NATIONAL DOSE ASSESSMENT WORKING GROUP

PAPER 13-03: GUIDANCE ON THE APPLICATION OF DOSE COEFFICIENTS FOR THE EMBRYO, FETUS AND THE BREAST FED INFANT IN DOSE ASSESSMENTS FOR MEMBERS OF THE PUBLIC

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1 Introduction

This paper summarises a report, recently published by the Radiation Protection Division of the Health Protection Agency (HPA-RPD), that provides guidance on the use of published dose coefficients when assessing the doses to members of the public. Reference to the HPA report (HPA, 2008) should be made for a full account of the recommendations presented within this paper.

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 (ICRP Publications 56, 67, 69 and 71 (ICRP 1989, 1993, 1995, 1996a), culminating in a compilation report ICRP 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 Bq ingested or inhaled by the infant, child or adult, integrated to age 70 years. 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 infant (Publication 95) (ICRP, 2004). In these cases, the values given are of committed effective dose to the offspring per Bq ingested or inhaled by the mother.

In Publication 101, ICRP (2007b) 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 (including in utero exposures) (infant), 6 – 15 years (child) and 16 - 70 years (adult) respectively.

However, Publication 101 (ICRP, 2007b) drew attention to the fact that some radionuclides, principally isotopes of phosphorus and the alkaline earth elements (calcium, strontium), can deliver significantly higher doses to the fetus and breast fed 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 breast feeding should be assessed separately.

ICRP did not, however, provide any guidance on how dose coefficients for exposure to the embryo/fetus and the breast fed infant are to be applied in practice. For example, there is no indication given of how the dose coefficients for chronic exposures of the embryo/fetus throughout gestation (which are for a 9 month exposure) and the infant throughout breast feeding (which assumes a 6 month exposure) should be combined in order to assess an annual dose.

This paper summarizes a report by the HPA (HPA, 2008) which provides guidance on the application of ICRP's 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. Although dose coefficients can vary considerably between the ages, sometimes by several orders of magnitude, there is often less of a difference with the dose dependent more on the exposure routes and habit data relating to the intake of radionuclides. As the dose from external irradiation can be taken to be essentially the same for all age groups within the same radiation field this paper is aimed at providing guidance on when and how to assess the dose to the embryo, fetus and breast fed infant for those radionuclides which have a significant internal component to the total dose.

2 Methodology

A previous review of the available dose coefficients was made (NRPB, 2005) that identified those radionuclides which have a larger fetal dose coefficient for chronic intake by the mother than the corresponding adult dose coefficient, meaning that the dose to the fetus could be higher than that to the adult. For all other radionuclides the dose to the adult would always be higher than that to the fetus.

Using the identified group of radionuclides where the fetal dose coefficient was higher than the corresponding dose coefficient of the adult, the doses to the different age groups were assessed for routine releases of radionuclides to the environment, either for a unit atmospheric discharge or for a unit release in liquid form into a river. The pathways included were those considered in calculations of generalised derived constraints (GDCs) (NRPB, 2000; NRPB, 2002), together with additional pathways based on advice from the European Commission (European Commission, 2002).

For assessing the exposure 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. In order to assess the dose to the fetus/breast fed infant four combinations of available dose coefficients were considered in

order to investigate the impact on the potential dose ranges. These combinations are presented below.

- The 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 presented by ICRP, to annual intakes by the mother.
- Six months exposure to the fetus followed by 6 months exposure whilst breast feeding (termed the limited pregnancy assessment). This assessment applied dose coefficients for chronic exposure throughout pregnancy and breast feeding 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.
- Nine month exposure to the fetus followed by 3 months exposure whilst breast feeding (termed the full pregnancy assessment). This assessment applied dose coefficients for chronic exposure throughout pregnancy and breast feeding 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.
- One year exposure of the breast fed infant following the annual ingestion or inhalation of radionuclides by the mother (termed the breast feeding assessment). This assumed that the dose coefficients for exposure to radionuclides in the mother's milk, presented by ICRP based on 6 months breast feeding, could be directly applied to an annual intake by the mother.

