Guidance on the Application of Dose Coefficients for the Embryo, Fetus and Breastfed Infant in Dose Assessments for Members of the Public

Advice from the Health Protection Agency

RCE-5

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Documents of the Health Protection Agency
Radiation, Chemical and Environmental Hazards
March 2008

Contents

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Abstract

The International Commission on Radiological Protection (ICRP) has published dose coefficients that consider *in utero* exposures of the embryo and fetus and transfer of radionuclides in breast milk to the newborn child. This document provides guidance on the application of these dose coefficients in relation to different exposure situations. Information is given on the dose coefficients and the related guidance previously given by the ICRP and the National Radiological Protection Board. The importance of considering doses resulting from *in utero* exposures to radionuclides and their transfer in breast milk is assessed, based on a series of calculations carried out for routine discharges of radionuclides to the environment. The applicability of the results for emergency exposure situations and solid waste disposal is also addressed. The recommendations made include that in many situations an explicit assessment of the dose to either the embryo/fetus or the breastfed infant is not required. However, for four radionuclides – ^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr – it is recommended that the fetus/breastfed infant is considered in all assessments where these radionuclides form a significant part of any release of radioactivity to the environment.

1 Introduction

The International Commission on Radiological Protection (ICRP) provides a system of protection against the risks from exposure to ionising radiation (ICRP, 1991, 2007a). An important component of that system is the provision of biokinetic and dosimetric models for the assessment of doses from the intakes of radionuclides. A series of reports – Publications 56, 67, 69 and 71 (ICRP, 1989, 1993, 1995, 1996a), culminating in a compilation report Publication 72 (ICRP, 1996b) – gave dose coefficients for the ingestion or inhalation of selected radioisotopes of 31 elements by 3 month old infants, children aged 1, 5, 10 and 15 years, and adult members of the public. In each case, the values given are of committed effective dose per becquerel (Bq) ingested or inhaled by the infant, child or adult, integrated to age 70 years. The ICRP has also published dose coefficients that consider *in utero* exposures of the embryo and fetus (Publication 88 – ICRP, 2001) and transfer of radionuclides in breast milk to the newborn child (Publication 95 – ICRP, 2004). In these cases, the values given are of committed effective dose to the offspring per becquerel ingested or inhaled by the mother.

In Publication 101, the ICRP (2007a) provided guidance on the assessment of doses to members of the public. Consideration was given to the need to assess doses to all age groups for which dose coefficients have been published. It was concluded that in most cases it will be sufficient to consider doses to just three of the age groups for which dose coefficients had been published: 1 year old infants, 10 year old children, and adults. These age groups should be considered to be representative of the age ranges 0–5 years (infant), 6–15 years (child), and 16–70 years (adult), respectively.

Advice was given by the National Radiological Protection Board (NRPB, 2005) (now the Radiation Protection Division of the Health Protection Agency) on the application of ICRP dose coefficients for the embryo and fetus in the context of both occupational and environmental exposures. For exposures of members of the public, it was concluded that it may, in some situations, be important to consider *in utero* exposures for those radionuclides for which doses to the offspring might substantially exceed those to the mother. In this NRPB advice it was recognised that the fetus may be more radiosensitive than the adult. However, as exposures resulting from planned operations, such as controlled discharges to the environment, are generally received over a number of years, the additional risk from exposures *in utero* will be small compared with the lifetime risk. It was therefore considered that the inclusion of the fetus in dose assessments for the public as a representative person/member of the potential critical group provided sufficient protection (NRPB, 2005).

This document provides guidance on the application of ICRP dose coefficients for *in utero* exposures and transfer of radionuclides in breast milk, in relation to different exposure situations. Section 2 provides further explanation of the dose coefficients provided by the ICRP for the embryo/fetus and breastfed infant. Section 3 summarises the advice and guidance given by the ICRP in Publication 101 (ICRP, 2007a) and by the NRPB (2005). Section 4 gives an overview of the approach used in this document to assess the importance of considering doses* resulting from *in utero* exposures to

* In this paper the dose is defined as the sum of the effective dose from external exposure in the specified period and the committed effective dose from radionuclides taken into the body via inhalation and ingestion in the same period.

radionuclides and their transfer in breast milk. Results presented in Section 5 are discussed in Section 6 in relation to routine exposures, accidents and emergencies. Finally, conclusions and recommendations are given in Section 7.

2 ICRP Dose Coefficients

In its publications dealing with dose coefficients for *in utero* exposures to radionuclides and transfer of radionuclides in breast milk, the ICRP (2001, 2004) considered the inhalation or ingestion of radionuclides by females prior to, during or after pregnancy. Dose coefficients (in sievert per becquerel, Sv Bq^{-1}) are given for the embryo and fetus, or the breastfed infant, per unit intake (Bq) by the mother. Continuous chronic and single acute intake scenarios are considered. For *in utero* exposures, the acute times are 2.5 years and 6 months prior to conception, at conception, and during pregnancy at 5, 10, 15, 25 and 35 weeks after conception. For radionuclide transfer in breast milk, again various acute intake times for *in utero* exposures are considered, together with intake at 1, 10 and 20 weeks after birth. Chronic intake scenarios are periods of 5 years or 1 year prior to pregnancy, throughout pregnancy (38 weeks, approximately 9 months), and additionally for breastfeeding, throughout lactation (26 weeks). Dose coefficients calculated for intakes by the infant during breastfeeding account for only the activity taken in with the breast milk; they do not include transfer to the infant *in utero*. It should be noted that the dose coefficients for the embryo/fetus and breastfed infant are for specific scenarios of intake by the mother and so differ from the dose coefficients for other age groups, which are for a single intake by the individual.

In the calculation of doses to the offspring resulting from intakes of radionuclides by the mother, there are four potential components that need to be taken into account:

a doses to the embryo and fetus from photon-emitting radionuclides in the mother's tissues,

b doses to the newborn child from photon-emitting radionuclides retained in the mother's tissues,

c doses to the embryo, fetus, and newborn child from radionuclides transferred to the offspring during gestation (pregnancy),

d doses to the newborn child from radionuclides ingested in the mother's milk.

The first component of dose is included in the dose coefficients for the embryo and fetus given in Publication 88 (ICRP, 2001). The dose coefficients therefore take account of doses received *in utero* from radionuclides transferred to the embryo and fetus and also photon irradiation from maternal tissues and the placenta. In addition, committed effective doses to the newborn child, from radionuclides retained in the body at birth, were calculated using models developed previously. The dose coefficients given in Publication 88 combine each of these contributions, giving the total committed effective dose received *in utero* and after birth following ingestion or inhalation of radionuclides by the mother before or during pregnancy.

The dose coefficients given in Publication 95 (ICRP, 2004) for the breastfed infant take account of the transfer of radionuclides in breast milk but not of photon irradiation of the suckling infant from radionuclides retained in the mother's body. Radionuclide transfer in breast milk was calculated assuming that consumption increases linearly over the first week of life to 800 ml per day and continues at this rate to 6 months after birth. No account was taken of the subsequent reduced consumption during weaning. However, it was recognised that daily production of milk varies substantially among individuals and that there is also a wide variation in the duration of breastfeeding and the time at which women choose to begin weaning their children. Some guidance was given in Publication 95 on the assessment of doses in situations that differ from default assumptions. The dose coefficients for the breastfed infant were calculated by applying the ingestion dose coefficient for a 3 month old infant to the total period of breast milk consumption. Dose coefficients for the breastfed infant were provided in Publication 95 following the acute intake of radionuclides by the mother before, during or after pregnancy. For chronic intake of radionuclides by the mother two dose coefficients were provided. The first was for intake by the mother during pregnancy and subsequent transfer to the baby through breastfeeding. The second was for intake by the mother during the period of breastfeeding.

Although doses to the suckling infant from photon-emitting radionuclides retained in the mother's body were not included in the dose coefficients given in Publication 95, examples of this source of exposure were considered in an annex to the report. The examples showed that external irradiation from the mother can contribute significantly to doses received by the breastfeeding infant in some cases (eg inhalation of insoluble forms of ^{60}Co), but for most radionuclides, including those considered in this document, this pathway contributed very little to the total committed dose of the infant, and so was not considered further.

While Publication 88 (ICRP, 2001) gave dose coefficients for the embryo and fetus without comment on their significance or practical use, Publication 95 (ICRP, 2004) provided a short discussion in which doses to the offspring were compared to doses to the adult. For the example of chronic ingestion of radionuclides throughout pregnancy and lactation, doses to the offspring resulting from *in utero* exposures were generally more important than doses received as a result of radionuclide transfer in breast milk. Exceptions for which transfer in breast milk was shown to result in similar or greater doses than *in utero* exposure include ^{60}Co, ^{75}Se, ^{99m}Tc, ^{110m}Ag, ^{131}I and ^{210}Po. For most radionuclides considered, doses to the offspring were smaller than doses to the adult. Notable exceptions were ^{32}P and ^{45}Ca, but dose ratios of 1.5 or greater were also obtained for tritium (as tritiated water or organically-bound tritium), ^{35}S, ^{90}Sr and ^{131}I.

The ICRP has not, however, provided any guidance on how these dose coefficients are to be applied when assessing, for example, an annual dose for comparison with dose limits or constraints for members of the public. There is no indication of how the dose coefficients for chronic exposures of the embryo/fetus throughout gestation (which are for 9 months' exposure) and the infant throughout breastfeeding (which assumes 6 months' exposure) should be combined in order to assess an annual dose. In radiological protection when considering intakes it is the committed dose from intake over a period that is evaluated. For both exposure of the embryo/fetus and exposure during breastfeeding the relevant intakes and periods of intake are those for the mother.

3 Current Guidance and Practice

Dose assessments for members of the public typically consider the dose to a limited group of people from a potentially larger number that could be exposed. Thus, for the purposes of protection of the public, it is necessary to provide assessments of dose that are representative of the more highly exposed individuals in the population. In Publication 101 and its new recommendations, the ICRP (2007a,b) has introduced the term 'representative person' for this purpose, as the equivalent of and to replace 'average member of the critical group' described in previous recommendations. In considering dose to the representative person, it is necessary to take account of a number of factors:

a the dose assessment must account for all relevant pathways of exposure,

b the dose assessment must consider the spatial distribution of radionuclides to ensure that the group receiving the highest dose is included in the assessment,

c habit data should be based on the group or population exposed and must be reasonable, sustainable and homogenous,

d dose coefficients have to be applied according to specific age categories.

The ICRP (2007a,b) recognises three types of exposure situation: normal (or planned), existing and emergency. Normal (planned) exposure situations involve the planned introduction and operation of sources. Existing exposure situations relate to sources that already exist when a decision on control has to be taken, eg such sources may have been introduced unintentionally or as a result of past human activities that have been abandoned. Emergency exposure situations are unintended or unexpected events that may occur during the operation of a planned situation or from a malicious act and which require urgent attention.

Doses from radionuclides in the environment can result from external photon irradiation as well as from internal irradiation following ingestion or inhalation. Annual doses are estimated as the sum of the external dose during the year and the committed effective dose from radionuclide ingestion or inhalation during the year. Because committed doses are integrated to age 70 years, the temporal pattern of internal dose delivery varies substantially depending on the radioactive half-life of the radionuclide and its retention in body organs. Thus for ^{131}I, for example, dose is delivered within weeks of intake and hence completely or largely within the year of intake. However, for ^{239}Pu, for example, dose is delivered throughout an individual's life-time and hence only a small proportion of the total dose is delivered within the year of intake.

While there is little variation in doses from external sources depending on age at irradiation, doses from intakes of radionuclides can vary substantially as a result of different food consumption and inhalation rates, and because dose coefficients are age dependent. Dose coefficients have been calculated by the ICRP for the ingestion or inhalation of radionuclides by 3 month old infants, children aged 1, 5, 10 and 15 years, and adult members of the public (ICRP, 1989, 1993, 1995, 1996a,b). However, Publication 101 (ICRP, 2007a) concludes that for general protection of the public it is necessary to consider only three age groups: 1 year old infants, 10 year old children, and adults. These age groups are taken to be representative of the age groups 0–5 years (infant), 6–15 years (child), and 16–70 years (adult), respectively. A number of points are made by the ICRP in support of this conclusion:

a uncertainties in dose estimates, particularly for prospective calculations, are generally not reduced significantly by consideration of more age categories, when uncertainties in habit data and environmental radionuclide concentrations are taken into account,

b particularly for normal (planned) and existing exposure situations, the fundamental concept of continuing exposure to the same individuals justifies the use of a limited number of age categories that cover several years of a person's life,

c the ICRP (1991, 2007b) allows dose averaging over a 5 year period in the evaluation of compliance with constraints and recommends that a similar approach is appropriate for establishing the number of age groups to be considered in prospective assessments of continuing exposure,

d comparisons show that doses assessed for 1 and 10 year old children are within a factor of three or four of doses assessed for 5 and 15 year old children, respectively.

This approach, of using a limited number of age groups to represent a generic population, has often been adopted in the UK and other countries. For example, this is the recommended approach of the European Commission as specified in its published guidance on dose assessments to the public from the normal operations of nuclear installations (EC, 2002) and, in the UK, in the principles for assessing prospective public doses published by the Environment Agency and other agencies (EA et al, 2002).

In Publication 101 the ICRP also gave some consideration to the need to address doses to the embryo and fetus and breastfed infant. This was done by comparing doses assessed for the 1 year old with doses to the child resulting from radionuclide intake of the mother throughout 9 months of pregnancy and 3 months of breastfeeding. It was concluded that, in most cases, there will be no substantial differences and doses to the 1 year old can be used in assessments to represent all exposures during early life, including *in utero* exposures. However, Publication 101 drew attention to the fact that some radionuclides, principally isotopes of phosphorus and the alkaline-earth elements (calcium, strontium, etc), can deliver significantly higher doses to the fetus and breastfed infant than to the mother. It was recommended that if assessed doses to other age groups are approaching the values of the relevant dose constraint and there is a significant contribution from such radionuclides, doses due to *in utero* exposure and breastfeeding should be assessed separately. Publication 101 also states that, because *in utero* development and breastfeeding represent a small proportion of an individual's life, an appropriate level of protection can be achieved by comparing the assessed dose with a higher dose constraint than normally applied to members of the public. The maximum value of this higher dose constraint should not exceed the dose limit for members of the public.

Advice was given by the NRPB on the application of ICRP dose coefficients for the embryo and fetus in the context of both occupational and environmental exposures (NRPB, 2005). Conclusions were based on comparisons of doses to the offspring and to the mother (reference adult). For occupational radiation exposure employers were advised to ensure that the risk to women of reproductive capacity (including those who have declared themselves pregnant) is adequately controlled. It was noted that for some radionuclides additional precautions may be required and in such circumstances it is particularly important to provide information to female workers on the need for early notification of pregnancy. This advice is still applicable and the consideration of additional precautions for certain radionuclides should be extended to women who have returned to work following pregnancy but who are still breastfeeding their child.

For exposures of members of the public, it was concluded that it may be important to consider *in utero* exposures for those radionuclides for which doses to the offspring might exceed those to the mother, particularly radioisotopes of elements required by the fetus for skeletal growth, including calcium and phosphorus. This document provides guidance on the application of ICRP dose coefficients for *in utero* exposures and transfer of radionuclides in breast milk, in relation to different exposure situations, including planned situations of radionuclide discharge into the environment from routine operations and in emergency situations. It provides a detailed comparison of assessed doses for the embryo and fetus and breastfed infant with doses for 1 year old infants, 10 year old children, and adults. A difficulty addressed in these comparisons is that the ICRP dose coefficients consider the normal 9 months' duration of pregnancy and assume 6 months of breastfeeding. In applying these dose coefficients to the estimated annual intake of radionuclides by the mother, different assumptions can be made regarding the proportions of the year assigned to pregnancy and lactation.

This guidance focuses on individual doses and does not provide advice for the calculation of collective doses, where it is generally considered adequate to consider doses to adults only (Simmonds et al, 1995).

4 Approach Used

4.1 Radionuclides considered

It is clear that any guidance given here can be confined to radionuclides for which the dose to the offspring is greater than that to the mother, following exposures occurring during pregnancy and lactation. External photon irradiation from environmental radionuclides will result in approximately the same dose to the embryo and fetus as to the mother, especially for exposure in high photon energy fields that expose the body in an essentially uniform way (those for which the external irradiation pathway is likely to be important). External irradiation doses to the breastfed infant are also likely to be similar to those of the mother and other age groups. Therefore, for this assessment, the external dose rate to both the offspring, either as an embryo or fetus or during breastfeeding, is considered to be equal to that of the mother. This means that this document is aimed at providing guidance on when and how to assess the dose to the embryo, fetus and breastfed infant for those radionuclides which have a significant internal component to the total dose. Greater doses to the offspring arise only for those radionuclides that are readily transferred across the placenta and/or in breast milk.

A review of the dose coefficients was made to identify those radionuclides where the embryo/fetus or breastfed infant could receive higher doses than those to other age groups. Information on the relative value of the dose coefficients was obtained from the guidance published by the NRPB on the application of the embryo/fetal dose coefficients (NRPB, 2005), supplemented by information provided by the ICRP

TABLE 4.1 Ratios of embryo/fetal dose coefficients to the corresponding adult dose coefficients for radionuclide ingestion or inhalation throughout pregnancy by a member of the public (from NRPB, 2005)

		Inhalation	
Radionuclide	**Ingestion**	**Gases and vapours**	**Particulate material**
^{3}H (inorganic)	1.7 (water)	1.7 (water vapour)	0.06 (M)
^{3}H (organic)	1.5	1.5	–
^{14}C	1.4	1.4 (organic vapours)	1.4 (F), 0.03 (M)
^{32}P	10	–	13 (F), 1.9 (M)
^{33}P	20	–	22 (F), 0.8 (M)
^{35}S (organic)	2.1	2.0 (carbon disulphide)	–
^{35}S (inorganic)	1.6	1.4 (sulphur dioxide)	1.3 (F), 0.01 (M)
^{45}Ca	12	–	0.6 (M)
^{47}Ca	4.8	–	0.5 (M)
^{75}Se	1.0	–	1.1 (F)
^{89}Sr	4.6	–	0.3 (M)
^{90}Sr	1.5	–	0.2 (M)
^{131}I	1.0	1.1 (elemental iodine)	1.0 (F)
^{224}Ra	3.4	–	0.01 (M)
^{226}Ra	1.1	–	0.03 (M)

Notes
Embryo/fetal dose coefficients are for chronic intakes only.
Ratios are given for the default lung absorption type recommended by the ICRP for environmental exposure of members of the public (ICRP, 1996b): F denotes Fast absorption to blood, M denotes Moderate absorption. Where a default has not been given all lung absorption types are presented. It is important to note that for forms more soluble than those given in the table, ratios could be higher and could even exceed one. However, it is unlikely that these soluble forms would be encountered in routine release assessments.

on the breastfed infant (ICRP, 2004). Radionuclides which have larger fetal dose coefficients for chronic intake by the mother than the corresponding dose to the adult are presented in Table 4.1, together with the ratio of those coefficients. It should be noted that, for inhalation, data are presented for selected lung solubility types. It is possible, although unlikely, that more soluble forms could be encountered and result in higher ratios than those tabulated. The dose coefficients used to calculate doses are given in Appendix A. For the ingestion of radionuclides in mother's milk, the ICRP noted that it is only for tritiated water, ^{45}Ca, ^{75}Se and ^{131}I that breastfed infant doses may exceed adult doses, by ratios of between just over one and three (ICRP, 2004). The radionuclides considered in this document are, therefore, as shown in Table 4.1. For all other radionuclides there is no need to specifically consider these age groups in dose assessments.

