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No. 14

ASSESSMENT OF DOSES TO THE PUBLIC FROM INGESTED RADIONUCLIDES

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ASSESSMENT OF DOSES TO THE PUBLIC FROM INGESTED RADIONUCLIDES

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FOREWORD

The use of radioactive material that is not under proper control carries with it the risk of accidents, with consequences for public health. Accidents that have occurred range from the loss or dispersion of medical and industrial sources to the reentry into the Earth's atmosphere of satellites carrying radioactive material, in addition to the major accident at the Chernobyl nuclear power plant in 1986. The Chernobyl accident led to the exposure of populations across national boundaries, in many instances leading to inconsistent national responses. It became evident that clarification of the criteria for intervention was necessary, and new recommendations were developed by several international organizations. Following this, a Safety Guide entitled 'Intervention Criteria in a Nuclear or Radiation Emergency', Safety Series No. 109, was published by the IAEA in 1994.

It is essential to know the values of doses per unit intake for those radionuclides which in the event of an accident involving radioactive material, might be transferred from environmental media into foodstuffs and thus ingested by members of the public. These values, together with knowledge of the kinds of food consumed, the annual consumption rates and the costs of various countermeasures, form the basis for establishing appropriate action and intervention levels, and operational levels. This Safety Report provides practical information as a basis for radiation protection for the public in the event of accidental releases of radionuclides to the environment.

The International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS), jointly sponsored by the Food and Agriculture Organization of the United Nations, the IAEA, the International Labour Organisation, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization, list committed effective doses per unit intake of radionuclides via ingestion. This Safety Report offers the scientific basis for these values and their application, providing the information necessary to assess the radiological implications, in terms of doses to population groups, of the measured concentrations of radionuclides in foodstuffs independent of the source of exposure.

The first draft of this Safety Report was produced at a Technical Committee meeting in 1990. It was further developed by an Advisory Group and completed, following the publication of the BSS in 1996, by a group of consultants. The IAEA gratefully acknowledges the assistance of all contributors.

The IAEA officer responsible for the preparation of this report was M. Gustafsson of the Division of Radiation and Waste Safety, Department of Nuclear Safety.

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CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

In 1985, the IAEA published Safety Series No.72 providing guidance on the principles for establishing intervention levels of dose for the protection of the public in the event of a nuclear accident or radiological emergency [1]. The accident at the Chernobyl nuclear power plant in 1986 demonstrated an urgent need for international agreement in the establishment of practical quantities that could be readily compared with the results of measurements made on environmental materials and foodstuffs, so called derived intervention levels (DILs). Shortly after the accident, these were provided in an IAEA Safety Series publication [2]. In 1989, a supporting report was published on the measurement of radionuclides in food and the environment [3].

In 1994, Safety Series No. 72 was superseded by a Safety Guide on intervention criteria in a nuclear or radiation emergency [4]. While giving recommendations on generic action levels for foodstuffs, this guide also states that the final selection of action levels must take due account of other factors such as national laws and public confidence. For assessment of doses from the intake of radionuclides, the new international Basic Safety Standards (BSS) [5] list committed effective doses per unit intake via ingestion based on the publications of the International Commission on Radiological Protection (ICRP) [6–8]. This Safety Report provides the background to the origin of these values and their application.

Values of doses per unit intake (dose coefficients) for those radionuclides which in the event of an accident involving radioactive material might be transferred from the environment into foodstuffs and thus ingested by members of the public, are an important component in the control of contaminated foodstuffs. Together with information on the kinds of foods, consumption rates and the costs of available countermeasures, these values are input for establishing appropriate action and intervention levels, and operational quantities. This report was therefore initiated with the aim of providing practical information for the radiation protection of members of the public in the event of accidental releases of radionuclides to the environment, but it may also be useful in estimating the radiological impact of routine discharges and waste repositories.

1.2. OBJECTIVE

The purpose of this Safety Report is to provide the information necessary to assess the implications of concentrations of radionuclides in food in terms of doses to population groups. The interpretation of measurements on individuals is also

considered, because although it is recognized that only a small number of people can be monitored, the information obtained provides valuable input to dose assessments for population groups.

1.3. SCOPE

This report summarizes information on the entry of radionuclides into the food chain and food consumption rates. Dose coefficients for the ingestion of radionuclides by infants (3 months), children (1, 5, 10 and 15 years) and adults are presented. They are based on the biokinetic and dosimetric models developed by the ICRP and are in all cases consistent with the ICRP's publications and the BSS [5]. The derivation of committed equivalent doses to body tissues and committed effective dose is explained. Biokinetic data for 29 elements are included. The use of the data and practical problems are discussed. Uncertainties in dose estimates are addressed to give the user an understanding of the accuracy to be expected. The estimation of doses to the developing embryo/foetus after intakes during pregnancy or prior to conception is also considered. Procedures for estimating doses from body or excretion measurements are explained for the radionuclides ^{3}H, ^{90}Sr, ^{131}I, ^{134}Cs, ^{137}Cs and ^{239}Pu. The report is intended largely for regulators, administrators and health physicists performing measurements and interpreting data in the event of a radiological accident. The scientific background to the information given is therefore presented in sufficient detail for this purpose.

1.4. STRUCTURE

Section 2 provides a brief description of the entry of radionuclides into the food chain, followed in Section 3 by a summary of data on food consumption, supported by tabulated data in Annex I on consumption rates in different countries. The main part of the text, in Section 4, is a description of the ICRP's biokinetic and dosimetric models and specific data for individual elements. Values of committed effective dose are also given in Section 4, with tables of committed equivalent doses to individual tissues for adults in Annex II. In addition, Section 4 gives a summary of the approach being used to estimate doses to the foetus from intakes of radionuclides by the mother and examples of uncertainty and variability in dose estimates. Section 5 outlines the use of body and excretion measurements to estimate doses; supporting data for the interpretation of measurements for situations of acute and chronic intake are given in Annex III.

2. ENTRY OF RADIONUCLIDES INTO THE FOOD CHAIN

2.1. POTENTIAL SOURCES OF EXPOSURE

The most significant potential source of internal exposure of human populations to radionuclides, in addition to background radiation and apart from the possible use of nuclear weapons and the use of radionuclides in nuclear medicine, is accidental releases from nuclear facilities.

Predictive studies [9–11] and the evidence available from accidents which have occurred, including those at Windscale in the United Kingdom in 1957, Three Mile Island in the United States of America in 1979 and Chernobyl in the former USSR in 1986 [12], have shown which radionuclides are likely to be important with regard to the contamination of foodstuffs. In the short term, isotopes of iodine, particularly ^{131}I, are of primary importance. In the longer term, ^{134}Cs and ^{137}Cs make major contributions to individual and collective doses via terrestrial food chain pathways. For such accidents there may also be subsidiary contributions from ^{89}Sr, ^{90}Sr, ^{95}Zr, ^{103}Ru, ^{106}Ru, $^{110}Ag^{m}$, ^{125}Sb, ^{132}Te, ^{140}Ba, ^{144}Ce and the actinides. In the case of potential accidental releases at reprocessing plants, the spectrum of radionuclides to be considered will be shifted to long lived ones owing to the storage of the fuel elements at the nuclear power plant before transport and reprocessing. In the accident at Khyshtym in the southern Urals in 1957, the dominant radionuclide giving internal doses was ^{90}Sr. The other radionuclides recorded were ^{95}Zr, ^{95}Nb, ^{106}Ru, ^{106}Rh, ^{137}Cs, ^{144}Ce, ^{144}Pr and trace amounts of ^{147}Pm, ^{155}Eu and $^{239/240}Pu$ [13, 14].

Exposure may also occur as a result of routine discharges from all stages of the nuclear fuel cycle. This includes uranium mines, fuel fabrication facilities, reactors, reprocessing plants and low, intermediate and high level radioactive waste repository sites [15–19]. Each of these releases involves mainly fission and neutron activation products as well as actinides. Uranium mining and fuel fabrication will also involve natural radionuclides of U, Th and their daughters. Another source of human exposure to radionuclides is nuclear weapons testing, which contributes fission and activation products and actinides.

2.2. TRANSFER OF RADIONUCLIDES INTO FOODS

Radionuclides released to the environment from different sources may enter the atmosphere, surface water or groundwater. After release to the atmosphere, which is

the most likely occurrence following an accident at a nuclear installation, deposed radionuclides may contaminate soil, agricultural crops and other plants, surface water and urban areas. The levels of contamination may vary greatly from one area to another. After the Chernobyl accident, deposition in terms of activity per unit surface area varied by a factor of 10 to 100 within the same village [12].

Following their initial deposition, intakes of radionuclides by humans may include the consumption of vegetables, meat or milk from animals from contaminated areas and fish from contaminated rivers, lakes or seas. The importance of food chain pathways depends in each case on several factors. The fraction of the deposited radionuclides that will be incorporated into plants depends on the time of year when the deposition occurs and whether wet or dry deposition is involved, as well as the physicochemical form and chemical nature of the radionuclide. The incorporation of radionuclides into plant tissues from the surface of vegetation is often the dominant process shortly after deposition, provided that it takes place during the growth season.

The importance of root uptake relative to direct deposition onto the plant surface increases with time in most cases. If the deposition occurs on fallow land, contamination of plants can only occur by root uptake and soil contamination after the crop is sown, and the resulting contamination will generally be significantly lower, particularly for short lived radionuclides. If the deposition occurs on snow covered land, the transport of short lived radionuclides to terrestrial and aquatic food chains is decreased.

The transfer to animals will depend on the intake of the animal and the metabolism of the various radionuclides by the animal. Radionuclides deposited directly onto plants or in soil associated with the plant are often bound to insoluble particles and are less available for intestinal absorption than radionuclides incorporated into the feedstuffs. There may be considerable variation in changes in radionuclide concentrations with time, depending on various factors, including the season of the year and resulting agricultural practices, and the types of soil and vegetation. Certain areas such as alpine pastures, forests and upland areas may show longer retention in soils than agricultural areas, and high levels of transfer to particular foods, e.g. berries and mushrooms in forests, may give rise to critical groups in the population.

For a detailed account of the different factors involved in food chain transfer, including the physicochemical form of the soil and the radionuclide, reference is made to the reviews of Coughtrey and Thorne [20] and the IAEA [21].

The deposition of radionuclides directly onto surface waters or their transport by runoff from the drainage area will result in the contamination of fish and aquatic plants. In this case the long lived radionuclides are the most important and the contamination level depends on the fish species and the properties (size, water volume and nutritional state) of the lake [22].

The transfer of radionuclides from the environment to humans has been studied extensively and a number of comprehensive models have been developed by different authors [23–27]. These models consider the time dependency of the transfer processes and take account of growing cycles of crops and feeding practices in different seasons of the year. Furthermore, the models have to be flexible enough to permit the simulation of the specific regional situation in the case of an emergency and the effect of taking countermeasures. An exact simulation usually will not be possible, so models may rather be used as an adjunct to measurements, useful for the prediction of likely changes in concentrations with time, particularly over long time-scales, or for the assessment of the effects of planned countermeasures.

Following the accident at Chernobyl, models were used to predict transfer through the food chain. The large number of measurements of radionuclide concentrations in air, soil, foodstuffs, etc., made in different countries after the accident have been used to test the reliability of the models [28–32]. Two international model validation studies, BIOMOVS [33] and VAMP [34, 35], have been undertaken; these have included the testing of terrestrial and aquatic food chain models. These studies have shown that the assumptions made in many models are robust and their applicability to site specific situations has been established. Areas for potential improvement have been identified.

3. FOOD CONSUMPTION AND DOSE ASSESSMENT

To estimate radiation doses to the population from measurements of radionuclide concentrations in food, food consumption data are needed. Annex I contains tables summarizing data on the consumption rates of 7 food categories for 8 regional and 140 national and area diets taken from guidelines published by the World Health Organization (WHO) in 1988 [36]. In general, these values are based on data for 1979–1981 published in 1984 [37]. Annual average consumption rates for the eight regional diet types (the European diet type also includes Australia, Canada, New Zealand and the USA) are presented in Table I, with the values rounded to two significant digits. This table is intended to give a general idea of the variation between countries, and the values in the annex may be used when no other data are available. It should be borne in mind that the food categories in these tables include food items of different composition. The foodstuffs that comprise a particular category may have significantly different radionuclide concentrations. For example, pork, beef and poultry probably will be affected very differently in an accident, but are all included as ‘meat’. The food consumption data in the tables do not give information on differences in consumption rates for different age groups (see Section 3.5). The

TABLE I. FOOD CONSUMPTION PATTERNS FOR DIFFERENT TYPES OF DIET (RAW UNPROCESSED FOOD PER YEAR PER CAPITA) [35]

Diet type	Cereals (kg)	Roots and tubers (kg)	Vegetables (kg)	Fruit (kg)	Meat (kg)	Fish (kg)	Milk (kg)
African	130	130	26	45	17	15	29
Central American	110	46	39	99	42	19	82
Chinese	170	86	85	5.5	15	8.9	1.9
Eastern Mediterranean	190	19	92	100	30	8.4	74
European	120	73	87	81	75	20	150
Far Eastern	210	28	54	48	22	24	34
North African	160	20	63	64	24	7.3	77
South American	130	68	34	83	48	14	71

consumption of contaminated drinking water should also be taken into account, especially when surface or rain water is used for drinking.

3.1. ASSESSMENT OF FOOD CONSUMPTION

The most commonly used method to obtain quantitative estimates of annual consumption rates for various categories of food is the ‘food balance sheet’ (FBS) method as described by FAO [38]. Other methods, such as the ‘household expenditure’ (HE) method, can often provide more precise information, but may not be representative of the whole population.

Food balance sheets are established at the national level. Using statistical data on food production, imports and exports and stock variations, the amount available for human consumption for the entire population can be calculated. Data refer to the raw unprepared product and calculated amounts per person usually overestimate actual consumption because losses during food distribution and preparation are not taken into account. Consumption values apply to average individuals, taking no account of age or sex.

Household expenditure studies are undertaken in a number of countries, estimating food consumption in large population groups (several thousand households). The quantities recorded refer to the products as purchased and usually take account of consumption away from home. Some surveys present information on the influence of factors such as social class, geographical area, season and level of

self-support. Information on food products consumed is more detailed than for food balance sheets.

Food consumption research is also undertaken on small groups defined by age, sex and possibly other factors. Generally, the number of participants is small and extrapolation of results to the entire population may be unreliable.

Examination of Tables I–1 to I–11 in Annex I suggests that the FBS method in many cases tends to overestimate the average food consumption in comparison with the HE method. The possible conservatism of the FBS method should be borne in mind when estimating potential average intakes and resulting doses to a population. It should also be noted that individual consumption patterns may differ by a factor of two or more for some food groups. In some special diet groups a certain food category may even be totally missing and may be replaced by increased consumption of some other food categories. In cases of the radioactive contamination of certain foodstuffs, people may also voluntarily avoid or reduce consumption of these foodstuffs, leading to overestimation of the consumption rates of radionuclide intake.

Total production data for foodstuffs from the affected area may be used to estimate the upper levels of collective radiation doses. Taking into account exports and real food losses (i.e. losses that are not recycled into the food chain), a rough estimate of the total radionuclide intake by the population can be obtained.

3.2. VARIATION BETWEEN WORLD REGIONS

Table I lists annual average consumption rates for seven food categories in eight world regions identified by dietary habits. The variation of annual per capita consumption of individual food categories between regions is greatest for milk. This type of information may be used to identify those food categories of particular importance for intake assessments in each region. For example, the annual per capita consumption of milk in China (in kg/a) represents less than 1% of the total Chinese diet, while the corresponding value for Europe is considerably greater.

3.3. VARIATION WITHIN WORLD REGIONS

Tables I–1 to I–11 in Annex I illustrate the variations in the intake of individual food categories within each of the eight identified global regions. Such regional consumption data may be used for assessing regional average doses, but may considerably overestimate or underestimate average doses for a particular country within that region.

3.4. VARIATION WITHIN COUNTRIES

Data published by the European Commission [39] and FAO [38] identify and quantify the magnitude of variations in food consumption rates.

The use of food consumption data as presented for a given country in Annex I may not be applicable to identifiable subpopulations with significantly different dietary habits. Examples of such subpopulations are farmers, fishermen, caribou hunters and reindeer herders. In addition, separate consideration should be given to other individuals or subpopulations who gather and consume products such as lake fish, game meat, mushrooms and wild berries. Other examples are vegetarians and religious and ethnic groups with dietary habits that differ from the national average. In assessing doses to such groups, specific food consumption data should be used, rather than those obtained for average consumption within a country. In order to estimate doses to such groups, the groups should be identified and their consumption pattern and amounts determined.

The variation of radionuclide intake is also affected by the transport of foodstuffs produced in an area with low deposition to an area with high deposition and vice versa. This tends to make variations in radionuclide intake smaller than would be expected by considering deposition values, although considerable variations in intake do nevertheless occur [40, 41].

3.5. DEPENDENCE ON AGE AND SEX

Factors such as social class and sex have a small effect on consumption rates with differences from the average of less than about 30%. Adult female consumption

TABLE II. RELATIVE FOOD CONSUMPTION AT DIFFERENT AGES

Foods	Age (years)			
	1–2	5	10	18+
Cereals	0.33	0.49	0.68	1
Meat	0.22	0.40	0.63	1
Fruit	0.33	0.49	0.69	1
Potatoes	0.29	0.45	0.66	1
Vegetables	0.49	0.61	0.76	1
Milk[a]	1.30	0.56	0.73	1
Total diet[b]	0.53	0.64	0.77	1

[a] According to Austrian average consumption.

[b] Including milk consumption in countries of the European Union.

rates have been shown to be about 0.8 of those for adult males. The difference between sexes is smaller in children [39].

Relative consumption rates for children of different ages in the European Union countries are summarized in Table II. More detailed data for Germany are given in Table III. The data show age dependence in the consumption of each food type. The specific data on milk consumption is taken from Austrian data [42]. For three month old infants a daily intake of 700 g of milk can be assumed. Generally this will be

TABLE III. AGE DEPENDENT FOOD CONSUMPTION RATES IN GERMANY

Foodstuff	Consumption rates (g/d)				
	Age group (years)				
	1	5	10	15	Adults
Spring wheat, whole grain	0.7	1.4	1.8	2	2.6
Spring wheat, flour	3.9	8.1	10	12	15
Winter wheat, whole grain	6	13	16	18	23
Winter flour	35	73	91	100	130
Rye, whole grain	2.2	4.8	6	6.9	8.7
Rye, flour	9.3	19	24	28	35
Oats	2.9	3.1	3.9	4.4	5.6
Potatoes	45	35	60	83	160
Leafy vegetables	58	74	79	86	94
Root vegetables	21	24	29	33	33
Fruit vegetables	12	36	41	46	47
Fruit	150	72	91	100	120
Berries	0	10	12	14	14
Milk	560	140	180	210	230
Condensed milk	0	11	14	16	18
Cream	0	9.6	13	14	16
Butter	0	6.1	9.5	12	18
Cheese (rennet)	0	10	14	19	26
Cheese (acid)	0	6.6	8.9	12	17
Beef (cow)	1.5	18	19	23	27
Beef (cattle)	3	35	38	46	55
Veal	0.2	1.4	1.5	1.8	2.2
Pork	3.9	72	78	90	108
Chicken	1.5	11	12	14	17
Roe deer	0	1.1	1.2	1.3	1.7
Eggs	5	18	25	36	43
Beer	0	0	12	130	610

breast milk, milk formula or, in some cases, diluted cow's milk. Radionuclide concentration levels will generally be lower in mother's milk than in cow's milk [43].

3.6. SAMPLING OF FOOD FOR ACTIVITY MEASUREMENTS

In estimating doses from intakes of radionuclides in food, it is clearly necessary to consider all food types. If direct measurement of all food items is not possible, weighting over the various food items comprising the respective categories will be necessary. Information on the relative contributions of these food items should be as detailed as possible and may be found in FAO FBSs or in local nutritional statistics.

In general, the measurement of the concentration of radioactive material associated with food should be performed as closely as possible to the consumption stage. Thus, flour shows decreases in radionuclide concentration by 20–70% as compared with cereal grain according to the fineness of grinding [39]. Processing of vegetables may decrease the concentration of radionuclides associated with plant surfaces. On the other hand, some processes may increase the concentration of radionuclides in food but decrease the mass of the food consumed.

Concentrations of radionuclides in milk and other foods may vary significantly with time. Measurements should be planned to ensure that a representative average concentration over a sampling period can be achieved. Special care is necessary in the case of short lived radionuclides in food items that are stored for periods longer than a few half-lives before consumption. For example, it should be noted that in the WHO/FAO tables the value for "milk" includes condensed milk, dried milk, cheese, etc., in addition to milk for drinking. For short lived radionuclides such as ^{131}I, the usual storage time for such products is sufficient for essentially complete radioactive decay.

Attention should be given to obtaining unbiased food samples. Bias may arise if samples are collected only from areas with suspected contamination. If concentration measurements are made on food obtained and sampled from near field locations and then applied to general or average food consumption rates for a large population, the potential intakes of radionuclides by these populations would be overestimated.

3.7. DOSE ASSESSMENTS FROM MEASUREMENTS IN FOODS

Doses from intakes of radionuclides in foods by population groups can be calculated from measurements of the concentrations of radionuclides in foods, daily consumption rates and dose coefficients. This can be described by the following equation:

$$E_{\mathrm{A}} = \sum_{j} \sum_{f} \int_{0}^{T} C_{fj}(t) \cdot M_{f\mathrm{A}}(t) dt \cdot h_{j\mathrm{A}} \qquad (1)$$

where

E_{A} is the committed effective dose (Sv) for age group A,

T is the total time (d) considered during which contaminated food is consumed,

$C_{fj}(t)$ is the average concentration (Bq/kg) of radionuclide j on or within food item f at time t,

$M_{f\mathrm{A}}(t)$ is the mass (kg/d) of food item f consumed per day by age group A at time t,

$h_{j\mathrm{A}}$ is the ingestion dose coefficient (Sv/Bq) of radionuclide j for age group A (see Table VI in Section 4).

This expression assumes that the time of integration is much shorter than the intervals used to specify the different age groups. If the time of integration is comparable with or longer than an age interval, then the estimation of committed dose will generally be conservative because in most cases the dose coefficients decrease with increasing age. The derivation of values of committed equivalent dose and committed effective dose for the ingestion of important radionuclides is explained in the next section.

Two special cases of the above formula can be distinguished. If the average activity concentration and the mass of food consumed per day is constant within the time T, which may be approximately valid for ^{137}Cs in many foodstuffs, then Eq. (1) is reduced to

$$E_{\mathrm{A}} = \sum_{j} \sum_{f} C_{fj} \cdot M_{f\mathrm{A}} \cdot T \cdot h_{j\mathrm{A}} \qquad (2)$$

In the case of radionuclides with short physical half-lives, e.g. ^{131}I with a half-life of about 8 d, Eq. (1) can be expressed as

$$_{\mathrm{A}} = \sum_{j} \sum_{f} \frac{C_{fj}(0)}{\lambda_j} (1 - e^{-\lambda_j \cdot T}) \cdot M_{f\mathrm{A}} \cdot h_{j\mathrm{A}} \qquad (3)$$

where λ_J is the radioactive decay constant (d^{-1}) of the radionuclide j.

This expression assumes a single contamination event at time zero. The actual sequence of food contamination may be a more complex function of time.

Furthermore, the loss of radioactive material from food may be hastened by other processes such as wash-off, plant growth and translocation to other plant parts (see Section 2).

In an accident involving significant releases, it is likely that dose assessments based on measurements of radionuclide concentrations in food would be supplemented by measurements on individuals. Section 5 outlines the approach taken to the interpretation of whole body and bioassay measurements.

4. DOSE COEFFICIENTS FOR INGESTED RADIONUCLIDES

To calculate doses to body organs and tissues from incorporated radionuclides, information is needed on physical and biological parameters. In this section, the general approach to calculating dose coefficients is explained, biokinetic data for the behaviour of elements with the most important radioisotopes are summarized and estimates of doses are given for infants, children and adults (Table VI). The information included is based on biokinetic and dosimetric models developed in ICRP Publications 56 [6], 67 [7] and 69 [8], and is in all cases consistent with ICRP publications and the BSS [5]. Uncertainty and variability in doses are considered for the examples of ^{137}I, ^{137}Cs and ^{239}Pu. The estimation of doses to the embryo and foetus following intakes by pregnant women or prior to conception are also discussed.

4.1. BIOKINETIC AND DOSIMETRIC MODELS

Biokinetic models which describe the behaviour of radionuclides in the body may be constructed as simple compartment models with retention half-times and uptake fractions. In more complex models, there may be chains of compartments, and recirculation between compartments may also be involved. These models are used to determine the distribution of cumulated radionuclides, radioactive materials within the body, taking account of physical half-life; that is, to calculate the number of decays in different regions of the body. Doses are commonly integrated over a 50 year period for adults and to age 70 for children. For single intakes of nuclides with short physical or biological half-lives, such as ^{131}I, dose is delivered over a period of days or weeks. However, for nuclides such as ^{239}Pu, with long physical and biological half-lives, dose is delivered over the lifetime of the individual.

It should be noted that the biological parameters included in models often cannot be observed or measured directly. Human data are used whenever available, as is the case for important nuclides such as ^{131}I and ^{137}Cs, but for other nuclides it is

often necessary to rely on animal data from studies in which the distribution, retention and excretion of radionuclides have been measured, or on knowledge of the behaviour of chemically similar elements.