3 Results

Table 1 presents the ratio of the doses, from the routine release of radionuclides to the atmosphere, to the embryo/fetus and breast fed infant to the maximum dose assessed for the other age groups considered for those radionuclides where the ratio was above 1. Table 2 presents corresponding results for routine liquid discharges to a river. For releases to atmosphere, the highest ratios seen (Table 1) are for ^{32}P and ^{33}P (up to 5), while for all other radionuclides the ratios are less than two. For liquid releases to a river the ratios (Table 2) are generally higher than those for atmospheric releases as well as being higher for more radionuclides. The ratios are significantly above 2 for ^{32}P, ^{33}P, ^{45}Ca and ^{89}Sr, with the highest ratios seen for the two phosphorus isotopes (up to 10 for ^{32}P and up to 20 for ^{33}P).

Table 1 Ratio[†] of the annual dose to the embryo/fetus/breast fed 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[§]	Simplified fetus[*]	Full pregnancy[#]	Limited pregnancy[‡]	Breast feeding[$]
^{3}H	1.1	≤ 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
^{45}Ca (M)	1.5	1.3	1.1	≤ 1

[†] ratios are shown rounded to 1 decimal place. Where the ratio is greater than 2 these are in bold to highlight them

* simplified fetus assumes exposure as an embryo/fetus to 12 months of chronic intake by the mother

full pregnancy assumes exposure as an embryo/fetus for 9 months followed by breast feeding for 3 months

‡ limited pregnancy assumes exposure as an embryo/fetus for 6 months followed by breast feeding for 6 months

$ breast feeding assessment assumes exposure as a breast fed infant to 12 months of chronic intake by the mother

§ the letter in parenthesis after the nuclide 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. Only those radionuclides where the ratio is greater than 1 are shown.

For routine releases of radionuclides to atmosphere the pathway that contributed most to the overall dose tended to be the ingestion of food. Where this was the case the dose to the 1 year old or to the simplified fetus was often the most limiting when the dose was compared across all the age groups. Milk products, milk or vegetables are the important terrestrial foods in most cases.

For routine liquid releases to a river, the most important exposure pathway was either ingestion of fish or ingestion of drinking water. The limiting age group was often one of the fetus/breast fed infant combinations, and of these the exposure to the simplified fetus was often the most limiting. This is because for fish and drinking water the adult ingestion rate, which is also relevant for exposure of the fetus/breast fed infant, was significantly higher than those for 1 and 10 year olds.

Table 2 Ratio[†] of the annual dose to the embryo/fetus/breast fed infant to the maximum of the annual dose to a 3 month old, 1 year old, 10 year old and adult for a liquid routine release of radioactivity

Radionuclide[§]	Simplified fetus[*]	Full pregnancy[#]	Limited pregnancy[‡]	Breast feeding[$]
^{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
^{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 (M)	**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)[¥]	1.4	1.2	≤ 1	≤ 1
^{131}I	≤ 1	≤ 1	≤ 1	1.1
^{224}Ra (M)[¥]	1.6	1.2	≤ 1	≤ 1

[†] ratios are shown rounded to 1 decimal place. Where the ratio is greater than 2 these are in bold to highlight them

* simplified fetus assumes exposure as an embryo/fetus to 12 months of chronic intake by the mother

full pregnancy assumes exposure as an embryo/fetus for 9 months followed by breast feeding for 3 months

‡ limited pregnancy assumes exposure as an embryo/fetus for 6 months followed by breast feeding for 6 months

$ breast feeding assessment assumes exposure as a breast fed infant to 12 months of chronic intake by the mother

§ the letter in parenthesis after the nuclide 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. Only those radionuclides where the ratio is greater than 1 are shown.

