( ^{141}\text{Ce} \)                        |       |       |       |       |       |       |       |
| \( ^{144}\text{Ce} \)                        |       |       |       |       |       |       |       |

\textit{Note:} A plane source on the ground surface is assumed except for \( ^{137}\text{Cs} \), for which the source is assumed to be exponentially distributed with a mean depth of 3 cm. \( ^{a} \) Including contributions from the daughter radionuclides, assumed in transient equilibrium.

145. The assessment of organ doses from absorbed doses in air is discussed in Annex A. A combined factor of 0.8 is used in this report to account for the change of material (air to tissue) and for back-scatter and shielding afforded by other tissues of the body. The estimation of the organ doses from external radiation due to fallout require the use of a further factor representing the shielding effect of buildings. This shielding is taken to reduce the absorbed dose rate in air in the building, on average, to 20 per cent of its outdoor value. Assuming that on the average 80 per cent of the time is spent indoors, the effective shielding factor of the building is 0.4 (241, 245).

146. The overall factor used in this report to convert air absorbed doses to organ doses is therefore 0.8 \( \times 0.4 = 0.32 \). Transfer factors \( P_{2,5} \) relating integrated depositions of selected gamma-emitting nuclides to the resulting doses in the tissues of interest to the Committee can be calculated by multiplying the conversion factors shown in table 22 by 0.32.

A. SHORT-LIVED RADIONUCLIDES

147. Although the deposition of short-lived radionuclides has not been measured over the whole period during which nuclear tests were conducted, there are sufficient data available to estimate approximately the mean integrated deposition density. This estimation is based on the use of ratios of the time-integrated air concentrations and of integrated deposition densities of the relevant nuclides, assessed from measurements at a
number of sites, and the known latitudinal distribution of the integrated deposition densities of some nuclides, such as $^{90}$Sr.

148. The integrated deposition density of $^{144}$Ce has been estimated by this procedure in previous sections of this Annex and is shown in Table 20. In paragraph 89 it was noted that the $^{106}$Ru/$^{144}$Ce activity ratio changes slowly with time and was estimated to be 0.5 during the period of deposition.

149. From the estimated values of the integrated deposition density of $^{144}$Ce and $^{106}$Ru and the conversion factors of Table 22 multiplied by 0.32 (para. 146) it is possible to assess the dose commitment from these nuclides (see Table 25).

150. The activity of a number of fission products in air has been monitored at sites varying in latitude in the vicinity of the meridian 80°W since 1963 (117). The ratio of the time-integrated air activity of $^{95}$Zr to that of $^{90}$Sr for the period 1966-1974 is plotted as a function of latitude in Figure XIII. By 1966 there was probably very little $^{95}$Zr activity left from tests prior to 1963. The deposition density of $^{95}$Zr in each latitude band in the period 1966-1973 was estimated from the corresponding data for $^{90}$Sr for the same period, using ratios taken from Figure XIII. The results are shown in Table 23 (117).

### Table 23: Latitudinal Distribution of $^{95}$Zr Integrated Deposition Density, 1966-1973

<table>
<thead>
<tr>
<th>Latitude band</th>
<th>Area of band (10^2 km^2)</th>
<th>Relative population of band (%)</th>
<th>Integrated deposition density of $^{95}$Zr (mCi km^-2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70°-80°N</td>
<td>11.6</td>
<td>0.0</td>
<td>8</td>
</tr>
<tr>
<td>60°-70°N</td>
<td>18.9</td>
<td>0.4</td>
<td>28</td>
</tr>
<tr>
<td>50°-60°N</td>
<td>25.6</td>
<td>12.2</td>
<td>61</td>
</tr>
<tr>
<td>40°-50°N</td>
<td>31.5</td>
<td>13.8</td>
<td>64</td>
</tr>
<tr>
<td>30°-40°N</td>
<td>36.4</td>
<td>18.2</td>
<td>59</td>
</tr>
<tr>
<td>20°-30°N</td>
<td>40.2</td>
<td>29.2</td>
<td>49</td>
</tr>
<tr>
<td>10°-20°N</td>
<td>42.8</td>
<td>9.8</td>
<td>27</td>
</tr>
<tr>
<td>0°-10°N</td>
<td>44.1</td>
<td>5.6</td>
<td>32</td>
</tr>
<tr>
<td>0°-10°S</td>
<td>44.1</td>
<td>5.8</td>
<td>98</td>
</tr>
<tr>
<td>10°-20°S</td>
<td>42.8</td>
<td>1.8</td>
<td>137</td>
</tr>
<tr>
<td>20°-30°S</td>
<td>40.2</td>
<td>1.6</td>
<td>195</td>
</tr>
<tr>
<td>30°-40°S</td>
<td>36.4</td>
<td>1.4</td>
<td>147</td>
</tr>
<tr>
<td>40°-50°S</td>
<td>31.5</td>
<td>0.1</td>
<td>105</td>
</tr>
<tr>
<td>50°-60°S</td>
<td>25.6</td>
<td>0.05</td>
<td>23</td>
</tr>
</tbody>
</table>