4.1.1. Gastrointestinal doses and absorption

For ingested radionuclides, the first consideration is doses to and absorption from the gastrointestinal (GI) tract, described by a specific compartment model [44]. In this model the GI tract has four compartments: the stomach, small intestine, upper large intestine and lower large intestine. Material is transferred successively between the four compartments of the model in an exponential manner, with half-times taken to be 0.69, 2.8, 9.2 and 17 h (transfer rates of 24, 6, 1.8 and 1 d^{-1}), respectively (Fig. 1); immediate mixing within the contents of the different compartments is assumed and doses are calculated separately for the mucosal wall of each compartment. Specific information on the age dependence of the half-time in the different compartments is not available and these data are therefore taken to apply to

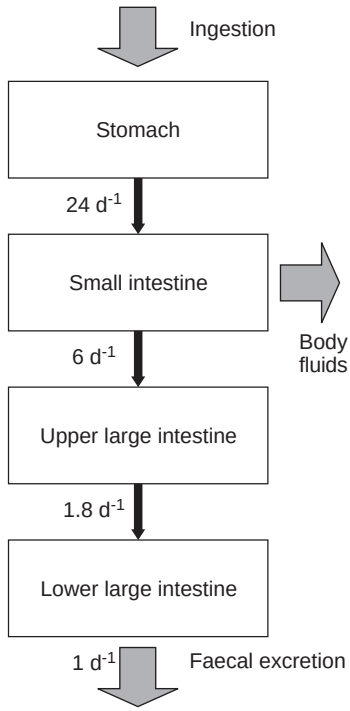

FIG. 1. Compartment model for the GI tract.

all ages. Since the total transit time in children is shorter than in adults [45], this may lead to some overestimation of the dose to the GI tract in children. The absorption of radionuclides into the blood from the GI tract (fractional absorption is referred to as f_1, also known as the gut transfer factor) is assumed to occur instantaneously, and only from the small intestine. The equivalent dose to the upper and lower large intestines includes that arising from radionuclides entering the GI tract from systemic circulation. Except where otherwise indicated, it is assumed that radionuclides lost in the faeces from systemic circulation are secreted into the upper large intestine.

The incorporation of radionuclides into foods may in general lead to greater availability for absorption from the GI tract. An Expert Group of the OECD Nuclear Energy Agency (OECD/NEA) [46] reviewed available data and proposed f_1 values for radiologically significant nuclides. These were adopted in most cases in ICRP Publications 56 [6], 67 [7] and 69 [8]. In accident situations, particularly in the short term, it is possible that a proportion of ingested radioactive material may be in an insoluble particulate form, for example on the surface of plants, and absorption may be lower than the recommended values. Where specific information is available on the physicochemical form of a radionuclide and its likely absorption, this should be used instead of the standard values. There is also evidence that the absorption of radionuclides tends to be greater in newborns, although animal studies suggest that the enhancement of gut transfer progressively decreases with increasing age, usually reaching adult values by about the time of weaning. The f_1 values for adults are therefore taken to apply in most cases to children of one year of age and older. The OECD/NEA Expert Group [46] recommended a general approach for estimating f_1 values for infants in the first year of life. For f_1 values between 0.01 and 0.5 in adults, an increase by a factor of two is assumed for the first year of life, but for elements with a fractional absorption in the adult of 0.001 or less, a value ten times the adult value is assumed. This approach was generally adopted by the ICRP [6–8], with the higher f_1 values used for calculating dose coefficients for the three month old infant. The f_1 values used by the ICRP and in the BSS [5] are shown in Table IV.

4.1.2. Distribution to tissues and excretion

Radionuclides absorbed from the GI tract into body fluids and circulated in blood are transferred to body tissues depending on their chemical nature. While this process is taking place, the radionuclides are regarded as being in the ‘transfer compartment’ and are assumed to be distributed uniformly throughout the whole body. Distribution and retention in body tissues may be age dependent, and in general retention half-times tend to be shorter at younger ages. For those radionuclides where sufficient data are available, this age dependence has been taken into account. If insufficient age specific data are available, adult biokinetic parameters are adopted for

TABLE IV. ICRP f_1[a] VALUES FOR MEMBERS OF THE PUBLIC

Element	Adult	Infant
H, C, I, Cs, S, Mo	1	1
Se	0.8	1
Zn, Tc, Po	0.5	1
Te, Sr[b]	0.3	0.6
Ba[b], Ra[b], Pb[b]	0.2	0.6
Co[b], Fe[b]	0.1	0.6
Sb	0.1	0.2
Ru, Ni, Ag	0.05	0.1
U	0.02	0.04
Zr, Nb	0.01	0.02
Ce, Th, Np, Pu, Am	0.0005	0.005

[a] f_1 is the fraction of the total activity of the radionuclide ingested that is absorbed to blood.

[b] Intermediate values for 1, 5, 10 and 15 year old children: Sr, Pb, 0.4; Co, Ra, Ba, 0.3; Fe, 0.2.

all ages. The age groups considered are 3 month old infants, 1 year, 5 year, 10 year and 15 year old children and adults (these age groups are given as ≤ 1 year, 1–2 years, 2–7 years, 7–12 years and 12–17 years old in the BSS).

Estimates of the overall proportions of urinary and faecal excretion are also given in the ICRP models for members of the public for most elements [6–8]. This ratio is not intended for the interpretation of bioassay measurements (see Section 5), but is necessary for dose calculations because the cancer risks from irradiation of the urinary bladder and the colon are considered explicitly in the new ICRP recommendations [47] (see Section 4.1.4). Age specific parameters for urine flow rates and the size of the bladder are used to calculate doses [7]. The fraction excreted in the faeces is assumed to pass through the large intestine. In practice these models are used to interpret bioassay measurements where no better information is available. For the alkaline earths and actinide elements, however, dynamic models have been introduced (see Section 4.1.3) which consider the time course of urinary and faecal excretion.

If a radionuclide has radioactive decay products, the contribution to dose from their buildup in the body is included. However, specific biokinetic data are given for these only when experimental evidence is available on their biological behaviour (e.g. iodine daughters of tellurium and the daughters of Pb, Ra, Th and U). In all other cases the biokinetic behaviour of the radioactive decay products is assumed to be the same as that of the parent radionuclide taken into the body.

4.1.3. Bone models

Calculating doses within the skeleton requires special attention because bone is a highly complex and heterogeneous tissue with cellular and mineral components. The absorbed dose from alpha and beta radiation will vary widely within the skeleton, depending on the site of deposition and the microscopic structure of the bone tissue at that point. The radiation sensitive parts of the skeleton are taken to be the red bone marrow and a layer of cells in the inner bone surface (endosteal cells) [44, 48, 49]. In adults, red bone marrow is contained exclusively in the trabecular or 'spongy' bone which constitutes, for example, the vertebrae and the ends of the long bones. Cortical or compact bone, which comprises the shafts of the long bones, contains only inactive fatty marrow in adults. The dosimetric model for the skeleton estimates doses to red bone marrow and endosteal surfaces, and also takes into account the different patterns of distribution of radionuclides in bone. Radionuclides are classified as bone surface or bone volume seekers according to their propensity to remain on endosteal surfaces or become distributed uniformly throughout bone mineral. Clearly, this will affect the doses received by the two target tissues from alpha and beta irradiation.

The assumptions of either surface or volume distribution of radionuclides in bone take no account of their movement between different skeletal components as a result of bone turnover and growth. In addition, the distribution of red marrow in bone changes with age, completely filling marrow spaces in young children and subsequently being progressively lost from cortical regions. Dynamic models for the skeleton developed by Leggett and his colleagues [50–53] have been adopted by the ICRP [6–8] for the main groups of bone seeking radionuclides, those of the alkaline earth elements (Ba, Ra and Sr) and the actinides (Pu, Am, Np, Th and U). The alkaline earth model is also used for lead. These models take into account the burial of surface deposits, transfer of radionuclides to marrow and recycling to the circulation and between organs.

4.1.4. Equivalent and effective dose

When the distribution of radionuclides in different body regions is known, the resulting distribution of the absorbed energy and absorbed dose, defined as absorbed energy per unit mass, can be calculated. For non-penetrating radiation, energy will in most cases be absorbed largely in the region in which the radionuclide is deposited. For penetrating radiation, however, it is necessary to take account of the cross-fire between tissues. This is done using a 'mathematical phantom' which describes the geometrical relationship between the different tissues and organs of the body (i.e. a phantom which can be described with simple mathematical equations). Such phantoms have been developed for persons of different ages [54]. Different mathematical methods, including Monte Carlo techniques, may then be used to

calculate the absorbed dose in a given organ from decays taking place in the same or another organ, making the assumption that the radionuclides in the source regions are homogeneously distributed. The values obtained are referred to as specific effective energy (SEE($T \leftarrow S$)) for a particular radionuclide expressing the energy absorbed in the tissue T per transformation in the source organ S.

To provide a tool for the interpretation of absorbed dose in different organs in terms of the total risk of cancer and hereditary effects, the ICRP uses the concepts of 'equivalent dose' and 'effective dose' [47, 49]. Radiation weighting factors take into account the relative biological effectiveness of different radiation types in causing malignancy or genetic damage. Thus, the absorbed dose in gray (Gy) (joules·kg^{-1}) is multiplied by a radiation weighting factor of 20 for alpha irradiation and 1 for beta and gamma irradiation to give the equivalent dose in sieverts. As discussed above, tissue doses are commonly integrated over a 50 year period for adults or to age 70 years for children, and the resulting values are referred to as 'committed equivalent doses'. Tissue weighting factors are attributed to different tissues and organs, taking into account the incidence of fatal cancer and hereditary effects, weighted for the incidence of non-fatal disease and years of life lost [47]. The committed effective dose is then the sum of all committed equivalent doses multiplied by the appropriate tissue weighting factors. The committed effective dose can be interpreted in terms of risk estimates for whole body exposure. It is applicable to workers and members of the public, including children.

The tissue weighting factors (w_T) specified by the ICRP in their 1990 recommendations [47] are given in Table V. These are rounded values, corresponding

TABLE V. ICRP TISSUE WEIGHTING FACTORS, w_T

Organ/tissue	Publication 60 [47]	Publication 26 [49]
Skin	0.01	
Bone surfaces	0.01	0.03
Thyroid	0.05	0.03
Liver	0.05	
Oesophagus	0.05	
Breast	0.05	0.15
Bladder	0.05	
Remainder	0.05	0.3
Lung	0.12	0.12
Red bone marrow	0.12	0.12
Stomach	0.12	
Colon	0.12	
Gonads	0.2	0.25
Total	1	1

to overall estimates of the risk of fatal cancer in the population of 0.05 Sv^{-1} and an estimate of total aggregated detriment of about 0.07 Sv^{-1}. It should be noted that the oesophagus and colon are assigned weighting factors, although the current dosimetric model for the GI tract does not include doses to these regions. As an approximation, therefore, doses to the oesophagus are taken to be the same as those to the thymus, and the colon is taken to be equivalent to the mass weighted average of doses to the upper and lower large intestine as defined in the dosimetric model of the GI tract. Also shown in Table V are the weighting factors used previously by the ICRP in 1977 [49], when cancer risk estimates were available for fewer organs, with none specified for regions of the GI tract. The earlier weighting factors corresponded to an estimated total risk of fatal cancer or serious hereditary disease in the first two generations of 0.0165 Sv^{-1}.

4.2. BIOKINETIC MODELS

The biokinetic data and models summarized below and the resulting dose coefficients (Table VI) are in all cases consistent with ICRP publications [6–8] and the BSS [5].

4.2.1. Hydrogen

Tritiated water and organically bound tritium (OBT) are considered separately. It is assumed that ingested tritiated water is instantaneously distributed uniformly throughout all body tissues and no allowance is made for delay in the GI tract [6, 44]. For OBT, as for other radionuclides, the ICRP model of the GI tract is used [44]. Complete absorption from the small intestine ($f_1 = 1$) is assumed.

For ^3H entering body fluids as tritiated water, doses to tissues are calculated assuming that 97% equilibrates with body water and is retained with a half-time of 10 d in adults (range 4–18 d). On the basis of animal data, the remaining 3% is assumed to be incorporated into organic molecules and retained with a half-time of 40 d. For ^3H absorbed following ingestion of OBT, the assumption made, based on the available animal data, is that 50% will be readily exchangeable with hydrogen from the body water pool and will therefore be retained with a half-time of 10 d in the adult. A half-time of 40 d is applied to the remaining 50%. On the basis of these assumptions and uniform distribution of retained ^3H, the equivalent dose to all body tissues from absorbed ^3H is the same and is about 2.5 times greater for OBT than HTO. The concentration of tritiated water in urine is assumed to be the same as in total body water, and urinary excretion is not assumed to result in a significant additional dose to the bladder wall.

TABLE VI. COMMITTED EFFECTIVE DOSES FOR INGESTION ($Sv \cdot Bq^{-1}$) FOR ADULTS, CHILDREN AND INFANTS

	3 months[a]	1 year[a]	5 years[a]	10 years[a]	15 years[a]	Adult[a]
^{3}H trit.	6.4×10^{-11}	4.8×10^{-11}	3.1×10^{-11}	2.3×10^{-11}	1.8×10^{-11}	1.8×10^{-11}
^{3}H org.	1.2×10^{-10}	1.2×10^{-10}	7.3×10^{-11}	5.7×10^{-11}	4.2×10^{-11}	4.2×10^{-11}
^{14}C	1.4×10^{-09}	1.6×10^{-09}	9.9×10^{-10}	8.0×10^{-10}	5.7×10^{-10}	5.8×10^{-10}
^{35}S inorg.	1.3×10^{-09}	8.7×10^{-10}	4.4×10^{-10}	2.7×10^{-10}	1.6×10^{-10}	1.3×10^{-10}
^{35}S org.	7.6×10^{-00}	5.3×10^{-09}	2.7×10^{-09}	1.6×10^{-09}	9.5×10^{-10}	7.8×10^{-10}
^{55}Fe	7.6×10^{-09}	2.4×10^{-09}	1.7×10^{-09}	1.1×10^{-09}	7.7×10^{-10}	3.3×10^{-10}
^{59}Fe	3.9×10^{-08}	1.3×10^{-08}	7.5×10^{-09}	4.7×10^{-09}	3.1×10^{-09}	1.8×10^{-09}
^{57}Co	2.9×10^{-09}	1.6×10^{-09}	8.9×10^{-10}	5.8×10^{-10}	3.7×10^{-10}	2.1×10^{-10}
^{58}Co	7.3×10^{-09}	4.4×10^{-09}	2.6×10^{-09}	1.7×10^{-09}	1.1×10^{-09}	7.4×10^{-10}
^{60}Co	5.4×10^{-08}	2.7×10^{-08}	1.7×10^{-08}	1.1×10^{-08}	7.9×10^{-09}	3.4×10^{-09}
^{59}Ni	6.4×10^{-10}	3.4×10^{-10}	1.9×10^{-10}	1.1×10^{-10}	7.3×10^{-11}	6.3×10^{-11}
^{63}Ni	1.6×10^{-09}	8.4×10^{-10}	4.6×10^{-10}	2.8×10^{-10}	1.8×10^{-10}	1.5×10^{-10}
^{65}Zn	3.6×10^{-08}	1.6×10^{-08}	9.7×10^{-09}	6.4×10^{-09}	4.5×10^{-09}	3.9×10^{-09}
^{75}Se	2.0×10^{-08}	1.3×10^{-08}	8.3×10^{-09}	6.0×10^{-09}	3.1×10^{-09}	2.6×10^{-09}
^{79}Se	4.1×10^{-08}	2.8×10^{-08}	1.9×10^{-08}	1.4×10^{-08}	4.1×10^{-09}	2.9×10^{-09}
^{89}Sr	3.6×10^{-08}	1.8×10^{-08}	8.9×10^{-09}	5.8×10^{-09}	4.0×10^{-09}	2.6×10^{-09}
^{90}Sr	2.3×10^{-07}	7.3×10^{-08}	4.7×10^{-08}	6.0×10^{-08}	8.0×10^{-08}	2.8×10^{-08}
^{95}Zr	8.5×10^{-09}	5.6×10^{-09}	3.0×10^{-09}	1.9×10^{-09}	1.2×10^{-09}	9.5×10^{-10}
^{95}Nb	4.6×10^{-09}	3.2×10^{-09}	1.8×10^{-09}	1.1×10^{-09}	7.4×10^{-10}	5.8×10^{-10}
^{99}Mo	5.5×10^{-09}	3.5×10^{-09}	1.8×10^{-09}	1.1×10^{-09}	7.6×10^{-10}	6.0×10^{-10}
^{99}Tc^{m}	2.0×10^{-10}	1.3×10^{-10}	7.2×10^{-11}	4.3×10^{-11}	2.8×10^{-11}	2.2×10^{-11}
^{99}Tc	1.0×10^{-08}	4.8×10^{-09}	2.3×10^{-09}	1.3×10^{-09}	8.2×10^{-10}	6.4×10^{-10}
^{103}Ru	7.1×10^{-09}	4.6×10^{-09}	2.4×10^{-09}	1.5×10^{-09}	9.2×10^{-10}	7.3×10^{-10}
^{106}Ru	8.4×10^{-08}	4.9×10^{-08}	2.5×10^{-08}	1.5×10^{-08}	8.6×10^{-09}	7.0×10^{-09}
^{108}Ag^{m}	2.1×10^{-08}	1.1×10^{-08}	6.5×10^{-09}	4.3×10^{-09}	2.8×10^{-09}	2.3×10^{-09}
^{110}Ag^{m}	2.4×10^{-08}	1.4×10^{-08}	7.8×10^{-09}	5.2×10^{-09}	3.4×10^{-09}	2.8×10^{-09}
^{124}Sb	2.5×10^{-08}	1.6×10^{-08}	8.4×10^{-09}	5.2×10^{-09}	3.2×10^{-09}	2.5×10^{-09}
^{125}Sb	1.1×10^{-08}	6.1×10^{-09}	3.4×10^{-09}	2.1×10^{-09}	1.4×10^{-09}	1.1×10^{-09}
^{126}Sb	2.0×10^{-08}	1.4×10^{-08}	7.6×10^{-09}	4.9×10^{-09}	3.1×10^{-09}	2.4×10^{-09}
^{127}Te^{m}	4.1×10^{-08}	1.8×10^{-08}	9.5×10^{-09}	5.2×10^{-09}	3.0×10^{-09}	2.3×10^{-09}
^{129}Te^{m}	4.4×10^{-08}	2.4×10^{-08}	1.2×10^{-08}	6.6×10^{-09}	3.9×10^{-09}	3.0×10^{-09}
^{131}Te^{m}	2.0×10^{-08}	1.4×10^{-08}	7.8×10^{-09}	4.3×10^{-09}	2.7×10^{-09}	1.9×10^{-09}
^{132}Te	4.8×10^{-08}	3.0×10^{-08}	1.6×10^{-08}	8.3×10^{-09}	5.3×10^{-09}	3.8×10^{-09}

	3 months[a]	1 year[a]	5 years[a]	10 years[a]	15 years[a]	Adult[a]
^{125}I	5.2×10^{-08}	5.7×10^{-08}	4.1×10^{-08}	3.1×10^{-08}	2.2×10^{-08}	1.5×10^{-08}
^{129}I	1.8×10^{-07}	2.2×10^{-07}	1.7×10^{-07}	1.9×10^{-07}	1.4×10^{-07}	1.1×10^{-07}
^{131}I	1.8×10^{-07}	1.8×10^{-07}	1.0×10^{-07}	5.2×10^{-08}	3.4×10^{-08}	2.2×10^{-08}
^{132}I	3.0×10^{-09}	2.4×10^{-09}	1.3×10^{-09}	6.2×10^{-10}	4.1×10^{-10}	2.9×10^{-10}
^{134}Cs	2.6×10^{-08}	1.6×10^{-08}	1.3×10^{-08}	1.4×10^{-08}	1.9×10^{-08}	1.9×10^{-08}
^{136}Cs	1.5×10^{-08}	9.5×10^{-09}	6.1×10^{-09}	4.4×10^{-09}	3.4×10^{-09}	3.0×10^{-09}
^{137}Cs	2.1×10^{-08}	1.2×10^{-08}	9.6×10^{-09}	1.0×10^{-08}	1.3×10^{-08}	1.3×10^{-08}
^{133}Ba	2.2×10^{-08}	6.2×10^{-09}	3.9×10^{-09}	4.6×10^{-09}	7.3×10^{-09}	1.5×10^{-09}
^{140}Ba	3.2×10^{-08}	1.8×10^{-08}	9.2×10^{-09}	5.8×10^{-09}	3.7×10^{-09}	2.6×10^{-09}
^{141}Ce	8.1×10^{-09}	5.1×10^{-09}	2.6×10^{-09}	1.5×10^{-09}	8.8×10^{-10}	7.1×10^{-10}
^{144}Ce	6.6×10^{-08}	3.9×10^{-08}	1.9×10^{-08}	1.1×10^{-08}	6.5×10^{-09}	5.2×10^{-09}
^{210}Pb	8.4×10^{-06}	3.6×10^{-06}	2.2×10^{-06}	1.9×10^{-06}	1.9×10^{-06}	6.9×10^{-07}
^{210}Po	2.6×10^{-05}	8.8×10^{-06}	4.4×10^{-06}	2.6×10^{-06}	1.6×10^{-06}	1.2×10^{-06}
^{224}Ra	2.7×10^{-06}	6.6×10^{-07}	3.5×10^{-07}	2.6×10^{-07}	2.0×10^{-07}	6.5×10^{-08}
^{226}Ra	4.7×10^{-06}	9.6×10^{-07}	6.2×10^{-07}	8.0×10^{-07}	1.5×10^{-06}	2.8×10^{-07}
^{228}Ra	3.0×10^{-05}	5.7×10^{-06}	3.4×10^{-06}	3.9×10^{-06}	5.3×10^{-06}	6.9×10^{-07}
^{228}Th	3.7×10^{-06}	3.7×10^{-07}	2.2×10^{-07}	1.5×10^{-07}	9.4×10^{-08}	7.2×10^{-08}
^{230}Th	4.1×10^{-06}	4.1×10^{-07}	3.1×10^{-07}	2.4×10^{-07}	2.2×10^{-07}	2.1×10^{-07}
^{232}Th	4.6×10^{-06}	4.5×10^{-07}	3.5×10^{-07}	2.9×10^{-07}	2.5×10^{-07}	2.3×10^{-07}
^{234}Th	4.0×10^{-08}	2.5×10^{-08}	1.3×10^{-08}	7.4×10^{-09}	4.2×10^{-09}	3.4×10^{-09}
^{232}U	2.5×10^{-06}	8.2×10^{-07}	5.8×10^{-07}	5.7×10^{-07}	6.4×10^{-07}	3.3×10^{-07}
^{233}U	3.8×10^{-07}	1.4×10^{-07}	9.2×10^{-08}	7.8×10^{-08}	7.8×10^{-08}	5.1×10^{-08}
^{234}U	3.7×10^{-07}	1.3×10^{-07}	8.8×10^{-08}	7.4×10^{-08}	7.4×10^{-08}	4.9×10^{-08}
^{235}U	3.5×10^{-07}	1.3×10^{-07}	8.5×10^{-08}	7.1×10^{-08}	7.0×10^{-08}	4.7×10^{-08}
^{236}U	3.5×10^{-07}	1.3×10^{-07}	8.4×10^{-08}	7.0×10^{-08}	7.0×10^{-08}	4.7×10^{-08}
^{238}U	3.4×10^{-07}	1.2×10^{-07}	8.0×10^{-08}	6.8×10^{-08}	6.7×10^{-08}	4.5×10^{-08}
^{237}Np	2.0×10^{-06}	2.1×10^{-07}	1.4×10^{-07}	1.1×10^{-07}	1.1×10^{-07}	1.1×10^{-07}
^{239}Np	8.9×10^{-09}	5.7×10^{-09}	2.9×10^{-09}	1.7×10^{-09}	1.0×10^{-09}	8.0×10^{-10}
^{238}Pu	4.0×10^{-06}	4.0×10^{-07}	3.1×10^{-07}	2.4×10^{-07}	2.2×10^{-07}	2.3×10^{-07}
^{239}Pu	4.2×10^{-06}	4.2×10^{-07}	3.3×10^{-07}	2.7×10^{-07}	2.4×10^{-07}	2.5×10^{-07}
^{240}Pu	4.2×10^{-06}	4.2×10^{-07}	3.3×10^{-07}	2.7×10^{-07}	2.4×10^{-07}	2.5×10^{-07}
^{241}Pu	5.6×10^{-08}	5.7×10^{-09}	5.5×10^{-09}	5.1×10^{-09}	4.8×10^{-09}	4.8×10^{-09}
^{241}Am	3.7×10^{-06}	3.7×10^{-07}	2.7×10^{-07}	2.2×10^{-07}	2.0×10^{-07}	2.0×10^{-07}

[a] The corresponding age intervals in the BSS are: ≤1 year, 1–2 years, 2–7 years, 7–12 years and 12–17 years old, respectively.

For children, half-times of retention lower than in adults have been calculated which take into account their smaller mass of total body water, together with values for the daily water balance based on their energy expenditure and, for the organically bound component, of carbon content and balance. For example, for a three month old infant, half-times of 3 and 8 d are applied to the same fractions as for adults. Despite the more rapid loss of ^{3}H from the body of children, doses are greater than for adults because the effect of smaller body mass dominates. For example, the committed effective dose to a one year old child from the ingestion of HTO is estimated to be about three times greater than the value for adults.

4.2.2. Carbon

For the ingestion of ^{14}C in foodstuffs by the public, organic forms are the most important. For all ^{14}C labelled organic compounds, including proteins, carbohydrates, fat and nucleic acids, the f_1 value is taken to be 1 for all ages.