4.2 Exposure scenarios and pathways

Doses to different age groups were assessed for routine releases of radionuclides to the environment, considering both atmospheric discharges and releases in liquid form into a river. Table 4.2 summarises the exposure pathways considered for each of these scenarios. The pathways included are those considered in calculations of generalised derived constraints (GDCs) (NRPB, 2000, 2002), together with additional pathways based on advice from the European Commission (EC, 2002). The age groups for which comparisons were made with the embryo/fetus and breastfed infant were the 1 year old infant, 10 year old child, and the adult. For atmospheric release of radionuclides, the 3 month old infant was also considered for the ingestion of radionuclides in cows' milk. As for the calculations performed in deriving GDCs (NRPB, 2000, 2002), the 3 month old was assumed to ingest milk at a rate corresponding to that of an older child to represent consumption during the first year of life. Exposures were assessed assuming a unit release of 1 Bq per second into the selected environment over one year. The total dose for each release was obtained by summing over all the pathways. Appendix A gives details of the methodology and data used in the dose calculations.

The European Commission (EC, 2002) discussed in some detail the selection of foods to be considered in a dose assessment. In this assessment only a limited range of foods was considered covering the main food groups, such as milk, meat and green vegetables. Other foods may also be consumed – for example, free foods or freshwater foods other than fish. However, the ingestion doses estimated here can be taken to be representative of the relative doses between the age groups to indicate the extent to which it is necessary to consider the fetus or breastfed infant.

The difference in the calculated dose between different age groups depends on the following variables: dose coefficients, intake rates, routes of intake and occupancy times. The dose coefficients can vary considerably between the ages, sometimes by several orders of magnitude. However, often there is less of a difference and the dose is therefore more dependent on the exposure routes and habit data. For example, for iodine and strontium the ingestion of milk is an important exposure pathway and in this case the doses to young children are relatively important due to the amount of milk they ingest.

4.3 Assessed age groups

For the 3 month old infant, 1 and 10 year old children, and adults, standard assessment methodologies were used in that the activity concentration in each part of the environment was calculated and the dose obtained by multiplying this value by the dose coefficient or dose rate and an annual intake or occupancy. For exposure from external irradiation the dose to the embryo/fetus and breastfed infant was assumed to be the same as that to the mother. However, for internal exposure to the embryo/fetus and breastfed infant the calculation of annual doses was not so straightforward as the dose coefficients

TABLE 4.2 Exposure pathways considered

Atmospheric release	River release
Inhalation of radionuclides within a plume	External irradiation from radionuclides deposited onto the river bank
Inhalation of ambient resuspended radionuclides	Inhalation of radionuclides associated with river bank sediments
External irradiation from deposited radionuclides	Ingestion of radionuclides associated with freshwater fish
External irradiation from radionuclides within the plume	Ingestion of radionuclides within river water used as drinking water
Ingestion of foods: Domestic fruit Green and other domestically grown vegetables Potatoes and root vegetables Cow meat Cow offal Sheep meat Sheep offal Milk Milk products	Ingestion of foods from land irrigated using river water: Green and other domestically grown vegetables Potatoes and root vegetables

published by the ICRP relate to 9 months' pregnancy and 6 months' lactation. To obtain doses corresponding to an annual exposure, four different combinations of the available dose coefficients were used, as follows.

a *Simplified fetus* assessment – used the annual ingestion or inhalation of radionuclides by the mother and the fetal dose coefficient for chronic exposure throughout pregnancy. This assessment applied dose coefficients for 9 months' exposure whilst a fetus, as provided by the ICRP, to annual intakes by the mother.

b *Limited pregnancy* assessment – 6 months' exposure to the fetus followed by 6 months' exposure whilst breastfeeding. This assessment applied dose coefficients for chronic exposure throughout pregnancy and breastfeeding each to periods of 6 months intake by the mother, but also applied dose coefficients for transfer in breast milk following chronic exposure during pregnancy.

c *Full pregnancy* assessment – 9 months' exposure to the fetus followed by 3 months' exposure whilst breastfeeding. This assessment applied dose coefficients for chronic exposure throughout pregnancy and breastfeeding to periods of 9 months and 3 months intake, respectively, and also applied dose coefficients for transfer in breast milk following chronic exposure during pregnancy.

d *Breastfeeding* assessment – 1 year's exposure of the breastfed infant following the annual ingestion or inhalation of radionuclides by the mother. This assumed that the dose coefficients for exposure to radionuclides in the mother's milk, provided by the ICRP based on 6 months' breastfeeding, could be directly applied to an annual intake by the mother.

The aim of this assessment was to address two questions.

a Does the dose to the embryo/fetus and the breastfed infant need to be included in a dose assessment of routine releases of radionuclides?

b If the dose to the embryo/fetus and the breastfed infant does need to be included, which is the best method for performing the assessment?

The latter question needs to consider both the available data, in terms of the dose coefficients provided by the ICRP and the assumptions that the ICRP made when calculating them, and the possibility of simplifying the dose assessment by limiting the combination of dose coefficients and intakes used.

Two of the methods considered use a simplified approach with a single dose coefficient applied to an annual intake by the mother even though it was derived based on exposure of 9 months for the fetus or 6 months for breastfeeding. Such an approach is relatively simple to implement and could be useful for scoping calculations. The other two methods considered represent a more realistic use of the dose coefficients, although increasing the complexity of the dose assessment. It should be noted that, strictly, the simplified fetus assessment should have also considered the transfer of radionuclides to breast milk from intake during pregnancy for which the ICRP provides dose coefficients. However, the aim was to investigate the possibility of a simplified approach and in most cases the dose coefficients for breastfeeding are small compared to those for exposure as a fetus so only the fetal dose coefficient was considered.

In most cases the dose coefficients provided by the ICRP for chronic intake by the mother and applicable to the 9 months of pregnancy and the 6 months of breastfeeding were used directly in the assessment. However, for iodine and phosphorus a more realistic approach was adopted for the full pregnancy assessment. Additional dose coefficients for exposure to the breastfed infant were obtained for an exposure period of 3 months, using the same methodology as was used in the calculation of the dose coefficients provided by the ICRP (Phipps, 2007).

5 Results

Table 5.1 presents results for routine releases of radionuclides to atmosphere, giving ratios of doses assessed for the embryo/fetus/breastfed infant compared to the maximum dose assessed for the other age groups considered. Table 5.2 presents corresponding results for liquid discharges to a river. From the tables it is seen that in many cases the ratio of the dose to the fetus/breastfed infant to the limiting age group is less than or equal to one, which means that one of the age groups other than the fetus or breastfed infant is limiting. For releases to atmosphere, the highest ratios seen are for ^{32}P and ^{33}P (up to five), while for all other radionuclides the ratios are less than two. For liquid releases to a river the ratios are generally higher than those for atmospheric releases, although still less than or equal to one in several cases. The fetal/breastfed infant doses are significantly above two for ^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr, with the highest ratios seen for the two phosphorus isotopes (up to ten for ^{32}P and up to twenty for ^{33}P).

TABLE 5.1 Ratio[a] of the annual dose to the embryo/fetus/breastfed infant to the maximum of the annual dose to a 3 month old, 1 year old, 10 year old and adult for a routine release of radioactivity to atmosphere

Radionuclide[b]	Simplified fetus[c]	Full pregnancy[d]	Limited pregnancy[e]	Breastfeeding[f]
^{3}H	1.1	≤ 1	≤ 1	≤ 1
^{14}C (M)	≤ 1	≤ 1	≤ 1	≤ 1
^{14}C (F)	≤ 1	≤ 1	≤ 1	≤ 1
^{14}C (vapour)	≤ 1	≤ 1	≤ 1	≤ 1
^{22}Na (F)	≤ 1	≤ 1	≤ 1	≤ 1
^{32}P (M)	1.7	1.3	≤ 1	≤ 1
^{32}P (F)	1.8	1.4	≤ 1	≤ 1
^{33}P (M)	**2.2**	1.8	1.4	≤ 1
^{33}P (F)	**5.2**	**4.0**	**2.8**	≤ 1
^{35}S (organic/inorganic particulate M)	≤ 1	≤ 1	≤ 1	≤ 1
^{35}S (organic/inorganic particulate F)	≤ 1	≤ 1	≤ 1	≤ 1
^{35}S (organic/organic vapour)	≤ 1	≤ 1	≤ 1	≤ 1
^{35}S (organic/inorganic vapour)	≤ 1	≤ 1	≤ 1	≤ 1
^{35}S (inorganic/inorganic particulate M)	≤ 1	≤ 1	≤ 1	≤ 1
^{35}S (inorganic/inorganic particulate F)	≤ 1	≤ 1	≤ 1	≤ 1
^{35}S (inorganic/organic vapour)	≤ 1	≤ 1	≤ 1	≤ 1
^{35}S (inorganic/inorganic vapour)	≤ 1	≤ 1	≤ 1	≤ 1
^{45}Ca (M)	1.5	1.3	1.1	≤ 1
^{47}Ca (F)	≤ 1	≤ 1	≤ 1	≤ 1
^{75}Se (F)	≤ 1	≤ 1	≤ 1	≤ 1
^{89}Sr (M)	≤ 1	≤ 1	≤ 1	≤ 1
^{90}Sr (M)[g]	≤ 1	≤ 1	≤ 1	≤ 1
^{131}I	≤ 1	≤ 1	≤ 1	≤ 1
^{224}Ra (M)[g]	≤ 1	≤ 1	≤ 1	≤ 1
^{226}Ra (M)[g]	≤ 1	≤ 1	≤ 1	≤ 1

Notes
(a) Ratios are shown rounded to one decimal place. Where the ratio is two or more, it is given in bold type.
(b) The letter in parentheses after the radionuclide relates to the lung absorption type considered: F denotes Fast absorption to blood, M denotes Moderate absorption. For ^{35}S the first chemical form refers to the ingestion dose coefficient and the second chemical form refers to the inhalation dose coefficient.
(c) Simplified fetus assumes exposure as an embryo/fetus to 12 months of chronic intake by the mother.
(d) Full pregnancy assumes exposure as an embryo/fetus for 9 months followed by breastfeeding for 3 months.
(e) Limited pregnancy assumes exposure as an embryo/fetus for 6 months followed by breastfeeding for 6 months.
(f) Breastfeeding assumes exposure as a breastfed infant to 12 months of chronic intake by the mother.
(g) Short-lived progeny considered to be in equilibrium. For ^{90}Sr this is ^{90}Y, for ^{224}Ra this includes ^{212}Pb, and for ^{226}Ra this includes ^{214}Po. For ^{226}Ra the ingrowth of ^{210}Po and ^{210}Pb was calculated explicitly.

TABLE 5.2 Ratio[(a)] of the annual dose to the embryo/fetus/breastfed infant to the maximum of the annual dose to a 1 year old, 10 year old and adult for a liquid routine release of radioactivity

Radionuclide[(b)]	Simplified fetus[(c)]	Full pregnancy[(d)]	Limited pregnancy[(e)]	Breastfeeding[(f)]
^{3}H	1.5	1.4	1.3	≤ 1
^{14}C (M)	1.4	1.2	≤ 1	≤ 1
^{14}C (F)	1.4	1.2	≤ 1	≤ 1
^{14}C (vapour)	n/a	n/a	n/a	n/a
^{22}Na (F)	≤ 1	≤ 1	≤ 1	≤ 1
^{32}P (M)	**10.4**	**7.9**	**5.5**	≤ 1
^{32}P (F)	**10.4**	**7.9**	**5.5**	≤ 1
^{33}P (M)	**20.0**	**15.1**	**10.3**	≤ 1
^{33}P (F)	**20.0**	**15.1**	**10.3**	≤ 1
^{35}S (organic/inorganic particulate M)	**2.1**	1.7	1.3	≤ 1
^{35}S (organic/inorganic particulate F)	**2.1**	1.7	1.3	≤ 1
^{35}S (inorganic/inorganic particulate M)	1.5	1.8	**2.1**	1.8
^{35}S (inorganic/inorganic particulate F)	1.5	1.8	**2.1**	1.8
^{45}Ca (M)	**4.2**	**3.3**	**2.5**	≤ 1
^{47}Ca (F)	**2.0**	1.6	1.2	≤ 1
^{75}Se (F)	≤ 1	1.1	1.2	1.1
^{89}Sr (M)	**3.7**	**3.0**	**2.2**	≤ 1
^{90}Sr (M)[(g)]	1.4	1.2	≤ 1	≤ 1
^{131}I	≤ 1	≤ 1	≤ 1	1.1
^{224}Ra (M)[(g)]	1.6	1.2	≤ 1	≤ 1
^{226}Ra (M)[(g)]	≤ 1	≤ 1	≤ 1	≤ 1

Notes
(a) Ratios are shown rounded to one decimal place. Where the ratio is two or more, it is given in bold type.
(b) The letter in parentheses after the radionuclide relates to the lung absorption type considered: F denotes Fast absorption to blood, M denotes Moderate absorption. For ^{35}S the first chemical form refers to the ingestion dose coefficient and the second chemical form refers to the inhalation dose coefficient .
(c) Simplified fetus assumes exposure as an embryo/fetus to 12 months of chronic intake by the mother.
(d) Full pregnancy assumes exposure as an embryo/fetus for 9 months followed by breastfeeding for 3 months.
(e) Limited pregnancy assumes exposure as an embryo/fetus for 6 months followed by breastfeeding for 6 months.
(f) Breastfeeding assumes exposure as a breastfed infant to 12 months of chronic intake by the mother.
(g) Short-lived progeny considered to be in equilibrium. For ^{90}Sr this is ^{90}Y, for ^{224}Ra this includes ^{212}Pb, and for ^{226}Ra this includes ^{214}Po. For ^{226}Ra the ingrowth of ^{210}Po and ^{210}Pb was calculated explicitly.

Tables 5.3 and 5.4 provide information on the most important exposure pathways and age groups for the scenarios assessed following a release to atmosphere and a liquid release, respectively. More detailed results are presented in Appendices B and C, which give the ratios for each exposure pathway for an atmospheric and a liquid release of radionuclides, respectively.

For atmospheric releases (Table 5.3) the most important pathway tends to be food ingestion and where this is the case the 1 year old infant or the ‘simplified fetus’ is the limiting age group. Milk products, milk or vegetables are the important terrestrial foods in most cases. The exception to this is ^{75}Se where it is the ingestion of offal that is important, followed by the ingestion of meat. The detailed results given in Appendix B show the relative importance of the different fetus/breastfed infant combinations and also how the situation changes for different exposure pathways. It is seen that the ratio of doses for individual pathways may be significantly higher than those for doses summed over all pathways. In many cases the dose to the simplified fetus, which is the use of the fetal dose coefficient with the annual intake by the mother, was higher than that for the other combinations of fetal/breastfed infant dose coefficients. There are exceptions to this, mainly where inhalation pathways are considered but also for some radionuclides and chemical forms for ingestion of foods. However, in these cases the differences between the results for the different combinations of dose coefficients are small.

For liquid releases to a river (Table 5.4), the most important exposure pathway was either ingestion of fish or ingestion of drinking water and the limiting age group was often one of the fetus/breastfed infant combinations. This is because for fish and drinking water the adult ingestion rate, which is also relevant for the fetus/breastfed infant, was significantly higher than those for 1 and 10 year olds. However, the detailed results presented in Appendix C show that the differences in ratio for the different fetus/breastfed infant combinations are often relatively small. Again the ratios may be significantly higher for the individual exposure pathways than for the overall dose. As for the case of releases to atmosphere, the results show that the simplified fetus gives higher doses than for the other combinations in many cases. However, the ‘limited pregnancy’ assessment, that is 6 months as a fetus plus 6 months of breastfeeding, gave the highest overall doses for ^{35}S (where ingestion is of the inorganic form of this radionuclide) and for ^{75}Se, although for some inhalation and ingestion exposure pathways the embryo/fetus and breastfed infant are found to have larger ratios. For example, for ^{35}S in all chemical forms, ^{131}I, ^{224}Ra and ^{226}Ra, the dose following the inhalation of river bank sediments was found to be largest for the ‘breastfeeding’ assessment. For ^{131}I the infant breastfed for 1 year was estimated to receive the highest doses both overall and for several of the exposure pathways. It should be noted, however, that where the simplified fetus was not limiting there were only small differences between the results for the different combinations of dose coefficients.