¥ short lived progeny considered to be in equilibrium. For ^{90}Sr this is ^{90}Y, for ^{224}Ra this includes ^{212}Pb

For most dose assessments it is the summed dose from all pathways that is important rather than the dose from any individual pathway. However, there can be seen large differences in the dose ratios for individual pathways, some being over an order of magnitude larger than the summed ratio. For more details of the variation of the dose with respect to different pathways reference to the full report (HPA, 2008) should be made. Care must therefore be taken when applying the guidance presented in this study to a particular assessment to ensure that changing the exposure pathways considered does not raise the importance of the fetus/breast fed infant within an assessment. Table 3 shows, for the example of ^{33}P for a routine liquid release of radioactivity, the relative importance of the different exposure pathways.

Table 3 Ratio[†] of the individual dose for each pathway to the embryo/fetus/breast fed infant to the maximum individual dose to the 3 month old, the 1 year old, the 10 year old and the adult for a liquid release of ^{32}P (F)[§]

		Simplified fetus[*]	Full pregnancy[#]	Limited pregnancy[‡]	Breast feeding[$]
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	Grvg & dom veg	**7.0**	**5.3**	**3.7**	0.4
	Pots and root veg	**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

[†] ratios are shown rounded to 1 decimal place. Where the ratio is greater than 2 these are in bold to highlight them

* simplified fetus assumes exposure as an embryo/fetus to 12 months of chronic intake by the mother

full pregnancy assumes exposure as an embryo/fetus for 9 months followed by breast feeding for 3 months

‡ limited pregnancy assumes exposure as an embryo/fetus for 6 months followed by breast feeding for 6 months

$ breast feeding assessment assumes exposure as a breast fed infant to 12 months of chronic intake by the mother

§ the letter in parenthesis after the nuclide relates to the lung absorption type considered: F denotes Fast absorption to blood, M denotes Moderate absorption.

4 Discussion

4.1 Routine release assessments

The study (HPA, 2008) showed that for most of the radionuclides considered the inclusion of a dose assessment for the embryo/fetus or the breast fed infant would alter the dose to the representative person by a factor of less than 2 or 3. Given the uncertainties elsewhere within the dose assessment process these differences are not considered significant. This is consistent with the latest advice from the ICRP (2007b) that in general assessments consideration can be limited to three age groups only. The effort involved in assessing doses to the embryo/fetus and breast fed 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, the study (HPA, 2008) showed that the dose to the embryo/fetus and the breast fed 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/breast fed 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 breast fed 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 to the embryo/fetus/breast fed infant several different calculations were performed. The simplest method to assess the dose was to take the dose coefficient of either the

embryo/fetus or that of the breast fed infant and use it with an annual intake by the mother. Two other cases were also considered in which the annual exposure occurred as a combination of exposure as a embryo/fetus and during breast feeding. 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 that lasted 12 months. This methodology is recommended for use in scoping assessments. If a more detailed assessment is required then doses should be assessed for 9 months exposed as an embryo/fetus followed by 3 months exposure during breast feeding. It is recognised that the dose coefficients for breast feeding provided by ICRP (ICRP, 2004) assume intake by the mother over 6 months. However the approximation of applying these dose coefficients for 3 months intake by the mother is judged acceptable for the purposes of comparison with annual dose limits.

4.2 Emergency exposure situations

There are some important differences in the assessment of doses for emergency exposure compared with routine release assessments. Most importantly this includes differences in the radionuclides of concern and the timescales of interest and this will affect the relative importance of the doses to different age groups.

Exposures during an emergency will often only occur for a relatively short time. ICRP (ICRP, 2001) has produced dose coefficients for exposure of the embryo and the fetus for acute intakes, taken to be instantaneous, at 8 different times before and during pregnancy. The range in value of these dose coefficients is large with most radionuclides having 3 or 4 orders of magnitude between the lowest and highest values, with 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 2 and 5. This means that for some additional radionuclides (^{50}Fe, ^{65}Zn, ^{99m}Tc, ^{131m}Te, ^{125}I, ^{132}I, ^{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 do not need to be considered.