There are indications of an increased rate of incorporation of ^{14}C into nucleic acids in metabolically active body tissues. However, it is not possible at present to take into account variations in the turnover of ^{14}C in different body tissues, so absorbed ^{14}C is assumed to be distributed uniformly throughout all tissues. The retention of ^{14}C is described by a single exponential function. The biological half-times are derived using values for the body content and daily balance of carbon, taken from ICRP Publication 23 [55]. The biological half-times used by the ICRP [6] increase with age from 8 d for a three month old infant to 40 d in adults.

Urinary excretion of ^{14}C is assumed not to result in a significant additional dose to the bladder wall and upper and lower large intestine wall. Because of this and the uniform distribution of carbon throughout all tissues, the equivalent doses for absorbed ^{14}C are the same for all organs and tissues. Committed effective doses are about four times greater in infants than in adults.

4.2.3. Sulphur

Human and animal data show almost complete absorption of ^{35}S ingested as amino acids or other organic compounds and this is taken to apply generally to ^{35}S incorporated in foodstuffs. A fractional absorption (f_1) of 1 is assumed for all ages.

In ICRP Publication 30 [56], it was assumed that of the sulphur reaching the circulation, a fraction of 0.8 is promptly excreted with a half-time of 0.25 d, and fractions of 0.15 and 0.05 are distributed uniformly within all organs and tissues and retained there with biological half-times of 20 d and 2000 d, respectively. In the absence of specific information on the biokinetics of the sulphur in children, these assumptions have been applied to all age groups [7]. For sulphur incorporated into amino acids and other organic forms of sulphur, rapid urinary excretion of a major

fraction of sulphur from blood would not be expected. For these compounds a uniform distribution throughout all organs and tissues with a retention half-time of 140 d is assumed. A urinary to faecal excretion ratio for sulphur of 9:1 is assumed [7].

Because of the uniform distribution of ^{35}S throughout the body, equivalent doses to most tissues are the same. The main exceptions are doses to the bladder and colon due to excretion. For example, the dose to the bladder in the adult is three times the dose to other tissues for intakes of inorganic forms of ^{35}S, but only 10% greater for intakes of organic forms. Committed effective doses for intakes of organic forms are about six times greater than those for inorganic forms. Values for three month old infants are about ten times greater than adult values in both cases.

4.2.4. Iron

An f_1 value of 0.1 is used for dietary intakes of iron in adults, recognizing that greater values may apply under particular circumstances, e.g. during pregnancy and iron deficient diets. Values for children are generally higher than those for adults, attributable in part to the relatively greater requirements for iron during growth and development. An f_1 value of 0.6 is assumed for three month old infants and 0.2 for children from 1 to 15 years of age.

After entering the circulation, most iron is transported to the red bone marrow, incorporated into haemoglobin in newly formed erythrocytes and rereleased to the circulation. Smaller amounts of iron are stored in other tissues, principally the liver. Iron from senescent red blood cells is transferred mainly to the red bone marrow, liver and spleen. Losses of iron from the body are largely due to exfoliation of cells from the skin and the GI tract, with smaller amounts in sweat, bile and urine. A model for the age dependent behaviour of iron in the body has been developed [8].

The greatest equivalent doses to tissues after ingestion of ^{55}Fe are to the spleen, liver, red bone marrow and bone surfaces. The committed effective dose for the three month old infant is about 20 times the value for adults.

4.2.5. Cobalt

An f_1 value of 0.3 for intakes of cobalt by adults was recommended in ICRP Publication 30 [44] and by the OECD/NEA [46]. Because human studies suggest that in most cases the fractional absorption of trace quantities of cobalt is less than 0.1, an f_1 of 0.1 has been recommended by the ICRP [7] for intakes of cobalt in foods by adults. For children from 1 to 15 years of age, an f_1 value of 0.3 was adopted, with a value of 0.6 for infants in the first year of life.

Following the entry of cobalt into the blood, a large fraction is rapidly excreted. On the basis of two studies of retention in humans, the ICRP [44] recommended a

model in which 50% of cobalt reaching the circulation is rapidly excreted with a half-time of 0.5 d, 5% is taken up by the liver and 45% is uniformly distributed in all other tissues. Fractions of 0.6, 0.2 and 0.2 are assumed to be lost from the liver and other tissues with biological half-times of 6, 60 and 800 d, respectively. Limited animal data on the effect of age on cobalt distribution and retention, reviewed by the ICRP [7], show no age dependence. The adult values have therefore been assumed to be valid for all ages. A urinary to faecal excretion ratio of 6:1 is assumed for cobalt that has entered the circulation.

Because of low absorption from the GI tract and rapid excretion of a large proportion after absorption, equivalent doses from ingested ^{60}Co in adults are greatest for the colon, resulting mostly from unabsorbed material. In children, because of greater absorption, doses to the colon are similar to doses to the liver. For the infant, the dose to the colon is less than the dose to the liver. The committed effective dose is about 16 times greater for the three month old infant than for adults.

4.2.6. Nickel

The ICRP [7, 57] recommended an f_1 value of 0.05 for nickel on the basis of human and animal data. An increase by a factor of two to 0.1 is recommended for infants in the first year of life [7, 46].

For nickel entering the circulation, it is assumed that a fraction of 0.68 is directly excreted with a half-time of 0.25 d, 0.02 is retained in the kidneys with a biological half-time of 0.2 d and 0.3 is distributed throughout all organs and tissues, including the kidneys, and retained with a half-time of 1200 d. In the absence of age dependent data, the same distribution and retention is assumed to apply to infants and children. A urinary to faecal excretion ratio of 20:1 is assumed for nickel that has entered the circulation.

Because of the largely uniform distribution of ^{63}Ni throughout the body, equivalent doses to most tissues are the same. The main exceptions are doses to the bladder and colon, due to excretion. For example, the equivalent dose to the colon in adults is about seven times greater than that to other tissues. The committed effective dose from ingestion of ^{63}Ni by three month old infants is ten times greater than the corresponding dose to adults.

4.2.7. Zinc

Human data on the gastrointestinal absorption of zinc indicate that dietary factors such as the presence of phytate or bran reduce uptake, while a beef diet increases uptake. On the basis of the available data, an f_1 value of 0.5 is used. In accordance with the general OECD/NEA [46] approach and consistent with the available animal data, absorption is taken to be doubled in the first year of life.

On the basis of the available human and animal data, it is assumed that 20% of zinc reaching the circulation is taken up by the skeleton and retained with a biological half-time of 400 d (97.5%) and 10 000 d (2.5%), respectively. The remainder is assumed to be uniformly distributed throughout all other organs and tissues, with 30% and 70% having biological half-times of 20 d and 400 d, respectively. It is assumed that, for calculating doses from ^{65}Zn, the element is uniformly distributed throughout the volume of mineral bone at all times after its deposition in the skeleton. For shorter lived isotopes of zinc it is assumed that they remain on bone surfaces. The limited available animal data reviewed by the ICRP [7] show no effect of age. Therefore these values have been assumed to be valid for all ages with the exception that the long term component for retention in bone is taken to be related to the rate of bone remodelling and has shorter half-times in children (100 d for three month old infants and 1000 d for ten year old children).

Equivalent doses to different tissues after ingestion of ^{65}Zn are similar, varying by up to a factor of about two. The committed effective dose to the three month old infant is an order of magnitude greater than that for the adult. A urinary to faecal excretion ratio of 1:4 is assumed for zinc that has entered the circulation [7].

4.2.8. Selenium

On the basis of the available animal data, an f_1 value of 0.8 is assumed for dietary intakes of selenium by adults. This value is also used for intakes by children from 1 to 15 years of age. An f_1 value of 1 is assumed for the three month old infant.

For selenium reaching the circulation, 25% is deposited in the liver, 10% in the kidneys, 1% in the spleen, 0.5% in the pancreas, 0.1% in testes and 0.02% in the ovaries, with the rest distributed throughout other tissues. Retention in body tissues is described by the sum of three components with half-times of 3 d (10%), 30 d (40%) and 200 d (50%).

The greatest equivalent doses to tissues after ingestion of ^{75}Se are to the kidneys and liver. The committed effective dose to the three month old infant is about eight times greater than the adult value.

4.2.9. Strontium

An f_1 value of 0.3 is assumed for strontium ingested in food by adults [6]. An f_1 value of 0.6, twice the adult value, is used for children in the first year of life, consistent with the OECD/NEA [46] approach and available data. For those aged 1–15 years, an intermediate value of 0.4 is assumed.

For strontium absorbed to body fluids, the age dependent model for alkaline earth elements developed by Leggett [53] has been adopted [7]. This model describes in detail the kinetics of alkaline earth elements in bone, which is the main site of

deposition and retention, and also considers retention in soft tissues and routes of excretion. It takes account of initial uptake onto bone surfaces, transfer from surface to bone volume and recycling from bone and soft tissues to blood. Age dependent parameters take account of greater uptake and retention during periods of rapid skeletal growth.

The committed effective dose for long lived strontium isotopes like ^{90}Sr is dominated by the contributions from the equivalent doses to bone surfaces and red bone marrow. Doses are greatest for three month old infants (about eight times the adult value) and one year old children because of their lower skeletal mass and high ^{90}Sr uptake during rapid bone growth. Doses are lower in older children and adults, but a peak value at 15 years of age similar to the dose for a one year old child corresponds to a renewal of rapid bone growth during adolescence. For ^{89}Sr, because of its shorter half-life (50.5 d compared with 29 years for ^{90}Sr) the committed effective dose has a larger contribution from the equivalent dose to the colon and is relatively insensitive to changes in bone remodelling rates.

4.2.10. Zirconium

An f_1 value of 0.01 is used for adults and for children of one year and older and a value of 0.02 for three month old infants [6].

It is assumed that 50% of systemic zirconium is retained in the skeleton with a half-time in the adult of 10 000 d, and that the other 50% is distributed throughout all other tissues and is retained with a biological half-time of 7 d. Zirconium is considered to be distributed uniformly over bone surfaces. Retention in the skeleton is taken to be related to the rate of bone remodelling with shorter half-times in children (1000 d for 10 year olds, 100 d for three month old). A urinary to faecal excretion ratio of 5 : 1 is assumed for systemic zirconium.

Committed effective doses for ingestion of ^{95}Zr are greatest for infants with values about nine times greater than in adults. Because of the low absorption of ingested Zr, the greatest equivalent doses are to the colon from unabsorbed material.

4.2.11. Niobium

An f_1 value of 0.01 is assumed for the ingestion of niobium in food by adults. This value is also applied to children of one year and older, while for a three month old infant, an f_1 value of 0.02 is adopted.

On the basis of the available animal data, the deposition fractions for systemic niobium assumed for adults are 0.4 for mineral bone, 0.2 for the liver, 0.03 for kidneys, and 0.37 for all other tissues [6]. The deposition fraction in the skeleton is increased for infants and children to 0.6 (three month old infants) and 0.5 (one and five year old children). The distribution in the remaining tissues is similar to that in

adults. The retention is described by a two component exponential function for all tissues and organs, with biological half-times of 6 d (0.5) and 200 d (0.5). In the skeleton ^{95}Nb is assumed to be distributed over bone surfaces. A urinary to faecal excretion ratio of 5 : 1 is assumed for niobium that has entered the transfer compartment [7].

Committed effective doses from ingested ^{95}Nb are about eight times greater for three month old infants than for adults. Because of its low absorption and relatively short physical half-life (35 d), the greatest equivalent doses are to the colon from unabsorbed ^{95}Nb.

4.2.12. Molybdenum

Experimental data for animals show a wide variation in the absorption of ingested molybdenum. An f_1 value of 1 is assumed for dietary intakes of molybdenum at all ages [7].

For absorbed molybdenum, 10% is assumed to be deposited in the skeleton and retained with a half-time of 10 000 d in adults related to the rate of bone remodelling. The remaining 90% of absorbed molybdenum is distributed to the liver (25%), kidneys (5%) and throughout other soft tissues (60%). For molybdenum retained in tissues other than the skeleton, fractions of 0.1 and 0.9 are assumed to be retained with half-times of 1 and 50 d, respectively. A urinary to faecal excretion ratio of 8 : 1 is assumed for systemic molybdenum.

The greatest equivalent doses to tissues after ingestion of ^{99}Mo (half-life of 66 h) are to the kidneys, liver and bone surfaces. The committed effective dose to the three month old infant is a factor of nine times greater than the adult value.

4.2.13. Technetium

Technetium as pertechnetate is readily absorbed from the gut. On the basis of the available animal and human data, an f_1 value of 0.8 was proposed by the OECD/NEA [46]. Animal experiments show that technetium in food is less readily absorbed than pertechnetate, and therefore an f_1 value of 0.5 is considered to be more appropriate for dietary intakes [7]. For infants in the first year of life, an f_1 of 1 is adopted.

The model recommended by the ICRP [7] for the distribution and retention of technetium assumes that 0.04 of technetium reaching the circulation is taken up by the thyroid gland and retained with a half-time of 0.5 d. Further fractions of 0.1 and 0.03 are assumed to be translocated to the stomach wall and liver, respectively, and the remaining fraction is assumed to be uniformly distributed in all other tissues. Biological half-times for the retention of technetium in all tissues other than the thyroid are taken to be 1.6, 3.7 and 22 d applying to fractions of 0.75, 0.2 and 0.05,

respectively. The biological half-time in blood is assumed to be 0.02 d. A urinary to faecal excretion ratio of 1:1 is assumed. In the absence of specific information on the effect of age, this model is applied to children of all ages [7].

The committed effective dose from ingestion of ^{99}Tc is dominated by the contribution from equivalent doses to the stomach wall, colon and thyroid. The committed effective dose to the three month old infant is about 16 times greater than that for adults.

4.2.14. Ruthenium

An f_1 value of 0.05 is considered to be appropriate for ruthenium in food and drinking water ingested by adults and children from one year of age. For infants in the first year of life, a value of 0.1 is adopted [6].

For ruthenium absorbed to body fluids, animal data have shown that the subsequent tissue distribution is fairly uniform. Biological half-times of 8 d (35%), 35 d (30%) and 1000 d (20%) have been derived from these data for adult animals, with 15% of systemic activity being assumed to be excreted directly with a biological half-time of 0.3 d. A urinary to faecal excretion ratio of 4 : 1 is assumed for systemic ruthenium.

In the absence of information on the effect of age on tissue distribution and retention, greater committed effective doses for the ingestion of ^{103}Ru or ^{106}Ru by younger children are due solely to their lower body mass. The value of the committed effective dose for the three month old infant also takes into account the increased gut transfer. However, the increase in f_1 from 0.05 to 0.1 results in only a small increase in committed effective dose because 70–80% in each case is due to equivalent doses to the colon from unabsorbed ^{103}Ru and ^{106}Ru.

4.2.15. Silver

The gastrointestinal absorption of silver in adults is taken to be 0.05 on the basis of limited data from monkeys, mice, rats and dogs [7, 56]. An increase by a factor of two to 0.1 is taken to apply to the first year of life.

Silver accumulates mainly in the liver. On the basis of the available human and animal data, it is assumed that 0.5 of silver reaching the circulation is taken up by the liver and the other 0.5 is distributed throughout all other tissues and organs, including the skeleton. Biological half-times in all tissues are taken to be 3.5, 50 and 500 days applying to fractions of 0.1, 0.8 and 0.1, respectively. A urinary to faecal excretion ratio of 1 : 20 is assumed for systemic silver.

The greatest equivalent dose to tissues from ingested ^{110}Ag^{m} are for the colon and liver. The committed effective dose for the three month old infant is about nine times greater than for the adult.

4.2.16. Antimony

Variable results have been reported for the absorption of antimony from the GI tract in experimental animals. A value of 0.1 is used for absorption by adults [7]. Limited experimental data for rats support the use of a value of 0.2 for infants.

On the basis of animal data and information on the body content of stable antimony in humans, it is assumed that of the antimony entering the circulation, a fraction 0.2 is rapidly excreted, 0.4 is taken up by mineral bone, 0.05 by the liver and the remaining fraction of 0.35 is uniformly distributed throughout all other organs. For all tissues, fractions of 0.85, 0.1 and 0.05 are assumed to be retained with biological half-times of 5, 100 and 5000 d, respectively. The limited available animal data indicate that whole body retention of antimony is independent of age. The same distribution and retention parameters are therefore applied to infants and children. Radioisotopes of antimony retained in the skeleton are assumed to be uniformly distributed on bone surfaces.

The greatest equivalent doses to tissues from ingested ^{125}Sb are for the bone surfaces, colon and red marrow. The committed effective dose for the three month old infant is ten times the adult value.

4.2.17. Iodine

Iodine absorption from the GI tract is rapid and virtually complete. An f_1 value of 1.0 is applied to intakes of iodine in food and water at all ages [6].

The biokinetic model for iodine assumes that of the iodine reaching blood a fraction of 0.3 is accumulated in the thyroid gland and 0.7 is excreted directly in the urine with a half-time of 0.25 d [6]. Iodide incorporated into thyroid hormones leaves the gland with a half-time of about 80 d in the adult and enters other tissues where it is retained with a half-time of 12 d. Most iodide (80%) is subsequently released and is available in the circulation for uptake by the gland and urinary excretion; the remainder (20%) is excreted in the faeces in organic form. Information on age related changes in the retention of radioiodine in the thyroid and in the other tissues is taken into account. The limited data available indicate that the turnover of iodine decreases with increasing age. Shorter biological half-times in the thyroid and in other tissues have therefore been adopted for children and infants.

The dose from isotopes of iodine is delivered very largely to the thyroid, with much lower doses to other tissues (differences of up to four orders of magnitude). For the long lived isotope ^{129}I (half-life of 1.6×10^7 a), the reduction in dose at younger ages due to shorter biological half-times counteracts the effect of a smaller thyroid mass which leads to similar committed effective doses for three month old infants and one, five and ten year old children, with slightly lower values for 15 year old children and adults. For ^{131}I, because of its shorter half-life (8 d), the effect of changes in

retention times is reduced and the dominant factor determining the age dependence of doses is the thyroid mass. Doses therefore show a progressive increase with decreasing age, with about an order of magnitude difference between adults and three month old infants.

There is a great variation in different regions in the uptake of iodine by the thyroid gland, according to the availability of stable iodine in the diet. However, because reduced intake results in a compensatory increase in the mass of the thyroid, the effect on the concentration of ^{129}I or ^{131}I in the thyroid and the committed equivalent dose to the thyroid is not very large. The uptake of radioactive iodine by the thyroid can be reduced to a large extent by the administration of stable iodine.

4.2.18. Tellurium

The f_1 value for tellurium in food, based on measurements in animals, is taken to be 0.3 [7]. An increase by a factor of two to 0.6 is assumed for the first year of life.

On the basis of animal and human data on the distribution and retention of tellurium, 50% of tellurium reaching the circulation is assumed to be directly excreted with a half-time of 0.8 d; 25%, 0.2% and 2.3% are taken up by the skeleton, thyroid and kidneys, respectively, and the remainder, 22.5%, is distributed throughout all other tissues [7]. The biological half-times assumed are 10 000 d for retention in the skeleton and 20 d for retention in all other tissues. Tellurium in bone is assumed to be deposited on bone surfaces. A urinary to faecal excretion ratio of 4:1 is assumed for systemic tellurium.

It is assumed that all iodine produced by the decay of tellurium isotopes in the body is translocated instantaneously to systemic circulation in organic form and has the same biokinetic behaviour as systemic iodine (see Section 4.2.14). Therefore, the committed equivalent dose to the thyroid is high for some isotopes of tellurium.

The greatest equivalent doses to tissues for ingestion of ^{127}Te^{m} are to bone surfaces. For ^{132}Te, because of its decay to ^{132}I, the equivalent dose to the thyroid is greatest, contributing 40–70% of the committed effective dose. The committed effective dose to the three month old infant for ingestion of ^{132}Te is 12 times greater than that for adults.

4.2.19. Caesium

Soluble forms of caesium are virtually completely absorbed from the GI tract. There is some evidence from human studies, such as post-Chernobyl studies by Henrichs [58], that absorption from food may not always be complete, but an f_1 value of 1 is adopted for all ages [6].

Caesium is distributed uniformly throughout all body tissues and retained there with biological half-times of 2 d (0.1) and 110 d (0.9), respectively [6, 44]. The

biological half-times for females, however, are significantly smaller than those for males (average values of less than 70 d instead of 110 d). There is also evidence that in some countries the mean biological half-time of caesium in adult males is shorter than 110 d [59, 60]. Thus the use of a value of 110 d for the biological half-time in adults will result in conservative estimates of effective dose. There is good evidence that the rates of loss of caesium from the body are greater in children than adults, and shorter biological half-times have therefore been used for children [61]. A urinary to faecal excretion ratio of 4:1 is assumed.

Because of the uniform distribution of caesium in the body, equivalent doses to all tissues after ingestion of ^{137}Cs are very similar. In general, the shorter biological half-times at younger ages counteract the effect of lower body mass, resulting in values of dose that are largely independent of age; only doses for the three month old infant are increased significantly, by about a factor of two, owing to a longer biological half-time (16 d) compared with that for the one year old child (13 d).

4.2.20. Barium

The f_1 value adopted for barium in food is 0.2, as for radium [7]. A value of 0.6 is used for infants and 0.4 for 1–15 year old children.

Barium absorbed to the circulation, like strontium and radium, behaves qualitatively in the same way as calcium. The biokinetic model used for strontium [6, 7] (see Section 4.2.9) is applied to the other alkaline earth elements using element specific parameters for uptake and retention in bone and other tissues.

For the long lived isotope ^{133}Ba (half-life 10.7 a), changes in bone remodelling and growth with age result in changes in equivalent doses to bone surfaces and red marrow such that, as for ^{90}Sr, the committed effective dose is greatest in infants, reduces progressively with age, but shows a peak at age 15 similar to the dose for the one year old child. For the short lived isotope ^{140}Ba (half-life 12.7 d), the committed effective dose has a larger contribution from the equivalent dose to the colon and is relatively insensitive to changes in bone remodelling. For both ^{133}Ba and ^{140}Ba, the committed effective dose to the three month old infant is 12–14 times greater than adult values.

4.2.21. Cerium

By analogy with the trivalent actinide elements, an f_1 value of 5×10^{-4} is considered to be appropriate for cerium ingested in food and water by adults and children from one year of age [7]. For infants in the first year of life, a value of 5×10^{-3} is adopted, taking into account measurements of increased absorption in rats, mice and pigs.

On the basis of measurements of the distribution of cerium in rats and dogs, it is assumed that of cerium entering the circulation in adults, fractions of 0.3, 0.5 and 0.2 are taken up by the skeleton, liver and other tissues, respectively, and retained in each case with a biological half-time of 3500 d. It appears that skeletal uptake is greater in younger animals. Thus, the initial distribution to the skeleton and liver is taken to be 0.7 and 0.1, respectively, in three month old infants, 0.5 and 0.3, respectively, in one and five year old children and 0.4 in both tissues for 10 and 15 year old children. A urinary to faecal excretion ratio of 1:9 is assumed for systemic cerium.

For ingestion of ^{144}Ce, the equivalent doses to the colon are highest for all ages, contributing about 90% or more to the committed effective dose. The committed effective dose for the three month old infant is about 13 times greater than the adult value.

4.2.22. Lead

An f_1 value of 0.2 is assumed for intakes of lead in food by adults [7]. Greater values are recommended for infants and children on the basis of human and animal data: 0.6 for a three month old infant and 0.4 for 1–15 year old children.

To model the biokinetics of lead, a modification of the age dependent alkaline earth model of Leggett [53] has been used. As well as considering uptake and retention in bone, the model is adapted for lead to include red blood cells as a separate compartment, to consider excretion via sweat and hair and to include two compartments for both the liver and kidneys. The model takes account of recognized differences in the time dependent distribution of lead and the alkaline earth elements.

The radioactive progeny of lead radioisotopes produced in bone volume are assumed to follow the behaviour of the parent radionuclide until removed from the bone volume. Outside the bone volume, the isotopes of bismuth and polonium produced inside the body by the decay of lead isotopes have their own biokinetic behaviour.

The greatest equivalent doses to tissues for the ingestion of ^{210}Pb are to bone surfaces, the kidneys and liver. The committed effective dose for the three month old infant is about 12 times greater than that for adults.

4.2.23. Polonium

The f_1 value for dietary forms of polonium is taken to be 0.5 on the basis of limited data for absorption in humans [7]. A factor of two increase to 1 is assumed for the first year of life.

On the basis of human and animal data, it is assumed that of the total quantity of polonium entering the circulation, fractions of 0.3, 0.1, 0.05, 0.1 and 0.45 are taken up by the liver, kidneys, spleen, red bone marrow and all other tissues, and retained

in all tissues with a biological half-time of 50 d [7]. A urinary to faecal excretion ratio of 1:2 is assumed for polonium that has entered the circulation.

The greatest equivalent doses to tissues from the ingestion of ^{210}Po are to the kidneys, spleen and liver. The committed effective dose for the three month old infant is about 18 times that for the adult.

4.2.24. Radium

The f_1 value for radium in foods is taken to be 0.2 on the basis of human and animal data [7]. Greater values are assumed for infants and children: 0.6 for three month old infants and 0.4 for 1–15 year old children.

Radium absorbed to the circulation, like strontium and barium, behaves qualitatively in the same way as calcium. The biokinetic model used for strontium [7] (see Section 4.2.9) is applied to the other alkaline earth elements using element specific parameters for uptake and retention in bone and other tissues. Isotopes of other elements produced in the body by the decay of radium isotopes are considered to have their own biokinetic behaviour depending on the site where they have been produced.

The committed effective dose for ingestion of ^{226}Ra, as for ^{90}Sr, is dominated by the contribution from the equivalent doses to bone surfaces and red bone marrow. Doses are greatest for three month old infants (17 times the adult value) and one year old children because of their lower skeletal mass and high ^{226}Ra uptake during rapid bone growth. Doses are lower in older children and adults, but a peak value at 15 years of age, similar to the dose for a one year old, corresponds to a renewal of rapid bone growth during adolescence.