TABLE 5.3 Limiting age group and most important exposure pathway for the release of radionuclides to atmosphere

Radionuclide[(a)]	Limiting age group[(b)]	Most important pathway	% of total dose from the most important exposure pathway
^{3}H	Simplified fetus	Food ingestion	56
^{14}C (M)	1 year old	Food ingestion	63
^{14}C (F)	1 year old	food ingestion	94
^{14}C (vapour)	1 year old	Food ingestion	88
^{22}Na (F)	Simplified fetus	External from deposition	86
^{32}P (M)	Simplified fetus	Food ingestion	94
^{32}P (F)	Simplified fetus	Food ingestion	90
^{33}P (M)	Simplified fetus	Food ingestion	70
^{33}P (F)	Simplified fetus	Food ingestion	59
^{35}S (organic/inorganic particulate M)	1 year old	Food ingestion	97
^{35}S (organic/inorganic particulate F)	1 year old	Food ingestion	100
^{35}S (organic/organic vapour)	1 year old	Food ingestion	97
^{35}S (organic/inorganic vapour)	1 year old	Food ingestion	100
^{35}S (inorganic/inorganic particulate M)	1 year old	Food ingestion	84
^{35}S (inorganic/inorganic particulate F)	1 year old	Food ingestion	98
^{35}S (inorganic/organic vapour)	1 year old	Food ingestion	83
^{35}S (inorganic/inorganic vapour)	1 year old	Food ingestion	97
^{45}Ca (M)	Simplified fetus	Food ingestion	70
^{47}Ca (F)	1 year old	Plume inhalation	58
^{75}Se (F)	1 year old	Food ingestion	94
^{89}Sr (M)	1 year old	Plume inhalation	72
^{90}Sr (M)[(c)]	3 month old	Food ingestion	75
^{131}I	1 year old	Food ingestion	94
^{224}Ra (M)[(c)]	Adult	Plume inhalation	100
^{226}Ra (M)[(c)]	Adult	Plume inhalation	63

Notes

(a) The letter in parentheses after the radionuclide relates to the lung absorption type considered: F denotes Fast absorption to blood, M denotes Moderate absorption. For ^{35}S the first chemical form refers to the ingestion dose coefficient and the second chemical form refers to the inhalation dose coefficient.

(b) Simplified fetus assumes exposure as an embryo/fetus to 12 months of chronic intake by the mother.

(c) Short-lived progeny considered to be in equilibrium. For ^{90}Sr this is ^{90}Y, for ^{224}Ra this includes ^{212}Pb, and for ^{226}Ra this includes ^{214}Po. For ^{226}Ra the ingrowth of ^{210}Po and ^{210}Pb was calculated explicitly.

TABLE 5.4 Limiting age group and most important exposure pathway for the release of radionuclides as a liquid

Radionuclide[(a)]	Limiting age group[(b)]	Most important pathway	% of total dose from the most important exposure pathway
^{3}H	Simplified fetus	Drinking water	97
^{14}C (M)	Simplified fetus	Fish ingestion	99
^{14}C (F)	Simplified fetus	Fish ingestion	99
^{22}Na (F)	1 year old	Drinking water	92
^{32}P (M)	Simplified fetus	Fish ingestion	100
^{32}P (F)	Simplified fetus	Fish ingestion	100
^{33}P (M)	Simplified fetus	Fish ingestion	100
^{33}P (F)	Simplified fetus	Fish ingestion	100
^{35}S (organic/inorganic particulate M)	Simplified fetus	Fish ingestion	87
^{35}S (organic/inorganic particulate F)	Simplified fetus	Fish ingestion	87
^{35}S (inorganic/inorganic particulate M)	Limited pregnancy	Fish ingestion	87
^{35}S (inorganic/inorganic particulate F)	Limited pregnancy	Fish ingestion	87
^{45}Ca (M)	Simplified fetus	Drinking water	98
^{47}Ca (F)	Simplified fetus	Drinking water	96
^{75}Se (F)	Limited pregnancy	Fish ingestion	85
^{89}Sr (M)	Simplified fetus	Fish ingestion	67
^{90}Sr (M)[(c)]	Simplified fetus	Fish ingestion	64
^{131}I	Breastfeeding	Drinking water	60
^{224}Ra (M)[(c)]	Simplified fetus	Fish ingestion	62
^{226}Ra (M)[(c)]	10 year old	Drinking water	41

Notes

(a) The letter in parentheses after the radionuclide relates to the lung absorption type considered: F denotes Fast absorption to blood, M denotes Moderate absorption. For ^{35}S the first chemical form refers to the ingestion dose coefficient and the second chemical form refers to the inhalation dose coefficient.

(b) Simplified fetus assumes exposure as an embryo/fetus to 12 months of chronic intake by the mother. Limited pregnancy assumes assessment of the dose to the individual as an embryo/fetus for 6 months followed by breastfeeding for 6 months. Breastfeeding assumes the exposure is to an individual whose only food intake of radionuclides is via ingesting breast milk for 12 months.

(c) Short-lived progeny considered to be in equilibrium. For ^{90}Sr this is ^{90}Y, for ^{224}Ra this includes ^{212}Pb, and for ^{226}Ra this includes ^{214}Po. For ^{226}Ra the ingrowth of ^{210}Po and ^{210}Pb was calculated explicitly.

6 Discussion

6.1 Selection of pathways

From the information in Appendices B and C it can be seen that for individual pathways the dose to the embryo/fetus or breastfed infant often may be higher than the dose to one of the other age groups, even though the summed dose from all pathways is not. This indicates that if that pathway was the only one being considered then the embryo/fetus/breastfed infant would be the limiting age group. For most dose assessments it is the total of the doses from all pathways that is important rather than the dose from any particular pathway. Also even where the fetus or breastfed infant is limiting for a specific exposure pathway the differences in dose with other age groups are often relatively small. However, care must be taken when applying the guidance presented in this document to a particular assessment if there are changes to the exposure pathways considered.

6.2 Routine release assessments

This assessment has shown that for most of the radionuclides considered the inclusion of a dose assessment for the embryo/fetus or breastfed infant would alter the dose to the representative person by a factor of less than two or three. Given the uncertainties elsewhere within the dose assessment process – for example, the requirement to consider the homogeneity of the group on which the representative person was based (ICRP, 1985), these differences are not considered significant. This is consistent with the latest advice from the ICRP (2007a) that in general assessments consideration can be limited to three age groups only. The effort involved in assessing doses to the embryo/fetus and breastfed infant may therefore not be warranted in terms of providing a better dose assessment. However, for four radionuclides, namely ^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr, this assessment has shown that the dose to the embryo/fetus and the breastfed infant could increase the dose to the representative person significantly given the inclusion of certain pathways. For these four radionuclides it will be important to consider the dose to the embryo/fetus/breastfed infant in assessing doses from routine releases. For assessing doses from releases containing a number of radionuclides the need to consider exposure of the embryo/fetus or breastfed infant will depend on the relative importance of the dose from these four radionuclides.

In order to investigate the best method for the assessment of doses, several different calculations were performed. The simplest assumptions were of exposure as an embryo/fetus to an entire annual intake of radionuclides by the mother and of exposure of the breastfed infant to the mother's annual intake. Two mixed scenarios were also considered in which the annual exposure occurred as a combination of pregnancy and breastfeeding. For most of the radionuclides considered in this study, including ^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr, the highest doses were estimated for exposure as an embryo/fetus to the annual intake by the mother. For a scoping assessment where it is the general level of exposure that is important, the simplified fetus case with an annual intake by the mother could be used, as generally giving the most cautious assumption. If a more detailed assessment was required then doses should be assessed for 9 months' pregnancy and 3 months' breastfeeding. This would involve the scaling of the dose from intakes via breastfeeding for 3 months, rather than the 6 months assumed by the ICRP (2004) but has the advantage that the embryo/fetal dose coefficients could be used as intended in their original derivation by the ICRP. For the simplified fetus assessment it is considered adequate to use the fetal dose coefficient from Publication 88 (ICRP, 2001) without inclusion of additional doses from the subsequent transfer of radionuclides in breast milk.

The results presented here are for routine releases to atmosphere and to a river. Based on the detailed results summarised in Appendices B and C it is also possible to consider the cases of routine releases to the marine environment and to sewers. For releases to the marine environment the important exposure pathway will be ingestion of seafood for the radionuclides of interest (Jones et al, 2006). The factors influencing the relative doses from the different age groups are broadly the same as for releases to rivers and so the same general conclusions apply. For releases to sewers the situation is more complicated as there are a number of different groups that may be exposed (NRPB, 2000, 2002). For workers exposed at a sewage works – treated as members of the public in dose assessments (EA et al, 2002) – there is the question of whether a pregnant or breastfeeding female should be used for the representative person within a dose assessment, given the likelihood of them being exposed for only part of a year. Treated sewage effluent may be discharged to a river and then the same conclusions can be drawn as discussed earlier (see Section 5). Sewage sludge may also contain radionuclides and it may be incinerated, which will give rise to a release to atmosphere, or used as land treatment with possible transfer to terrestrial foods. For disposal of sewage sludge again the same broad conclusions relating to the assessment of doses to the fetus/breastfed infant discussed earlier will generally apply (Section 5).

6.3 Emergency exposure situations

There are some important differences in the parameters that are used in assessing the dose for emergency exposures – for example, during or immediately after an accidental release of radioactivity – compared to those used in routine release assessments. The radionuclides of concern and the timescales of interest may be different and this will affect the relative importance of the doses to different age groups.

Given the exposure pathways considered here, and what is expected to be different for an assessment carried out for an emergency exposure, the results of this assessment can be used to provide some guidance on the relative importance of assessing the dose to the embryo/fetus and the breastfed infant when dealing with such an exposure.

6.3.1 Dose coefficients

Emergency exposure, by its very nature, only occurs for a relatively short time. The ICRP (2001) has produced dose coefficients for exposure of the embryo and fetus for acute intakes, taken to be instantaneous, at eight different times before and during pregnancy (see Section 2). These range from intake by the mother 130 weeks before conception to intake just before birth. The range in value of these dose coefficients is large, with most radionuclides having three or four orders of magnitude between their lowest and highest values, and the highest dose coefficients generally being those where the intake is closest to birth.

For exposure of the embryo/fetus the chronic exposure dose coefficients are often slightly smaller than the maximum acute exposure dose coefficients, usually by a factor of between two and five. This is seen both for those radionuclides included in this assessment as well as for those that were not. This means that for some additional radionuclides – ^{50}Fe, ^{65}Zn, ^{99m}Tc, ^{125}I, ^{131m}Te, ^{132}I and ^{228}Ra (NRPB, 2005) – the dose to the embryo/fetus may be higher than that to an adult for some exposure situations, although not necessarily higher than the dose to children, which may be limiting. However, for many radionuclides the dose to the embryo/fetus will be less than that for the adult and so still does not need to be considered. For the radionuclides included here, the relative importance of the embryo/fetus may increase compared to that seen for routine releases so that the dose is more than a factor of three greater than that to the other age groups. Care must therefore be used when deciding on which age groups to consider in a dose assessment where the dose to the embryo/fetus could be limiting.

For exposure to the breastfed infant the ICRP (2004) has produced seven dose coefficients for acute intakes at different times (see Section 2). These again span a large range in exposure times, from 26 weeks before conception to 20 weeks after birth. Again it is noted that the range in values of the dose coefficients can span several orders of magnitude, with the largest values being for intakes of radionuclides by the mother at the various times after birth. For all radionuclides the dose coefficient for ingestion of the mother's milk from the chronic intake of radionuclides by the mother during the period of lactation is essentially equal to the maximum of the dose coefficient for any of the acute exposures. Given this, guidance on doses to the breastfed infant made earlier in this document is valid for both routine and acute exposure situations. The breastfed infant is relatively important for intakes of ^{131}I by the mother and generally receives higher doses than the fetus, which is of note as ^{131}I is an important radionuclide in many potential accidental releases from nuclear sites. For accidental exposure to isotopes of iodine, stable iodine may be supplied to reduce the exposure (NRPB, 2001). In the recommendations on stable iodine prophylaxis it is stated that priority for the issue of stable iodine should be nursing mothers and very young children. If this advice is followed then the fetus and breastfed infant should be adequately protected.

6.3.2 Exposure pathways

In an emergency situation the exposure pathways of interest are likely to be the same as those considered for routine release assessments. However, following an accidental release various measures may be introduced such as sheltering indoors. Potential doses may be rapidly estimated to see if such measures are required or to see what residual exposures there are with the measures in place. Restrictions on food supplies may also be introduced if measured or estimated activity concentrations in the food exceed the appropriate European Union intervention levels. The introduction of such measures could affect the relative importance of different exposure pathways and hence the applicability of the conclusions discussed above for routine releases.

The intake of radionuclides by inhalation is potentially an important exposure pathway in the short term after an accidental release of radionuclides to atmosphere. This may influence whether immediate action is taken to reduce exposures, through sheltering, evacuation or the issue of stable iodine prophylaxis. Table 6.1 gives information on when the dose to the fetus is greater than that to an adult or a 10 year old child (the age groups normally considered for emergency situations) for acute intake by inhalation. Ratios are given for relevant radionuclides and a range of chemical forms. The results are presented for the time of intake relative to conception that gives the highest dose coefficients; lower values would be obtained for other times during or before pregnancy. From Table 6.1 it can be seen that, in many cases, although the doses received by the fetus following inhalation of radionuclides by the mother would be greater than doses to the adult or 10 year old, the differences are less than a factor of three and often less than a factor of two. Also accidental releases from nuclear sites are likely to consist of a mix of radionuclides, for some of which the inhalation dose to the fetus would be less than that to the other age groups. Given this, together with the short period during pregnancy to which the highest ratios apply, the other uncertainties associated with assessing doses in the short term following an accidental release and the caution built into current off-site emergency plans, changes to these plans for these radionuclides seem unnecessary. This is generally considered to be the case even though the increased radiosensitivity of the fetus is recognised. However, for ^{32}P and ^{33}P ratios of ten or more are possible and so if an accidental release involved isotopes of phosphorus then it would be important to consider the exposure of the fetus explicitly.

Following a radiological accident restrictions could be introduced on food and water. Of particular relevance in this case are the regulations from the Council of the European Communities on intervention levels for food. Advice has been given previously on the application of these intervention levels (termed CFILs – Council Food Intervention Levels) in the UK (NRPB, 1994). This advice considered the radiation doses that might be received if food was consumed for 1 year at the CFILs; the age groups considered were adults, 1 year olds and 3 month olds. Similar calculations were carried out here to estimate the indicative maximum dose that might be received by the fetus if the mother ingested food at the CFIL for a year, assuming that 10% of the food was contaminated. For radionuclides that have a short half-life with respect to a year the resulting dose from ingesting 10% of their food contaminated to a level of the CFIL was further scaled by the fraction of a year equal to ten half-lives. The same methodology as considered previously was applied (NRPB, 1994) and the radionuclides considered were ^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr. The estimated committed effective doses were around 0.06 mSv for ^{32}P, 0.02 mSv for ^{33}P, 0.05 mSv for ^{45}Ca and 0.04 mSv for ^{89}Sr. From this it is concluded that the CFILs are adequate to protect the fetus as well as other age groups.

It should be noted that the CFILs apply only to marketed foods and the calculations undertaken here assume that context. Some individuals consume large amounts of certain foods from a limited geographical area. In areas where these foods are contaminated at levels close to, or in excess of, the CFILs, some of these individuals may be exposed to higher doses than those indicated here. For these circumstances, the HPA continues to recommend that appropriate advice is provided to assist the individuals in managing their own risk.

TABLE 6.1 Relative importance of doses to the fetus following acute intakes by the mother from inhalation

Radionuclide	Chemical form and lung type[a]	Time of highest dose coefficient (weeks after conception)	Ratio of doses[b] Fetus to 10 year old	Fetus to adult
^{3}H	Inhalation of elemental hydrogen vapour	10	**2.3**	**2.0**
^{3}H	Inhalation of tritiated methane	10	**2.3**	**2.0**
^{3}H	Inhalation of tritiated water	10	**2.3**	**2.0**
^{3}H	Inhalation of organically bound tritium	10	**2.0**	**1.9**
^{14}C	Inhalation of carbon monoxide	10	**2.1**	***3.1***
^{14}C	Inhalation of carbon labelled methane	10	**1.8**	**1.7**
^{14}C	Inhalation of carbon dioxide	0	**1.2**	**1.2**
^{14}C	Inhalation of organic gases and vapours	10	**1.8**	**1.7**
^{22}Na	AMAD[c] = 1 μm (F)	15–25	0.8	**1.0**
^{32}P	AMAD = 1 μm (M)	35	**2.3**	**2.5**
^{32}P	AMAD = 1 μm (F)	25–35	***10.4***	***16.9***
^{33}P	AMAD = 1 μm (M)	15–25	**1.1**	**1.1**
^{33}P	AMAD = 1 μm (F)	15–25	***17.3***	***26.1***
^{35}S	Inhalation of sulphur dioxide	35	**1.2**	**1.6**
^{35}S	Inhalation of carbon disulphide	10–15	**1.6**	**2.3**
^{75}Se	AMAD = 1 μm (F)	25	0.7	**1.2**
^{125}I	AMAD = 1 μm (F)	35	0.8	**1.3**
^{125}I	Inhalation of elemental iodine vapour	35	0.9	**1.2**
^{125}I	Inhalation of methyl iodide	35	0.9	**1.3**

Continued

6.4 Solid waste disposal

The disposal of radionuclides in solid waste through burial in the ground at a waste disposal site may also lead to exposures of members of the public. For disposal of solid wastes the main difference to that considered for routine releases is the time between disposal and exposure. For modern landfill sites the migration of radionuclides from landfill to areas where people could be exposed may take many tens or, for some radionuclides, hundreds or thousands of years. For deeper sites, such as those that would be used for deep geological disposal of intermediate or high level waste, it would take even longer for radionuclides to reach areas where people would be exposed. However, the longest half-life of any of the four radionuclides that this guidance states should always be considered for routine releases – ^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr – is only 165 days (for ^{45}Ca) and therefore it is unnecessary to include them in an assessment for solid waste disposal.

TABLE 6.1 ***Continued***

Radionuclide	Chemical form and lung type(a)	Time of highest dose coefficient (weeks after conception)	Ratio of doses(b)	
			Fetus to 10 year old	Fetus to adult
^{131}I	AMAD = 1 µm (F)	35	**1.6**	**2.8**
^{131}I	Inhalation of elemental iodine vapour	35	**1.6**	**2.8**
^{131}I	Inhalation of methyl iodide	35	**1.7**	**2.9**
^{132}I	AMAD = 1 µm (F)	35	**1.4**	**2.3**
^{132}I	Inhalation of elemental iodine vapour	35	**1.3**	**1.9**
^{132}I	Inhalation of methyl iodide	35	**1.6**	**2.6**
^{133}I	AMAD = 1 µm (F)	35	**1.7**	**2.9**
^{133}I	Inhalation of elemental iodine vapour	35	**1.8**	***3.0***
^{133}I	Inhalation of methyl iodide	35	**1.7**	**2.9**
^{134}I	Inhalation of methyl iodide	35	**1.3**	**2.0**
^{135}I	AMAD = 1 µm (F)	35	**1.7**	**2.9**
^{135}I	Inhalation of elemental iodine vapour	35	**1.6**	**2.6**
^{135}I	Inhalation of methyl iodide	35	**1.8**	**2.9**
^{132}Te	Inhalation of tellurium vapour	35	**2.2**	***3.5***

Notes
(a) The letter in parentheses relates to the lung absorption type considered: F denotes Fast absorption to blood, M denotes Moderate absorption.
(b) For ratios, a value greater than one indicates the dose to the fetus is the higher. Ratios greater than one are given in bold type. Ratios of three or more are also italicised for convenience.
(c) AMAD: Activity Median Aerodynamic Diameter.