*Source: Reference 155.*

![Figure XIII. Latitudinal variation of the ratio of time-integrated air concentrations of $^{95}$Zr and $^{90}$Sr for the period 1966-1974](image)

151. There are few data on the global deposition of $^{95}$Zr prior to 1963, and it is probable in this period that the greatest deposition occurred in the northern hemisphere. It is possible to estimate the $^{95}$Zr integrated deposition density from that of $^{90}$Sr if some reliable estimate for their ratio could be made. The $^{95}$Zr/$^{90}$Sr ratio only changes with a half-time of about 200 days owing to radioactive decay. The ratio of the time-integrated air concentrations $\Sigma^{95}\text{Zr}/\Sigma^{90}\text{Sr}$ in 1963 at Thule (Greenland), Moosonee (Canada), Sterling and Miami (United States) were 2.3, 2.7, 2.9 and 3.0, respectively, with a mean of 2.7 (117). The mean ratio at seven northern hemisphere sites in 1962 was 1.5 (60.115, 242). The northern hemisphere deposition of $^{90}$Sr in 1962 and 1963 of 27 and 15 MCl respectively, reported by Hardy (111), leads to a weighted mean of 1.93 for the integrated concentration ratio $\Sigma^{95}\text{Zr}/\Sigma^{90}\text{Sr}$.

152. Between 1961 and 1969 the deposition density of $^{90}$Sr in the 40°-50°N latitude band was 346 mCi km^-2 (111). Using the $^{90}$Sr deposition data given in Table 2 as a guide, the $^{90}$Sr deposition density in this zone up to 1966 is estimated to be 477 mCi km^-2 in the northern hemisphere and 57 mCi km^-2 for the same zone in the southern hemisphere. The $^{95}$Zr deposition densities in the northern and southern 40°-50° zones up to 1966 are estimated as 920 and 110 mCi km^-2 respectively, using the $\Sigma^{95}\text{Zr}/\Sigma^{90}\text{Sr}$ ratio of 1.93 given in paragraph 151. Adding to these numbers the corresponding values for the period 1966-1974 from Table 3, the estimated $^{95}$Zr deposition densities up to the end of 1973 are 984 and 214 mCi km^-2 for the northern and southern 40°-50° zones, respectively. The population-weighted global average $^{95}$Zr deposition density is estimated, using the $^{90}$Sr data as a guide, to be 650 mCi km^-2.
153. It is possible to estimate the dose commitment from $^{103}$Ru, $^{141}$Ce and $^{146}$Ba from the calculated $^{95}$Zr integrated deposition density. Table 24 gives the ratios of the integrated air concentrations or integrated depositions of these radionuclides to that for $^{95}$Zr for several sites and periods of time. If $F_j$ is the integrated deposition density of radionuclide $j$ and $K_j$ is the conversion factor of table 22 multiplied by 0.32 (para. 146), the total external dose commitment can be expressed as

$$D^* = \sum_j K_j F_j = K_a F_a + F_a \sum_j \frac{K_j}{F_a}$$

and therefore

$$D = K^*_a F_a$$

where $K^*_a$, the effective $P_{25}$ factor for nuclide $a$, is defined by

$$K^*_a = K_a + \sum_{j \neq a} \frac{F_j}{F_a}$$

154. In this way the dose commitment from a group of radionuclides can be estimated from the integrated deposition density of a given radionuclide $a$. The effective $P_{25}$ factor for computing the dose commitment due to $^{95}$Zr, $^{103}$Ru, $^{141}$Ce and $^{146}$Ba from the $^{95}$Zr deposition density was determined using equation 15 together with the integrated activity ratios of table 24 and the conversion factors of table 22 multiplied by 0.32 (para. 146). The estimated value of this effective conversion factor is 0.034 mrad per mCi km$^{-2}$, with upper and lower limits of 0.04 and 0.03 mrad per mCi km$^{-2}$, respectively, obtained by using the largest and smallest ratios shown in table 24.