4.2.25. Thorium

On the basis of measurements of the absorption of thorium and other actinide elements in human volunteers, together with the available animal data, an f_1 value of 5×10^{-4} is assumed for intakes of thorium in food by adults [7]. This value is applied, in the absence of specific information, to children from one year of age. For infants in the first year of life, a value of 5×10^{-3} is used.

For thorium absorbed to body fluids, as for plutonium, the main sites of deposition are the liver and skeleton. As discussed for plutonium (see Section 4.2.28), an actinide model is used which takes into account the redistribution of elements between and within tissues, particularly bone, and loss by excretion [7]. The model uses element specific data for transfer rates. Isotopes of other elements produced in the body by the decay of thorium isotopes are considered to have their own biokinetic behaviour depending on the site where they have been produced.

The committed effective dose from the ingestion of ^{230}Th or ^{232}Th is due largely to doses received by bone surfaces, red bone marrow, the liver and kidneys

and gonads. For infants, the greater f_1 value of 5×10^{-3} results in a proportional increase in doses. The committed effective dose for the three month old infant is about 15 times greater than that for the adult. Committed effective doses for intakes by children of one year of age and older differ by less than a factor of two because greater doses due to lower skeletal mass at younger ages are counteracted by shorter retention half-times. For ^{228}Th, because of its relatively short half-life (1.9 a), the effect of changes of retention half-time with age is less important and the committed effective dose for the one year old is about five times greater than adult values.

4.2.26. Uranium

On the basis of the available human data, an f_1 value of 0.02 is used for dietary intakes of uranium by adults and is also applied to children from one year of age [8]. A value of 0.04 is applied to infants.

The principal site of retention of uranium in the body is the skeleton. Because uranium tends to follow the qualitative behaviour of calcium to a large extent with regard to its behaviour in bone, the model used for the alkaline earth elements is applied to uranium, using data for transfer rates specific for uranium (see strontium, Section 4.2.9). Isotopes of other elements produced in the body by the decay of uranium isotopes are considered to have their own biokinetic behaviour depending on the site where they have been produced.

The greatest committed equivalent doses for the ingestion of ^{234}U, ^{235}U or ^{238}U are to the bone surfaces, red bone marrow, the kidneys and liver. The committed effective dose for the three month old infant is about seven times greater than that for the adult.

4.2.27. Neptunium

On the basis of measurements of the absorption of neptunium and other actinide elements in human volunteers, together with the available animal data, an f_1 value of 5×10^{-4} is assumed for intakes of neptunium in food by adults [7]. This value is applied, in the absence of specific information, to children from one year of age. For infants in the first year of life, a value of 5×10^{-3} is used.

For neptunium absorbed to body fluids, as for plutonium, the main sites of deposition are the liver and skeleton. As discussed for plutonium (Section 4.2.28), an actinide model is used which takes into account the redistribution of elements between and within tissues, particularly bone, and loss by excretion [7]. The model uses element specific data for transfer rates.

The committed effective dose from the ingestion of ^{237}Np is due largely to doses received by bone surfaces, red bone marrow, liver and gonads. For infants, the greater f_1 value of 5×10^{-3} results in a proportional increase in doses. The committed effective dose for the three month old infant is about 15 times greater than that for the

adult. Committed effective doses for intakes by children of one year of age and older differ by less than a factor of two because greater doses due to lower skeletal mass at younger ages are counteracted by shorter retention half-times.

4.2.28. Plutonium

On the basis of measurements of absorption of plutonium and other actinide elements in human volunteers, together with the available animal data, an f_1 value of 5×10^{-4} is assumed for intakes of plutonium in food by adults [7]. This value is applied, in the absence of specific information, to children from one year of age. For infants in the first year of life, a value of 5×10^{-3} is used.

For plutonium absorbed to body fluids, the main sites of deposition are the liver and skeleton. Leggett and his colleagues have developed an actinide model, adopted by the ICRP, which takes into account bone remodelling and the recycling of elements from the skeleton and soft tissues to body fluids [7, 50–52]. The movement of plutonium and other actinides within the skeleton is modelled, taking into account the burial of initial surface deposits and transfer from surfaces and bone volume to the marrow. The model also applies to children, taking into account the greater initial deposition on bone surfaces and greater bone turnover.

The committed effective dose from the ingestion of ^{239}Pu is due largely to doses received by bone surfaces, red bone marrow, the liver and gonads. The dose for infants takes into account the greater gut transfer of 5×10^{-3}, compared with 5×10^{-4} for children of one year of age and older. This results in a proportional increase in the doses to the skeleton, liver and gonads. The committed effective dose for the three month old infant is about 17 times greater than that for the adult. Committed effective doses for intakes by children of one year of age and older differ by less than a factor of two.

4.2.29. Americium

On the basis of measurements of the absorption of americium and other actinide elements in human volunteers, together with the available animal data, an f_1 value of 5×10^{-4} is assumed for intakes of americium in food by adults [7]. This value is applied, in the absence of specific information, to children from one year of age. For infants in the first year of life, a value of 5×10^{-3} is used.

For americium absorbed to body fluids, as for plutonium, the main sites of deposition are the liver and skeleton. As discussed for plutonium, an actinide model is used which takes account of the redistribution of elements between and within tissues, particularly bone, and loss by excretion [7]. The model uses element specific data for transfer rates. The overall half-time of retention in the liver is shorter for americium than for plutonium, while overall retention in bone is the same.

The committed effective dose from ingestion of ^{241}Am, as for ^{239}Pu, is due largely to doses received by bone surfaces, red bone marrow, the liver and gonads. For infants, the greater f_1 value of 5×10^{-3} results in a proportional increase in doses. The committed effective dose for the three month old infant is about 18 times greater than that for the adult. Committed effective doses for intakes by children of one year of age and older differ by less than a factor of two because greater doses due to lower skeletal mass at younger ages are counteracted by shorter retention half-times.

4.2.30. Dose coefficients

Table VI gives values of committed effective dose for the ingestion of the main isotopes of the elements considered above, for adults, children and infants. The values are expressed as Sv per Bq ingested. Annex II tabulates committed equivalent tissue doses, in the same units, for ingestion of the same radionuclides by adults.

4.3. UNCERTAINTIES AND VARIABILITY IN DOSE ESTIMATES

For ingested radionuclides, a major source of uncertainty is absorption from the GI tract. The f_1 values used will in some cases be based on measurements of absorption in animals with little or no human data available. The chemical form of the radionuclide may not be known and the recommended f_1 value may not be applicable. This will apply, for example, when insoluble particulate materials containing radionuclides are ingested as surface contamination on vegetables. Variations in absorption between individuals may be large for some radionuclides, particularly those of elements for which absorption is affected by dietary constituents. Uncertainties in biokinetic models will depend on whether human data are available and on the quality of animal data. For many elements, model parameters are based on measurements in animals and adult models are applied to children in the absence of age specific information. Variation between individuals will depend on the element concerned and dose estimates will also be subject to variations due to the normal distribution of body and organ sizes in each age group. Quantitative information for the radionuclides ^{131}I, ^{137}Cs and ^{239}Pu is presented below.

4.3.1. Iodine

The most important isotope of iodine is normally ^{131}I. As discussed in Section 4.2.17, the committed effective dose from ^{131}I is dominated by the dose to the thyroid. This isotope has a relatively short physical half-life (8 d) compared with the biological half-life, and as a result the variability in the period of retention has a small effect on the dose, particularly in the case of adults. The main factors which will

affect the variability in dose coefficients are the mass of the thyroid gland and the fractional uptake of iodine by the thyroid. ICRP Publication 23 [55] presents data on the mass of the thyroid, but does not give standard deviations or other measures of the variability of the thyroid mass. However, Dunning and Schwarz [62] reviewed the data and concluded that the distribution is approximately log normal. The 95% confidence interval is spanned by a factor between 6 and 7 and the upper 95th percentile is about 2–2.5 times the mean. The same authors have investigated the variability in fractional uptake by the thyroid. This was also found to be log normally distributed. Here the 95% confidence limit spanned a factor of 3–4 for one year old children and for adults and a factor of 5–6 for ten year old children. The upper 95th percentile was about twice the mean for all ages. When the contributions from thyroid mass and from fractional uptake are combined, the 95% confidence intervals for dose coefficients span about an order of magnitude for all three age groups considered here. The upper 95th percentile of the distribution is higher than the mean by a factor of 2–3. Correlation between the uptake of iodine and the mass of the thyroid, for which there is some evidence, will decrease the overall variability in dose.

4.3.2. Caesium

Ingested caesium is assumed to be completely absorbed from the GI tract. It is possible that absorption may be significantly lower depending on the chemical form and dietary constituents. Henrichs [58] reported measurements of the uptake of ^{137}Cs in ten volunteers following the consumption of venison contaminated as a result of the Chernobyl accident and obtained values of fractional absorption from about 0.6 to 0.9 (mean 0.8). In similar experiments, however, Tracy et al. [63] measured ^{137}Cs absorption in seven volunteers who consumed caribou meat; a combination of faecal and whole body measurements gave absorption values between 0.97 and 0.99.

For absorbed caesium, taken to be uniformly distributed throughout the body, the sources of variability are the retention half-times and body mass. Leggett [61, 64] presented data on retention in 19 adult males. Using these data, the half-time in the short term compartment was calculated to be 1.3 ± 0.7 d (mean ± standard deviation (SD)) and that in the long term compartment 98 ± 30 d. The fraction clearing with the shorter half-time was 11.3 ± 4.2%. Monte Carlo techniques were used to calculate the resulting variability in dose coefficients. It was assumed here that all the data points considered by Leggett carried the same weight and that the parameters entering into the calculation were independent. Neither assumption is strictly true, but they probably do not affect the conclusion that variability in retention results in a variability of one quarter to one third in dose coefficients for ^{134}Cs and ^{137}Cs. The coefficient of variation for the body mass of adult males is about 15% [55]. There is some evidence for a correlation between body mass and retention times for caesium [65], so a reasonable estimate for the coefficient of variation for these long lived

isotopes of caesium might be one third for adult males. This estimate is in reasonable agreement with those of Schwarz and Dunning [66] and Henrichs and Paretzke [67]. There are few published data on retention in women and children, but it is probably not unreasonable to assume that the coefficient of variation is similar to that for adult males.

4.3.3. Plutonium

The main factors affecting doses from the ingestion of plutonium isotopes are the f_1 value, the deposition in individual organs and retention times in these organs, and the fraction of the alpha energy which is absorbed by sensitive cells. Differences in diet and the chemical form ingested can affect absorption. Human volunteer studies in which plutonium was ingested as ^{244}Pu citrate, ^{239}Pu in winkles and ^{239}Pu in reindeer meat gave f_1 values in the range of 10^{-4} to 10^{-3}. These and other data provided the basis for the recommendation by the ICRP of an f_1 value of 5×10^{-4} for intakes in food or as unidentified chemical forms by adults and children from one year of age [7, 68–71]. The ICRP also recommends specific values of 10^{-4} for plutonium nitrate (and related forms) and 10^{-5} for oxides [44, 72]. Given the uncertainty associated with the chemical form of material likely to be ingested with food, a range of 10^{-5} to 10^{-3} might reasonably be assumed unless specific information was available.

The variability in the fractions of plutonium and americium retained in different body tissues has been considered by Kathren et al. [73] using autopsy data. For the 43 cases for which data were analysed, the fractional retention was about 0.45 ± 0.2 (mean ± SD) for the liver and about 0.55 ± 0.2 for the skeleton. If this distribution is taken to apply to 90% of plutonium reaching the circulation, as in the ICRP model [44, 72], the deposition fractions would be about 0.4 (range 0.2–0.6) for the liver and 0.5 (range 0.3–0.7) for the skeleton. The analyses of autopsy data on which half-times of retention in the liver and skeleton were based do not allow the associated ranges to be simply defined. Excretion data for human subjects given plutonium intravenously suggest that the overall half-time in the body is about 40–100 years [72]. On the basis of the available data, it would appear reasonable to assume ranges of about 10–40 years for the liver and 25–100 years for the skeleton.

The ICRP [44, 72] values for actinide uptake by the gonads of 3.5×10^{-4} for testes and 1.1×10^{-4} for ovaries were based on a review by Richmond and Thomas [74], who concluded that plutonium deposition was about 10^{-5} per gram of gonadal tissue. The available data suggest that a reasonable assumption for the range in uptake might be an order of magnitude for both ovaries and testes. The ICRP [44, 72] assumption of infinite retention in the gonads is based on observations of the long term retention of plutonium in testes and ovaries, with no appreciable loss of activity in a number of species including rats and dogs. However, a retention half-time of one year has been reported for plutonium in the testes of the Macaque

monkey [75]. Females of the same species similarly showed a half-time of retention of about one year for a residual component of activity after rapid clearance of the major fraction.

Taking into account all sources of uncertainty and arbitrarily assuming normal distributions, the 95% confidence interval for the dose coefficients for plutonium isotopes spans about an order of magnitude. The upper 95th percentile lies about a factor of two above the mean.

4.4. DOSES TO THE EMBRYO/FOETUS

Intakes of radionuclides before or during pregnancy may lead to irradiation of the foetus (taken here for brevity to apply to the embryo and foetus). There is as yet no international consensus on a scheme for calculating foetal doses, although this is within the remit of the ICRP Task Group on age dependent dosimetry, and a report is being prepared.

In developing foetal models, a number of problems have to be considered. The foetus will take up material from maternal blood. Shortly after conception the placenta begins to form, controlling the transfer of materials to the foetus with the likely result in many cases that concentrations of radionuclides in the foetus will be lower than in the mother. Less commonly, and particularly late in gestation, there is evidence in the case of some radionuclides of higher concentrations in the foetus than in the mother. Little is known about the processes of transfer across the human placenta and estimates rely largely on animal data. However, different mammalian species have different types of placenta and care is therefore needed in extrapolating to humans.

In addition to the direct transfer of radionuclides to the foetus for intakes during pregnancy, mobilization of nuclides from maternal tissues may also occur and is, of course, the only source after intakes prior to conception.

The foetus grows very rapidly, increasing from a single cell at conception to about 10^9 cells at birth, when the infant weighs about 3.5 kg. This rapid growth will in general reduce radionuclide concentrations and tend to reduce foetal doses, although this dilution is to some extent offset by continuing transfer from maternal tissues. The importance of different cell types will change during development and consequences may therefore depend considerably on the stage at which an intake occurs. Differences in the rate of development in different mammalian species need to be taken into account in the use of animal data.

The general approach being adopted by the ICRP in estimating in utero doses is to assume that the dose to the embryo up to eight weeks can be taken to be equal to the dose to the uterus, and to use foetus: mother concentration ratios derived from the available human and animal data in estimates of doses from 8 weeks to term at

38 weeks. For radionuclides with long half-lives and long retention times, an important consideration is the dose to the child after birth from activity accumulated in utero. The activity of the radionuclides present at birth is again estimated from foetus: mother concentration ratios. Doses are calculated for four different types of intake: both acute and chronic intake, during pregnancy and prior to conception.

The transfer of strontium to the foetus can be expected to be related to calcium requirements. Animal studies suggest, however, that the placenta discriminates against strontium in favour of calcium. Thus, the accumulation of strontium isotopes by the foetus can be estimated from a knowledge of the calcium requirement and by using a discrimination ratio. On this basis, the dose to the foetus from chronic intake throughout pregnancy would be of the same order as the corresponding maternal dose.

For iodine, human data indicate a foetus: mother ratio for ^{131}I of about 2 for chronic intakes by the mother, although higher values have been obtained at short times after acute intakes. The foetal thyroid does not begin functioning until after about ten weeks of gestation. It may therefore be assumed that for chronic intakes of iodine, the concentration in the foetal thyroid is twice that of the mother from the end of the tenth week to term at 38 weeks.

Studies of ^{137}Cs concentrations arising from weapons fallout in newborn children measured within a few days of birth showed values very similar to maternal concentrations. Although no information is available on the transfer of ^{137}Cs to the human foetus during gestation, results of animal studies indicate that it transfers readily between maternal and foetal tissues. It may therefore be assumed that the dose to the embryo and foetus will be the same as that to the mother.

Available animal data for plutonium and related actinide elements (neptunium, americium) generally show lower concentrations in the foetus than in maternal tissues, but with greatest transfer late in gestation.

5. DOSE ASSESSMENT FROM MEASUREMENTS ON INDIVIDUALS

The most convenient method of dose assessment for members of the public is from measurements of foods, as described in Section 3.7. However, such measurements give only rough estimates of doses received and are often overestimates. To obtain more reliable dose estimates for the public, direct and indirect measurements of body burden and their subsequent interpretation are necessary. These measurements, however, are only applicable to the assessment of intakes by ingestion if intakes by inhalation are known to be small or negligible.

5.1.1. Estimation of intake by direct measurements of body burden

Direct measurements of body burden are performed by external detection of photons emitted by incorporated radionuclides. This method is suitable only for radionuclides emitting γ or X radiation with energies above several tens of keV. It is therefore an appropriate measurement method for ^{131}I, ^{134}Cs and ^{137}Cs, but cannot be used, for example, to determine the body content of ^{3}H. Because of the very low photon energy of ^{90}Sr (bremsstrahlung) and ^{239}Pu, this method can only be used in situations involving high levels of contamination with these radionuclides.

Measurements can also be made of activity in parts of the body, for example the thyroid. For direct measurements it must be ensured that there is no contamination of skin and clothes. For measurements on parts of the body, account must also be taken of radiation emitted from other sites in the body. Therefore, this kind of measurement is suitable only for radionuclides with sufficiently high concentration at specific sites.

Details of requirements, techniques of investigation and interpretation of spectra necessary to perform direct measurements are given in Ref. [76]. To interpret direct measurements, information on the paths of intake and the time dependent intake pattern is required.

For an acute intake at time t before the measurement, the activity of the radionuclides ingested can be calculated by

$$_{\mathrm{A}j} = \frac{R_j}{r_{a\mathrm{A}j}(t)} \tag{4}$$

where

$I_{\mathrm{A}j}$ is the activity (Bq) of the radionuclide j ingested by a member of age group A;

R_j is the whole body activity of the radionuclide j or the activity of the radionuclide j in the organ considered, obtained by direct measurement (Bq);

$r_{a\mathrm{A}j}(t)$ is the fractional activity in total body or in the organ considered at time t after an acute ingestion a of the radionuclide j by a member of age group A.

Values of $r_{a\mathrm{A}j}(t)$ have been calculated using the biokinetic models and data described in Section 4.2 and are tabulated and plotted for various radionuclides and all age groups in Annex III.

If a continuous ingestion with a constant intake rate can be assumed, beginning at time t before measurement, the resulting activity of the radionuclides ingested can be calculated by

$$_{\mathrm{A}j} = \frac{R_j t}{r_{c\mathrm{A}j}(t)} \tag{5}$$

where

$I_{\mathrm{A}j}$ is the activity (Bq) of the radionuclide j ingested by a member of age group A during t days since the beginning of incorporation;

$r_{c\mathrm{A}j}(t)$ is the fractional activity at time t in total body, in relation to the intake per day of a continuous ingestion c of the radionuclide j by a member of age group A;

t is the time period of continuous intake (d).

Values of $r_{c\mathrm{A}j}(t)$ have been calculated using the biokinetic models and data described in Section 4.2 and are tabulated and plotted for various radionuclides and all age groups in Annex III.

5.1.2. Estimation of intake by measurements on excreta

Dose assessment based on measurements of urine samples is a suitable method for most radionuclides. In some cases (e.g. ^{90}Sr and ^{239}Pu), faecal excretion may also be analysed. Because of the inconvenience of sample collection, it is likely that only small numbers of measurements will be made by these methods. The sampling time for measurements on excreta should be 24 h. Shorter urine sampling periods are possible, relying on measurements of ^{40}K or creatinine in the sample to correct for daily excretion, but this introduces additional errors.

For an acute intake at time t before the measurement, the activity of the radionuclides ingested can be calculated by

$$_{\mathrm{A}j} = \frac{E_j}{e_{a\mathrm{A}j}(t)} \tag{6}$$

where

$I_{\mathrm{A}j}$ is the activity (Bq) of the radionuclide j ingested by a member of age group A,

E_j is the measured activity of the radionuclide j in daily urine or faecal samples (Bq),

$e_{a\mathrm{A}j}(t)$ is the fraction of activity in 24 hour urine or faeces at time t after an acute ingestion of the radionuclide j by a member of age group A.

Values of $e_{a\mathrm{A}j}(t)$ have been calculated for urine and in some cases for faeces using the biokinetic models and data described in Section 4.2, and are tabulated and plotted for various radionuclides and all age groups in Annex III.

In the case of chronic intake, measurements on excreta are often dominated by the intake during the time just before measurement. Therefore, there is an additional uncertainty in interpreting these measurements when the real time dependent intake pattern differs from that assumed (generally a constant intake rate).

If continuous ingestion with a constant intake rate can be assumed, beginning at time t before measurement, the resulting intake can be calculated by

$$I_{\mathrm{A}j} = \frac{E_j t}{e_{c\mathrm{A}j}(t)} \tag{7}$$

where

$I_{\mathrm{A}j}$ is the activity (Bq) of the radionuclide j ingested by a member of age group A during t days;

$e_{c\mathrm{A}j}(t)$ is the fractional activity at time t in 24 hour urine or faeces, in relation to the intake per day of a continuous ingestion c of the radionuclide j by a member of age group A;

t is the time period of continuous intake (d).

Values of $e_{c\mathrm{A}j}(t)$ have been calculated for urine and in some cases for faeces using the biokinetic models and data described in Section 4.2 and are tabulated and plotted for various radionuclides and all age groups in Annex III.

5.1.3. Estimation of doses

From the calculated values of ingested activities of various radionuclides obtained by the formulas given in Sections 5.1.1 and 5.1.2, the committed effective dose and the committed equivalent dose can be calculated as follows:

$$_{\mathrm{A}} = \sum_j I_{\mathrm{A}j} h_{\mathrm{A}j} \tag{8}$$

where

H_A is the committed effective dose or the committed equivalent dose (Sv) by ingestion for a member of age group A,

h_{Aj} is the ingestion dose coefficient (Sv/Bq) for the effective dose or for the target organ considered for the radionuclide j and age group A.

The ingestion dose coefficients for the effective dose are tabulated for various age groups in Table VI. Organ dose coefficients for adults are given in Annex II.

For example, 20 d after an intake of ^{131}I by ingestion by an adult, there may be a measured activity of 100 Bq in the thyroid. Assuming an acute intake 20 d before the measurement, Eq. (4), together with the values given in Annex III, gives an intake value of 2200 Bq. When, instead of an acute intake, a chronic intake is assumed, an intake value of 800 Bq is obtained using Eq. (5). For an adult these values would result in an estimated effective dose of 48 and 18 μSv, respectively, using Eq. (8) and Table VI.

5.2. SPECIFIC SITUATIONS

5.2.1. Direct dose assessment by external measurements

An approach to obtain more reliable dose estimates for the population is by repeated measurements at given intervals for a number of individuals. These individuals must be representative in age and sex distribution, dietary habits, physiological status, etc. From measurement values of activity in the total body or in specific organs, the effective dose received in a time interval between two measurements can be estimated:

$$H_{Aj\Delta t} = \frac{R_j(t) + R_j(t+\Delta t)}{2} \Delta t S_{Aj} \quad (9)$$

where

$H_{Aj\Delta t}$ is the effective dose (Sv) from radionuclide j during the time period Δt for persons of age group A;

$R_j(t)$ is the measured activity (Bq) of radionuclide j in the total body or in a specified source organ at the time of the previous measurement;

$R_j(t+\Delta t)$ is the measured activity (Bq) of radionuclide j in the total body or in a specified source organ at the time of the recent measurement;

Δt is the time interval between two measurements;

S_{Aj} is the effective dose rate per unit activity of radionuclide *j* in the total body or in a specified source organ for a member of age group A ($Sv \cdot s^{-1} \cdot Bq^{-1}$).

This calculated effective dose is the effective dose received during the time interval considered and not the committed effective dose. By summing the dose values derived from the formula above, repeated measurements can give a dose estimate for a longer period of time. If measurements are performed until the activity has declined to a non-significant level, and it can be assumed that there will be no further increase of activity, an estimate of the committed effective dose beginning from the first measurement can be obtained. To obtain an estimate of the committed effective dose by the radionuclide considered due to a nuclear event, the effective dose received before the first measurement must be estimated.

This method has been applied, for example, after the Chernobyl accident to assess doses to children in different Bavarian regions from the ingestion of ^{134}Cs and ^{137}Cs [77]. For a period of four years, whole body measurements of representative groups were available which in most cases showed no great changes of measured specific activity from month to month. The values of S_{Aj} are tabulated in Annex III for all age groups, taking into account whole body retention of ^{134}Cs and ^{137}Cs and retention in the thyroid for ^{131}I.

5.2.2. Special measurements

Measurements of radionuclide concentrations in autopsy tissue samples can provide valuable information for the estimation of doses to individuals and as input to the development of biokinetic models, particularly for α and ß emitting radionuclides for which direct external measurements are not possible (e.g. ^{90}Sr or ^{239}Pu). Collection of teeth samples for groups of a population can also provide useful information. For example, the specific activity of ^{90}Sr in teeth is considered to be approximately the same as that in the skeleton with an error of not more than a factor of 2 [78, 79].

A suggested method which provides a rough estimate of the average dose for a population group from ^{137}Cs is measurement of hair samples. The specific activity of ^{137}Cs in the total body is reported to be 3.6 times the specific activity in hair [80].