Of the radionuclides considered in Table 4.1 the only ones that are likely to be relevant to the assessment of doses from the land disposal of solid wastes are ^{3}H, ^{14}C, ^{224}Ra and ^{226}Ra. The exposure pathways of interest in this case are likely to be those for ingestion of terrestrial foods or fish. The detailed results given in Appendices B and C show that for these radionuclides the dose to the fetus may be limiting for several of the food ingestion pathways. However, the ratios are all less than a factor of three, and these values would also apply to solid waste disposal. For solid waste disposal it will also be important to take into account exposures due to the in-growth of radioactive progeny. However, for the progeny of these radionuclides (eg ^{210}Pb and ^{210}Po) the dose coefficients for the embryo/fetus or breastfed infant are lower than those for adults and so do not need to be considered. For disposals of solid waste to land the chemical form of the radionuclide may be different from the default given by the ICRP and that considered in this assessment and this may need to be taken into account. However, for solid waste disposals it will generally be unnecessary to consider the embryo/fetus/breastfed infant as any increases in doses over those to other age groups will be small compared to the overall uncertainty in the assessed doses. This also applies to other solid waste management options such as the reuse or recycling of contaminated materials.

7 Conclusions and Recommendations

7.1 Assessment of doses to the public

a For most radionuclides, including some of those for which the dose coefficient for either the embryo/fetus or the breastfed infant is larger than that for the adult, the dose to one of the normally assessed age groups of adult, 1 year old infant, or 10 year old child will be limiting. An explicit assessment of the dose to either the embryo/fetus or the breastfed infant is therefore not required except where indicated below.

b For four radionuclides – ^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr – it is recommended that the fetus/breastfed infant is considered in all assessments where these radionuclides form a significant part of any release of radioactivity to the environment.

c If assessed doses are approaching the values of relevant dose constraints or reference levels and there is a significant contribution from radionuclides where the dose to the fetus/breastfed infant can be higher than the dose to the mother, then doses to the fetus and breastfed infant should be considered separately.

d In general, it is unnecessary to consider the exposure of the embryo/fetus or breastfed infants when assessing radiation doses from the disposal of solid waste to land.

e For the radionuclides ^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr, or where the situation of the assessment requires that the fetus/breastfed infant is assessed, it will generally be adequate to carry out a simplified dose assessment, assuming an annual intake by the mother and using the fetal dose coefficient for chronic exposure throughout pregnancy. For a more detailed assessment it is recommended that the annual intake by the mother is assumed to occur throughout pregnancy and the first 3 months of breastfeeding. This approach should be applied to all exposure pathways with intakes of radionuclides; for external gamma exposure it is reasonable to assume that the effective dose to the fetus is the same as that for the mother.

f For detailed assessments of doses to specific population groups whose habits are known to sufficient detail, it is recommended that all age groups are assessed using site-specific parameters. This includes the use of, for example, local food ingestion rates and occupancy times.

7.2 Emergency exposure situations

a It may be necessary to consider the exposure of the embryo/fetus or breastfed infant in more situations when carrying out a detailed radiation dose assessment for emergency exposures than for routine releases.

b It is considered unnecessary to change existing off-site emergency plans to explicitly take into account exposure of the fetus or breastfed infant. However, if an accidental release were to involve isotopes of phosphorus then it would be important to consider the exposure of the fetus explicitly in planning the response.

c Previous recommendations on stable iodine prophylaxis state that priority for the issue of stable iodine should be nursing mothers and very young children. If this advice is followed then the fetus and breastfed infant should be adequately protected in the event of an accidental release of radioactivity.

d The regulations from the Council of the European Communities on intervention levels in food (CFILs) are considered adequate to protect the fetus and breastfed infant as well as other age groups for all radionuclides.

7.3 Occupational exposure

For occupational exposure to radionuclides employers were advised (NRPB, 2005) to ensure that the risk to women of reproductive capacity (including those who have declared themselves pregnant) is adequately controlled. It was noted that for some radionuclides additional precautions may be required and in such circumstances it is particularly important to provide information to female workers on the need for early notification of pregnancy. Although occupational exposure is not considered in detail in this document, it is noted that this advice is still applicable and the consideration of additional precautions for certain radionuclides should be extended to women who have returned to work following pregnancy but who are still breastfeeding their child.

8 Acknowledgement

The authors would like to acknowledge the contribution to this assessment made by N Hesketh (formerly of the Radiation Protection Division of the Health Protection Agency).

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Appendix A

Assessment Methodology

Calculation of doses received by the age groups under consideration in general follows the methodology used for calculating generalised derived constraints (GDCs) (NRPB, 2000), with the exception of the fetus/breastfed infant where the approach follows the methodology adopted for calculating generalised derived limits (GDLs) (NRPB, 2005).

A1 Atmospheric discharges

Five exposure pathways were considered for exposure to individuals following the release of radiation to atmosphere. They are as follows:

a internal exposure from inhalation of activity in the plume,

b internal exposure from inhalation of resuspended activity,

c external exposure from activity deposited on to the soil,

d external exposure to activity in the plume,

e internal exposure from ingestion of foods produced on land contaminated by deposited activity from the plume.

An annual occupancy at 100 m from the point of release was assumed. For pathways involving an intake of radioactivity, no reduction in the radioactivity was considered for time spent inside buildings.

A1.1 Inhalation of activity in the plume

The effective dose to each age group from the inhalation of activity in the plume was calculated using the following equation:

$$D_{ip} = A_a \, B \, D_{inh} \qquad \text{(A1)}$$

where

D_{ip} = effective dose from inhalation of the plume 100 m from the point of discharge (Sv y^{-1} per Bq s^{-1}),
A_a = activity concentration in the plume 100 m from the point of discharge, 8.8 10^{-5} Bq m^{-3} per Bq s^{-1}, calculated using the ESCLOUD model (Jones, 1980),
B = breathing rate: 3 month old infant 1050 m^3 y^{-1}, 1 year old infant 1900 m^3 y^{-1}, 10 year old child 5600 m^3 y^{-1}, and adult 8100 m^3 y^{-1} (Smith and Jones, 2003),
D_{inh} = inhalation dose coefficient (Sv Bq^{-1}) (Table A1).

A1.2 Inhalation of resuspended activity

The effective dose to each age group from the inhalation of resuspended activity was calculated using the following equation:

$$D_{ires} = A_{res}\ B\ D_{inh} \qquad (A2)$$

where

D_{ires} = effective dose from inhalation of resuspended activity deposited 100 m from the point of discharge (Sv y^{-1} per Bq s^{-1}),

A_{res} = activity concentration from resuspension of activity deposited 100 m from the point of discharge in the 50th year (Bq m^{-3} per Bq s^{-1}). This was calculated using:

$$A_{res} = A_{res(u)}\ R_n$$

where

$A_{res(u)}$ = activity concentration from the resuspension of activity per unit deposition rate in the 50th year of discharge (Bq m^{-3} per Bq m^{-2} s^{-1}), obtained from the RESUS model which forms part of the PC CREAM suite of models (Mayall et al, 1997) (Table A2),

R_n = deposition rate on to ground of activity from the plume 100 m from the release point. For ^{131}I it is equal to 8.05 10^{-7} Bq m^{-2} s^{-1} per Bq s^{-1} and for all other radionuclides considered it is equal to 9.0 10^{-8} Bq m^{-2} s^{-1} per Bq s^{-1}. These values were obtained from the ESCLOUD model (Jones, 1980),

B = breathing rate: 3 month old infant 1050 m^3 y^{-1}, 1 year old infant 1900 m^3 y^{-1}, 10 year old child 5600 m^3 y^{-1}, and adult 8100 m^3 y^{-1} (Smith and Jones, 2003),

D_{inh} = inhalation dose coefficient (Sv Bq^{-1}) (Table A1).

A1.3 External exposure from deposited activity

The effective dose to each age group from external exposure from activity deposited over 50 years on to soil from the plume was calculated using the following equation:

$$D_{dep} = (F_{ind}\ T_{ind} + F_{out}\ T_{out})\ D_{ext} \qquad (A3)$$

where

D_{dep} = effective dose from external irradiation from soil contaminated by deposition from the plume, in the 50th year 100 m from the point of release (Sv y^{-1} per Bq s^{-1}),

F_{ind} = fraction of year spent indoors: breastfed infant/3 month old infant/1 year old infant 0.9, 10 year old child 0.8, and adult 0.5 (NRPB, 2000),

T_{ind} = indoor location factor, 0.1 (Simmonds et al, 1995),

F_{out} = fraction of year spent outdoors: breastfed infant/3 month old infant/1 year old infant 0.1, 10 year old child 0.2, and adult 0.5 (NRPB, 2000),

T_{out} = outdoor location factor, 1.0 (Simmonds et al, 1995),

D_{ext} = external dose rate in the 50th year from deposition of activity 100 m from the point of release (Sv y^{-1} per Bq s^{-1}). This was calculated using:

$$D_{ext} = D_{ext(u)}\ R_n$$

where

$D_{ext(u)}$ = external dose rate in the 50th year per unit deposition rate (Sv y^{-1} per Bq m^{-2} s^{-1}), determined using the HPA model GRANIS (Kowe et al, 2007) (Table A3),

R_n = deposition rate on to ground of activity from the plume 100 m from the release point. For ^{131}I it is equal to 8.05 10^{-7} Bq m^{-2} s^{-1} per Bq s^{-1} and for all other radionuclides considered it is equal to 9.0 10^{-8} Bq m^{-2} s^{-1} per Bq s^{-1}. These values were obtained from the ESCLOUD model (Jones, 1980).

A1.4 External exposure from activity in the plume

The effective dose from external exposure to radionuclides in the plume, 100 m from the point of discharge, was estimated using dose rates modelled using a semi-infinite cloud model. The dose was obtained using the following equation:

$$D_{ext,p} = (F_{ind}\, T_{ind} + F_{out}\, T_{out})\, DR_p \qquad \text{(A4)}$$

where

$D_{ext,p}$ = effective dose from external irradiation from radionuclides in the plume (Sv y^{-1} per Bq s^{-1}),

F_{ind} = fraction of year spent indoors: breastfed infant/3 month old infant/1 year old infant 0.9, 10 year old child 0.8, and adult 0.5 (NRPB, 2000),

T_{ind} = indoor location factor, 0.1 (Simmonds et al, 1995),

F_{out} = fraction of year spent outdoors: breastfed infant/3 month old infant/1 year old infant 0.1, 10 year old child 0.2, and adult 0.5 (NRPB, 2000),

T_{out} = outdoor location factor, 1.0 (Simmonds et al, 1995),

DR_p = external dose rate from exposure to a semi-infinite cloud of radioactivity (Sv y^{-1} per Bq s^{-1}), calculated using the PLUME model within the PC CREAM suite of models (Mayall et al, 1997) (Table A3).

A1.5 Ingestion of foods

The ingestion dose to each age group from eating foods produced 500 m from the point of discharge was calculated using the following equation:

$$D_{food} = \Sigma_f\, I_f\, D_{ing}\, A_f \qquad \text{(A5)}$$

where

D_{food} = effective dose (summed for all foods) from foods produced 500 m from the point of discharge (Sv y^{-1} per Bq s^{-1}),

I_f = ingestion rate of each food (kg y^{-1}) (Table A4),

D_{ing} = ingestion dose coefficient (Sv Bq^{-1}) (Table A5),

A_f = food product activity concentration in the 50th year for food grown 500 m from the point of discharge (Bq kg^{-1} per Bq s^{-1}) (Table A6). This was calculated using:

$$A_f = A_{f(u)}\, R_f$$

where

$A_{f(u)}$ = food product activity concentration in the 50th year per unit deposition rate (Bq kg^{-1} per Bq m^{-2} s^{-1}), calculated using the FARMLAND model within the PC CREAM suite of models (Mayall et al, 1997),

R_f = deposition rate on to ground of activity from the plume 500 m from the release point. For ^{131}I it is equal to 3.4 10^{-8} Bq m^{-2} s^{-1} per Bq s^{-1} and for all other radionuclides considered it is equal to 4.7 10^{-9} Bq m^{-2} s^{-1} per Bq s^{-1}. These values were obtained from the ESCLOUD model (Jones, 1980).

For ^{3}H and ^{14}C element-specific models were used to derive the food concentrations (NRPB, 2005). These concentrations were in units of Bq kg^{-1} per Bq m^{-3} so equation A5 was modified so that these values were multiplied by the air concentration, calculated using ESCLOUD (Jones, 1980), rather than the deposition rate.

The terrestrial foods considered are those taken from national surveys and diets agreed by the then Ministry of Agriculture, Fisheries and Food and NRPB (Byrom et al, 1995), with the ingestion rates of each food being appropriate for those individuals ingesting above-average amounts of food. These habit data are discussed in detail elsewhere (Smith and Jones, 2003). The food groups are domestic fruit, green and other domestically grown vegetables, potatoes and root vegetables, cow meat, sheep meat, cow offal, sheep offal, milk, and milk products.

A2 River discharges

Five exposure pathways were considered in the assessment of the dose to individuals following the release of radioactivity as a liquid. They are as follows:

a external exposure to river bed sediments,

b internal exposure from inhalation of resuspended river bed sediments,

c internal exposure from ingestion of drinking water,

d internal exposure from ingestion of freshwater fish,

e internal exposure from ingestion of foods produced on land irrigated with river water.

The doses were assessed assuming that the exposed individual was 500 m downstream of the release point. The effects of dilution of the released activity within the river were included.

A2.1 External exposure from bed sediments

The effective dose to each age group from external exposure to well-mixed river bed sediment 500 m downstream of the discharge point was calculated using the following equation:

$$D_{RB,ext} = D_{ext(u)}\ R_B\ T \qquad \text{(A6)}$$

where

$D_{RB,ext}$ = external dose above well-mixed sediment in the 50th year of discharge 500 m downstream from the point of discharge (Sv y^{-1} per Bq s^{-1}),

$D_{ext(u)}$ = external dose rate above well-mixed sediment per unit activity concentration (Sv h^{-1} per Bq kg^{-1}), calculated using the HPA model GRANIS (Kowe et al, 2007) (Table A7),

R_B = activity concentration in river bed sediment from a unit discharge rate to a river flowing at 1 m^3 s^{-1}, at 500 m downstream from the release point (Bq kg^{-1} per Bq s^{-1}), calculated using a compartmental model developed at the HPA (Table A7),

T = occupancy of river bank sediment: breastfeeding infant/3 month old infant/infant 30 h y^{-1}, child 500 h y^{-1}, and adult 1000 h y^{-1} (Smith and Jones, 2003).

A2.2 Inhalation of resuspended bed sediments

The effective dose to each age group from inhalation of resuspended river bed sediments was calculated using the following equation:

$$D_{RB,inh} = R_B \, B \, L \, D_{inh} \, T_{frac} \quad \text{(A7)}$$

where

$D_{RB,inh}$ = effective dose from inhalation of resuspended river bed sediment (Sv y^{-1} per Bq s^{-1}),

R_B = activity concentration in river bed sediment from a unit discharge rate to a river flowing at 1 m^3 s^{-1}, at 500 m downstream from the release point (Bq kg^{-1} per Bq s^{-1}), calculated using a compartmental model developed at the HPA (Table A7),

B = breathing rate: 3 month old infant 1050 m^3 y^{-1}, 1 year old infant 1900 m^3 y^{-1}, 10 year old child 5600 m^3 y^{-1}, and adult 8100 m^3 y^{-1} (Smith and Jones, 2003),

L = concentration of suspended sediments in air, 10^{-7} kg m^{-3} (Simmonds et al, 1995),

D_{inh} = inhalation dose coefficient (Sv Bq^{-1}) (Table A1),

T_{frac} = fraction of year spent occupying sediment: 3 month old infant/1 year old infant 0.003, 10 year old child 0.057, and adult 0.114 (NRPB, 2000).

A2.3 Ingestion of drinking water

The effective dose to each age group from the ingestion of filtered river water extracted 500 m downstream of the discharge point was calculated using the following equation:

$$D_{water} = R_{fil} \, I_{water} \, D_{ing} \quad \text{(A8)}$$

where

D_{water} = effective dose from drinking filtered water 500 m downstream from the point of discharge (Sv y^{-1} per Bq s^{-1}),

R_{fil} = activity concentration in filtered river water 500 m downstream from the point of discharge (Bq m^{-3} per Bq s^{-1}), calculated using a compartmental model developed at the HPA (Table A8),

I_{water} = ingestion rate of water: 1 year old infant 0.26 m^3 y^{-1}, 10 year old child 0.35 m^3 y^{-1}, and adult 0.60 m^3 y^{-1} (Smith and Jones, 2003),

D_{ing} = ingestion dose coefficient (Sv Bq^{-1}) (Table A5).

A2.4 Ingestion of freshwater fish

The ingestion dose to each age group from eating freshwater fish caught 500 m downstream of the discharge point was calculated using the following equation:

$$D_{fish} = R_{fil}\, I_{fish}\, C_{fish}\, D_{ing} \quad \text{(A9)}$$

where

D_{fish} = effective dose from ingestion of freshwater fish caught 500 m downstream from the point of discharge (Sv y^{-1} per Bq s^{-1}),

R_{fil} = activity concentration in filtered river water 500 m downstream from the point of discharge (Bq m^{-3} per Bq s^{-1}), calculated using a compartmental model developed at the HPA (Table A8),

I_{fish} = ingestion rate of freshwater fish: 1 year old infant 0.001 t y^{-1}, 10 year old child 0.005 t y^{-1}, and adult 0.02 t y^{-1} (Smith and Jones, 2003),

C_{fish} = concentration factor for freshwater fish (Bq t^{-1} per Bq m^{-3}) (Table A9),

D_{ing} = ingestion dose coefficient (Sv Bq^{-1}) (Table A5).