155. The combined dose commitments from $^{95}$Zr, $^{103}$Ru, $^{141}$Ce and $^{146}$Ba, calculated using this effective $P_{25}$ factor and the estimated $^{95}$Zr integrated deposition density given in paragraph 152, is shown in table 25, which also shows the total dose commitment from short-lived radionuclides.

<p>| TABLE 24. RATIO OF THE INTEGRATED DEPOSITION DENSITIES OR OF THE TIME-INTEGRATED AIR CONCENTRATIONS OF $^{103}$Ru, $^{141}$Ce, $^{146}$Ba and $^{95}$Zr AT VARIOUS LOCATIONS AND TIMES |
|-----------------|----------------|----------------|</p>
<table>
<thead>
<tr>
<th>Location</th>
<th>Period</th>
<th>Type of ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buenos Aires, Argentina</td>
<td>1966-1974</td>
<td>Deposition density</td>
</tr>
<tr>
<td>Pretoria, South Africa</td>
<td>1966-1973</td>
<td>Air concentration</td>
</tr>
<tr>
<td>Stockholm, Sweden</td>
<td>1969-1972</td>
<td>Air concentration</td>
</tr>
<tr>
<td>Chilton, United Kingdom</td>
<td>1961-1964</td>
<td>Deposition density</td>
</tr>
<tr>
<td>Chilton, United Kingdom</td>
<td>1967-1970</td>
<td>Deposition density</td>
</tr>
<tr>
<td>Pittsburg, United States</td>
<td>1961-1963</td>
<td>Deposition density</td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\frac{^{103}\text{Ru}}{^{95}\text{Zr}}$</td>
<td>0.72</td>
<td>0.92</td>
</tr>
<tr>
<td>$\frac{^{141}\text{Ce}}{^{95}\text{Zr}}$</td>
<td>0.88</td>
<td>0.89</td>
</tr>
<tr>
<td>$\frac{^{146}\text{Ba}}{^{95}\text{Zr}}$</td>
<td>0.19</td>
<td>0.52</td>
</tr>
</tbody>
</table>

156. It is interesting to compare the estimated values of table 25 with actual determinations of the external dose in both hemispheres. At Chilton in the United Kingdom the total gamma absorbed dose in air from fallout has been determined by a combined procedure including direct measurements and computation from measured depositions (61). The estimate, for the period 1951 to 1973, is 137.7 mrad; the contribution from $^{137}$Cs is estimated as 33.3 mrad, so that the contribution from short-lived radionuclides is 104.4 mrad. The corresponding tissue dose (applying the factor 0.32) is 33 mrad. In the southern hemisphere, for Buenos Aires up to 1975, a tissue dose of 15 mrad has been estimated (19, 20, 166, 167), based upon direct calculation from measured deposition densities of individual short-lived fission products.

B. CAESIUM-137

157. The integrated deposition density of $^{137}$Cs from all tests was given in paragraph 115. Using this information and the conversion factor for caesium from table 22, multiplied by 0.32 (para. 146), the dose commitment to body tissue is estimated to be (mrad): northern temperate zone, 62; southern temperate zone, 18; world population, 38.

C. TOTAL DOSE COMMITMENT FROM EXTERNAL IRRADIATION

158. The global dose commitment from external irradiation is estimated to be 68 mrad, the combined short-lived nuclides and $^{137}$Cs contributing each about half of this value. As $^{137}$Cs released in nuclear detonations is accompanied by a given proportion of short-lived products, it is possible to assess the collective dose commitment from external exposure normalized to unit activity of $^{137}$Cs released. The value calculated by the procedures indicated in Annex A is of the order of 10 man rad Ci$^{-1}$.