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Annex I

FOOD CONSUMPTION IN DIFFERENT COUNTRIES

I–1. INTRODUCTION

Tables I–1 to I–11 show food consumption data for food categories with consumption rates of more than 20 kg per year and for fish[1]. Most of the values are based on the food balance sheets of the FAO[2]. Some rely on national and local studies by nutrition research institutes and others (see Section 3). The following abbreviations are used to classify the method used for the assessment:

DS	Diet survey
FBS	Food balance sheet
HE	Household expenditure
INT	Interview
INV	Inventory
RC	Recall
WS	Weighing survey
—	No data available.

The most common method, FBS, gives figures for the amount of food in different categories available for human consumption, taking into account production data and imports balanced against exports, losses during transport and storage and other uses (seed, feed for livestock). The figures apply to raw, unprocessed food and do not consider food preparation losses and waste. Therefore, the actual intake values for several of the cited categories may be significantly lower.

The tables serve as a rough indication of the consumption pattern in different countries. When applying the data it should be recognized that the composition of the food categories may vary from country to country. Cereals might include different quantities of wheat, rice, barley, maize, rye, oats and others which should be considered separately if possible. Similarly, different types of meat and fish should be considered separately. The food category ‘milk’ includes the amounts of all milk products except butter. Drinking milk may be less than half the values listed. Conversion into dry milk or cheese, and storage, will reduce doses of short lived radionuclides such as ^{131}I.

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[1] WORLD HEALTH ORGANIZATION, Derived Intervention Levels for Radionuclides in Food, WHO, Geneva (1988).

[2] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, Food Balance Sheets, 1979–1981 Averages, FAO, Rome (1984).

TABLE I–1. AN AFRICAN TYPE CEREAL BASED DIET (PER CAPITA IN g/d)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
Botswana	FBS	404.8	27.7	76.7	48.6	90.0	4.2	309.1
Burkina Faso	FBS	441.3	41.2	24.9	20.5	26.9	4.2	59.6
Cape Verde	FBS	528.9	146.6	43.9	105.8	19.3	65.8	162.4
Gambia	FBS	529.5	27.3	33.8	14.3	39.3	65.2	62.3
Kenya	FBS	374.5	185.7	60.2	72.7	55.6	8.7	161.8
Kenya	HE	422.0	219.0	60.0	81.0	37.0	7.0	131.0
Lesotho	FBS	611.6	16.6	63.3	44.5	54.0	8.2	105.2
Madagascar	FBS	598.5	447.2	79.3	188.5	70.6	14.7	17.7
Malawi	FBS	505.9	64.5	80.2	86.3	14.9	24.4	21.3
Mali	FBS	461.6	45.4	45.7	4.1	53.0	26.6	59.8
Mauritius	FBS	545.9	41.8	74.9	31.8	39.1	44.6	267.8
Niger	FBS	682.5	93.1	63.4	20.0	56.8	2.8	102.8
Niger	INT	635.0	4.2	20.1	0.4	14.1	—	70.9
Réunion	FBS	519.1	54.9	71.3	158.5	116.4	63.8	159.0
Senegal	FBS	611.9	17.1	42.6	33.8	40.5	69.5	97.5
Senegal	WS	420.6	4.8	—	—	25.7	47.4	46.2
Senegal	HE	329.4	36.4	116.0	10.5	29.3	147.2	14.6
Sierra Leone	FBS	471.0	79.5	114.6	90.6	16.4	50.7	38.9
Somalia	FBS	333.2	19.6	15.9	113.3	126.6	5.1	470.9
Swaziland	FBS	431.9	63.5	53.1	108.6	106.8	0.0	180.5
Zambia	FBS	511.6	92.3	89.2	32.5	40.6	24.5	28.1
Zimbabwe	FBS	469.4	26.1	45.2	32.5	40.2	4.9	49.1
Average (g/d)		492.7	79.8	60.7	61.9	50.6	32.8	118.9
Average (kg/a)		179.9	29.1	22.2	22.6	18.5	12.0	43.4

TABLE I–2. AN AFRICAN TYPE ROOT AND TUBER BASED DIET (PER CAPITA IN g/d)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
Benin	FBS	261.8	767.2	85.7	99.9	21.1	29.3	14.8
Burundi	FBS	191.8	1020.3	87.0	224.7	14.9	8.6	48.8
Cameroon	FBS	255.2	483.0	110.0	260.7	38.5	30.1	25.9
Central African Rep.	FBS	112.1	1159.9	47.5	160.1	48.1	15.2	9.9
Central African Rep.	HE	41.9	328.2	57.5	40.0	76.0	18.3	—
Comoros	FBS	340.7	684.3	18.4	257.9	30.0	30.9	30.7
Congo	FBS	139.3	1155.4	54.2	313.7	30.0	79.7	26.5
Congo	HE	8.9	699.5	131.0	47.3	32.7	34.1	0.0
Côte d'Ivoire	FBS	391.7	705.2	102.3	248.2	50.3	55.3	57.6
Fiji	FBS	385.2	506.7	84.8	61.5	56.2	119.8	151.4
Ghana	FBS	192.7	633.5	82.5	179.9	28.9	63.9	11.7
Guinea	FBS	306.8	359.9	191.6	220.5	20.9	17.0	26.2
Kiribati	FBS	311.8	527.4	179.6	204.4	41.5	178.3	25.9
Liberia	FBS	478.3	483.5	83.2	155.4	30.6	45.6	27.5
Mozambique	FBS	222.1	685.3	43.2	71.1	18.7	9.1	25.6
Nigeria	FBS	326.8	667.3	98.4	75.5	32.1	44.2	30.5
Rwanda	FBS	77.5	988.5	87.6	263.9	16.1	0.7	26.7
Samoa	FBS	153.2	597.0	13.3	668.6	130.2	96.6	37.0
Sao Tome and Principe	FBS	308.5	419.0	72.5	116.0	20.4	56.4	76.0
Solomon Islands	FBS	170.9	897.2	48.9	150.6	30.3	138.2	39.2
Togo	FBS	293.6	815.7	66.0	38.0	25.1	29.7	5.7
Tonga	FBS	152.3	1393.7	147.8	219.9	135.6	98.7	34.9
Uganda	FBS	183.6	326.5	51.0	418.6	32.7	35.5	71.2
United Rep. of Tanzania	FBS	215.4	666.5	126.9	236.1	32.1	32.5	70.2
Vanuatu	FBS	202.4	422.3	147.1	119.7	112.5	94.8	124.0
Zaire	FBS	106.4	1182.4	43.5	193.7	18.7	16.6	7.7
Average (g/d)		205.6	658.7	81.3	185.7	41.2	49.4	39.5
Average (kg/a)		75.0	240.4	29.7	67.8	15.0	18.1	14.4

TABLE I–3. AVERAGES FOR AFRICAN TYPE DIETS (PER CAPITA)[a]

	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
g/d	349.2	369.2	71.0	123.8	45.9	41.1	79.2
kg/a	127.4	134.8	25.9	45.2	16.8	15.0	28.9

[a] North African type diets are not included.

TABLE I–4. A CENTRAL AMERICAN TYPE DIET (PER CAPITA IN g/d)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
Antigua	FBS	259.6	35.8	43.1	314.3	83.8	63.1	353.6
Bahamas	FBS	244.9	36.6	195.3	181.2	188.4	35.9	254.6
Barbados	FBS	323.0	172.6	124.4	157.1	249.0	76.5	235.7
Barbados	WS	206.0	145.0	52.0	28.0	135.0	—	114.0
Belize	FBS	351.4	226.8	67.5	293.8	97.9	13.0	399.8
Bermuda	FBS	228.5	77.6	311.1	264.9	288.8	101.9	355.3
Costa Rica	FBS	344.5	31.5	57.0	273.1	90.5	17.1	331.3
Cuba	FBS	420.0	204.7	94.1	172.4	104.3	46.7	422.3
Dominica	FBS	232.0	364.3	138.3	519.2	73.3	58.5	168.5
Dominican Republic	FBS	279.2	76.5	80.1	534.0	64.7	21.0	217.6
Grenada	FBS	247.8	83.9	56.9	337.1	88.0	90.8	228.5
Guadeloupe	FBS	368.4	124.5	183.4	213.7	136.9	133.6	246.7
Guatemala	FBS	373.4	14.6	55.8	122.2	54.9	2.2	100.9
Haiti	FBS	256.9	243.0	119.9	332.9	34.2	8.5	34.5
Honduras	FBS	357.6	15.4	47.0	280.8	36.7	3.7	118.5
Jamaica	FBS	320.9	233.1	88.3	246.2	104.8	49.6	78.2
Martinique	FBS	336.8	151.7	282.7	284.5	145.0	127.5	181.0
Mexico	FBS	475.1	37.5	86.6	251.0	69.6	28.8	274.5
Netherlands Antilles	FBS	309.3	86.6	111.4	243.3	199.0	53.2	420.7
Panama	FBS	344.6	92.2	58.6	285.3	108.9	19.8	168.6
Saint Kitts and Nevis	FBS	206.1	149.1	76.6	104.1	107.6	83.4	138.6
Saint Lucia	FBS	253.2	230.4	33.4	715.3	138.9	83.6	160.7
Saint Vincent	FBS	250.3	44.5	16.4	226.6	80.0	33.9	166.1
Trinidad and Tobago	FBS	437.0	108.1	107.8	197.0	114.3	33.8	345.2
Trinidad and Tobago	INV	325.0	161.0	171.0	173.0	103.0	40.0	115.0
Average (g/d)		310.1	125.9	106.4	270.0	115.9	51.1	225.2
Average (kg/a)		113.2	46.0	38.8	98.6	42.3	18.7	82.2

TABLE I–5. A CHINESE TYPE DIET (PER CAPITA IN g/d)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
China	FBS	627.1	300.9	180.7	30.0	62.7	15.6	13.4
China	DS	451.0	—	286.0	0.0	45.0	38.0	2.0
Viet Nam	FBS	387.0	273.0	—	—	43.5	4.6	5.4
Viet Nam	DS	416.0	131.0	—	—	13.0	39.0	0.0
Average (g/d)		470.3	235.0	233.4	15.0	41.1	24.3	5.2
Average (kg/a)		171.7	85.8	85.2	5.5	15.0	8.9	1.9

TABLE I–6. AN EASTERN MEDITERRANEAN TYPE DIET (PER CAPITA IN g/d)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
Bangladesh	FBS	631.7	44.8	26.9	39.6	10.8	20.3	36.7
Democratic Yemen	FBS	469.5	6.3	80.3	206.3	34.5	50.4	204.8
Egypt	FBS	694.3	64.3	328.6	208.3	42.0	13.6	57.4
Kuwait	FBS	469.2	49.2	329.6	374.3	217.0	28.2	457.4
Saudi Arabia	FBS	454.7	28.0	220.7	520.7	133.1	25.1	319.0
Sudan	FBS	390.2	40.9	93.1	112.0	69.8	4.1	179.4
Syrian Arab Republic	FBS	525.7	68.3	563.0	474.6	61.2	4.7	184.8
Turkey	FBS	576.6	140.0	343.8	462.0	61.1	17.8	175.0
Turkey	RC	544.8	51.0	193.1	79.4	36.8	8.6	107.8
United Arab Emirates	FBS	366.0	40.3	467.3	449.4	188.6	67.7	378.7
Yemen	FBS	550.1	47.5	112.7	130.9	60.1	11.7	138.9
Average (g/d)		515.7	52.8	250.8	278.0	83.2	22.9	203.6
Average (kg/a)		188.2	19.3	91.6	101.5	30.4	8.4	74.3

TABLE I–7. A EUROPEAN TYPE DIET (PER CAPITA IN g/d)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
Australia	FBS	311.2	136.9	182.7	247.7	283.0	39.0	331.3
Australia	RC	232.0	—	268.0	178.0	192.0	19.0	427.0
Austria	FBS	255.7	229.1	218.6	315.0	265.3	24.3	417.7
Belgium and Luxembourg	FBS	265.3	273.9	231.3	229.7	267.9	51.5	361.0
Bulgaria	FBS	616.9	77.7	270.3	312.3	185.2	15.2	243.2
Canada	FBS	253.7	218.3	260.5	326.9	262.0	59.7	468.3
Czech Republic	FBS	399.1	217.8	187.2	141.3	260.9	22.3	426.2
Denmark	FBS	239.3	207.4	137.4	172.3	220.0	133.4	432.2
Denmark	HE?	264.0	213.0	—	—	149.0	27.0	681.0
Faroe Islands	FBS	367.1	247.0	73.5	157.7	220.9	272.0	203.0
Finland	FBS	266.7	238.4	87.1	219.1	168.9	78.4	711.2
France	FBS	290.2	218.6	305.6	187.0	273.7	66.0	346.6
France	HE?	233.0	—	397.0	196.0	187.0	26.0	294.0
Germany (east)	FBS	362.8	389.1	206.0	195.5	293.1	38.1	389.3
Germany (west)	FBS	254.3	221.1	187.5	104.8	267.7	27.2	328.7
Greece	FBS	414.1	182.2	495.7	453.7	185.7	44.7	262.1
Hungary	FBS	423.8	162.3	226.8	217.7	284.4	9.9	315.3
Iceland	FBS	226.8	171.4	60.5	160.0	250.1	291.2	695.9
Ireland	FBS	366.5	313.7	255.6	180.2	228.5	43.2	637.2
Ireland	HE	318.4	59.9	—	—	—	—	456.0
Israel	FBS	394.1	113.1	296.4	391.3	190.8	46.8	315.3
Israel	HE	215.0	67.0	232.0	297.0	99.0	17.0	400.0
Israel	FBS	306.5	107.3	318.9	400.4	178.6	23.3	330.0
Italy	FBS	503.1	112.8	457.0	353.8	200.3	34.2	299.7
Malta	FBS	391.3	62.8	261.8	176.4	154.7	57.5	416.8
Netherlands	HE?	329.0	276.0	210.0	256.0	—	9.0	602.0
New Zealand	FBS	291.8	157.9	232.3	212.3	320.8	27.2	856.9
Norway	FBS	296.3	233.5	120.5	220.3	146.5	141.2	692.6
Norway	HE	203.2	151.0	87.2	131.8	79.7	54.1	460.1
Poland	FBS	495.2	326.3	309.5	102.1	193.3	46.0	437.2
Poland	HE	318.4	291.5	185.5	105.2	148.8	15.6	389.9
Portugal	FBS	442.5	265.8	337.7	191.0	139.4	77.0	146.8
Romania	FBS	523.9	193.3	382.8	154.6	189.2	16.7	403
Spain	FBS	324.6	306.9	405.0	347.8	187.2	86.8	328.7
Spain	HE	245.0	230.8	213.5	248.0	170.5	71.7	489.0
Sweden	FBS	230.5	202.2	129.8	218.8	179.7	83.3	502.0
Switzerland	FBS	271.9	133.4	191.9	312.7	239.6	29.4	460.9
UK	FBS	258.9	281.2	197.5	151.9	205.2	45.1	455.0
UK	HE	226.3	169.9	181.5	113.1	159.8	20.0	367.0
Ukraine	HE	256.2	248.0	240	240	188.8	41.6	249.3
USA	FBS	250.0	146.7	271.6	309.3	312.2	44.2	462.3
USSR	FBS	504.1	300.5	258.9	106.8	169.7	69.7	382.1
Yugoslavia	FBS	599.4	158.7	217.2	194.8	176.7	8.5	298.3
Yugoslavia	HE	285.0	98.0	184.0	148.0	175.0	13.0	330.0
Average (g/d)		331.8	199.1	237.4	222.9	206.4	55.4	424.5
Average (kg/a)		21.1	72.7	86.7	81.4	75.3	20.2	154.9

TABLE I–8. A FAR EASTERN TYPE DIET (PER CAPITA IN g/d)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
Brunei Darussalam	FBS	509.4	73.5	87.5	181.4	95.3	94.5	161.2
Burma	FBS	799.2	10.1	130.1	73.8	17.4	39.2	14.4
Hong Kong	FBS	387.4	35.3	253.4	180.8	203.4	135.5	95.2
India	FBS	502.2	53.6	160.4	63.4	3.7	8.4	104.7
India	WS	498.0	47.0	76.0	21.0	5.0	10.0	78.0
Indonesia	FBS	597.0	197.2	34.8	50.9	9.4	31.9	10.3
Indonesia	HE	624.0	284.1	147.8	100.4	32.3	43.4	20.1
Japan	FBS	502.8	72.0	299.1	178.2	82.4	231.8	135.5
Macao	FBS	437.8	17.8	202.1	141.5	170.3	130.9	45.7
Malaysia	FBS	536.8	61.5	91.4	130.2	51.5	123.6	55.4
Nepal	FBS	575.1	47.2	30.2	23.0	14.9	0.9	115.1
Pakistan	FBS	462.0	14.9	58.1	66.5	26.3	4.7	192.0
Pakistan	FBS	412.3	15.1	69.5	78.1	24.9	3.5	228.7
Pakistan	HE	409.0	24.0	63.1	70.0	20.4	2.0	170.7
Philippines	FBS	569.2	176.4	94.5	266.2	44.0	86.1	48.1
Philippines	WS	367.0	37.0	145.0	142.0	54.0	8.0	33.0
Republic of Korea	FBS	865.2	78.2	520.2	95.8	43.4	138.9	32.4
Singapore	FBS	559.3	84.9	190.0	219.8	174.5	86.6	113.1
Sri Lanka	FBS	511.0	94.1	47.4	215.8	6.6	38.6	72.0
Thailand	FBS	631.3	53.4	123.2	216.4	40.0	52.6	21.6
Average (g/d)		566.1	77.8	148.6	132.4	58.9	66.9	91.0
Average (kg/a)		206.6	28.4	54.3	48.3	21.5	24.4	33.6

TABLE I–9. A NORTH AFRICAN TYPE DIET (PER CAPITA IN g/d)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
Algeria	FBS	527.2	80.9	104.9	142.9	30.7	5.7	221.0
Libyan Arab Jamahiriya	FBS	569.3	80.4	265.7	402.3	145.2	22.0	280.2
Mauritania	FBS	383.0	14.5	10.1	30.7	82.0	44.7	421.1
Morocco	FBS	589.0	49.0	107.0	111.7	41.2	15.2	85.9
Morocco	HE	592.9	—	243.0	127.4	49.0	9.9	81.1
Tunisia	FBS	531.7	49.2	312.1	235.8	46.6	21.9	179.6
Average (g/d)		443.6	54.8	173.8	175.1	65.8	19.9	211.5
Average (kg/a)		161.9	20.0	63.4	63.9	24.0	7.3	77.2

TABLE I–10. A SOUTH AMERICAN TYPE DIET (PER CAPITA IN g/d)

Country or area	Type of data	Cereal	Roots and tubers	Vegetables	Fruit	Meat	Fish	Milk
Argentina	FBS	380.2	212.0	181.6	288.9	346.5	16.0	269.6
Bolivia	FBS	298.5	335.2	122.6	195.6	90.4	7.9	83.7
Brazil	FBS	371.3	264.0	75.9	205.6	96.2	19.4	183.2
Brazil	HE	224.0	99.0	47.0	53.0	—	—	138.0
Chile	FBS	466.8	127.4	188.6	183.3	92.6	78.1	250.1
Colombia	FBS	295.5	297.7	118.6	272.3	96.5	11.3	168.1
Ecuador	FBS	253.9	131.5	75.2	447.6	78.4	47.0	220.9
French Guiana	FBS	361.7	148.1	123.0	266.0	215.3	80.0	163.7
Guyana	FBS	514.6	37.0	24.9	114.9	61.5	65.6	171.7
Guyana	WS	322.0	95.0	91.0	39.0	93.0	—	70.0
Paraguay	FBS	287.1	515.5	80.6	586.4	197.4	2.3	140.5
Peru	FBS	339.6	275.7	90.1	206.9	64.2	81.5	130.1
Suriname	FBS	522.6	50.4	56.1	81.6	105.4	61.7	109.9
Uruguay	FBS	368.4	140.5	123.0	172.0	255.0	20.3	441.8
Venezuela	FBS	353.2	80.9	58.4	325.3	133.3	30.2	366.4
Venezuela	HE	317.4	155.2	41.6	208.2	62.4	29.2	190.1
Average (g/d)		354.8	185.3	93.6	227.9	132.5	39.3	193.6
Average (kg/a)		129.5	67.6	34.2	83.2	48.4	14.4	70.7

TABLE I–11. SELF-SUPPORT OF DIFFERENT PRODUCTS IN RURAL AREAS IN FRANCE AND GREECE

Foods	Percentage of consumption coming from own production	
	Minimum	Maximum
Cereals	1	22
Potatoes	20	84
Vegetables	56	61
Fruit	20	30
Milk and milk products	62	63
Meat	20	47
Fish	4	8

Annex II

COMMITTED EQUIVALENT TISSUE DOSES PER UNIT ACTIVITY INGESTED BY ADULTS ($Sv \cdot Bq^{-1}$)

	^{3}H trit.	^{3}H organic	^{14}C	^{35}S inorganic	^{35}S organic	^{55}Fe
Adrenals	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Bladder wall	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	2.9×10^{-10}	8.4×10^{-10}	8.6×10^{-11}
Bone surfaces	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	6.0×10^{-10}
Brain	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Breast	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
GI tract						
Stomach wall	1.8×10^{-11}	4.8×10^{-11}	6.3×10^{-10}	1.5×10^{-10}	8.1×10^{-10}	9.3×10^{-11}
SI[a] wall	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.8×10^{-11}	7.6×10^{-10}	1.0×10^{-10}
ULI[b] wall	1.8×10^{-11}	4.2×10^{-11}	5.8×10^{-10}	1.8×10^{-10}	8.0×10^{-10}	1.8×10^{-10}
LLI[c] wall	1.8×10^{-11}	4.4×10^{-11}	6.0×10^{-10}	3.5×10^{-10}	8.8×10^{-10}	3.6×10^{-10}
Kidneys	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Liver	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	7.3×10^{-10}
Lungs	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Muscle	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Ovaries	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Pancreas	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Red marrow	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	1.1×10^{-09}
Skin	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Spleen	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	2.5×10^{-09}
Testes	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Thymus	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Thyroid	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Uterus	1.8×10^{-11}	4.1×10^{-11}	5.7×10^{-10}	9.6×10^{-11}	7.6×10^{-10}	8.6×10^{-11}
Effective dose	1.8×10^{-11}	4.2×10^{-11}	5.8×10^{-10}	1.3×10^{-10}	7.8×10^{-10}	3.3×10^{-10}

	^{59}Fe	^{57}Co	^{58}Co	^{60}Co	^{59}Ni	^{63}Ni
Adrenals	1.1×10^{-09}	7.8×10^{-11}	2.3×10^{-10}	2.5×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Bladder wall	9.0×10^{-10}	1.2×10^{-10}	4.7×10^{-10}	2.6×10^{-09}	3.8×10^{-11}	9.0×10^{-11}
Bone surfaces	1.1×10^{-09}	1.2×10^{-10}	2.2×10^{-10}	2.1×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Brain	4.5×10^{-10}	4.6×10^{-11}	1.0×10^{-10}	1.4×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Breast	5.0×10^{-10}	4.0×10^{-10}	1.1×10^{-10}	1.4×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
GI tract						
Stomach wall	1.1×10^{-09}	1.2×10^{-10}	4.5×10^{-10}	2.6×10^{-09}	4.5×10^{-11}	1.1×10^{-10}

	^{59}Fe	^{57}Co	^{58}Co	^{60}Co	^{59}Ni	^{63}Ni
SI[a] wall	1.9×10^{-09}	2.4×10^{-10}	1.1×10^{-09}	4.2×10^{-09}	5.6×10^{-11}	1.3×10^{-10}
ULI[b] wall	4.0×10^{-09}	5.9×10^{-10}	2.0×10^{-09}	6.6×10^{-09}	1.5×10^{-10}	3.7×10^{-10}
LLI[c] wall	8.4×10^{-09}	1.4×10^{-09}	4.0×10^{-09}	1.2×10^{-08}	3.8×10^{-10}	9.2×10^{-10}
Kidneys	9.8×10^{-10}	8.0×10^{-11}	2.8×10^{-10}	2.4×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Liver	3.0×10^{-09}	1.7×10^{-10}	4.0×10^{-10}	4.5×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Lungs	6.9×10^{-10}	5.9×10^{-11}	1.5×10^{-10}	1.8×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Muscle	7.0×10^{-10}	6.5×10^{-11}	2.3×10^{-10}	1.9×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Ovaries	1.8×10^{-09}	2.0×10^{-10}	1.1×10^{-09}	4.3×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Pancreas	1.1×10^{-09}	8.9×10^{-11}	2.9×10^{-10}	2.6×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Red marrow	1.6×10^{-09}	7.7×10^{-11}	3.1×10^{-10}	2.2×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Skin	4.7×10^{-10}	4.1×10^{-11}	1.3×10^{-10}	1.3×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Spleen	2.0×10^{-09}	7.0×10^{-11}	2.3×10^{-10}	2.1×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Testes	6.0×10^{-10}	5.9×10^{-11}	2.2×10^{-10}	1.8×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Thymus	6.1×10^{-10}	5.3×10^{-11}	1.4×10^{-10}	1.7×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Thyroid	5.5×10^{-10}	5.4×10^{-11}	1.3×10^{-10}	1.7×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Uterus	1.1×10^{-09}	1.3×10^{-10}	5.8×10^{-10}	3.1×10^{-09}	3.6×10^{-11}	8.7×10^{-11}
Effective dose	1.8×10^{-09}	2.1×10^{-10}	7.5×10^{-10}	3.4×10^{-09}	6.3×10^{-11}	1.5×10^{-10}