A2.5 Ingestion of foods

The ingestion dose to each group from eating foods produced on land irrigated with river water abstracted 500 m downstream from the point of discharge was calculated using the following equation:

$$D_{food} = \Sigma_f\, I_f\, D_{ing}\, A_f \quad \text{(A10)}$$

where

D_{food} = effective dose (summed for all foods) from foods produced on land irrigated with river water abstracted 500 m downstream from the point of discharge (Sv y^{-1} per Bq s^{-1}),

I_f = ingestion rate of each food (kg y^{-1}) (Table A4),

D_{ing} = ingestion dose coefficient (Sv Bq^{-1}) (Table A5),

A_f = activity concentrations in each food after irrigation with river water (Bq kg^{-1} per Bq s^{-1}). The activity concentration in foods was calculated using:

$$A_f = A_{f(u)}\, I_{app}\, [R_{fil} + (R_{sus}\, S)]$$

where

$A_{f(u)}$ = food product activity concentration in the 50th year per unit deposition rate (Bq kg^{-1} per Bq m^{-2} y^{-1}), calculated using a compartmental model developed at the HPA (Table A10),

I_{app} = irrigation water application rate (m^3 per m^2 y^{-1}) (NRPB, 2000),

R_{fil} = activity concentration in filtered river water 500 m downstream from the point of discharge (Bq m^{-3} per Bq s^{-1}), calculated using a compartmental model developed at the HPA (Table A8),

R_{sus} = activity concentration in river water suspended sediment per unit discharge (Bq kg^{-1} per Bq s^{-1}), calculated using a compartmental model developed at the HPA (Table A8),

S = suspended sediment load, 0.04 kg m^{-3} (NRPB, 2000).

The terrestrial foods considered are those taken from national surveys and diets agreed by the then Ministry of Agriculture, Fisheries and Food and NRPB (Byrom et al, 1995), with the ingestion rates of each food being appropriate for those individuals ingesting above-average amounts of food. These habit data are discussed in detail elsewhere (Smith and Jones, 2003). The food groups are green and other domestically grown vegetables, and potatoes and root vegetables.

A3 Assessing the exposure for the fetus/breastfed infant

The equations given above were modified to account for the exposure routes to the fetus and breastfed infant.

A3.1 External irradiation

For external irradiation the fetus and breastfed infant were assumed to be exposed for the same duration, and to the same dose rate, as the adult. Thus there are no modifications required to the above equations in order to estimate the dose to members of these age groups.

A3.2 Inhalation and ingestion

All of the radioactivity taken in by the fetus comes solely from the adult. The above equations were therefore used with adult parameters for the inhalation and ingestion rates. The dose coefficients in the equations were then replaced by those for the fetus (from ICRP, 2001). These dose coefficients were then scaled to the required time spent as a fetus.

For times spent breastfeeding the doses to the infant were calculated using the above equations for exposure to the mother but with the breastfeeding infant dose coefficients being used in place of those for the adult (ICRP, 2004). In addition, the breastfeeding infant was also assumed to directly inhale radionuclides from the air. For the infant spending 3 or 6 months breastfeeding the intake rate was assumed to be that of a 3 month old (Smith and Jones, 2003), whilst the intake rate for the infant assumed to spend 1 year breastfeeding was assumed to be equal to that of a 1 year old (Smith and Jones, 2003).

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TABLE A1 Dose coefficients for inhalation for members of the public including the fetus and breastfed infant (ICRP, 1996, 2001, 2004)

	Inhalation dose coefficients (Sv Bq^{-1})						
						Breastfed infant	
Radionuclide[a]	Adult	10 year old child	1 year old infant	3 month old infant	Fetus	Pregnancy[b]	Lactation[c]
^{3}H (inorganic) (M)	4.5 10^{-11}	8.2 10^{-11}	2.7 10^{-10}	3.4 10^{-10}	2.6 10^{-12}	5.4 10^{-13}	1.5 10^{-12}
^{3}H (inorganic water vapour)	1.8 10^{-11}	2.3 10^{-11}	4.8 10^{-11}	6.4 10^{-11}	3.1 10^{-11}	1.0 10^{-12}	2.0 10^{-11}
^{3}H (organic) (V)	4.1 10^{-11}	5.5 10^{-11}	1.1 10^{-10}	1.1 10^{-10}	6.3 10^{-11}	4.0 10^{-12}	3.0 10^{-11}
^{14}C (M)	2.0 10^{-9}	2.8 10^{-9}	6.6 10^{-9}	8.3 10^{-9}	6.6 10^{-11}	1.3 10^{-11}	1.9 10^{-11}
^{14}C (F)	2.0 10^{-10}	2.9 10^{-10}	6.7 10^{-10}	6.1 10^{-10}	2.7 10^{-10}	2.5 10^{-11}	8.9 10^{-11}
^{14}C (organic) (V)	5.8 10^{-10}	7.9 10^{-10}	1.6 10^{-9}	1.3 10^{-9}	8.0 10^{-10}	7.3 10^{-11}	2.6 10^{-10}
^{22}Na (F)	1.3 10^{-9}	2.4 10^{-9}	7.3 10^{-9}	9.7 10^{-9}	1.2 10^{-9}	2.1 10^{-11}	4.3 10^{-10}
^{32}P (M)	3.4 10^{-9}	5.3 10^{-9}	1.5 10^{-8}	2.2 10^{-8}	6.5 10^{-9}	8.1 10^{-12}	4.1 10^{-10}
^{32}P (F)	7.7 10^{-10}	1.8 10^{-9}	7.5 10^{-9}	1.2 10^{-8}	1.0 10^{-8}	9.4 10^{-12}	6.4 10^{-10}
^{33}P (M)	1.5 10^{-9}	2.1 10^{-9}	4.6 10^{-9}	6.1 10^{-9}	1.2 10^{-9}	1.5 10^{-12}	4.2 10^{-11}
^{33}P (F)	9.2 10^{-11}	2.0 10^{-10}	7.8 10^{-10}	1.2 10^{-9}	2.0 10^{-9}	1.5 10^{-12}	6.4 10^{-11}

TABLE A1 ***Continued***

	Inhalation dose coefficients (Sv Bq^{-1})						
						Breastfed infant	
Radionuclide[(a)]	Adult	10 year old child	1 year old infant	3 month old infant	Fetus	Pregnancy[(b)]	Lactation[(c)]
^{35}S (inorganic) (M)	1.4 10^{-9}	2.0 10^{-9}	4.5 10^{-9}	5.9 10^{-9}	1.5 10^{-11}	n/a	n/a
^{35}S (inorganic) (F)	5.1 10^{-11}	1.1 10^{-10}	3.9 10^{-10}	5.5 10^{-10}	6.6 10^{-11}	n/a	n/a
^{35}S (organic, carbon disulphide) (V)	7.0 10^{-10}	1.4 10^{-9}	4.8 10^{-9}	6.9 10^{-9}	1.4 10^{-9}	8.4 10^{-11}	2.1 10^{-10}
^{35}S (inorganic, sulphur dioxide) (V)	1.1 10^{-10}	2.1 10^{-10}	6.6 10^{-10}	9.4 10^{-10}	1.5 10^{-10}	8.4 10^{-11}	2.1 10^{-10}
^{45}Ca (M)	2.7 10^{-9}	3.9 10^{-9}	8.8 10^{-9}	1.2 10^{-8}	1.7 10^{-9}	9.9 10^{-11}	4.0 10^{-10}
^{47}Ca (M)	1.9 10^{-9}	2.9 10^{-9}	7.7 10^{-9}	1.0 10^{-8}	1.0 10^{-9}	3.1 10^{-12}	2.5 10^{-10}
^{75}Se (F)	1.0 10^{-9}	2.5 10^{-9}	6.0 10^{-9}	7.8 10^{-9}	1.1 10^{-9}	2.4 10^{-10}	1.2 10^{-9}
^{89}Sr (M)	6.1 10^{-9}	9.1 10^{-9}	2.4 10^{-8}	3.3 10^{-8}	2.1 10^{-9}	4.1 10^{-11}	4.3 10^{-10}
^{90}Sr (M)[(d)]	3.8 10^{-8}	5.4 10^{-8}	1.2 10^{-7}	1.6 10^{-7}	8.8 10^{-9}	1.5 10^{-9}	3.9 10^{-9}
^{131}I (F)	7.4 10^{-9}	1.9 10^{-8}	7.2 10^{-8}	7.2 10^{-8}	8.1 10^{-9}	1.1 10^{-11}	1.9 10^{-8}
^{131}I (elemental iodine) (V)	2.0 10^{-8}	4.8 10^{-8}	1.6 10^{-7}	1.7 10^{-7}	2.1 10^{-8}	2.8 10^{-11}	5.0 10^{-8}
^{224}Ra (M)[(d)]	3.2 10^{-6}	4.1 10^{-6}	8.7 10^{-6}	1.1 10^{-5}	4.0 10^{-8}	5.9 10^{-12}	2.9 10^{-9}
^{226}Ra (M)[(d)]	3.5 10^{-6}	4.9 10^{-6}	1.1 10^{-5}	1.5 10^{-5}	9.9 10^{-8}	3.4 10^{-9}	1.1 10^{-8}

Notes

(a) Dose coefficients are given for the default lung absorption type recommended by the ICRP for environmental exposure of members of the public (ICRP, 1996): F denotes Fast absorption to blood, M denotes Moderate absorption. V indicates the vapour form of the element.

(b) Dose coefficient for intake of radionuclides by the breastfeeding infant from radionuclides ingested by the mother during pregnancy.

(c) Dose coefficient for intake of radionuclides by the breastfeeding infant from radionuclides ingested by the mother over the duration of breastfeeding.

(d) Short-lived progeny considered to be in equilibrium. For ^{90}Sr this is ^{90}Y, for ^{224}Ra this includes ^{212}Pb and for ^{226}Ra this includes ^{214}Po. For ^{226}Ra the ingrowth of ^{210}Po and ^{210}Pb was calculated explicitly.

TABLE A2 Resuspended air concentration per unit activity deposited following a release of radioactivity to atmosphere

Radionuclide	Air concentration (Bq m^{-3} per Bq m^{-2} s^{-1})
^{3}H	$8.5\ 10^{-1}$
^{14}C	$1.0\ 10^{0}$
^{22}Na	$6.9\ 10^{-1}$
^{32}P	$2.6\ 10^{-1}$
^{33}P	$3.2\ 10^{-1}$
^{35}S (organic)	$4.4\ 10^{-1}$
^{35}S (inorganic)	$4.4\ 10^{-1}$
^{45}Ca	$5.1\ 10^{-1}$
^{47}Ca	$1.5\ 10^{-1}$
^{75}Se	$4.8\ 10^{-1}$
^{89}Sr	$3.9\ 10^{-1}$
^{90}Sr	$9.2\ 10^{-1}$
^{131}I	$2.0\ 10^{-1}$
^{224}Ra	$1.3\ 10^{-1}$
^{226}Ra	$1.0\ 10^{0}$

TABLE A3 External dose rates from radionuclides in a plume 100 m from the point of release, and above soil following 50 years of deposition from a plume resulting from the unit release of radioactivity to atmosphere

Radionuclide	Dose rate from plume ($Sv\ y^{-1}$ per $Bq\ s^{-1}$)	Dose rate above soil ($Sv\ y^{-1}$ per $Bq\ s^{-1}$)
^{3}H	$0.0\ 10^{0}$	$0.0\ 10^{0}$
^{14}C	$0.0\ 10^{0}$	$0.0\ 10^{0}$
^{22}Na	$1.4\ 10^{-11}$	$3.5\ 10^{-7}$
^{32}P	$0.0\ 10^{0}$	$0.0\ 10^{0}$
^{33}P	$0.0\ 10^{0}$	$0.0\ 10^{0}$
^{35}S (organic)	$0.0\ 10^{0}$	$0.0\ 10^{0}$
^{35}S (inorganic)	$0.0\ 10^{0}$	$0.0\ 10^{0}$
^{45}Ca	$2.5\ 10^{-20}$	$1.5\ 10^{-17}$
^{47}Ca	$6.6\ 10^{-12}$	$1.1\ 10^{-9}$
^{75}Se	$2.9\ 10^{-12}$	$9.9\ 10^{-9}$
^{89}Sr	$5.5\ 10^{-16}$	$9.3\ 10^{-13}$
^{90}Sr	$1.4\ 10^{-22}$	$7.2\ 10^{-15}$
^{131}I	$2.6\ 10^{-12}$	$6.3\ 10^{-9}$
^{224}Ra	$7.4\ 10^{-14}$	$2.8\ 10^{-10}$
^{226}Ra	$5.2\ 10^{-14}$	$1.5\ 10^{-6}$

TABLE A4 Food ingestion rates (Smith and Jones, 2003)

	Intake rates (97.5 percentile) ($kg\ y^{-1}$ or $l\ y^{-1}$)			
Food	**Adult**	**10 year old child**	**1 year old infant**	**3 month old infant**
Domestic fruit	75	50	35	–
Green and other domestically grown vegetables	80	35	15	–
Potatoes and root vegetables	130	95	45	–
Cow meat	45	30	10	–
Sheep meat	25	10	3	–
Cow offal	10	5	2.75	–
Sheep offal	10	5	2.75	–
Milk	240	240	320	350
Milk products	60	45	45	–

TABLE A5 Dose coefficients for ingestion for members of the public including the fetus and breastfed infant (ICRP, 1996, 2001, 2004)

	Ingestion dose coefficients (Sv Bq^{-1})						
						Breastfed infant	
Radionuclide	Adult	10 year old child	1 year old infant	3 month old infant	Fetus	Pregnancy[(a)]	Lactation[(b)]
^{3}H (inorganic, water)	$1.8\ 10^{-11}$	$2.3\ 10^{-11}$	$4.8\ 10^{-11}$	$6.4\ 10^{-11}$	$3.1\ 10^{-11}$	$1.0\ 10^{-12}$	$2.0\ 10^{-11}$
^{3}H (organic)	$4.2\ 10^{-11}$	$5.7\ 10^{-11}$	$1.2\ 10^{-10}$	$1.2\ 10^{-10}$	$6.3\ 10^{-11}$	$3.9\ 10^{-12}$	$3.0\ 10^{-11}$
^{14}C	$5.8\ 10^{-10}$	$8.0\ 10^{-10}$	$1.6\ 10^{-9}$	$1.4\ 10^{-9}$	$8.0\ 10^{-10}$	$7.2\ 10^{-11}$	$2.6\ 10^{-10}$
^{22}Na	$3.2\ 10^{-9}$	$5.5\ 10^{-9}$	$1.5\ 10^{-8}$	$2.1\ 10^{-8}$	$3.6\ 10^{-9}$	$6.2\ 10^{-11}$	$1.3\ 10^{-9}$
^{32}P	$2.4\ 10^{-9}$	$5.3\ 10^{-9}$	$1.9\ 10^{-8}$	$3.1\ 10^{-8}$	$2.5\ 10^{-8}$	$2.3\ 10^{-11}$	$1.6\ 10^{-9}$
^{33}P	$2.4\ 10^{-10}$	$5.3\ 10^{-10}$	$1.8\ 10^{-9}$	$2.7\ 10^{-9}$	$4.8\ 10^{-9}$	$3.8\ 10^{-12}$	$1.6\ 10^{-10}$
^{35}S (organic)	$7.7\ 10^{-10}$	$1.6\ 10^{-9}$	$5.4\ 10^{-9}$	$7.7\ 10^{-9}$	$1.6\ 10^{-9}$	$9.4\ 10^{-11}$	$2.4\ 10^{-10}$
^{35}S (inorganic)	$1.3\ 10^{-10}$	$2.7\ 10^{-10}$	$8.7\ 10^{-10}$	$1.3\ 10^{-9}$	$2.0\ 10^{-10}$	$9.4\ 10^{-11}$	$2.4\ 10^{-10}$
^{45}Ca	$7.1\ 10^{-10}$	$1.8\ 10^{-9}$	$4.9\ 10^{-9}$	$1.1\ 10^{-8}$	$8.7\ 10^{-9}$	$1.9\ 10^{-10}$	$1.7\ 10^{-9}$
^{47}Ca	$1.6\ 10^{-9}$	$3.0\ 10^{-9}$	$9.3\ 10^{-9}$	$1.3\ 10^{-8}$	$7.7\ 10^{-9}$	$2.1\ 10^{-11}$	$1.5\ 10^{-9}$
^{75}Se	$2.6\ 10^{-9}$	$6.0\ 10^{-9}$	$1.3\ 10^{-8}$	$2.0\ 10^{-8}$	$2.7\ 10^{-9}$	$6.0\ 10^{-10}$	$2.9\ 10^{-9}$
^{89}Sr	$2.6\ 10^{-9}$	$5.8\ 10^{-9}$	$1.8\ 10^{-8}$	$3.6\ 10^{-8}$	$1.2\ 10^{-8}$	$9.1\ 10^{-11}$	$2.0\ 10^{-9}$
^{90}Sr[(c)]	$3.1\ 10^{-8}$	$6.6\ 10^{-8}$	$9.3\ 10^{-8}$	$2.6\ 10^{-7}$	$4.3\ 10^{-8}$	$1.8\ 10^{-9}$	$1.5\ 10^{-8}$
^{131}I	$2.2\ 10^{-8}$	$5.2\ 10^{-8}$	$1.8\ 10^{-7}$	$1.8\ 10^{-7}$	$2.3\ 10^{-8}$	$3.1\ 10^{-11}$	$5.5\ 10^{-8}$
^{224}Ra[(c)]	$7.1\ 10^{-8}$	$2.8\ 10^{-7}$	$7.3\ 10^{-7}$	$2.9\ 10^{-6}$	$2.2\ 10^{-7}$	$2.0\ 10^{-11}$	$1.2\ 10^{-8}$
^{226}Ra[(c)]	$2.8\ 10^{-7}$	$8.0\ 10^{-7}$	$9.6\ 10^{-7}$	$4.7\ 10^{-6}$	$3.2\ 10^{-7}$	$1.4\ 10^{-9}$	$2.8\ 10^{-8}$

Notes

(a) Dose coefficient for intake of radionuclides by the breastfeeding infant from radionuclides ingested by the mother during pregnancy.

(b) Dose coefficient for intake of radionuclides by the breastfeeding infant from radionuclides ingested by the mother over the duration of breastfeeding.

(c) Short-lived progeny considered to be in equilibrium. For ^{90}Sr this is ^{90}Y, for ^{224}Ra this includes ^{212}Pb and for ^{226}Ra this includes ^{214}Po. For ^{226}Ra the ingrowth of ^{210}Po and ^{210}Pb was calculated explicitly.