IV. SUMMARY OF DOSES AND DOSE COMMITMENTS FROM NUCLEAR EXPLOSIONS

159. It is difficult to summarize the doses for the whole world population from nuclear test explosions because they arise from a variety of radionuclides which differ widely in their behaviour in the environment and in their dosimetric characteristics. To state current annual doses would reveal only a small part of an exposure situation.
which is known to vary not only with time, but also with geographical location, living conditions and age. For a given group of individuals, for whom these factors are known, the annual doses from external and internal exposures may be presented as a function of age for some selected organs and tissues of interest; that would give a full picture of the annual doses for the particular groups. For some long-lived radionuclides that are globally distributed, such as $^{137}$Cs, this information may be derived for the whole world population as per $\text{caput}$ annual doses which would be representative of individuals irrespective of age and location. For other radionuclides, however, the individual annual doses will vary substantially with location and age. That is the case with short-lived radionuclides, such as $^{131}$I, $^{131}$I, as regards location, and with bone-seeking radionuclides, such as $^{90}$Sr, as regards age. Even for these radionuclides, however, once the population group of interest has been identified, it is possible to describe the current and expected exposure situations for the individuals involved, drawing on the information given in the various sections of this Annex.

160. If the variation of individual organ dose rates with time were known for all locations, living conditions and ages, a world population per $\text{caput}$ dose rate could be calculated. Its integral over infinite time would be the global dose commitment from the nuclear explosions to date. Using the methods described in this Annex, however, this integral can be evaluated even though the per $\text{caput}$ dose rate as a function of time is not known or is difficult to derive. Because the global dose commitment, as described in Annex A, can be used as a relative measure of the detriment, the Committee, as in previous reports, has found this quantity to be a useful single measure of the irradiation consequences for the whole world population. It is therefore summarized in table 26.

**TABLE 26. SUMMARY OF DOSE COMMITMENT FROM RADIONUCLIDES PRODUCED IN ALL NUCLEAR TESTS CARRIED OUT BEFORE 1976**

(mrad)

<table>
<thead>
<tr>
<th>Source of radiation</th>
<th>Northern temperate zone</th>
<th>Southern temperate zone</th>
<th>World population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gonads</td>
<td>Bone marrow</td>
<td>Bone lining cells</td>
</tr>
<tr>
<td><strong>External</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short-lived</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{137}$Cs</td>
<td>48</td>
<td>48</td>
<td>48</td>
</tr>
<tr>
<td><strong>Internal</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^3$H</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>7</td>
<td>32</td>
<td>29</td>
</tr>
<tr>
<td>$^{54}$Mn</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$^{55}$Fe</td>
<td>1</td>
<td>0.6</td>
<td>1</td>
</tr>
<tr>
<td>$^{90}$Sr</td>
<td>84</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>$^{90}$Sr</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>150</td>
<td>260</td>
<td>290</td>
</tr>
</tbody>
</table>

**Notes:**
1. The dose commitments for $^{54}$K, $^{134}$Cs and $^{135}$Ba, although discussed in the text, are not shown in this table because they are negligible compared with the values included.
2. For internal irradiation, where body activities have been measured, uncertainties are probably within a factor of 2. For external irradiation and for lung-dose estimates, where the models used were not checked by direct measurement, the uncertainties are probably within a factor of 5.
3. Dose accumulated up to the year 2000. The total dose commitment to gonads and lung is about 120 mrad, to bone lining cells 414 mrad and to bone marrow 455 mrad, delivered over some 8300 y.
4. These dose commitments appear to be the same in different organs because of rounding. Only inhalation contributions are shown; for discussion on the ingestion pathway see chapter II, section N.
5. Rounded to two significant figures.

161. The values shown in table 26, taken from the relevant paragraphs in the preceding sections, have been rounded off. For this reason, when the differences between the estimated organ dose commitments are small, the table gives the appearance of a uniform dose over several organs. In the case of doses from external gamma radiation, or from internal emitters that are homogeneously distributed in the body, such as $^3$H and $^{137}$Cs, the dose commitment is essentially the same for all the relevant organs of the body. For the radionuclides listed in table 26, the irradiation to which the world population was committed by nuclear tests up to 1975 is already largely completed for all except $^{137}$Cs (external and internal), $^3$H, $^{14}$C, $^{90}$Sr and $^{239}$Pu. Therefore, in terms of current annual doses, only these five nuclides need to be considered. Caesium-137 makes major contributions for
all body tissues which are essentially independent of age; whereas the further substantial contribution from $^{90}$Sr in bone marrow and bone lining cells is strongly dependent on age. In comparison, the contributions of $^3$H, $^{14}$C and $^{239}$Pu to current annual doses are very small.