	^{65}Zn	^{75}Se	^{79}Se	^{89}Sr	^{90}Sr	^{95}Zr
Adrenals	4.4×10^{-09}	4.0×10^{-09}	9.7×10^{-10}	2.0×10^{-10}	6.6×10^{-10}	1.3×10^{-10}
Bladder wall	3.6×10^{-09}	1.5×10^{-09}	1.1×10^{-10}	6.7×10^{-10}	1.5×10^{-09}	2.9×10^{-10}
Bone surfaces	5.5×10^{-09}	2.4×10^{-09}	9.7×10^{-10}	6.0×10^{-09}	4.1×10^{-07}	2.3×10^{-09}
Brain	3.2×10^{-09}	1.0×10^{-09}	9.7×10^{-10}	2.0×10^{-10}	6.6×10^{-10}	5.3×10^{-11}
Breast	2.5×10^{-09}	1.1×10^{-09}	9.7×10^{-10}	2.0×10^{-10}	6.6×10^{-10}	3.7×10^{-11}
GI tract						
Stomach wall	3.5×10^{-09}	2.3×10^{-09}	1.0×10^{-09}	8.8×10^{-10}	9.1×10^{-10}	3.9×10^{-10}
SI[a] wall	4.3×10^{-09}	2.3×10^{-09}	1.0×10^{-09}	1.4×10^{-09}	1.1×10^{-09}	1.1×10^{-09}
ULI[b] wall	4.3×10^{-09}	2.5×10^{-09}	1.4×10^{-09}	7.8×10^{-09}	5.9×10^{-09}	3.1×10^{-09}
LLI[c] wall	5.3×10^{-09}	2.2×10^{-09}	2.3×10^{-09}	2.2×10^{-08}	2.2×10^{-08}	7.8×10^{-09}
Kidneys	3.8×10^{-09}	1.4×10^{-08}	3.2×10^{-08}	2.0×10^{-10}	6.6×10^{-10}	1.7×10^{-10}
Liver	3.7×10^{-09}	1.0×10^{-08}	1.4×10^{-08}	2.0×10^{-10}	6.6×10^{-10}	1.1×10^{-10}
Lungs	3.3×10^{-09}	2.0×10^{-09}	9.7×10^{-10}	2.0×10^{-10}	6.6×10^{-10}	6.0×10^{-11}
Muscle	3.4×10^{-09}	1.5×10^{-09}	9.7×10^{-10}	2.0×10^{-10}	6.6×10^{-10}	1.4×10^{-10}
Ovaries	4.5×10^{-09}	2.1×10^{-09}	1.8×10^{-09}	2.0×10^{-10}	6.6×10^{-10}	8.8×10^{-10}
Pancreas	4.2×10^{-09}	4.8×10^{-09}	5.0×10^{-09}	2.0×10^{-10}	6.6×10^{-10}	1.5×10^{-10}
Red marrow	4.8×10^{-09}	1.8×10^{-09}	9.7×10^{-10}	4.8×10^{-09}	1.8×10^{-07}	4.8×10^{-10}
Skin	2.4×10^{-09}	9.5×10^{-10}	9.7×10^{-10}	2.0×10^{-10}	6.6×10^{-10}	6.3×10^{-11}
Spleen	3.7×10^{-09}	4.3×10^{-09}	5.6×10^{-09}	2.0×10^{-10}	6.6×10^{-10}	1.1×10^{-10}
Testes	3.2×10^{-09}	1.7×10^{-09}	2.9×10^{-09}	2.0×10^{-10}	6.6×10^{-10}	1.0×10^{-10}
Thymus	3.3×10^{-09}	1.4×10^{-09}	9.7×10^{-10}	2.0×10^{-10}	6.6×10^{-10}	4.3×10^{-11}

	^{65}Zn	^{75}Se	^{79}Se	^{89}Sr	^{90}Sr	^{95}Zr
Thyroid	3.6×10^{-09}	1.3×10^{-09}	9.7×10^{-10}	2.0×10^{-10}	6.6×10^{-10}	4.3×10^{-11}
Uterus	4.2×10^{-09}	1.8×10^{-09}	9.7×10^{-10}	2.0×10^{-10}	6.6×10^{-10}	4.0×10^{-10}
Effective dose	3.9×10^{-09}	2.6×10^{-09}	2.9×10^{-09}	2.6×10^{-09}	2.8×10^{-08}	9.6×10^{-10}

	^{95}Nb	^{99}Mo	^{99}Tc^{m}	^{99}Tc	^{103}Ru	^{106}Ru
Adrenals	7.7×10^{-11}	3.4×10^{-10}	3.9×10^{-12}	3.9×10^{-11}	1.0×10^{-10}	1.5×10^{-09}
Bladder wall	2.6×10^{-10}	4.3×10^{-10}	7.8×10^{-12}	1.6×10^{-10}	2.4×10^{-10}	1.7×10^{-09}
Bone surfaces	2.1×10^{-10}	1.0×10^{-09}	5.2×10^{-12}	3.9×10^{-11}	1.1×10^{-10}	1.5×10^{-09}
Brain	1.1×10^{-11}	2.4×10^{-10}	1.2×10^{-12}	3.9×10^{-11}	5.8×10^{-11}	1.4×10^{-09}
Breast	2.0×10^{-11}	2.4×10^{-10}	1.3×10^{-12}	3.9×10^{-11}	5.9×10^{-11}	1.4×10^{-09}
GI tract						
Stomach wall	2.9×10^{-10}	7.5×10^{-10}	5.6×10^{-11}	2.2×10^{-09}	3.1×10^{-10}	3.2×10^{-09}
SI[a] wall	8.3×10^{-10}	3.0×10^{-10}	3.8×10^{-11}	1.9×10^{-10}	8.0×10^{-10}	5.6×10^{-09}
ULI[b] wall	1.8×10^{-09}	4.2×10^{-10}	7.7×10^{-11}	1.4×10^{-09}	2.6×10^{-09}	2.6×10^{-08}
LLI[c] wall	4.0×10^{-09}	5.8×10^{-10}	5.4×10^{-11}	3.9×10^{-09}	6.6×10^{-09}	7.2×10^{-08}
Kidneys	1.6×10^{-10}	3.1×10^{-09}	5.5×10^{-12}	3.9×10^{-11}	1.4×10^{-10}	1.5×10^{-09}
Liver	1.4×10^{-10}	2.8×10^{-09}	4.4×10^{-12}	5.2×10^{-11}	1.1×10^{-10}	1.5×10^{-09}
Lungs	3.0×10^{-11}	2.8×10^{-10}	2.1×10^{-12}	3.9×10^{-11}	7.2×10^{-11}	1.4×10^{-09}
Muscle	1.1×10^{-10}	2.6×10^{-10}	3.5×10^{-12}	3.9×10^{-11}	1.2×10^{-10}	1.5×10^{-09}
Ovaries	8.2×10^{-10}	2.8×10^{-10}	1.7×10^{-11}	3.9×10^{-11}	5.7×10^{-10}	1.7×10^{-09}
Pancreas	1.2×10^{-10}	3.3×10^{-10}	9.0×10^{-12}	3.9×10^{-11}	1.3×10^{-10}	1.5×10^{-09}
Red marrow	1.9×10^{-10}	6.1×10^{-10}	4.4×10^{-12}	3.9×10^{-11}	1.6×10^{-10}	1.5×10^{-09}
Skin	4.3×10^{-11}	2.4×10^{-10}	1.6×10^{-12}	3.9×10^{-11}	7.0×10^{-11}	1.4×10^{-09}
Spleen	9.0×10^{-11}	2.8×10^{-10}	6.3×10^{-12}	3.9×10^{-11}	1.2×10^{-10}	1.5×10^{-09}
Testes	8.9×10^{-11}	2.5×10^{-10}	2.1×10^{-12}	3.9×10^{-11}	1.1×10^{-10}	1.5×10^{-09}
Thymus	1.9×10^{-11}	2.6×10^{-10}	1.6×10^{-12}	3.9×10^{-11}	7.1×10^{-11}	1.4×10^{-09}
Thyroid	1.3×10^{-11}	2.5×10^{-10}	4.7×10^{-11}	1.0×10^{-09}	6.7×10^{-11}	1.4×10^{-09}
Uterus	3.7×10^{-10}	2.7×10^{-10}	1.1×10^{-11}	3.9×10^{-11}	3.0×10^{-10}	1.6×10^{-09}
Effective dose	5.9×10^{-10}	6.1×10^{-10}	2.2×10^{-11}	6.4×10^{-10}	7.3×10^{-10}	7.0×10^{-09}

	^{108}Ag^{m}	^{110}Ag^{m}	^{124}Sb	^{125}Sb	^{126}Sb	^{127}Te^{m}
Adrenals	2.0×10^{-09}	1.9×10^{-09}	3.9×10^{-10}	4.3×10^{-10}	3.6×10^{-10}	1.5×10^{-10}
Bladder wall	1.1×10^{-09}	1.4×10^{-09}	8.6×10^{-10}	4.4×10^{-10}	1.1×10^{-09}	3.6×10^{-10}
Bone surfaces	8.9×10^{-10}	8.6×10^{-10}	2.7×10^{-09}	9.1×10^{-09}	1.1×10^{-09}	3.2×10^{-08}
Brain	3.9×10^{-10}	3.4×10^{-10}	1.8×10^{-10}	2.6×10^{-10}	1.2×10^{-10}	1.4×10^{-10}
Breast	6.1×10^{-10}	5.7×10^{-10}	1.7×10^{-10}	2.1×10^{-10}	1.2×10^{-10}	1.3×10^{-10}
GI tract						
Stomach wall	1.5×10^{-09}	1.7×10^{-09}	1.1×10^{-09}	5.0×10^{-10}	1.2×10^{-09}	2.5×10^{-10}
SI[a] wall	2.7×10^{-09}	3.5×10^{-09}	2.6×10^{-09}	9.8×10^{-10}	3.2×10^{-09}	4.3×10^{-10}

	$^{108}Ag^{m}$	$^{110}Ag^{m}$	^{124}Sb	^{125}Sb	^{126}Sb	$^{127}Te^{m}$
ULI[b] wall	4.7×10^{-09}	6.3×10^{-09}	8.6×10^{-09}	2.5×10^{-09}	8.0×10^{-09}	3.0×10^{-09}
LLI[c] wall	8.6×10^{-09}	1.2×10^{-08}	2.2×10^{-08}	6.2×10^{-09}	1.8×10^{-08}	1.0×10^{-08}
Kidneys	1.6×10^{-09}	1.6×10^{-09}	4.6×10^{-10}	3.8×10^{-10}	5.2×10^{-10}	2.3×10^{-09}
Liver	8.9×10^{-09}	7.6×10^{-09}	6.4×10^{-10}	7.9×10^{-10}	5.1×10^{-10}	1.4×10^{-10}
Lungs	1.1×10^{-09}	9.9×10^{-10}	2.3×10^{-10}	2.9×10^{-10}	1.8×10^{-10}	1.4×10^{-10}
Muscle	8.9×10^{-10}	9.5×10^{-10}	3.8×10^{-10}	3.1×10^{-10}	4.3×10^{-10}	1.4×10^{-10}
Ovaries	2.5×10^{-09}	3.5×10^{-09}	1.9×10^{-09}	8.0×10^{-10}	2.8×10^{-09}	1.7×10^{-10}
Pancreas	1.9×10^{-09}	1.8×10^{-09}	4.4×10^{-10}	3.9×10^{-10}	4.9×10^{-10}	1.4×10^{-10}
Red marrow	1.1×10^{-09}	1.2×10^{-09}	1.2×10^{-09}	1.5×10^{-09}	9.2×10^{-10}	8.2×10^{-09}
Skin	5.2×10^{-10}	5.4×10^{-10}	2.2×10^{-10}	2.1×10^{-10}	1.9×10^{-10}	1.3×10^{-10}
Spleen	9.1×10^{-10}	9.4×10^{-10}	3.5×10^{-10}	3.1×10^{-10}	3.8×10^{-10}	1.4×10^{-10}
Testes	6.3×10^{-10}	6.9×10^{-10}	3.2×10^{-10}	2.6×10^{-10}	3.6×10^{-10}	1.3×10^{-10}
Thymus	6.7×10^{-10}	6.3×10^{-10}	2.0×10^{-10}	2.5×10^{-10}	1.4×10^{-10}	1.4×10^{-10}
Thyroid	5.2×10^{-10}	4.6×10^{-10}	1.9×10^{-10}	2.6×10^{-10}	1.2×10^{-10}	3.1×10^{-09}
Uterus	1.5×10^{-09}	1.9×10^{-09}	9.3×10^{-10}	5.0×10^{-10}	1.3×10^{-09}	1.4×10^{-10}
Effective dose	2.4×10^{-09}	2.8×10^{-09}	2.5×10^{-09}	1.1×10^{-09}	2.5×10^{-09}	2.3×10^{-09}

	$^{129}Te^{m}$	$^{131}Te^{m}$	^{132}Te	^{125}I	^{129}I	^{131}I	^{132}I
Adrenals	2.5×10^{-10}	1.2×10^{-10}	3.1×10^{-10}	2.7×10^{-11}	1.2×10^{-10}	5.1×10^{-11}	3.6×10^{-11}
Bladder wall	7.0×10^{-10}	4.4×10^{-10}	3.2×10^{-09}	1.5×10^{-10}	4.3×10^{-10}	7.6×10^{-10}	3.1×10^{-10}
Bone surfaces	1.2×10^{-08}	5.0×10^{-10}	1.2×10^{-09}	1.7×10^{-10}	4.0×10^{-10}	1.3×10^{-10}	2.6×10^{-11}
Brain	2.3×10^{-10}	5.7×10^{-11}	2.0×10^{-10}	3.5×10^{-11}	1.4×10^{-10}	1.4×10^{-10}	1.9×10^{-11}
Breast	2.2×10^{-10}	5.7×10^{-11}	1.8×10^{-10}	2.2×10^{-11}	1.1×10^{-10}	5.9×10^{-11}	2.0×10^{-11}
GI tract							
Stomach wall	7.0×10^{-10}	6.8×10^{-10}	7.7×10^{-10}	6.3×10^{-11}	2.0×10^{-10}	3.1×10^{-10}	6.5×10^{-10}
SI[a] wall	1.4×10^{-09}	1.4×10^{-09}	1.5×10^{-09}	2.8×10^{-11}	1.3×10^{-10}	5.4×10^{-11}	4.8×10^{-11}
ULI[b] wall	8.1×10^{-09}	4.4×10^{-09}	7.5×10^{-09}	4.1×10^{-11}	2.3×10^{-10}	8.9×10^{-11}	5.3×10^{-11}
LLI[c] wall	2.3×10^{-08}	7.9×10^{-09}	1.9×10^{-08}	7.3×10^{-11}	4.3×10^{-10}	1.6×10^{-10}	3.8×10^{-11}
Kidneys	3.5×10^{-09}	3.0×10^{-10}	5.3×10^{-10}	2.6×10^{-11}	1.2×10^{-10}	4.6×10^{-11}	3.3×10^{-11}
Liver	2.3×10^{-10}	1.3×10^{-10}	3.3×10^{-10}	2.6×10^{-11}	1.2×10^{-10}	4.9×10^{-11}	2.9×10^{-11}
Lungs	2.3×10^{-10}	7.4×10^{-11}	2.3×10^{-10}	4.1×10^{-11}	1.5×10^{-10}	1.0×10^{-10}	2.6×10^{-11}
Muscle	2.3×10^{-10}	1.4×10^{-10}	3.7×10^{-10}	1.4×10^{-10}	3.0×10^{-10}	1.3×10^{-10}	2.7×10^{-11}
Ovaries	3.1×10^{-10}	7.3×10^{-10}	1.6×10^{-09}	3.0×10^{-11}	1.3×10^{-10}	5.2×10^{-11}	3.3×10^{-11}
Pancreas	2.4×10^{-10}	1.8×10^{-10}	3.7×10^{-10}	2.9×10^{-11}	1.2×10^{-10}	6.1×10^{-11}	7.4×10^{-11}
Red marrow	5.3×10^{-09}	2.7×10^{-10}	5.6×10^{-10}	3.3×10^{-11}	1.4×10^{-10}	1.0×10^{-10}	2.6×10^{-11}
Skin	2.2×10^{-10}	7.5×10^{-11}	2.2×10^{-10}	3.6×10^{-11}	1.4×10^{-10}	6.9×10^{-11}	1.9×10^{-11}
Spleen	2.3×10^{-10}	1.4×10^{-10}	3.3×10^{-10}	2.7×10^{-11}	1.2×10^{-10}	5.4×10^{-11}	5.3×10^{-11}
Testes	2.2×10^{-10}	1.1×10^{-10}	3.6×10^{-10}	2.3×10^{-11}	1.2×10^{-10}	4.0×10^{-11}	2.4×10^{-11}
Thymus	2.2×10^{-10}	6.8×10^{-11}	2.3×10^{-10}	5.0×10^{-11}	1.7×10^{-10}	1.5×10^{-10}	2.5×10^{-11}
Thyroid	4.6×10^{-09}	1.9×10^{-08}	2.9×10^{-08}	3.1×10^{-07}	2.1×10^{-06}	4.3×10^{-07}	3.4×10^{-09}

	$^{129}Te^{m}$	$^{131}Te^{m}$	^{132}Te	^{125}I	^{129}I	^{131}I	^{132}I
Uterus	2.6×10^{-10}	3.8×10^{-10}	8.8×10^{-10}	3.0×10^{-11}	1.3×10^{-10}	5.9×10^{-11}	3.9×10^{-11}
Effective dose	3.0×10^{-09}	2.0×10^{-09}	3.7×10^{-09}	1.5×10^{-08}	1.1×10^{-07}	2.2×10^{-08}	2.9×10^{-10}

	^{134}Cs	^{136}Cs	^{137}Cs	^{133}Ba	^{140}Ba	^{141}Ce	^{144}Ce
Adrenals	2.1×10^{-08}	3.3×10^{-09}	1.4×10^{-08}	1.2×10^{-09}	2.1×10^{-10}	5.4×10^{-12}	1.6×10^{-11}
Bladder wall	2.0×10^{-08}	3.2×10^{-09}	1.4×10^{-08}	6.2×10^{-10}	4.5×10^{-10}	3.2×10^{-11}	3.0×10^{-11}
Bone surfaces	2.0×10^{-08}	3.2×10^{-09}	1.4×10^{-08}	6.6×10^{-09}	1.6×10^{-09}	4.9×10^{-11}	3.3×10^{-10}
Brain	1.5×10^{-08}	2.4×10^{-09}	1.2×10^{-08}	8.4×10^{-10}	1.0×10^{-10}	2.5×10^{-13}	1.2×10^{-11}
Breast	1.4×10^{-08}	2.1×10^{-09}	1.1×10^{-08}	3.6×10^{-10}	7.5×10^{-11}	7.6×10^{-13}	1.2×10^{-11}
GI tract							
Stomach wall	1.9×10^{-08}	3.3×10^{-09}	1.3×10^{-08}	6.5×10^{-10}	6.3×10^{-10}	2.3×10^{-10}	1.1×10^{-09}
SI[a] wall	2.1×10^{-08}	3.3×10^{-09}	1.4×10^{-08}	1.3×10^{-09}	1.7×10^{-09}	5.8×10^{-10}	3.7×10^{-09}
ULI[b] wall	2.0×10^{-08}	3.3×10^{-09}	1.4×10^{-08}	2.3×10^{-09}	8.5×10^{-09}	3.1×10^{-09}	2.3×10^{-08}
LLI[c] wall	2.3×10^{-08}	3.7×10^{-09}	1.7×10^{-08}	4.9×10^{-09}	2.9×10^{-08}	8.7×10^{-09}	6.7×10^{-08}
Kidneys	2.0×10^{-08}	3.1×10^{-09}	1.3×10^{-08}	8.2×10^{-10}	2.3×10^{-10}	1.2×10^{-11}	2.0×10^{-11}
Liver	2.0×10^{-08}	3.1×10^{-09}	1.4×10^{-08}	5.5×10^{-10}	1.5×10^{-10}	2.4×10^{-11}	9.6×10^{-10}
Lungs	1.8×10^{-08}	2.7×10^{-09}	1.3×10^{-08}	6.6×10^{-10}	1.1×10^{-10}	1.4×10^{-12}	1.3×10^{-11}
Muscle	1.7×10^{-08}	2.7×10^{-09}	1.3×10^{-08}	6.8×10^{-10}	2.0×10^{-10}	1.1×10^{-11}	1.8×10^{-11}
Ovaries	2.2×10^{-08}	3.4×10^{-09}	1.4×10^{-08}	1.4×10^{-09}	1.1×10^{-09}	1.0×10^{-10}	7.5×10^{-11}
Pancreas	2.2×10^{-08}	3.5×10^{-09}	1.4×10^{-08}	7.7×10^{-10}	1.9×10^{-10}	1.1×10^{-11}	1.9×10^{-11}
Red marrow	1.9×10^{-08}	2.9×10^{-09}	1.3×10^{-08}	3.7×10^{-09}	1.2×10^{-09}	1.9×10^{-11}	1.9×10^{-10}
Skin	1.3×10^{-08}	1.9×10^{-09}	1.1×10^{-08}	4.3×10^{-10}	1.1×10^{-10}	3.2×10^{-12}	1.4×10^{-11}
Spleen	2.0×10^{-08}	3.1×10^{-09}	1.4×10^{-08}	5.6×10^{-10}	1.6×10^{-10}	8.9×10^{-12}	1.7×10^{-11}
Testes	1.7×10^{-08}	2.7×10^{-09}	1.3×10^{-08}	3.8×10^{-10}	1.6×10^{-10}	7.9×10^{-12}	1.7×10^{-11}
Thymus	1.9×10^{-08}	2.9×10^{-09}	1.3×10^{-08}	5.1×10^{-10}	8.9×10^{-11}	6.3×10^{-13}	1.2×10^{-11}
Thyroid	1.9×10^{-08}	2.9×10^{-09}	1.3×10^{-08}	6.0×10^{-10}	8.7×10^{-11}	2.9×10^{-13}	1.2×10^{-11}
Uterus	2.2×10^{-08}	3.5×10^{-09}	1.4×10^{-08}	8.4×10^{-10}	5.0×10^{-10}	4.5×10^{-12}	3.8×10^{-11}
Effective dose	1.9×10^{-08}	3.1×10^{-09}	1.4×10^{-08}	1.5×10^{-09}	2.6×10^{-09}	7.1×10^{-10}	5.2×10^{-09}

	^{210}Pb	^{210}Po	^{224}Ra	^{226}Ra	^{228}Ra	^{228}Th
Adrenals	9.1×10^{-08}	2.8×10^{-07}	8.1×10^{-09}	4.1×10^{-08}	1.1×10^{-07}	6.2×10^{-09}
Bladder wall	9.2×10^{-08}	2.8×10^{-07}	8.4×10^{-09}	4.0×10^{-08}	1.1×10^{-07}	6.2×10^{-09}
Bone surfaces	2.3×10^{-05}	1.6×10^{-06}	1.8×10^{-06}	1.3×10^{-05}	2.5×10^{-05}	6.3×10^{-06}
Brain	9.1×10^{-08}	2.8×10^{-07}	8.0×10^{-09}	4.1×10^{-08}	1.1×10^{-07}	6.1×10^{-09}
Breast	9.1×10^{-08}	2.8×10^{-07}	8.0×10^{-09}	4.0×10^{-08}	1.0×10^{-07}	6.1×10^{-09}
GI tract						
Stomach wall	9.1×10^{-08}	2.8×10^{-07}	1.3×10^{-08}	4.1×10^{-08}	1.0×10^{-07}	7.5×10^{-09}
SI[a] wall	9.1×10^{-08}	2.8×10^{-07}	1.8×10^{-08}	4.3×10^{-08}	1.1×10^{-07}	9.9×10^{-09}
ULI[b] wall	9.4×10^{-08}	2.9×10^{-07}	8.2×10^{-08}	6.7×10^{-08}	1.3×10^{-07}	3.7×10^{-08}

	^{210}Pb	^{210}Po	^{224}Ra	^{226}Ra	^{228}Ra	^{228}Th
LLI[c] wall	1.0×10^{-07}	3.2×10^{-07}	2.2×10^{-07}	1.5×10^{-07}	1.8×10^{-07}	1.4×10^{-07}
Kidneys	3.7×10^{-06}	1.3×10^{-05}	3.6×10^{-08}	5.9×10^{-08}	7.5×10^{-07}	1.2×10^{-07}
Liver	1.9×10^{-06}	6.6×10^{-06}	5.2×10^{-08}	1.8×10^{-07}	1.3×10^{-06}	8.7×10^{-08}
Lungs	9.1×10^{-08}	2.8×10^{-07}	8.0×10^{-09}	4.0×10^{-08}	1.1×10^{-07}	6.1×10^{-09}
Muscle	9.1×10^{-08}	2.8×10^{-07}	8.1×10^{-09}	4.0×10^{-08}	1.1×10^{-07}	6.1×10^{-09}
Ovaries	9.1×10^{-08}	2.8×10^{-07}	8.8×10^{-09}	4.1×10^{-08}	1.1×10^{-07}	4.2×10^{-08}
Pancreas	9.1×10^{-08}	2.8×10^{-07}	8.1×10^{-09}	4.0×10^{-08}	1.1×10^{-07}	6.1×10^{-09}
Red marrow	2.4×10^{-06}	2.6×10^{-06}	1.7×10^{-07}	8.9×10^{-07}	2.1×10^{-06}	4.5×10^{-07}
Skin	9.1×10^{-08}	2.8×10^{-07}	8.1×10^{-09}	4.0×10^{-08}	1.0×10^{-07}	6.1×10^{-09}
Spleen	2.7×10^{-06}	1.1×10^{-05}	6.3×10^{-09}	5.3×10^{-08}	8.5×10^{-08}	6.1×10^{-09}
Testes	9.1×10^{-08}	2.8×10^{-07}	8.1×10^{-09}	4.0×10^{-08}	1.0×10^{-07}	4.3×10^{-08}
Thymus	9.1×10^{-08}	2.8×10^{-07}	8.0×10^{-09}	4.0×10^{-08}	1.0×10^{-07}	6.1×10^{-09}
Thyroid	9.1×10^{-08}	2.8×10^{-07}	8.0×10^{-09}	4.0×10^{-08}	1.1×10^{-07}	6.1×10^{-09}
Uterus	9.1×10^{-08}	2.8×10^{-07}	8.4×10^{-09}	4.0×10^{-08}	1.1×10^{-07}	6.2×10^{-09}
Effective dose	7.0×10^{-07}	1.2×10^{-06}	6.3×10^{-08}	2.8×10^{-07}	6.6×10^{-07}	1.4×10^{-07}