TABLE A6 Food activity concentration (Bq kg^{-1} per Bq s^{-2}), in the 50th year following a continuous deposition of radionuclides on to soil, assuming an unit activity release of radionuclides to atmosphere

Food	$^{3}H^{(a)}$	$^{14}C^{(a)}$	^{22}Na	^{32}P	^{33}P	^{35}S (organic)	^{35}S (inorganic)	^{45}Ca	^{47}Ca
Domestic fruit	$4.3\ 10^{-4}$	$2.3\ 10^{-3}$	$3.6\ 10^{-4}$	$2.0\ 10^{-4}$	$2.4\ 10^{-4}$	$3.1\ 10^{-4}$	$3.1\ 10^{-4}$	$8.1\ 10^{-5}$	$2.5\ 10^{-5}$
Green and other domestically grown vegetables	$4.8\ 10^{-4}$	$1.1\ 10^{-3}$	$6.7\ 10^{-4}$	$3.0\ 10^{-4}$	$4.0\ 10^{-4}$	$5.8\ 10^{-4}$	$5.8\ 10^{-4}$	$5.4\ 10^{-4}$	$1.2\ 10^{-4}$
Potatoes and root vegetables	$4.3\ 10^{-4}$	$2.3\ 10^{-3}$	$6.2\ 10^{-4}$	$2.4\ 10^{-3}$	$2.2\ 10^{-4}$	$4.6\ 10^{-4}$	$4.6\ 10^{-4}$	$9.9\ 10^{-6}$	$2.1\ 10^{-7}$
Cow meat	$3.7\ 10^{-4}$	$3.4\ 10^{-3}$	$1.0\ 10^{-2}$	$2.0\ 10^{-3}$	$4.6\ 10^{-4}$	$3.0\ 10^{-2}$	$3.0\ 10^{-2}$	$3.7\ 10^{-5}$	$1.9\ 10^{-6}$
Cow offal	$3.7\ 10^{-4}$	$3.4\ 10^{-3}$	$1.0\ 10^{-2}$	$2.0\ 10^{-3}$	$4.6\ 10^{-4}$	$3.0\ 10^{-2}$	$3.0\ 10^{-2}$	$3.7\ 10^{-5}$	$1.9\ 10^{-6}$
Sheep meat	$3.7\ 10^{-4}$	$3.4\ 10^{-3}$	$3.1\ 10^{-3}$	$4.9\ 10^{-3}$	$1.2\ 10^{-3}$	$7.1\ 10^{-2}$	$7.1\ 10^{-2}$	$8.5\ 10^{-5}$	$2.6\ 10^{-6}$
Sheep offal	$3.7\ 10^{-4}$	$3.4\ 10^{-3}$	$3.1\ 10^{-3}$	$2.0\ 10^{-3}$	$4.7\ 10^{-4}$	$2.8\ 10^{-2}$	$2.8\ 10^{-2}$	$6.6\ 10^{-5}$	$2.6\ 10^{-6}$
Milk	$4.8\ 10^{-4}$	$1.1\ 10^{-3}$	$8.4\ 10^{-3}$	$2.3\ 10^{-3}$	$3.2\ 10^{-4}$	$4.6\ 10^{-3}$	$4.6\ 10^{-3}$	$2.9\ 10^{-4}$	$9.3\ 10^{-5}$
Milk products	$4.8\ 10^{-4}$	$1.3\ 10^{-2}$	$9.2\ 10^{-2}$	$2.6\ 10^{-2}$	$3.5\ 10^{-3}$	$5.1\ 10^{-2}$	$5.1\ 10^{-2}$	$3.2\ 10^{-3}$	$1.0\ 10^{-3}$

Food	^{75}Se	^{89}Sr	^{90}Sr	^{131}I	^{210}Pb	^{210}Po	^{224}Ra	^{226}Ra
Domestic fruit	$3.3\ 10^{-4}$	$7.1\ 10^{-5}$	$6.2\ 10^{-4}$	$1.0\ 10^{-3}$	$8.4\ 10^{-4}$	$3.2\ 10^{-4}$	$2.2\ 10^{-5}$	$1.8\ 10^{-3}$
Green and other domestically grown vegetables	$6.9\ 10^{-4}$	$4.2\ 10^{-4}$	$2.9\ 10^{-3}$	$1.4\ 10^{-3}$	$6.0\ 10^{-4}$	$5.6\ 10^{-4}$	$1.0\ 10^{-4}$	$6.6\ 10^{-4}$
Potatoes and root vegetables	$5.8\ 10^{-4}$	$3.3\ 10^{-6}$	$4.2\ 10^{-4}$	$2.9\ 10^{-4}$	$7.4\ 10^{-5}$	$4.6\ 10^{-4}$	$4.4\ 10^{-9}$	$1.5\ 10^{-5}$
Cow meat	$1.2\ 10^{-2}$	$1.9\ 10^{-5}$	$1.4\ 10^{-4}$	$8.4\ 10^{-4}$	$1.5\ 10^{-4}$	$3.0\ 10^{-4}$	$2.5\ 10^{-6}$	$9.5\ 10^{-5}$
Cow offal	$3.1\ 10^{-1}$	$1.9\ 10^{-5}$	$1.4\ 10^{-4}$	$8.4\ 10^{-4}$	$3.2\ 10^{-4}$	$7.9\ 10^{-3}$	$2.5\ 10^{-6}$	$9.5\ 10^{-5}$
Sheep meat	$2.1\ 10^{-2}$	$2.7\ 10^{-5}$	$1.1\ 10^{-4}$	$1.1\ 10^{-3}$	$2.1\ 10^{-4}$	$9.2\ 10^{-4}$	$3.3\ 10^{-6}$	$2.0\ 10^{-4}$
Sheep offal	$4.3\ 10^{-1}$	$2.7\ 10^{-5}$	$1.1\ 10^{-4}$	$1.1\ 10^{-3}$	$4.2\ 10^{-4}$	$1.1\ 10^{-2}$	$3.3\ 10^{-6}$	$2.0\ 10^{-4}$
Milk	$1.5\ 10^{-3}$	$9.3\ 10^{-5}$	$6.6\ 10^{-4}$	$2.0\ 10^{-3}$	$5.8\ 10^{-5}$	$1.3\ 10^{-5}$	$1.6\ 10^{-5}$	$7.7\ 10^{-5}$
Milk products	$1.7\ 10^{-2}$	$1.0\ 10^{-3}$	$7.2\ 10^{-3}$	$2.2\ 10^{-2}$	$6.4\ 10^{-4}$	$1.4\ 10^{-4}$	$1.7\ 10^{-4}$	$8.5\ 10^{-4}$

Note (a) The activity concentrations for ^{3}H and ^{14}C were obtained using element-specific models (NRPB, 2005).

TABLE A7 External dose rate above sediment and sediment activity concentration 500 m downstream from a point of release of unit activity concentration of radioactivity as a liquid

Radionuclide	Dose rate above sediment ($Sv\ h^{-1}$ per $Bq\ kg^{-1}$)	River bed sediment activity concentration ($Bq\ kg^{-1}$ per $Bq\ s^{-1}$)
^{3}H	$0.0\ 10^{0}$	$0.0\ 10^{0}$
^{14}C	$0.0\ 10^{0}$	$1.4\ 10^{-2}$
^{22}Na	$4.4\ 10^{-10}$	$6.7\ 10^{-5}$
^{32}P	$0.0\ 10^{0}$	$1.4\ 10^{-3}$
^{33}P	$0.0\ 10^{0}$	$2.3\ 10^{-3}$
^{35}S (organic)	$0.0\ 10^{0}$	$5.7\ 10^{-3}$
^{35}S (inorganic)	$0.0\ 10^{0}$	$5.7\ 10^{-3}$
^{45}Ca	$1.2\ 10^{-20}$	$7.9\ 10^{-3}$
^{47}Ca	$2.2\ 10^{-10}$	$5.7\ 10^{-4}$
^{75}Se	$6.1\ 10^{-11}$	$6.8\ 10^{-3}$
^{89}Sr	$1.7\ 10^{-14}$	$4.0\ 10^{-3}$
^{90}Sr	$1.6\ 10^{-18}$	$1.4\ 10^{-2}$
^{131}I	$6.9\ 10^{-11}$	$8.3\ 10^{-4}$
^{224}Ra	$1.6\ 10^{-12}$	$3.9\ 10^{-4}$
^{226}Ra	$1.0\ 10^{-12}$	$1.4\ 10^{-2}$

TABLE A8 Activity concentration in the dissolved fraction and in the suspended sediment fraction of river water 500 m downstream from a point of release of unit activity concentration of radioactivity

Radionuclide	Dissolved fraction water activity concentration ($Bq\ m^{-3}$ per $Bq\ s^{-1}$)	Suspended sediment activity concentration ($Bq\ kg^{-1}$ per $Bq\ s^{-1}$)
^{3}H	$1.0\ 10^{0}$	$3.0\ 10^{-5}$
^{14}C	$9.3\ 10^{-1}$	$1.8\ 10^{0}$
^{22}Na	$9.7\ 10^{-1}$	$5.8\ 10^{-3}$
^{32}P	$9.6\ 10^{-1}$	$9.6\ 10^{-1}$
^{33}P	$9.6\ 10^{-1}$	$9.6\ 10^{-1}$
^{35}S (organic)	$8.9\ 10^{-1}$	$2.7\ 10^{0}$
^{35}S (inorganic)	$8.9\ 10^{-1}$	$2.7\ 10^{0}$
^{45}Ca	$9.6\ 10^{-1}$	$9.6\ 10^{-1}$
^{47}Ca	$9.6\ 10^{-1}$	$9.6\ 10^{-1}$
^{75}Se	$8.9\ 10^{-1}$	$2.7\ 10^{0}$
^{89}Sr	$9.2\ 10^{-1}$	$1.8\ 10^{0}$
^{90}Sr	$9.3\ 10^{-1}$	$1.8\ 10^{0}$
^{131}I	$9.8\ 10^{-1}$	$3.0\ 10^{-1}$
^{224}Ra	$9.7\ 10^{-1}$	$4.9\ 10^{-1}$
^{226}Ra	$9.8\ 10^{-1}$	$4.9\ 10^{-1}$

TABLE A9 Concentration factors for freshwater fish

Element	Freshwater fish concentration factors ($Bq\ t^{-1}$ per $Bq\ m^{-3}$)	Source
H	0.9	Simmonds et al (1995)
C	4550	Simmonds et al (1995)
Na	20	NCRP (1996)
P	50000	NCRP (1996)
S	200	Mayall et al (1997)
Ca	0.4	Mayall et al (1997)
Se	200	NCRP (1996)
Sr	60	Simmonds et al (1995)
I	20	Simmonds et al (1995)
Ra	50	NCRP (1996)

TABLE A10 Food activity concentration factors: activity within the edible part of the food per unit activity deposited on to the soil surface

Radionuclide	Green and other domestically grown vegetables ($Bq\ kg^{-1}$ per $Bq\ m^{-2}\ y^{-1}$)	Potatoes and root vegetables ($Bq\ kg^{-1}$ per $Bq\ m^{-2}\ y^{-1}$)
^{3}H	$5.9\ 10^{-5}$	$5.9\ 10^{-5}$
^{3}H (OBT)	$1.3\ 10^{-5}$	$1.3\ 10^{-5}$
^{14}C	$2.6\ 10^{-3}$	$2.1\ 10^{-3}$
^{22}Na	$1.3\ 10^{-3}$	$2.3\ 10^{-4}$
^{32}P	$2.1\ 10^{-4}$	$8.2\ 10^{-5}$
^{33}P	$2.7\ 10^{-4}$	$1.6\ 10^{-4}$
^{35}S (organic)	$3.9\ 10^{-4}$	$3.2\ 10^{-4}$
^{35}S (inorganic)	$3.9\ 10^{-4}$	$3.2\ 10^{-4}$
^{45}Ca	$4.4\ 10^{-4}$	$4.4\ 10^{-5}$
^{47}Ca	$1.0\ 10^{-4}$	$4.4\ 10^{-5}$
^{75}Se	$5.5\ 10^{-4}$	$3.7\ 10^{-4}$
^{89}Sr	$2.8\ 10^{-4}$	$1.1\ 10^{-5}$
^{90}Sr	$6.7\ 10^{-3}$	$1.8\ 10^{-3}$
^{131}I	$1.4\ 10^{-4}$	$3.0\ 10^{-5}$
^{210}Pb[(a)]	$5.7\ 10^{-3}$	$1.5\ 10^{-3}$
^{210}Po[(a)]	$5.4\ 10^{-3}$	$1.5\ 10^{-3}$
^{224}Ra	$7.5\ 10^{-5}$	$8.1\ 10^{-9}$
^{226}Ra	$9.9\ 10^{-3}$	$2.8\ 10^{-3}$

Note (a) These progeny radionuclides were assumed to be applied to the soil at an activity concentration equal to that of the parent radionuclide (^{226}Ra).

Appendix B

Detailed Results for Atmospheric Releases

This appendix tabulates the ratio of the individual dose for each pathway to the embryo/fetus and breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult following a constant release of radioactivity for 1 year to the atmosphere. The following notes apply to the tables in this appendix.

(a) The letter in parentheses after the nuclide relates to the lung absorption type considered. For ^{35}S the first chemical form refers to the ingestion dose coefficient and the second chemical form refers to the inhalation dose coefficient.

(b) *Simplified fetus* assessment – used the annual ingestion or inhalation of radionuclides by the mother and the fetal dose coefficient for chronic exposure throughout pregnancy. This assessment applied dose coefficients for 9 months' exposure whilst a fetus, as provided by the ICRP, to annual intakes by the mother.

(c) *Full pregnancy* assessment – 9 months' exposure to the fetus followed by 3 months' exposure whilst breastfeeding. This assessment applied dose coefficients for chronic exposure throughout pregnancy and breastfeeding to periods of 9 months and 3 months intake, respectively, and also applied dose coefficients for transfer in breast milk following chronic exposure during pregnancy.

(d) *Limited pregnancy* assessment – 6 months' exposure to the fetus followed by 6 months' exposure whilst breastfeeding. This assessment applied dose coefficients for chronic exposure throughout pregnancy and breastfeeding each to periods of 6 months intake by the mother, but also applied dose coefficients for transfer in breast milk following chronic exposure during pregnancy.

(e) *Breastfeeding* assessment – 1 year's exposure of the breastfed infant following the annual ingestion or inhalation of radionuclides by the mother. This assumed that the dose coefficients for exposure to radionuclides in the mother's milk, provided by the ICRP based on 6 months' breastfeeding, could be applied directly to an annual intake by the mother.

It should be noted that all progeny were considered to be in equilibrium: for ^{90}Sr this is ^{90}Y, for ^{224}Ra this includes ^{212}Pb. For ^{226}Ra the ingrowth of ^{210}Po and ^{210}Pb was calculated explicitly.

In the tables ratios over one are given in bold type for convenience.

TABLE B1 Atmospheric release of ^{3}H

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	**1.7**	**1.7**	**1.7**	**1.7**
Inhalation of ambient resuspended soil	–	–	–	–
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	**1.2**	**1.1**	0.9	0.7
Green and other domestically grown vegetables	**1.6**	**1.4**	**1.2**	0.9
Potatoes and root vegetables	**1.6**	**1.4**	**1.2**	0.9
Cow meat	**1.6**	**1.4**	**1.2**	0.9
Cow offal	**1.6**	**1.4**	**1.2**	0.9
Sheep meat	**1.6**	**1.4**	**1.2**	0.9
Sheep offal	**1.6**	**1.4**	**1.2**	0.9
Milk	0.4	0.3	0.3	0.2
Milk products	0.7	0.7	0.6	0.4
Summed over foods	0.8	0.7	0.6	0.4
Summed over all pathways	**1.1**	1.0	1.0	0.9

For an explanation of the notes to the tables see page 42

TABLE B2 Atmospheric release of ^{14}C (M)[a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
Inhalation of the plume	< 0.1	0.2	0.3	0.8
Inhalation of ambient resuspended soil	–	–	–	–
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	**1.1**	0.9	0.8	0.4
Green and other domestically grown vegetables	**1.4**	**1.2**	1.0	0.6
Potatoes and root vegetables	**1.4**	**1.2**	1.0	0.6
Cow meat	**1.4**	**1.2**	1.0	0.6
Cow offal	**1.4**	**1.2**	1.0	0.6
Sheep meat	**1.4**	**1.2**	1.0	0.6
Sheep offal	**1.4**	**1.2**	1.0	0.6
Milk	0.4	0.3	0.3	0.2
Milk products	0.7	0.6	0.5	0.3
Summed over foods	0.8	0.7	0.6	0.3
Summed over all pathways	0.5	0.5	0.5	0.6

For an explanation of the notes to the tables see page 42

TABLE B3 Atmospheric release of ^{14}C (F)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	**1.3**	**1.3**	**1.2**	**1.2**
Inhalation of ambient resuspended soil	–	–	–	–
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	**1.1**	0.9	0.8	0.4
Green and other domestically grown vegetables	**1.4**	**1.2**	1.0	0.6
Potatoes and root vegetables	**1.4**	**1.2**	1.0	0.6
Cow meat	**1.4**	**1.2**	1.0	0.6
Cow offal	**1.4**	**1.2**	1.0	0.6
Sheep meat	**1.4**	**1.2**	1.0	0.6
Sheep offal	**1.4**	**1.2**	1.0	0.6
Milk	0.4	0.3	0.3	0.2
Milk products	0.7	0.6	0.5	0.3
Summed over foods	0.8	0.7	0.6	0.3
Summed over all pathways	0.8	0.7	0.6	0.4

For an explanation of the notes to the tables see page 42

TABLE B4 Atmospheric release of ^{14}C (organic vapour) [a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
Inhalation of the plume	**1.4**	**1.3**	**1.1**	**1.1**
Inhalation of ambient resuspended soil	–	–	–	–
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	**1.1**	0.9	0.8	0.4
Green and other domestically grown vegetables	**1.4**	**1.2**	1.0	0.6
Potatoes and root vegetables	**1.4**	**1.2**	1.0	0.6
Cow meat	**1.4**	**1.2**	1.0	0.6
Cow offal	**1.4**	**1.2**	1.0	0.6
Sheep meat	**1.4**	**1.2**	1.0	0.6
Sheep offal	**1.4**	**1.2**	1.0	0.6
Milk	0.4	0.3	0.3	0.2
Milk products	0.7	0.6	0.5	0.3
Summed over foods	0.8	0.7	0.6	0.3
Summed over all pathways	1.0	0.8	0.7	0.5