For exposure to the breast fed infant ICRP (ICRP, 2004) has produced 7 dose coefficients for acute intakes representing intakes at different times. These again span a large range in exposure times and cover several orders of magnitude, with the largest values being for intakes of radionuclides by the mother at 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 breast fed infant made previously for routine releases is valid for both routine and acute exposure situations. In addition to using this advice derived from the routine release of radionuclides, exposure to isotopes of iodine were considered further due to the importance of these radionuclides in emergency situations and the fact that

for some isotopes, for example ^{131}I, the dose coefficient for the breast fed infant are larger than that for an adult and therefore, in some situations, the dose to the breast fed infant could be higher than that to the adult for these radionuclides. However it is noted that 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 states that priority for the issue of stable iodine should be to nursing mothers and very young children. If this advice is followed then the fetus and breast fed infant should be adequately protected.

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. The introduction of such measures could have an effect on the relative importance of different exposure pathways and hence the applicability of the conclusions discussed earlier for routine releases.

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. Previous advice has been given on the application of these intervention levels (termed CFILs – Council Food Intervention Levels) in the UK (NRPB, 1994). The study described in the report by the HPA (HPA, 2008) included an assessment of the indicative maximum dose that might be received by the fetus if the mother ingested food at the CFIL for a year. The same methodology as considered previously was applied (NRPB, 1994) and the radionuclides considered were ^{45}Ca, ^{32}P, ^{33}P and ^{89}Sr. The estimated committed effective doses to the fetus were all less than 0.06 mSv. From this it is concluded that the CFILs are adequate to protect the fetus.

4.3 Solid Waste disposal

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 the landfill to areas where people could be exposed may take many tens or, for some radionuclides, hundreds or thousands of years. 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). Therefore it is not necessary to include them in an assessment for solid waste disposal.

Of the radionuclides where the dose coefficients of the embryo/fetus are larger than those of the adult (NRPB, 2005) 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 calculated by the study (HPA, 2008) 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 3. 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 breast fed infant are lower than those for adults and so do not need to be considered. For solid waste disposals it is concluded that an assessment of the doses to the embryo/fetus or the breast fed infant will generally not be necessary as any increases in doses over those to other age groups will be small compared to the overall uncertainty in the assessed doses.

5 Recommendations

Assessment of all doses to the public

- For most radionuclides, including some of those for which the dose coefficient for either the embryo/fetus or the breast fed infant are larger than those 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 breast fed infant is therefore not required except where indicated below.
- For four radionuclides, ^{32}P and ^{33}P, ^{45}Ca and ^{89}Sr, it is recommended that the fetus/breast fed infant is considered in all assessments where these radionuclides form a significant part of any release of radioactivity to the environment.
- 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/breast fed infant can be higher than the dose to the mother then doses to the fetus and breast fed infant should be considered separately.
- For the radionuclides ^{32}P and ^{33}P, ^{45}Ca and ^{89}Sr, or where the situation of the assessment requires that the fetus/breast fed infant is assessed, it will generally be adequate to carry out a 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 breast feeding.
- 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, occupancy times etc.

Emergency Exposure Situations

For emergency situations, in addition to the above points, the following recommendations are also made.

- It may be necessary to consider the exposure of the embryo/fetus or breast fed infant in more situations when carrying out a detailed radiation dose assessment for emergency exposures than for routine releases.
- It is not considered necessary to change existing off-site emergency plans to explicitly take into account exposure of the fetus or breast fed 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.

- Previous recommendations on stable iodine prophylaxis state that priority for the issue of stable iodine should be to nursing mothers and very young children. If this advice is followed then the fetus and breast fed infant should be adequately protected in the event of an accidental release of radioactivity.
- The regulations from the Council of the European Communities on intervention levels in food (CFILs) are considered adequate to protect the fetus and breast fed infant as well as other age groups for all radionuclides.

Disposal situations

- In general it is not necessary to consider the exposure of the embryo/fetus or breast fed infants when assessing radiation doses from the disposal of solid waste to land.

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