164. Although $^{137}$Cs and $^{90}$Sr are the only substantial contributors to current annual doses to the body organs and tissues included in table 26, it is not possible to summarize this annual dose situation in a simple description for the whole world population. It may be helpful, however, to indicate the magnitude of the annual doses in 1975 using $^{137}$Cs as an illustrative example. Whole-body contents of $^{137}$Cs in 1975 (table 19) ranged from 8 to 29 pCi (gK)\(^{-1}\), which would have caused annual doses to body tissues in the range 0.1-0.5 mrad. The external exposure from $^{137}$Cs deposition in soil would have added less than 0.2 mrad to these doses. Because of the long half-life of $^{137}$Cs, the world population is committed to continued exposure from this radionuclide for many years. This accounts for the substantial contribution of $^{137}$Cs to the dose commitment.

165. For nuclear tests carried out in the atmosphere in the northern and southern hemispheres since the Committee's 1972 report, $^{131}$I in milk supplies has led to irradiation of the thyroid glands of exposed populations in the periods immediately following the tests. Doses due to $^{131}$I in infant thyroids—the most highly exposed organ—ranged up to 15 mrad in the northern hemisphere in 1974 and 1976, whereas, in the southern hemisphere, doses to infant thyroid ranged up to about 100 mrad in 1973 and up to some hundreds of mrad in 1974.
REFERENCES

1. Aarkrog, A. Personal communication.


16. Beninson, D. Personal communication.


155
22. Bennett, B. G. Personal communication.


74. Comitato Nazionale Energia Nucleare. Italy. Data on environmental radioactivity collected in Italy. Reports for years 1966 to 1968.

75. Comitato Nazionale Energia Nucleare. Italy. Data on environmental radioactivity collected in Italy. Reports for the years 1966 to 1970.

76. Coulon, R. Unpublished.


125. Health and Safety Laboratory. Cesium-137 in various Chicago foods, in Health and Safety Laboratory fallout program quarterly summary reports HASL-257, 259, 274 and 278.


159


152. Liniecki, J. Instytut Medycyny Pracy, Poland. Communication.


174. Misono, K. Personal communication.

175. Mohindra, V. K. and J. H. Gordon. Caesium-137 levels in the Canadian North, January to June 1965, p. 3-12 in Data from Radiation Protection Programs 3: 10 (1965).


178. Morley, F. Personal communication.


180. Moroney, J. R. Personal communication.


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


205. Radiation Protection Division, Department of National Health and Welfare, Ottawa, Canada. Data from Radiation Protection Programs. Vols. 4-6 (1966-1968).


218. Salo, A. Personal communication.


227. Stieve, F. E. Personal communication.


248. Voîleque, P. G. and C. A. Pelletier. Comparison of external irradiation and consumption of cows milk as critical pathways for $^{137}$Cs, $^{54}$Mn and $^{144}$Ce-$^{144}$Pr released into the atmosphere. Health Phys. 27: 189-199 (1974).


258. Книжников, В. А., Э. В. Петухова, Р. М. Бархударов. Поступление $^{56}$Fe и $^{137}$Cs населения Советского Союза с пищевым рационом в 1967-1969 гг. Гигиена и санитария: 8: 54 (1971).

259. Мареи, А. Н., Б. К. Борисов. О содержании стронция-90 в костных тканях населения Советского Союза в 1969 году. Неопубликовано.


261. Мареи, А. Н., Р. М. Бархударов, Н. Я. Новикова. Цезий-137 глобальных выпадений как источник облучения населения полесья в печати.

262. Моисеев, А. А., П. В. Рамзаев. Цезий-137 в биосфере. Москва, Атомиздат, 1975.

263. Петухова, Э. В., В. А. Книжников. Содержание стронция-90 и цезия-137 в пищевом рационе населения Советского Союза в 1967-1969 гг. Неопубликовано.


265. Прокофьев, О. Н., М. А. Невструева, А. А. Перова и др. Цезий-137 глобальных выпадений в продуктах питания в организме человека, Атомиздат, Москва, 1969.

266. Сивицев, Ю. В., В. А. Канарейкин, О. М. Арутюнов. Изменение концентрации Cs$^{137}$ в организме человека. Радиобиология 6: 822-825 (1966).

267. Тюрокова, Э. Б. О миграции стронция-90 и цезия-137 в почвах. Государственный комитет по использованию атомной энергии СССР, Москва, 1972.