For an explanation of the notes to the tables see page 42

TABLE B5 Atmospheric release of ^{22}Na (F)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	0.7	0.8	0.9	**1.3**
Inhalation of ambient resuspended soil	0.7	0.8	0.9	**1.3**
External from deposition	1.0	0.8	0.7	0.3
External doses from the plume	1.0	1.0	1.0	1.0
Ingestion of foods				
Domestic fruit	0.5	0.4	0.4	0.2
Green and other domestically grown vegetables	**1.1**	1.0	0.8	0.4
Potatoes and root vegetables	0.7	0.6	0.5	0.3
Cow meat	1.0	0.8	0.7	0.4
Cow offal	0.9	0.7	0.6	0.3
Sheep meat	**1.1**	1.0	0.8	0.4
Sheep offal	0.9	0.7	0.6	0.3
Milk	0.1	0.1	0.1	< 0.1
Milk products	0.3	0.3	0.2	0.1
Summed over foods	0.3	0.2	0.2	0.1
Summed over all pathways	1.0	0.9	0.7	0.4

For an explanation of the notes to the tables see page 42

TABLE B6 Atmospheric release of ^{32}P (M)[a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
Inhalation of the plume	**1.8**	**1.5**	**1.3**	**1.1**
Inhalation of ambient resuspended soil	**1.8**	**1.5**	**1.3**	**1.1**
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	**2.8**	**2.1**	**1.5**	0.2
Green and other domestically grown vegetables	**7.0**	**5.3**	**3.7**	0.5
Potatoes and root vegetables	**3.8**	**2.9**	**2.0**	0.2
Cow meat	**5.9**	**4.5**	**3.2**	0.4
Cow offal	**4.8**	**3.6**	**2.5**	0.3
Sheep meat	**10.4**	**7.9**	**5.5**	0.7
Sheep offal	**4.8**	**3.6**	**2.5**	0.3
Milk	0.6	0.4	0.3	< 0.1
Milk products	**1.8**	**1.3**	0.9	0.1
Summed over foods	**1.7**	**1.3**	0.9	0.1
Summed over all pathways	**1.7**	**1.3**	0.9	0.2

 For an explanation of the notes to the tables see page 42

TABLE B7 Atmospheric release of ^{32}P (F)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	**5.7**	**4.6**	**3.5**	**1.4**
Inhalation of ambient resuspended soil	**5.7**	**4.6**	**3.5**	**1.4**
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	**2.8**	**2.1**	**1.5**	0.2
Green and other domestically grown vegetables	**7.0**	**5.3**	**3.7**	0.5
Potatoes and root vegetables	**3.8**	**2.9**	**2.0**	0.2
Cow meat	**5.9**	**4.5**	**3.2**	0.4
Cow offal	**4.8**	**3.6**	**2.5**	0.3
Sheep meat	**10.4**	**7.9**	**5.5**	0.7
Sheep offal	**4.8**	**3.6**	**2.5**	0.3
Milk	0.6	0.4	0.3	< 0.1
Milk products	**1.8**	**1.3**	0.9	0.1
Summed over foods	**1.7**	**1.3**	0.9	0.1
Summed over all pathways	**1.8**	**1.4**	1.0	0.2

For an explanation of the notes to the tables see page 42

TABLE B8 Atmospheric release of ^{33}P (M)[a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
Inhalation of the plume	0.8	0.7	0.7	0.7
Inhalation of ambient resuspended soil	0.8	0.7	0.7	0.7
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	**5.7**	**4.3**	**3.0**	0.2
Green and other domestically grown vegetables	**14.2**	**10.7**	**7.4**	0.5
Potatoes and root vegetables	**7.7**	**5.8**	**4.0**	0.3
Cow meat	**12.0**	**9.1**	**6.2**	0.4
Cow offal	**9.7**	**7.3**	**5.0**	0.3
Sheep meat	**20.0**	**15.1**	**10.3**	0.7
Sheep offal	**9.7**	**7.3**	**5.0**	0.3
Milk	**1.2**	0.9	0.6	< 0.1
Milk products	**3.6**	**2.7**	**1.8**	0.1
Summed over foods	**3.8**	**2.9**	**2.0**	0.1
Summed over all pathways	**2.2**	**1.8**	**1.4**	0.7

 For an explanation of the notes to the tables see page 42

TABLE B9 Atmospheric release of ^{33}P (F)[a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
Inhalation of the plume	**10.9**	**8.5**	**6.1**	**1.3**
Inhalation of ambient resuspended soil	**10.9**	**8.5**	**6.1**	**1.3**
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	**5.7**	**4.3**	**3.0**	0.2
Green and other domestically grown vegetables	**14.2**	**10.7**	**7.4**	0.5
Potatoes and root vegetables	**7.7**	**5.8**	**4.0**	0.3
Cow meat	**12.0**	**9.1**	**6.2**	0.4
Cow offal	**9.7**	**7.3**	**5.0**	0.3
Sheep meat	**20.0**	**15.1**	**10.3**	0.7
Sheep offal	**9.7**	**7.3**	**5.0**	0.3
Milk	**1.2**	0.9	0.6	< 0.1
Milk products	**3.6**	**2.7**	**1.8**	0.1
Summed over foods	**3.8**	**2.9**	**2.0**	0.1
Summed over all pathways	**5.2**	**4.0**	**2.8**	0.4

For an explanation of the notes to the tables see page 42

TABLE B10 Atmospheric release of ^{35}S (organic-inorganic particulate (M))[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	< 0.1	0.2	0.4	0.9
Inhalation of ambient resuspended soil	< 0.1	0.2	0.4	0.9
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	0.6	0.5	0.4	0.1
Green and other domestically grown vegetables	**1.6**	**1.3**	1.0	0.3
Potatoes and root vegetables	0.9	0.7	0.5	0.2
Cow meat	**1.3**	**1.1**	0.8	0.3
Cow offal	**1.1**	0.9	0.7	0.2
Sheep meat	**2.1**	1.7	1.3	0.4
Sheep offal	**1.1**	0.9	0.7	0.2
Milk	0.1	0.1	0.1	< 0.1
Milk products	0.4	0.3	0.2	0.1
Summed over foods	0.5	0.4	0.3	0.1
Summed over all pathways	0.5	0.4	0.3	0.1

For an explanation of the notes to the tables see page 42

TABLE B11 Atmospheric release of ^{35}S (organic-inorganic particulate (F))[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	0.7	**1.5**	**2.4**	**3.3**
Inhalation of ambient resuspended soil	0.7	**1.5**	**2.4**	**3.3**
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	0.6	0.5	0.4	0.1
Green and other domestically grown vegetables	**1.6**	**1.3**	1.0	0.3
Potatoes and root vegetables	0.9	0.7	0.5	0.2
Cow meat	**1.3**	**1.1**	0.8	0.3
Cow offal	**1.1**	0.9	0.7	0.2
Sheep meat	**2.1**	**1.7**	**1.3**	0.4
Sheep offal	**1.1**	0.9	0.7	0.2
Milk	0.1	0.1	0.1	< 0.1
Milk products	0.4	0.3	0.2	0.1
Summed over foods	0.5	0.4	0.3	0.1
Summed over all pathways	0.5	0.4	0.3	0.1

For an explanation of the notes to the tables see page 42

TABLE B12 Atmospheric release of ^{35}S (organic-organic vapour)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	**1.2**	**1.2**	**1.2**	**1.2**
Inhalation of ambient resuspended soil	**1.2**	**1.2**	**1.2**	**1.2**
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	0.6	0.5	0.4	0.1
Green and other domestically grown vegetables	**1.6**	**1.3**	1.0	0.3
Potatoes and root vegetables	0.9	0.7	0.5	0.2
Cow meat	**1.3**	**1.1**	0.8	0.3
Cow offal	**1.1**	0.9	0.7	0.2
Sheep meat	**2.1**	**1.7**	**1.3**	0.4
Sheep offal	**1.1**	0.9	0.7	0.2
Milk	0.1	0.1	0.1	< 0.1
Milk products	0.4	0.3	0.2	0.1
Summed over foods	0.5	0.4	0.3	0.1
Summed over all pathways	0.6	0.4	0.3	0.1

For an explanation of the notes to the tables see page 42

TABLE B13 Atmospheric release of ^{35}S (organic-inorganic vapour)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	1.0	**1.4**	**1.8**	**2.4**
Inhalation of ambient resuspended soil	1.0	**1.4**	**1.8**	**2.4**
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	0.6	0.5	0.4	0.1
Green and other domestically grown vegetables	**1.6**	**1.3**	1.0	0.3
Potatoes and root vegetables	0.9	0.7	0.5	0.2
Cow meat	**1.3**	**1.1**	0.8	0.3
Cow offal	**1.1**	0.9	0.7	0.2
Sheep meat	**2.1**	**1.7**	**1.3**	0.4
Sheep offal	**1.1**	0.9	0.7	0.2
Milk	0.1	0.1	0.1	< 0.1
Milk products	0.4	0.3	0.2	0.1
Summed over foods	0.5	0.4	0.3	0.1
Summed over all pathways	0.5	0.4	0.3	0.1

For an explanation of the notes to the tables see page 42

TABLE B14 Atmospheric release of ^{35}S (inorganic-inorganic particulate (M))[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	< 0.1	0.2	0.4	0.9
Inhalation of ambient resuspended soil	< 0.1	0.2	0.4	0.9
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	0.5	0.6	0.7	0.8
Green and other domestically grown vegetables	**1.2**	**1.4**	**1.6**	**2.0**
Potatoes and root vegetables	0.7	0.8	0.9	**1.1**
Cow meat	1.0	**1.2**	**1.4**	**1.7**
Cow offal	0.8	1.0	**1.1**	**1.4**
Sheep meat	**1.5**	**1.8**	**2.1**	**2.6**
Sheep offal	0.8	1.0	**1.1**	**1.4**
Milk	0.1	0.1	0.1	0.2
Milk products	0.3	0.4	0.4	0.5
Summed over foods	0.4	0.5	0.5	0.7
Summed over all pathways	0.3	0.4	0.5	0.8

 For an explanation of the notes to the tables see page 42

TABLE B15 Atmospheric release of ^{35}S (inorganic-inorganic particulate (F))[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	0.7	**1.5**	**2.4**	**3.3**
Inhalation of ambient resuspended soil	0.7	**1.5**	**2.4**	**3.3**
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	0.5	0.6	0.7	0.8
Green and other domestically grown vegetables	**1.2**	**1.4**	**1.6**	**2.0**
Potatoes and root vegetables	0.7	0.8	0.9	**1.1**
Cow meat	1.0	**1.2**	**1.4**	**1.7**
Cow offal	0.8	1.0	**1.1**	**1.4**
Sheep meat	**1.5**	**1.8**	**2.1**	**2.6**
Sheep offal	0.8	1.0	**1.1**	**1.4**
Milk	0.1	0.1	0.1	0.2
Milk products	0.3	0.4	0.4	0.5
Summed over foods	0.4	0.5	0.5	0.7
Summed over all pathways	0.4	0.5	0.6	0.7

For an explanation of the notes to the tables see page 42

TABLE B16 Atmospheric release of ^{35}S (inorganic-organic vapour)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	**1.2**	**1.2**	**1.2**	**1.2**
Inhalation of ambient resuspended soil	**1.2**	**1.2**	**1.2**	**1.2**
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	0.5	0.6	0.7	0.8
Green and other domestically grown vegetables	**1.2**	**1.4**	**1.6**	**2.0**
Potatoes and root vegetables	0.7	0.8	0.9	**1.1**
Cow meat	1.0	**1.2**	**1.4**	**1.7**
Cow offal	0.8	1.0	**1.1**	**1.4**
Sheep meat	**1.5**	**1.8**	**2.1**	**2.6**
Sheep offal	0.8	1.0	**1.1**	**1.4**
Milk	0.1	0.1	0.1	0.2
Milk products	0.3	0.4	0.4	0.5
Summed over foods	0.4	0.5	0.5	0.7
Summed over all pathways	0.6	0.6	0.7	0.8

 For an explanation of the notes to the tables see page 42

TABLE B17 Atmospheric release of ^{35}S (inorganic-inorganic vapour)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	1.0	**1.4**	**1.8**	**2.4**
Inhalation of ambient resuspended soil	1.0	**1.4**	**1.8**	**2.4**
External from deposition	–	–	–	–
External doses from the plume	–	–	–	–
Ingestion of foods				
Domestic fruit	0.5	0.6	0.7	0.8
Green and other domestically grown vegetables	**1.2**	**1.4**	**1.6**	**2.0**
Potatoes and root vegetables	0.7	0.8	0.9	**1.1**
Cow meat	1.0	**1.2**	**1.4**	**1.7**
Cow offal	0.8	1.0	**1.1**	**1.4**
Sheep meat	**1.5**	**1.8**	**2.1**	**2.6**
Sheep offal	0.8	1.0	**1.1**	**1.4**
Milk	0.1	0.1	0.1	0.2
Milk products	0.3	0.4	0.4	0.5
Summed over foods	0.4	0.5	0.5	0.7
Summed over all pathways	0.4	0.5	0.6	0.7

For an explanation of the notes to the tables see page 42

TABLE B18 Atmospheric release of ^{45}Ca (M)[a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[b]	**Full pregnancy[c]**	**Limited pregnancy[d]**	**Breastfeeding[e]**
Inhalation of the plume	0.6	0.7	0.7	0.9
Inhalation of ambient resuspended soil	0.6	0.7	0.7	0.9
External from deposition	1.0	0.8	0.7	0.3
External doses from the plume	1.0	1.0	1.0	1.0
Ingestion of foods				
Domestic fruit	**3.8**	**3.1**	**2.3**	0.8
Green and other domestically grown vegetables	**9.5**	**7.6**	**5.8**	**2.1**
Potatoes and root vegetables	**5.1**	**4.1**	**3.1**	**1.1**
Cow meat	**7.3**	**5.8**	**4.4**	**1.6**
Cow offal	**6.5**	**5.2**	**3.9**	**1.4**
Sheep meat	**12.1**	**9.7**	**7.4**	**2.6**
Sheep offal	**6.5**	**5.2**	**3.9**	**1.4**
Milk	0.5	0.4	0.3	0.1
Milk products	**2.4**	**1.9**	**1.4**	0.5
Summed over foods	**2.3**	**1.8**	**1.4**	0.5
Summed over all pathways	**1.5**	**1.3**	**1.1**	0.9

 For an explanation of the notes to the tables see page 42

TABLE B19 Atmospheric release of ^{47}Ca (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	0.5	0.6	0.6	1.0
Inhalation of ambient resuspended soil	0.5	0.6	0.6	1.0
External from deposition	1.0	0.8	0.7	0.3
External doses from the plume	1.0	1.0	1.0	1.0
Ingestion of foods				
Domestic fruit	**1.8**	**1.4**	**1.1**	0.4
Green and other domestically grown vegetables	**4.4**	**3.5**	**2.6**	0.9
Potatoes and root vegetables	**2.4**	**1.9**	**1.4**	0.5
Cow meat	**3.7**	**3.0**	**2.2**	0.7
Cow offal	**3.0**	**2.4**	**1.8**	0.6
Sheep meat	**4.8**	**3.8**	**2.9**	1.0
Sheep offal	**3.0**	**2.4**	**1.8**	0.6
Milk	0.4	0.3	0.2	0.1
Milk products	**1.1**	0.9	0.7	0.2
Summed over foods	1.0	0.8	0.6	0.2
Summed over all pathways	0.9	0.9	0.8	0.8

TABLE B20 Atmospheric release of ^{75}Se (F)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	0.6	0.8	1.0	**1.5**
Inhalation of ambient resuspended soil	0.6	0.8	1.0	**1.5**
External from deposition	1.0	0.8	0.7	0.3
External doses from the plume	1.0	1.0	1.0	1.0
Ingestion of foods				
Domestic fruit	0.4	0.5	0.5	0.6
Green and other domestically grown vegetables	1.0	**1.1**	**1.2**	**1.3**
Potatoes and root vegetables	0.6	0.6	0.7	0.8
Cow meat	0.7	0.7	0.8	0.9
Cow offal	0.8	0.8	0.9	1.0
Sheep meat	1.0	**1.1**	**1.2**	**1.3**
Sheep offal	0.8	0.8	0.9	1.0
Milk	0.1	0.1	0.1	0.1
Milk products	0.3	0.3	0.3	0.4
Summed over foods	0.6	0.6	0.7	0.8
Summed over all pathways	0.7	0.7	0.7	0.8

 For an explanation of the notes to the tables see page 42

TABLE B21 Atmospheric release of ^{89}Sr (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	0.3	0.4	0.6	1.0
Inhalation of ambient resuspended soil	0.3	0.4	0.6	1.0
External from deposition	1.0	0.8	0.7	0.3
External doses from the plume	1.0	1.0	1.0	1.0
Ingestion of foods				
Domestic fruit	**1.4**	**1.1**	0.8	0.2
Green and other domestically grown vegetables	**3.6**	**2.8**	**2.1**	0.6
Potatoes and root vegetables	**1.9**	**1.5**	**1.1**	0.3
Cow meat	**3.0**	**2.4**	**1.8**	0.5
Cow offal	**2.4**	**1.9**	**1.4**	0.4
Sheep meat	**4.6**	**3.7**	**2.7**	0.8
Sheep offal	**2.4**	**1.9**	**1.4**	0.4
Milk	0.2	0.2	0.1	< 0.1
Milk products	0.9	0.7	0.5	0.2
Summed over foods	1.0	0.8	0.6	0.2
Summed over all pathways	0.5	0.6	0.6	0.8

TABLE B22 Atmospheric release of ^{90}Sr (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	0.2	0.4	0.5	0.8
Inhalation of ambient resuspended soil	0.2	0.4	0.5	0.8
External from deposition	1.0	0.8	0.7	0.3
External doses from the plume	1.0	1.0	1.0	1.0
Ingestion of foods				
Domestic fruit	1.0	0.8	0.7	0.4
Green and other domestically grown vegetables	**1.4**	**1.2**	1.0	0.5
Potatoes and root vegetables	0.9	0.8	0.6	0.3
Cow meat	1.0	0.8	0.7	0.4
Cow offal	**1.3**	**1.1**	0.9	0.5
Sheep meat	**1.4**	**1.2**	1.0	0.5
Sheep offal	**1.3**	**1.1**	0.9	0.5
Milk	0.1	0.1	0.1	< 0.1
Milk products	0.6	0.5	0.4	0.2
Summed over foods	0.7	0.6	0.5	0.3
Summed over all pathways	0.6	0.5	0.5	0.5