	^{230}Th	^{232}Th	^{234}Th	^{232}U	^{233}U	^{234}U
Adrenals	1.0×10^{-08}	6.1×10^{-08}	2.1×10^{-12}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Bladder wall	1.0×10^{-08}	6.1×10^{-08}	9.9×10^{-12}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Bone surfaces	1.2×10^{-05}	7.0×10^{-05}	4.9×10^{-11}	4.0×10^{-06}	8.1×10^{-07}	8.0×10^{-07}
Brain	1.0×10^{-08}	6.1×10^{-08}	5.9×10^{-13}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Breast	1.0×10^{-08}	6.1×10^{-08}	8.2×10^{-13}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
GI tract						
Stomach wall	1.1×10^{-08}	6.1×10^{-08}	1.1×10^{-09}	1.6×10^{-07}	2.9×10^{-08}	2.9×10^{-08}
SI[a] wall	1.3×10^{-08}	6.3×10^{-08}	2.6×10^{-09}	1.6×10^{-07}	3.1×10^{-08}	3.0×10^{-08}
ULI[b] wall	2.7×10^{-08}	7.5×10^{-08}	1.5×10^{-08}	1.8×10^{-07}	4.5×10^{-08}	4.4×10^{-08}
LLI[c] wall	5.9×10^{-08}	1.0×10^{-07}	4.3×10^{-08}	2.2×10^{-07}	7.7×10^{-08}	7.6×10^{-08}
Kidneys	1.5×10^{-07}	7.8×10^{-07}	1.1×10^{-11}	1.0×10^{-06}	2.9×10^{-07}	2.9×10^{-07}
Liver	1.3×10^{-07}	7.4×10^{-07}	7.4×10^{-12}	6.3×10^{-07}	1.1×10^{-07}	1.1×10^{-07}
Lungs	1.0×10^{-08}	6.1×10^{-08}	9.8×10^{-13}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Muscle	1.0×10^{-08}	6.1×10^{-08}	3.8×10^{-12}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Ovaries	8.3×10^{-08}	4.8×10^{-07}	3.3×10^{-11}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Pancreas	1.0×10^{-08}	6.1×10^{-08}	3.7×10^{-12}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Red marrow	4.1×10^{-07}	2.0×10^{-06}	3.0×10^{-11}	4.1×10^{-07}	8.3×10^{-08}	8.2×10^{-08}
Skin	1.0×10^{-08}	6.1×10^{-08}	1.6×10^{-12}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Spleen	1.0×10^{-08}	6.1×10^{-08}	3.0×10^{-12}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Testes	8.5×10^{-08}	4.9×10^{-07}	4.4×10^{-12}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Thymus	1.0×10^{-08}	6.1×10^{-08}	7.6×10^{-13}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Thyroid	1.0×10^{-08}	6.1×10^{-08}	6.2×10^{-13}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Uterus	1.0×10^{-08}	6.1×10^{-08}	1.3×10^{-11}	1.6×10^{-07}	2.8×10^{-08}	2.8×10^{-08}
Effective dose	2.0×10^{-07}	1.1×10^{-06}	3.4×10^{-09}	2.6×10^{-07}	5.0×10^{-08}	5.0×10^{-08}

	^{235}U	^{236}U	^{238}U	^{237}Np	^{239}Np	^{238}Pu
Adrenals	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-09}	9.0×10^{-12}	1.3×10^{-08}
Bladder wall	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-09}	4.7×10^{-11}	1.3×10^{-08}
Bone surfaces	7.4×10^{-07}	7.6×10^{-07}	7.1×10^{-07}	5.5×10^{-06}	2.4×10^{-11}	7.5×10^{-06}
Brain	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-09}	4.9×10^{-14}	1.3×10^{-08}
Breast	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.1×10^{-09}	1.1×10^{-12}	1.3×10^{-08}
GI tract						
Stomach wall	2.7×10^{-08}	2.7×10^{-08}	2.6×10^{-08}	8.4×10^{-09}	3.5×10^{-10}	1.4×10^{-08}
SI[a] Wall	2.9×10^{-08}	2.9×10^{-08}	2.7×10^{-08}	1.0×10^{-08}	8.6×10^{-10}	1.6×10^{-08}
ULI[b] wall	4.3×10^{-08}	4.2×10^{-08}	3.9×10^{-08}	2.5×10^{-08}	3.9×10^{-09}	3.2×10^{-08}
LLI[c] wall	7.8×10^{-08}	7.2×10^{-08}	6.9×10^{-08}	6.0×10^{-08}	8.7×10^{-09}	7.0×10^{-08}
Kidneys	2.7×10^{-07}	2.7×10^{-07}	2.5×10^{-07}	1.9×10^{-08}	2.1×10^{-11}	3.2×10^{-08}
Liver	1.0×10^{-07}	1.0×10^{-07}	9.6×10^{-08}	8.7×10^{-08}	1.4×10^{-11}	1.6×10^{-06}
Lungs	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-09}	2.1×10^{-12}	1.3×10^{-08}
Muscle	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-09}	1.7×10^{-11}	1.3×10^{-08}
Ovaries	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-08}	1.5×10^{-10}	9.7×10^{-08}
Pancreas	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-09}	2.0×10^{-11}	1.3×10^{-08}
Red marrow	7.7×10^{-08}	7.8×10^{-08}	7.5×10^{-08}	2.1×10^{-07}	2.6×10^{-11}	3.7×10^{-07}
Skin	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.1×10^{-09}	4.9×10^{-12}	1.3×10^{-08}
Spleen	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-09}	1.5×10^{-11}	1.3×10^{-08}
Testes	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.4×10^{-08}	1.2×10^{-11}	9.9×10^{-08}
Thymus	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.1×10^{-09}	8.0×10^{-13}	1.3×10^{-08}
Thyroid	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-09}	1.4×10^{-13}	1.3×10^{-08}
Uterus	2.6×10^{-08}	2.6×10^{-08}	2.5×10^{-08}	7.2×10^{-09}	7.0×10^{-11}	1.3×10^{-08}
Effective dose	4.7×10^{-08}	4.7×10^{-08}	4.5×10^{-08}	1.1×10^{-07}	8.0×10^{-10}	2.3×10^{-07}

	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
Adrenals	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Bladder wall	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Bone surfaces	8.4×10^{-06}	8.4×10^{-06}	1.7×10^{-07}	9.2×10^{-06}
Brain	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Breast	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
GI tract				
Stomach wall	1.6×10^{-08}	1.6×10^{-08}	3.0×10^{-10}	1.7×10^{-08}
SI[a] wall	1.8×10^{-08}	1.8×10^{-08}	3.1×10^{-10}	1.9×10^{-08}
ULI[b] wall	3.3×10^{-08}	3.3×10^{-08}	3.9×10^{-10}	3.6×10^{-08}
LLI[c] wall	6.8×10^{-08}	6.8×10^{-08}	5.7×10^{-10}	7.5×10^{-08}
Kidneys	3.4×10^{-08}	3.4×10^{-08}	5.0×10^{-10}	4.6×10^{-08}
Liver	1.7×10^{-06}	1.7×10^{-06}	3.4×10^{-08}	5.5×10^{-07}
Lungs	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}

	^{239}Pu	^{240}Pu	^{241}Pu	^{241}Am
Muscle	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Ovaries	1.1×10^{-07}	1.1×10^{-07}	2.2×10^{-09}	1.8×10^{-07}
Pancreas	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Red marrow	4.0×10^{-07}	4.0×10^{-07}	6.5×10^{-09}	3.1×10^{-07}
Skin	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Spleen	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Testes	1.1×10^{-07}	1.1×10^{-07}	2.2×10^{-09}	1.7×10^{-07}
Thymus	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Thyroid	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Uterus	1.5×10^{-08}	1.5×10^{-08}	3.0×10^{-10}	1.5×10^{-08}
Effective dose	2.5×10^{-07}	2.5×10^{-07}	4.8×10^{-09}	2.1×10^{-07}

[a] SI: small intestine.

[b] ULI: Upper large intestine.

[c] LLI: Lower large intestine.

Annex III

ACTIVITY IN TOTAL BODY, THYROID AND EXCRETA AFTER ACUTE AND CHRONIC INTAKE BY INGESTION OF SELECTED RADIONUCLIDES

This annex presents a table (Table III–1) and graphs (Figs III–1 to III–12) of activity in the total body, thyroid and excreta after acute and chronic intake by ingestion of some important radionuclides. These values are calculated with the biokinetic models of ICRP Publication 67[1] and are consistent with the dose coefficients given in Table VI in the main text and in Annex II. These data are given here for all age groups even though the difficulty in obtaining representative excreta samples from babies and small children is recognized.

The values $r_{a\mathrm{A}j}(t)$ (the fractional activity in the total body or in the organ considered at time t after an acute ingestion a of the radionuclide j by a member of age group A) are given for ^{137}Cs (total body) and ^{131}I (thyroid) in terms of the fraction of ingested activity present in the total body or thyroid at t days after acute ingestion; values $r_{c\mathrm{A}j}(t)$ (the fractional activity at time t in the total body in relation to the intake per day of a continuous ingestion c of the radionuclide j by a member of age group A) are given for the same radionuclides in terms of the fractional activity at t days after the beginning of continuous (chronic) ingestion, in relation to the activity of the radionuclides ingested per day.

The values $e_{a\mathrm{A}j}(t)$ (the fractional activity in 24 hour urine or faeces at time t after an acute ingestion a of the radionuclide j by a member of age group A) are given for organically bound tritium and ^{90}Sr for urine, and for ^{239}Pu for urine and faeces in terms of the fraction of the activity of the radionuclides ingested in 24 h excreta at t days after an acute ingestion; values $e_{c\mathrm{A}j}(t)$ (the fractional activity at time t in 24 h urine or faeces in relation to the intake per day of a continuous ingestion c of the radionuclide j by a member of age group A) are given for the same radionuclides in terms of the fractional activity at t days after the beginning of continuous (chronic) ingestion in relation to the activity of the radionuclides ingested per day.

The retention and excretion values for continuous (chronic) ingestion have been calculated assuming an acute intake of 1 Bq each day.

Table III–1 gives the effective dose rates $S_{\mathrm{A}j}$, per unit activity of ^{134}Cs and ^{137}Cs in the total body and of ^{131}I in the thyroid in $\mathrm{Sv}\cdot\mathrm{s}^{-1}\cdot\mathrm{Bq}^{-1}$.

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[1] INTERNATIONAL COMMISSION ON RADIOLOGICAL PROTECTION, Age-dependent Doses to Members of the Public from Intake of Radionuclides, Part 2: Ingestion Dose Coefficients, ICRP Publication 67, Pergamon Press, Oxford and New York (1993).

TABLE III–1. EFFECTIVE DOSE RATES S_{Aj} PER UNIT ACTIVITY OF ^{134}Cs AND ^{137}Cs IN THE TOTAL BODY, AND OF ^{131}I IN THE THYROID (IN $Sv \cdot s^{-1} \cdot Bq^{-1}$)

	Newborn	1 year old	5 years old	10 years old	15 years old	Adult
^{134}Cs	2.0×10^{-14}	8.6×10^{-15}	4.8×10^{-15}	3.1×10^{-15}	2.1×10^{-15}	1.8×10^{-15}
^{137}Cs	1.6×10^{-14}	6.3×10^{-15}	3.3×10^{-15}	2.1×10^{-15}	1.3×10^{-15}	1.1×10^{-15}
^{131}I	1.2×10^{-12}	8.9×10^{-13}	4.6×10^{-13}	2.0×10^{-13}	1.3×10^{-13}	8.2×10^{-14}

^{3}H urine, acute intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	5.6×10^{-2}	4.0×10^{-2}	3.2×10^{-2}	2.5×10^{-2}	1.9×10^{-2}	1.5×10^{-2}
2	7.8×10^{-2}	5.7×10^{-2}	4.6×10^{-2}	3.6×10^{-2}	2.8×10^{-2}	2.3×10^{-2}
3	6.9×10^{-2}	5.1×10^{-2}	4.2×10^{-2}	3.4×10^{-2}	2.7×10^{-2}	2.2×10^{-2}
5	5.1×10^{-2}	3.9×10^{-2}	3.4×10^{-2}	2.9×10^{-2}	2.4×10^{-2}	2.0×10^{-2}
10	2.6×10^{-2}	2.3×10^{-2}	2.2×10^{-2}	2.0×10^{-2}	1.8×10^{-2}	1.6×10^{-2}
20	8.7×10^{-3}	1.0×10^{-2}	1.1×10^{-2}	1.1×10^{-2}	1.1×10^{-2}	1.0×10^{-2}
30	3.5×10^{-3}	6.1×10^{-3}	6.7×10^{-3}	6.9×10^{-3}	7.3×10^{-3}	7.3×10^{-3}
50	6.6×10^{-4}	2.3×10^{-3}	3.0×10^{-3}	3.6×10^{-3}	3.9×10^{-3}	4.2×10^{-3}
100	1.3×10^{-5}	2.3×10^{-4}	4.8×10^{-4}	9.2×10^{-4}	1.2×10^{-3}	1.5×10^{-3}
200	1.5×10^{-8}	2.4×10^{-6}	1.3×10^{-5}	6.4×10^{-5}	1.4×10^{-4}	2.6×10^{-4}
300		5.4×10^{-9}	3.5×10^{-7}	4.6×10^{-6}	1.6×10^{-5}	4.6×10^{-5}
500				5.0×10^{-9}	2.2×10^{-7}	1.4×10^{-6}
1000						

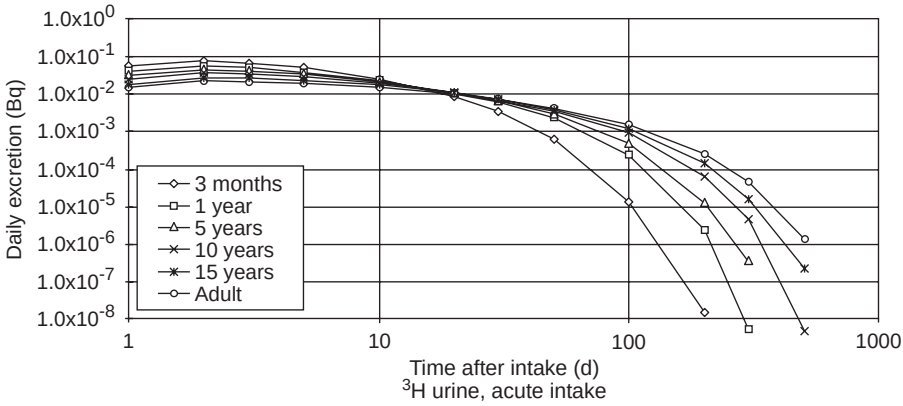

FIG. III–1. Daily excretion (Bq) in urine after ingestion of 1 Bq of organically bound tritium (acute intake).

^{90}Sr urine, acute intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	3.3×10^{-2}	5.2×10^{-2}	5.6×10^{-2}	3.9×10^{-2}	2.2×10^{-2}	5.7×10^{-2}
2	1.1×10^{-2}	1.9×10^{-2}	2.2×10^{-2}	1.5×10^{-2}	8.0×10^{-3}	2.2×10^{-2}
3	1.0×10^{-2}	1.5×10^{-2}	1.6×10^{-2}	1.2×10^{-2}	7.1×10^{-3}	1.4×10^{-2}
5	8.1×10^{-3}	1.0×10^{-2}	1.1×10^{-2}	9.0×10^{-3}	5.7×10^{-3}	8.3×10^{-3}
10	5.1×10^{-3}	5.2×10^{-3}	5.3×10^{-3}	4.8×10^{-3}	3.4×10^{-3}	3.7×10^{-3}
20	2.3×10^{-3}	2.1×10^{-3}	2.2×10^{-3}	1.9×10^{-3}	1.5×10^{-3}	1.6×10^{-3}
30	1.3×10^{-3}	1.1×10^{-3}	1.2×10^{-3}	1.0×10^{-3}	7.6×10^{-4}	8.5×10^{-4}
50	6.5×10^{-4}	4.5×10^{-4}	4.4×10^{-4}	4.2×10^{-4}	3.3×10^{-4}	2.9×10^{-4}
100	5.2×10^{-4}	2.1×10^{-4}	1.7×10^{-4}	1.9×10^{-4}	1.8×10^{-4}	8.7×10^{-5}
200	4.8×10^{-4}	1.5×10^{-4}	1.1×10^{-4}	1.2×10^{-4}	1.3×10^{-4}	4.4×10^{-5}
300	3.5×10^{-4}	1.1×10^{-4}	7.8×10^{-5}	8.6×10^{-5}	8.9×10^{-5}	2.5×10^{-5}
500	2.1×10^{-4}	7.1×10^{-5}	4.8×10^{-5}	5.2×10^{-5}	5.7×10^{-5}	1.1×10^{-5}
1000	7.3×10^{-5}	2.5×10^{-5}	2.2×10^{-5}	2.7×10^{-5}	3.6×10^{-5}	5.7×10^{-6}

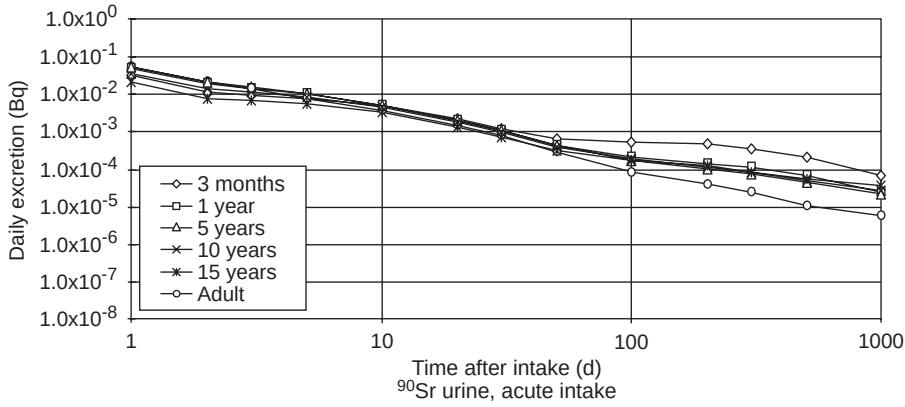

FIG. III–2. Daily excretion (Bq) in urine after ingestion of 1 Bq of ^{90}Sr (acute intake).

^{131}I thyroid, acute intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	2.4×10^{-1}	2.5×10^{-1}	2.5×10^{-1}	2.5×10^{-1}	2.5×10^{-1}	2.5×10^{-1}
2	2.3×10^{-1}	2.3×10^{-1}	2.4×10^{-1}	2.4×10^{-1}	2.4×10^{-1}	2.5×10^{-1}
3	2.0×10^{-1}	2.1×10^{-1}	2.1×10^{-1}	2.2×10^{-1}	2.2×10^{-1}	2.2×10^{-1}
5	1.5×10^{-1}	1.6×10^{-1}	1.7×10^{-1}	1.8×10^{-1}	1.8×10^{-1}	1.9×10^{-1}
10	7.8×10^{-2}	8.8×10^{-2}	9.8×10^{-2}	1.1×10^{-1}	1.1×10^{-1}	1.2×10^{-1}
20	2.1×10^{-2}	2.6×10^{-2}	3.3×10^{-2}	4.3×10^{-2}	4.4×10^{-2}	4.5×10^{-2}
30	5.7×10^{-3}	7.9×10^{-3}	1.1×10^{-2}	1.7×10^{-2}	1.7×10^{-2}	1.8×10^{-2}
50	4.2×10^{-4}	7.1×10^{-4}	1.3×10^{-3}	2.5×10^{-3}	2.7×10^{-3}	2.8×10^{-3}
100	6.8×10^{-7}	1.8×10^{-6}	5.8×10^{-6}	2.2×10^{-5}	2.4×10^{-5}	2.7×10^{-5}
200	2.4×10^{-12}	1.2×10^{-11}	1.2×10^{-10}	1.6×10^{-9}	2.6×10^{-9}	2.6×10^{-9}
300						
500						
1000						

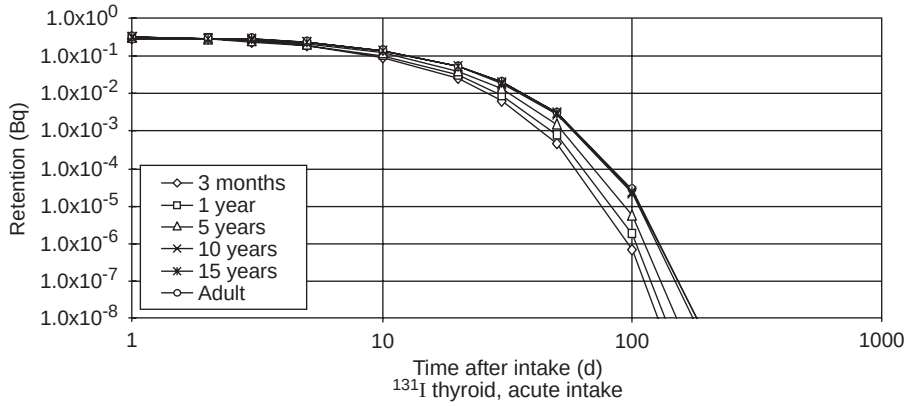

FIG. III–3. Retention (Bq) in the thyroid after ingestion of 1 Bq of ^{131}I (acute intake).

^{137}Cs total body, acute intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	9.8×10^{-1}	9.7×10^{-1}	9.8×10^{-1}	9.8×10^{-1}	9.8×10^{-1}	9.8×10^{-1}
2	9.4×10^{-1}	9.3×10^{-1}	9.3×10^{-1}	9.4×10^{-1}	9.4×10^{-1}	9.5×10^{-1}
3	9.0×10^{-1}	8.8×10^{-1}	8.9×10^{-1}	9.0×10^{-1}	9.1×10^{-1}	9.3×10^{-1}
5	8.2×10^{-1}	7.9×10^{-1}	8.2×10^{-1}	8.3×10^{-1}	8.7×10^{-1}	8.9×10^{-1}
10	6.6×10^{-1}	6.1×10^{-1}	6.6×10^{-1}	7.1×10^{-1}	8.1×10^{-1}	8.4×10^{-1}
20	4.3×10^{-1}	3.6×10^{-1}	4.5×10^{-1}	5.6×10^{-1}	7.5×10^{-1}	7.9×10^{-1}
30	2.7×10^{-1}	2.1×10^{-1}	3.2×10^{-1}	4.7×10^{-1}	6.9×10^{-1}	7.4×10^{-1}
50	1.1×10^{-1}	7.2×10^{-2}	1.8×10^{-1}	3.5×10^{-1}	5.9×10^{-1}	6.5×10^{-1}
100	1.1×10^{-2}	5.3×10^{-3}	5.6×10^{-2}	1.8×10^{-1}	4.1×10^{-1}	4.7×10^{-1}
200	8.4×10^{-5}	3.3×10^{-5}	5.8×10^{-3}	4.6×10^{-2}	1.9×10^{-1}	2.5×10^{-1}
300	4.4×10^{-7}	2.5×10^{-7}	6.4×10^{-4}	1.2×10^{-2}	9.2×10^{-2}	1.3×10^{-1}
500	1.6×10^{-11}	2.8×10^{-11}	9.1×10^{-6}	9.8×10^{-4}	2.1×10^{-2}	3.7×10^{-2}
1000			5.3×10^{-10}	3.3×10^{-6}	6.1×10^{-4}	1.5×10^{-3}

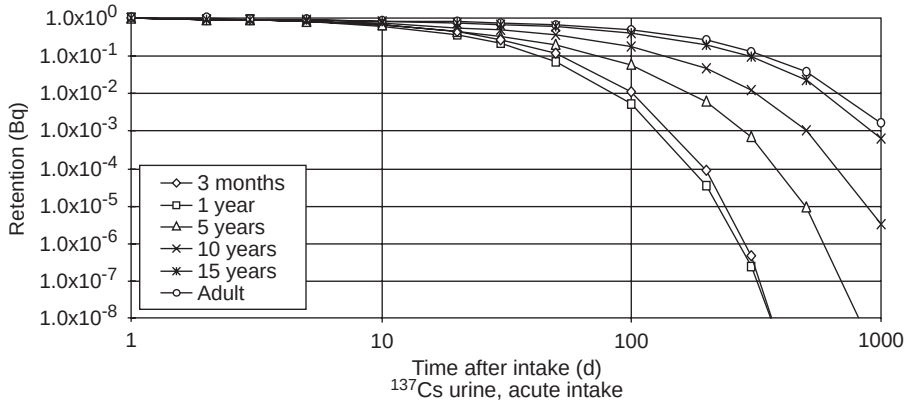

FIG. III–4. Total body retention (Bq) after ingestion of 1 Bq of ^{137}Cs (acute intake).

^{239}Pu urine, acute intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	3.6×10^{-5}	3.6×10^{-6}	3.4×10^{-6}	3.4×10^{-6}	3.4×10^{-6}	3.4×10^{-6}
2	2.5×10^{-5}	2.5×10^{-6}	2.6×10^{-6}	2.6×10^{-6}	2.6×10^{-6}	2.6×10^{-6}
3	1.4×10^{-5}	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}	1.4×10^{-6}
5	6.3×10^{-6}	6.4×10^{-7}	6.5×10^{-7}	6.5×10^{-7}	6.5×10^{-7}	6.5×10^{-7}
10	1.8×10^{-6}	1.8×10^{-7}	1.8×10^{-7}	1.8×10^{-7}	1.8×10^{-7}	1.8×10^{-7}
20	9.3×10^{-7}	8.9×10^{-8}	8.8×10^{-8}	8.8×10^{-8}	8.8×10^{-8}	8.7×10^{-8}
30	8.7×10^{-7}	8.1×10^{-8}	7.9×10^{-8}	7.9×10^{-8}	7.8×10^{-8}	7.8×10^{-8}
50	8.1×10^{-7}	7.2×10^{-8}	6.9×10^{-8}	6.8×10^{-8}	6.7×10^{-8}	6.6×10^{-8}
100	7.3×10^{-7}	5.9×10^{-8}	5.3×10^{-8}	5.1×10^{-8}	4.9×10^{-8}	4.7×10^{-8}
200	6.7×10^{-7}	5.2×10^{-8}	4.2×10^{-8}	3.8×10^{-8}	3.6×10^{-8}	3.3×10^{-8}
300	6.2×10^{-7}	5.1×10^{-8}	4.0×10^{-8}	3.5×10^{-8}	3.2×10^{-8}	2.8×10^{-8}
500	5.6×10^{-7}	5.0×10^{-8}	3.8×10^{-8}	3.3×10^{-8}	2.9×10^{-8}	2.4×10^{-8}
1000	4.7×10^{-7}	4.5×10^{-8}	3.4×10^{-8}	2.9×10^{-8}	2.5×10^{-8}	1.9×10^{-8}

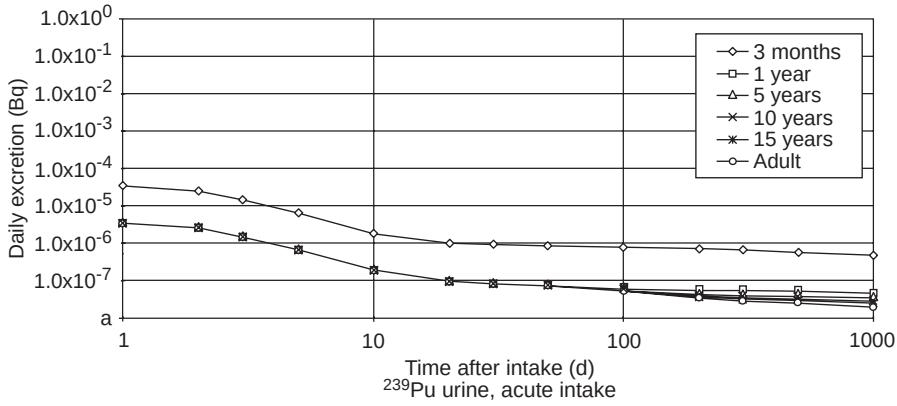

FIG. III–5. Daily excretion (Bq) in urine after ingestion of 1 Bq of ^{239}Pu (acute intake).

^{239}Pu faeces, acute intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	2.8×10^{-1}	2.8×10^{-1}	2.8×10^{-1}	2.8×10^{-1}	2.8×10^{-1}	2.8×10^{-1}
2	3.9×10^{-1}	3.9×10^{-1}	3.9×10^{-1}	3.9×10^{-1}	3.9×10^{-1}	3.9×10^{-1}
3	2.0×10^{-1}	2.0×10^{-1}	2.0×10^{-1}	2.0×10^{-1}	2.0×10^{-1}	2.0×10^{-1}
5	3.1×10^{-2}	3.1×10^{-2}	3.1×10^{-2}	3.1×10^{-2}	3.1×10^{-2}	3.1×10^{-2}
10	2.2×10^{-4}	2.2×10^{-4}	2.2×10^{-4}	2.2×10^{-4}	2.2×10^{-4}	2.2×10^{-4}
20	1.8×10^{-7}	2.4×10^{-8}	2.9×10^{-8}	2.9×10^{-8}	2.9×10^{-8}	3.5×10^{-8}
30	1.5×10^{-7}	1.0×10^{-8}	1.5×10^{-8}	1.5×10^{-8}	1.4×10^{-8}	2.0×10^{-8}
50	2.0×10^{-7}	1.2×10^{-8}	1.6×10^{-8}	1.5×10^{-8}	1.4×10^{-8}	1.9×10^{-8}
100	2.6×10^{-7}	1.6×10^{-8}	1.7×10^{-8}	1.5×10^{-8}	1.4×10^{-8}	1.8×10^{-8}
200	2.6×10^{-7}	1.8×10^{-8}	1.8×10^{-8}	1.5×10^{-8}	1.4×10^{-8}	1.6×10^{-8}
300	2.3×10^{-7}	1.9×10^{-8}	1.7×10^{-8}	1.5×10^{-8}	1.3×10^{-8}	1.4×10^{-8}
500	1.8×10^{-7}	1.8×10^{-8}	1.6×10^{-8}	1.3×10^{-8}	1.1×10^{-8}	1.1×10^{-8}
1000	1.4×10^{-7}	1.4×10^{-8}	1.2×10^{-8}	9.9×10^{-9}	8.3×10^{-9}	7.1×10^{-9}

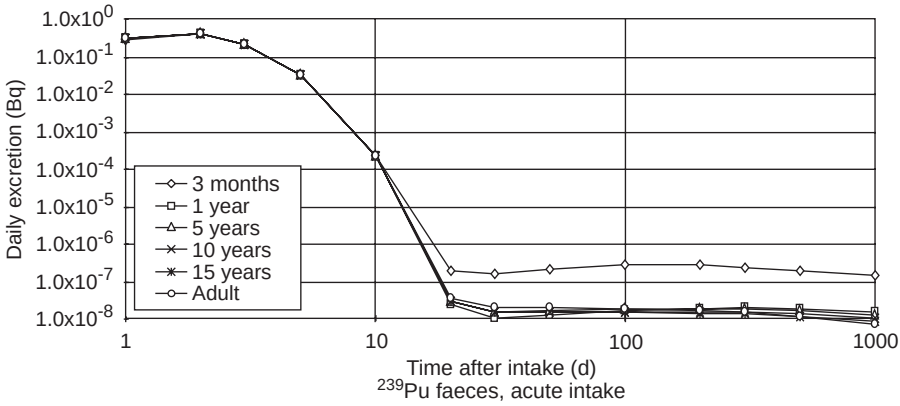

FIG. III–6. Daily excretion (Bq) in faeces after ingestion of 1 Bq of ^{239}Pu (acute intake).

^{3}H urine, chronic intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	4.2×10^{-2}	3.3×10^{-2}	2.6×10^{-2}	2.0×10^{-2}	1.5×10^{-2}	4.6×10^{-3}
2	1.0×10^{-1}	7.9×10^{-2}	6.2×10^{-2}	5.0×10^{-2}	3.8×10^{-2}	2.1×10^{-2}
3	1.5×10^{-1}	1.2×10^{-1}	9.5×10^{-2}	7.8×10^{-2}	6.0×10^{-2}	3.9×10^{-2}
5	2.3×10^{-1}	1.8×10^{-1}	1.5×10^{-1}	1.3×10^{-1}	9.8×10^{-2}	7.3×10^{-2}
10	3.3×10^{-1}	2.8×10^{-1}	2.4×10^{-1}	2.1×10^{-1}	1.7×10^{-1}	1.4×10^{-1}
20	4.1×10^{-1}	3.6×10^{-1}	3.4×10^{-1}	3.0×10^{-1}	2.7×10^{-1}	2.3×10^{-1}
30	4.4×10^{-1}	4.0×10^{-1}	3.8×10^{-1}	3.5×10^{-1}	3.2×10^{-1}	2.9×10^{-1}
50	4.5×10^{-1}	4.4×10^{-1}	4.2×10^{-1}	4.0×10^{-1}	3.8×10^{-1}	3.5×10^{-1}
100	4.6×10^{-1}	4.6×10^{-1}	4.5×10^{-1}	4.4×10^{-1}	4.3×10^{-1}	4.2×10^{-1}
200	4.5×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.5×10^{-1}	4.5×10^{-1}
300	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}
500	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}
1000	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}	4.6×10^{-1}

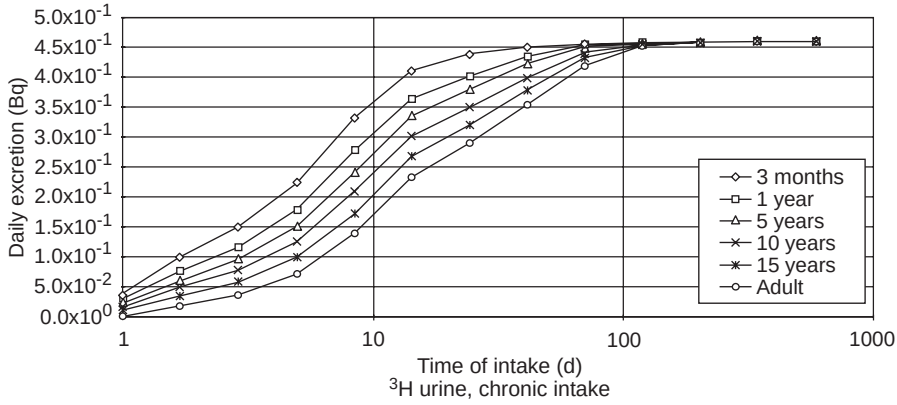

FIG. III–7. Daily excretion (Bq) in urine after daily ingestion of 1 Bq of organically bound tritium (continuous intake).

^{90}Sr urine, chronic intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	3.2×10^{-2}	5.2×10^{-2}	5.6×10^{-2}	3.9×10^{-2}	2.2×10^{-2}	5.6×10^{-2}
2	4.4×10^{-2}	7.1×10^{-2}	7.8×10^{-2}	5.4×10^{-2}	3.0×10^{-2}	7.8×10^{-2}
3	5.4×10^{-2}	8.6×10^{-2}	9.5×10^{-2}	6.6×10^{-2}	3.7×10^{-2}	9.3×10^{-2}
5	7.1×10^{-2}	1.1×10^{-1}	1.2×10^{-1}	8.5×10^{-2}	4.9×10^{-2}	1.1×10^{-1}
10	1.1×10^{-1}	1.4×10^{-1}	1.5×10^{-1}	1.2×10^{-1}	7.0×10^{-2}	1.4×10^{-1}
20	1.4×10^{-1}	1.7×10^{-1}	1.9×10^{-1}	1.5×10^{-1}	9.1×10^{-2}	1.6×10^{-1}
30	1.6×10^{-1}	1.9×10^{-1}	2.0×10^{-1}	1.6×10^{-1}	1.0×10^{-1}	1.7×10^{-1}
50	1.9×10^{-1}	2.0×10^{-1}	2.2×10^{-1}	1.7×10^{-1}	1.1×10^{-1}	1.8×10^{-1}
100	2.3×10^{-1}	2.2×10^{-1}	2.3×10^{-1}	1.8×10^{-1}	1.2×10^{-1}	1.9×10^{-1}
200	2.9×10^{-1}	2.4×10^{-1}	2.4×10^{-1}	1.9×10^{-1}	1.5×10^{-1}	1.9×10^{-1}
300	2.8×10^{-1}	2.5×10^{-1}	2.4×10^{-1}	2.0×10^{-1}	1.6×10^{-1}	2.0×10^{-1}
500	2.9×10^{-1}	2.7×10^{-1}	2.5×10^{-1}	2.1×10^{-1}	1.9×10^{-1}	2.0×10^{-1}
1000	3.0×10^{-1}	2.9×10^{-1}	2.6×10^{-1}	2.1×10^{-1}	2.2×10^{-1}	2.0×10^{-1}

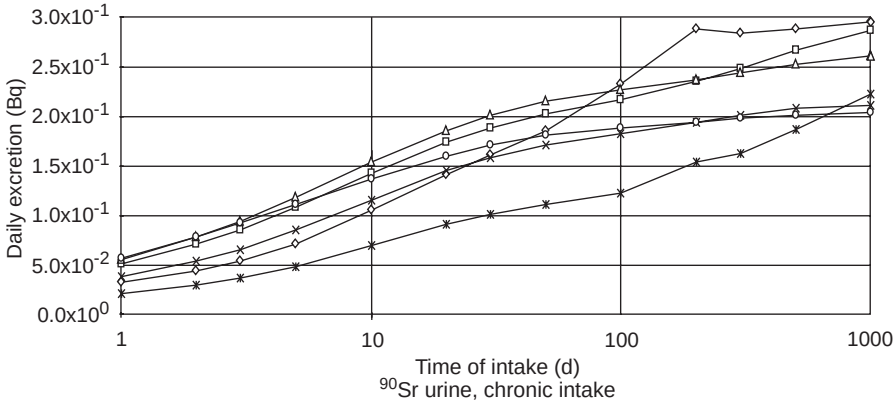

FIG. III–8. Daily excretion (Bq) in urine after daily ingestion of 1 Bq of ^{90}Sr (continuous intake).

^{131}I thyroid, chronic intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	2.4×10^{-1}	2.5×10^{-1}	2.5×10^{-1}	2.5×10^{-1}	2.5×10^{-1}	2.5×10^{-1}
2	4.7×10^{-1}	4.8×10^{-1}	4.9×10^{-1}	5.0×10^{-1}	5.0×10^{-1}	5.0×10^{-1}
3	6.7×10^{-1}	6.8×10^{-1}	7.0×10^{-1}	7.2×10^{-1}	7.2×10^{-1}	7.2×10^{-1}
5	9.9×10^{-1}	1.0×10^{0}	1.1×10^{0}	1.1×10^{0}	1.1×10^{0}	1.1×10^{0}
10	1.5×10^{0}	1.6×10^{0}	1.7×10^{0}	1.8×10^{0}	1.8×10^{0}	1.8×10^{0}
20	2.0×10^{0}	2.1×10^{0}	2.2×10^{0}	2.5×10^{0}	2.5×10^{0}	2.5×10^{0}
30	2.1×10^{0}	2.2×10^{0}	2.4×10^{0}	2.8×10^{0}	2.8×10^{0}	2.8×10^{0}
50	2.2×10^{0}	2.3×10^{0}	2.5×10^{0}	2.9×10^{0}	2.9×10^{0}	3.0×10^{0}
100	2.2×10^{0}	2.3×10^{0}	2.5×10^{0}	2.9×10^{0}	3.0×10^{0}	3.0×10^{0}
200	2.3×10^{0}	2.3×10^{0}	2.6×10^{0}	2.9×10^{0}	3.0×10^{0}	3.0×10^{0}
300	2.3×10^{0}	2.4×10^{0}	2.6×10^{0}	2.9×10^{0}	3.0×10^{0}	3.0×10^{0}
500	2.3×10^{0}	2.4×10^{0}	2.6×10^{0}	3.0×10^{0}	3.0×10^{0}	3.0×10^{0}
1000	2.4×10^{0}	2.4×10^{0}	2.7×10^{0}	2.9×10^{0}	3.0×10^{0}	3.0×10^{0}

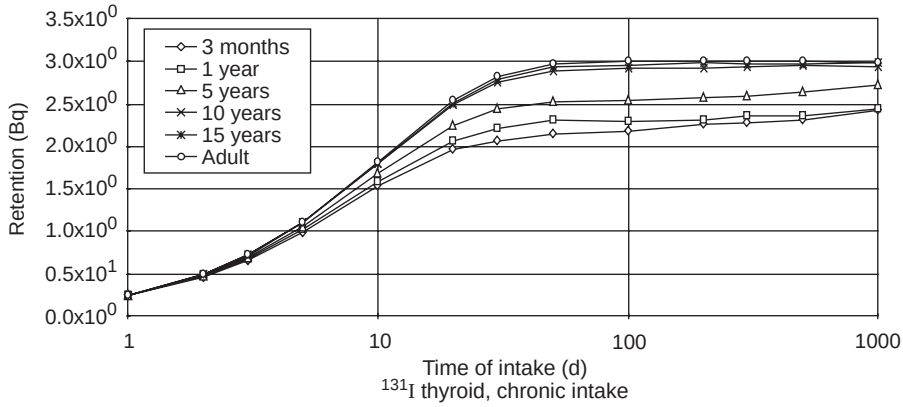

FIG. III–9. Retention (Bq) in the thyroid after daily ingestion of 1 Bq of ^{131}I (continuous intake).

^{137}Cs total body, chronic intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	9.8×10^{-1}	9.7×10^{-1}	9.8×10^{-1}	9.8×10^{-1}	9.8×10^{-1}	9.8×10^{-1}
2	1.9×10^{0}	1.9×10^{0}	1.9×10^{0}	1.9×10^{0}	1.9×10^{0}	1.9×10^{0}
3	2.8×10^{0}	2.8×10^{0}	2.8×10^{0}	2.8×10^{0}	2.8×10^{0}	2.9×10^{0}
5	4.5×10^{0}	4.4×10^{0}	4.5×10^{0}	4.5×10^{0}	4.6×10^{0}	4.7×10^{0}
10	8.4×10^{0}	7.8×10^{0}	8.1×10^{0}	8.3×10^{0}	8.7×10^{0}	9.0×10^{0}
20	1.4×10^{1}	1.2×10^{1}	1.3×10^{1}	1.4×10^{1}	1.6×10^{1}	1.7×10^{1}
30	1.8×10^{1}	1.5×10^{1}	1.7×10^{1}	2.0×10^{1}	2.4×10^{1}	2.5×10^{1}
50	2.2×10^{1}	1.8×10^{1}	2.2×10^{1}	2.8×10^{1}	3.6×10^{1}	3.9×10^{1}
100	2.4×10^{1}	1.9×10^{1}	2.7×10^{1}	4.1×10^{1}	6.1×10^{1}	6.6×10^{1}
200	2.3×10^{1}	2.0×10^{1}	3.0×10^{1}	5.1×10^{1}	9.0×10^{1}	1.0×10^{2}
300	2.1×10^{1}	2.1×10^{1}	3.1×10^{1}	5.6×10^{1}	1.0×10^{2}	1.2×10^{2}
500	2.0×10^{1}	2.2×10^{1}	3.3×10^{1}	6.1×10^{1}	1.2×10^{2}	1.3×10^{2}
1000	2.3×10^{1}	2.5×10^{1}	3.8×10^{1}	7.3×10^{1}	1.3×10^{2}	1.4×10^{2}

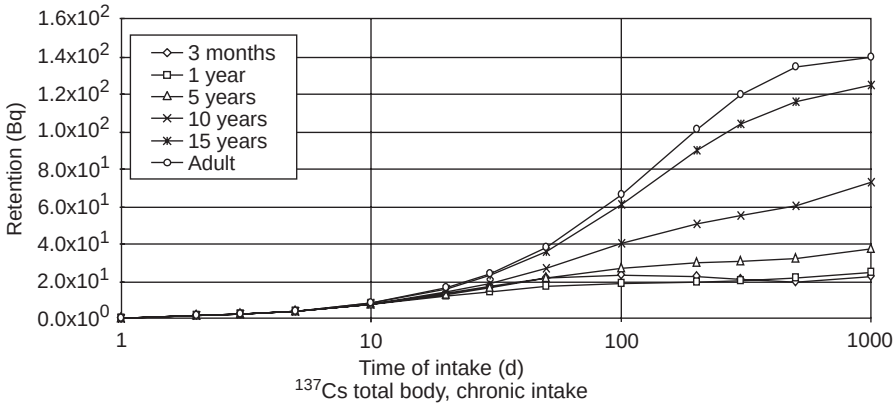

FIG. III–10. Total body retention (Bq) after daily ingestion of 1 Bq of ^{137}Cs (continuous intake).

^{239}Pu urine, chronic intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	3.6×10^{-5}	3.6×10^{-6}	3.4×10^{-6}	3.4×10^{-6}	3.4×10^{-6}	3.4×10^{-6}
2	6.0×10^{-5}	6.1×10^{-6}	6.0×10^{-6}	6.0×10^{-6}	6.0×10^{-6}	6.0×10^{-6}
3	7.4×10^{-5}	7.5×10^{-6}	7.4×10^{-6}	7.4×10^{-6}	7.4×10^{-6}	7.4×10^{-6}
5	9.0×10^{-5}	9.0×10^{-6}	9.0×10^{-6}	9.0×10^{-6}	9.0×10^{-6}	9.0×10^{-6}
10	1.0×10^{-4}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}	1.0×10^{-5}
20	1.1×10^{-4}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
30	1.2×10^{-4}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}	1.2×10^{-5}
50	1.2×10^{-4}	1.4×10^{-5}	1.4×10^{-5}	1.4×10^{-5}	1.4×10^{-5}	1.4×10^{-5}
100	1.4×10^{-4}	1.7×10^{-5}	1.7×10^{-5}	1.7×10^{-5}	1.7×10^{-5}	1.7×10^{-5}
200	1.3×10^{-4}	2.3×10^{-5}	2.1×10^{-5}	2.1×10^{-5}	2.1×10^{-5}	2.0×10^{-5}
300	1.0×10^{-4}	2.8×10^{-5}	2.5×10^{-5}	2.5×10^{-5}	2.4×10^{-5}	2.3×10^{-5}
500	1.1×10^{-4}	3.7×10^{-5}	3.3×10^{-5}	3.1×10^{-5}	3.0×10^{-5}	2.9×10^{-5}
1000	1.2×10^{-4}	5.8×10^{-5}	5.0×10^{-5}	4.6×10^{-5}	4.2×10^{-5}	3.9×10^{-5}

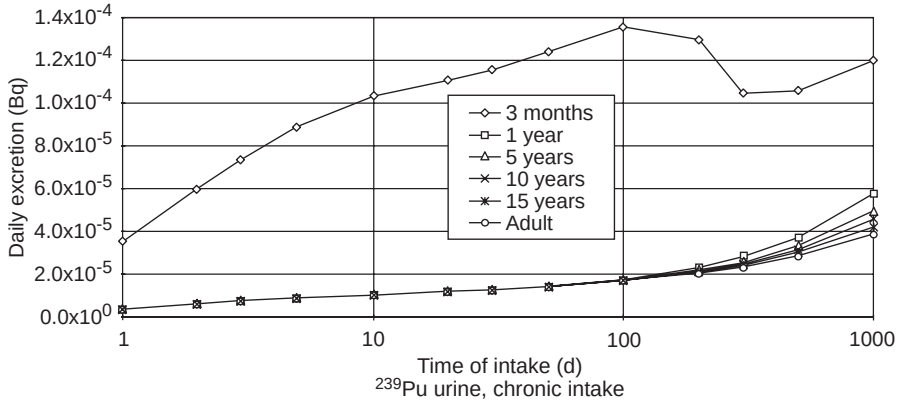

FIG. III–11. Daily excretion (Bq) in urine after daily ingestion of 1 Bq of ^{239}Pu (continuous intake).

^{239}Pu faeces, chronic intake

Days	3 months	1 year	5 years	10 years	15 years	Adult
1	2.8×10^{-1}	2.8×10^{-1}	2.8×10^{-1}	2.8×10^{-1}	2.8×10^{-1}	2.8×10^{-1}
2	6.7×10^{-1}	6.7×10^{-1}	6.7×10^{-1}	6.7×10^{-1}	6.7×10^{-1}	6.7×10^{-1}
3	8.6×10^{-1}	8.7×10^{-1}	8.7×10^{-1}	8.7×10^{-1}	8.7×10^{-1}	8.7×10^{-1}
5	9.8×10^{-1}	9.8×10^{-1}	9.8×10^{-1}	9.8×10^{-1}	9.8×10^{-1}	9.8×10^{-1}
10	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}
20	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}
30	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}
50	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}
100	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}
200	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}
300	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}
500	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}
1000	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}	1.0×10^{0}

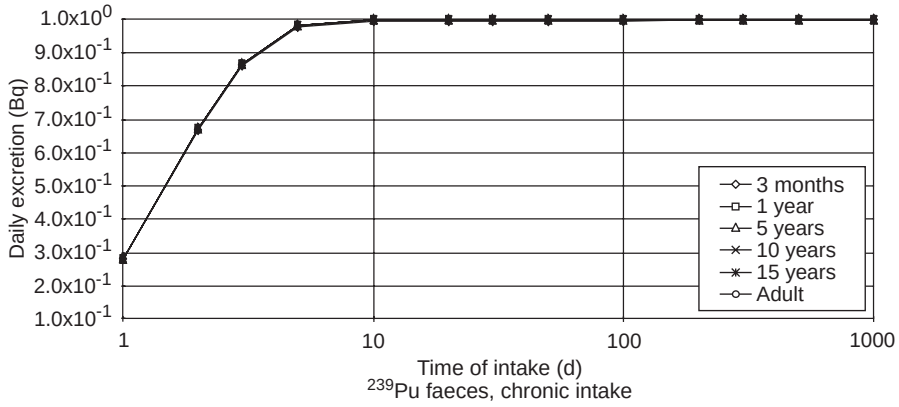

FIG. III–12. Daily excretion (Bq) in faeces after daily ingestion of 1 Bq of ^{239}Pu (continuous intake).

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Technical Committee Meeting

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Advisory Group Meeting

Vienna, Austria: 28 September–2 October 1992

Consultants Meetings

Vienna, Austria: 30 March–3 April 1992, 10–14 May 1993,
16–19 May 1994
Oxford, United Kingdom: 3–5 July 1995

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Evaluating the Reliability of Predictions Made using Environmental Transfer Models, Safety Series No. 100 (1989).

Generic Models and Parameters for Assessing the Environmental Transfer of Radionuclides from Routine Releases. Exposures of Critical Groups, Safety Series No. 57 (1982).

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