For an explanation of the notes to the tables see page 42

TABLE B23 Atmospheric release of ^{131}I

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	0.5	0.7	**1.2**	**2.3**
Inhalation of ambient resuspended soil	0.5	0.7	**1.2**	**2.3**
External from deposition	1.0	0.8	0.7	0.3
External doses from the plume	1.0	1.0	1.0	1.0
Ingestion of foods				
Domestic fruit	0.3	0.4	0.5	0.7
Green and other domestically grown vegetables	0.7	0.9	**1.2**	**1.6**
Potatoes and root vegetables	0.4	0.5	0.6	0.9
Cow meat	0.6	0.8	1.0	**1.4**
Cow offal	0.5	0.6	0.8	**1.1**
Sheep meat	1.0	**1.4**	**1.8**	**2.5**
Sheep offal	0.5	0.6	0.8	**1.1**
Milk	0.1	0.1	0.1	0.2
Milk products	0.2	0.2	0.3	0.4
Summed over foods	0.2	0.2	0.3	0.4
Summed over all pathways	0.2	0.2	0.3	0.5

For an explanation of the notes to the tables see page 42

TABLE B24 Atmospheric release of ^{224}Ra (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	< 0.1	0.1	0.3	0.6
Inhalation of ambient resuspended soil	< 0.1	0.1	0.3	0.6
External from deposition	1.0	0.8	0.7	0.3
External doses from the plume	1.0	1.0	1.0	1.0
Ingestion of foods				
Domestic fruit	0.7	0.5	0.3	< 0.1
Green and other domestically grown vegetables	**1.6**	**1.2**	0.9	0.1
Potatoes and root vegetables	0.9	0.7	0.5	< 0.1
Cow meat	**1.2**	0.9	0.6	0.1
Cow offal	**1.1**	0.8	0.6	0.1
Sheep meat	**2.0**	**1.5**	**1.0**	0.1
Sheep offal	**1.1**	0.8	0.6	0.1
Milk	0.1	< 0.1	< 0.1	< 0.1
Milk products	0.4	0.3	0.2	< 0.1
Summed over foods	0.3	0.3	0.2	< 0.1
Summed over all pathways	< 0.1	0.1	0.3	0.6

 For an explanation of the notes to the tables see page 42

TABLE B25 Atmospheric release of ^{226}Ra (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 3 month old, 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
Inhalation of the plume	< 0.1	0.2	0.3	0.7
Inhalation of ambient resuspended soil	< 0.1	0.2	0.3	0.8
External from deposition	1.0	0.8	0.7	0.3
External doses from the plume	1.0	1.0	1.0	1.0
Ingestion of foods				
Domestic fruit	0.2	0.2	0.2	0.1
Green and other domestically grown vegetables	0.3	0.3	0.3	0.3
Potatoes and root vegetables	< 0.1	0.1	0.1	0.2
Cow meat	0.1	0.2	0.2	0.3
Cow offal	0.1	0.1	0.1	0.2
Sheep meat	0.2	0.2	0.3	0.4
Sheep offal	0.1	0.1	0.1	0.2
Milk	< 0.1	< 0.1	< 0.1	< 0.1
Milk products	0.1	0.1	0.1	0.1
Summed over foods	0.1	0.1	0.1	0.2
Summed over all pathways	0.3	0.3	0.4	0.6

For an explanation of the notes to the tables see page 42

Appendix C

Detailed Results for Liquid Releases

This appendix tabulates the ratio of the individual dose for each pathway to the embryo/fetus and breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult following a constant release of radioactivity in liquid form for 1 year. The following notes apply to the tables in this appendix.

(a) The letter in parentheses after the nuclide relates to the lung absorption type considered. For ^{35}S the first chemical form refers to the ingestion dose coefficient and the second chemical form refers to the inhalation dose coefficient.

(b) *Simplified fetus* assessment – used the annual ingestion or inhalation of radionuclides by the mother and the fetal dose coefficient for chronic exposure throughout pregnancy. This assessment applied dose coefficients for 9 months' exposure whilst a fetus, as provided by the ICRP, to annual intakes by the mother.

(c) *Full pregnancy* assessment – 9 months' exposure to the fetus followed by 3 months' exposure whilst breastfeeding. This assessment applied dose coefficients for chronic exposure throughout pregnancy and breastfeeding to periods of 9 months and 3 months intake, respectively, and also applied dose coefficients for transfer in breast milk following chronic exposure during pregnancy.

(d) *Limited pregnancy* assessment – 6 months' exposure to the fetus followed by 6 months' exposure whilst breastfeeding. This assessment applied dose coefficients for chronic exposure throughout pregnancy and breastfeeding each to periods of 6 months intake by the mother, but also applied dose coefficients for transfer in breast milk following chronic exposure during pregnancy.

(e) *Breastfeeding* assessment – 1 year's exposure of the breastfed infant following the annual ingestion or inhalation of radionuclides by the mother. This assumed that the dose coefficients for exposure to radionuclides in the mother's milk, provided by the ICRP based on 6 months' breastfeeding, could be applied directly to an annual intake by the mother.

It should be noted that all progeny were considered to be in equilibrium: for ^{90}Sr this is ^{90}Y, for ^{224}Ra this includes ^{212}Pb. For ^{226}Ra the ingrowth of ^{210}Po and ^{210}Pb was calculated explicitly.

In the tables ratios over one are given in bold type for convenience.

TABLE C1 Liquid release of ^{3}H

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	–	–	–	–
Ingestion of fresh water fish	**1.7**	**1.6**	**1.4**	**1.1**
Ingestion of drinking water	**1.5**	**1.4**	**1.3**	1.0
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.6**	**1.5**	**1.3**	1.0
Potatoes and root vegetables	**1.6**	**1.5**	**1.3**	1.0
Summed over irrigation foods	**1.6**	**1.5**	**1.3**	1.0
Summed over all pathways	**1.5**	**1.4**	**1.3**	1.0

TABLE C2 Liquid release of ^{14}C (M)[a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	**1.4**	**1.2**	1.0	0.5
Ingestion of fresh water fish	**1.4**	**1.2**	1.0	0.4
Ingestion of drinking water	**1.2**	1.0	0.8	0.4
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.4**	**1.2**	1.0	0.4
Potatoes and root vegetables	**1.4**	**1.2**	1.0	0.4
Summed over irrigation foods	**1.4**	**1.2**	1.0	0.4
Summed over all pathways	**1.4**	**1.2**	1.0	0.4

For an explanation of the notes to the tables see page 68

TABLE C3 Liquid release of ^{14}C (F)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	**1.4**	**1.2**	1.0	0.5
Ingestion of fresh water fish	**1.4**	**1.2**	1.0	0.4
Ingestion of drinking water	**1.2**	1.0	0.8	0.4
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.4**	**1.2**	1.0	0.4
Potatoes and root vegetables	**1.4**	**1.2**	1.0	0.4
Summed over irrigation foods	**1.4**	**1.2**	1.0	0.4
Summed over all pathways	**1.4**	**1.2**	1.0	0.4

TABLE C4 Liquid release of ^{22}Na (F)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	1.0	0.8	0.5	< 0.1
Inhalation of river bank sediments	0.9	0.8	0.6	0.4
Ingestion of fresh water fish	**1.1**	1.0	0.8	0.4
Ingestion of drinking water	0.6	0.5	0.4	0.2
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.1**	1.0	0.8	0.4
Potatoes and root vegetables	0.7	0.6	0.5	0.3
Summed over irrigation foods	**1.1**	0.9	0.7	0.4
Summed over all pathways	0.9	0.7	0.6	0.3

For an explanation of the notes to the tables see page 68

TABLE C5 Liquid release of ^{32}P (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	**1.9**	**1.5**	1.0	0.2
Ingestion of fresh water fish	**10.4**	**7.9**	**5.5**	0.7
Ingestion of drinking water	**3.0**	**2.3**	**1.6**	0.2
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**7.0**	**5.3**	**3.7**	0.4
Potatoes and root vegetables	**3.8**	**2.9**	**2.0**	0.2
Summed over irrigation foods	**5.3**	**4.0**	**2.8**	0.3
Summed over all pathways	**10.4**	**7.9**	**5.5**	0.7

TABLE C6 Liquid release of ^{32}P (F)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	**13.0**	**9.9**	**6.9**	0.9
Ingestion of fresh water fish	**10.4**	**7.9**	**5.5**	0.7
Ingestion of drinking water	**3.0**	**2.3**	**1.6**	0.2
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**7.0**	**5.3**	**3.7**	0.4
Potatoes and root vegetables	**3.8**	**2.9**	**2.0**	0.2
Summed over irrigation foods	**5.3**	**4.0**	**2.8**	0.3
Summed over all pathways	**10.4**	**7.9**	**5.5**	0.7

For an explanation of the notes to the tables see page 68

TABLE C7 Liquid release of ^{33}P (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	0.8	0.6	0.4	< 0.1
Ingestion of fresh water fish	**20.0**	**15.1**	**10.3**	0.7
Ingestion of drinking water	**6.2**	**4.6**	**3.2**	0.2
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**14.2**	**10.7**	**7.4**	0.5
Potatoes and root vegetables	**7.7**	**5.8**	**4.0**	0.3
Summed over irrigation foods	**10.1**	**7.6**	**5.2**	0.3
Summed over all pathways	**20.0**	**15.1**	**10.3**	0.7

TABLE C8 Liquid release of ^{33}P (F)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	**21.7**	**16.4**	**11.3**	0.8
Ingestion of fresh water fish	**20.0**	**15.1**	**10.3**	0.7
Ingestion of drinking water	**6.2**	**4.6**	**3.2**	0.2
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**14.2**	**10.7**	**7.4**	0.5
Potatoes and root vegetables	**7.7**	**5.8**	**4.0**	0.3
Summed over irrigation foods	**10.1**	**7.6**	**5.2**	0.3
Summed over all pathways	**20.0**	**15.1**	**10.3**	0.7

For an explanation of the notes to the tables see page 68

TABLE C9 Liquid release of ^{35}S (organic-inorganic particulate (M))[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	< 0.1	0.1	0.1	0.2
Ingestion of fresh water fish	**2.1**	**1.7**	**1.3**	0.3
Ingestion of drinking water	0.7	0.5	0.4	0.1
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.6**	**1.3**	1.0	0.2
Potatoes and root vegetables	0.9	0.7	0.5	0.1
Summed over irrigation foods	**1.1**	0.9	0.6	0.2
Summed over all pathways	**2.1**	**1.7**	**1.3**	0.3

TABLE C10 Liquid release of ^{35}S (organic-inorganic particulate (F))[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	**1.3**	**2.4**	**3.6**	**4.2**
Ingestion of fresh water fish	**2.1**	**1.7**	**1.3**	0.3
Ingestion of drinking water	0.7	0.5	0.4	0.1
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.6**	**1.3**	1.0	0.2
Potatoes and root vegetables	0.9	0.7	0.5	0.1
Summed over irrigation foods	**1.1**	0.9	0.6	0.2
Summed over all pathways	**2.1**	**1.7**	**1.3**	0.3

For an explanation of the notes to the tables see page 68

TABLE C11 Liquid release of ^{35}S (inorganic-inorganic particulate (M))[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	< 0.1	0.1	0.1	0.2
Ingestion of fresh water fish	**1.5**	**1.8**	**2.1**	**1.8**
Ingestion of drinking water	0.5	0.6	0.7	0.6
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.2**	**1.4**	**1.6**	**1.5**
Potatoes and root vegetables	0.7	0.8	0.9	0.8
Summed over irrigation foods	0.8	1.0	**1.1**	1.0
Summed over all pathways	**1.5**	**1.8**	**2.1**	**1.8**

TABLE C12 Liquid release of ^{35}S (inorganic-inorganic particulate (F))[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	–	–	–	–
Inhalation of river bank sediments	**1.3**	**2.4**	**3.6**	**4.2**
Ingestion of fresh water fish	**1.5**	**1.8**	**2.1**	**1.8**
Ingestion of drinking water	0.5	0.6	0.7	0.6
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.2**	**1.4**	**1.6**	**1.5**
Potatoes and root vegetables	0.7	0.8	0.9	0.8
Summed over irrigation foods	0.8	1.0	**1.1**	1.0
Summed over all pathways	**1.5**	**1.8**	**2.1**	**1.8**

For an explanation of the notes to the tables see page 68

TABLE C13 Liquid release of ^{45}Ca (M)[a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
External irradiation from river bank	1.0	0.8	0.5	< 0.1
Inhalation of river bank sediments	0.6	0.5	0.4	0.2
Ingestion of fresh water fish	**12.3**	**9.9**	**7.5**	**2.4**
Ingestion of drinking water	**4.1**	**3.3**	**2.5**	0.8
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**9.5**	**7.6**	**5.8**	**1.9**
Potatoes and root vegetables	**5.1**	**4.1**	**3.1**	1.0
Summed over irrigation foods	**8.5**	**6.8**	**5.2**	**1.7**
Summed over all pathways	**4.2**	**3.3**	**2.5**	0.8

TABLE C14 Liquid release of ^{47}Ca (M)[a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
External irradiation from river bank	1.0	0.8	0.5	< 0.1
Inhalation of river bank sediments	0.5	0.4	0.3	0.2
Ingestion of fresh water fish	**4.8**	**3.8**	**2.9**	0.9
Ingestion of drinking water	**1.9**	**1.5**	**1.1**	0.4
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**4.4**	**3.5**	**2.6**	0.9
Potatoes and root vegetables	**2.4**	**1.9**	**1.4**	0.5
Summed over irrigation foods	**3.3**	**2.6**	**2.0**	0.6
Summed over all pathways	**2.0**	**1.6**	**1.2**	0.4

For an explanation of the notes to the tables see page 68

TABLE C15 Liquid release of ^{75}Se (F)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	1.0	0.8	0.5	< 0.1
Inhalation of river bank sediments	**1.1**	**1.2**	**1.3**	**1.2**
Ingestion of fresh water fish	1.0	**1.1**	**1.2**	**1.1**
Ingestion of drinking water	0.5	0.5	0.6	0.5
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	1.0	**1.1**	**1.2**	**1.1**
Potatoes and root vegetables	0.6	0.6	0.7	0.6
Summed over irrigation foods	0.8	0.8	0.9	0.8
Summed over all pathways	1.0	**1.1**	**1.2**	**1.1**

TABLE C16 Liquid release of ^{89}Sr (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	1.0	0.8	0.5	< 0.1
Inhalation of river bank sediments	0.3	0.3	0.2	0.1
Ingestion of fresh water fish	**4.6**	**3.7**	**2.7**	0.8
Ingestion of drinking water	**1.5**	**1.2**	0.9	0.3
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**3.6**	**2.8**	**2.1**	0.6
Potatoes and root vegetables	**1.9**	**1.5**	**1.1**	0.3
Summed over irrigation foods	**3.4**	**2.7**	**2.0**	0.6
Summed over all pathways	**3.7**	**3.0**	**2.2**	0.6

 For an explanation of the notes to the tables see page 68

TABLE C17 Liquid release of ^{90}Sr (M)[a]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
External irradiation from river bank	1.0	0.8	0.5	< 0.1
Inhalation of river bank sediments	0.2	0.2	0.2	0.1
Ingestion of fresh water fish	**1.4**	**1.2**	1.0	0.5
Ingestion of drinking water	**1.1**	0.9	0.7	0.4
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.4**	**1.2**	1.0	0.5
Potatoes and root vegetables	0.9	0.8	0.6	0.3
Summed over irrigation foods	**1.2**	**1.1**	0.9	0.4
Summed over all pathways	**1.4**	**1.2**	1.0	0.5

TABLE C18 Liquid release of ^{131}I

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[b]	Full pregnancy[c]	Limited pregnancy[d]	Breastfeeding[e]
External irradiation from river bank	1.0	0.8	0.5	< 0.1
Inhalation of river bank sediments	**1.1**	**1.1**	**1.8**	**2.6**
Ingestion of fresh water fish	1.0	**1.4**	**1.8**	**2.5**
Ingestion of drinking water	0.3	0.4	0.5	0.7
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	0.7	0.9	**1.2**	**1.6**
Potatoes and root vegetables	0.4	0.5	0.6	0.9
Summed over irrigation foods	0.6	0.7	0.9	**1.3**
Summed over all pathways	0.5	0.6	0.8	**1.1**

For an explanation of the notes to the tables see page 68

TABLE C19 Liquid release of ^{224}Ra (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	1.0	0.8	0.5	< 0.1
Inhalation of river bank sediments	< 0.1	< 0.1	< 0.1	< 0.1
Ingestion of fresh water fish	**3.1**	**2.4**	**1.6**	0.2
Ingestion of drinking water	0.7	0.5	0.4	< 0.1
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	**1.6**	**1.2**	0.9	0.1
Potatoes and root vegetables	0.9	0.7	0.5	< 0.1
Summed over irrigation foods	**1.6**	**1.2**	0.9	0.1
Summed over all pathways	**1.6**	**1.2**	0.8	0.1

TABLE C20 Liquid release of ^{226}Ra (M)[(a)]

Ratio of the individual dose for each pathway to the embryo/fetus/breastfed infant to the maximum individual dose to the 1 year old, 10 year old and adult

	Simplified fetus[(b)]	Full pregnancy[(c)]	Limited pregnancy[(d)]	Breastfeeding[(e)]
External irradiation from river bank	1.0	0.8	0.5	< 0.1
Inhalation of river bank sediments	< 0.1	< 0.1	< 0.1	< 0.1
Ingestion of fresh water fish	**1.1**	0.9	0.6	0.1
Ingestion of drinking water	0.7	0.5	0.4	0.1
Ingestion of foods grown on irrigated land				
Green and other domestically grown vegetables	0.3	0.3	0.3	0.3
Potatoes and root vegetables	0.2	0.2	0.2	0.1
Summed over irrigation foods	0.3	0.3	0.3	0.2
Summed over all pathways	0.8	0.7	0.5	0.1

For an explanation of the notes to the tables see page 68

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Documents of the Health Protection Agency
Radiation, Chemical and Environmental Hazards
RCE-5
March 2008
ISBN 978-0-85951-614-3
£21.00

Printed on chlorine-free paper