DOCUMENTS OF THE NRPB

Revised Generalised Derived Limits for Radioisotopes of Strontium, Ruthenium, Iodine, Caesium, Plutonium, Americium and Curium

Application of Generalised Derived Limits

VOLUME 9 NO 1 1998

National Radiological Protection Board
Chilton, Didcot, Oxon OX11 0RQ

The National Radiological Protection Board was created by the Radiological Protection Act 1970. The functions of the Board are to give advice, to conduct research, and to provide technical services in the field of protection against both ionising and non-ionising radiations.

In 1977 the Board received Directions under the Radiological Protection Act which require it to give advice on the acceptability to and the application in the UK, of standards recommended by international or intergovernmental bodies, and to specify emergency reference levels (ERLs) of dose for limiting radiation doses in accident situations.

Documents of the NRPB contain both the formal advice of the Board on standards of protection as well as guidance on their application in practice.

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REVISED GENERALISED DERIVED LIMITS FOR RADIOISOTOPES OF STRONTIUM, RUTHENIUM, IODINE, CAESIUM, PLUTONIUM, AMERICIUM AND CURIUM

ABSTRACT

The publication of the 1990 recommendations of the International Commission on Radiological Protection and the Board's response to them has necessitated the revision of generalised derived limits (GDLs) previously published by the Board. Generalised derived limits have been calculated in various environmental materials for the radiologically significant isotopes of strontium, ruthenium, iodine, caesium, plutonium, americium and curium, derived from the annual effective dose limit of 1 mSv. The most recent age-dependent dosimetric models have been used and the opportunity has been taken to review and update where necessary the methods and data used in calculating the GDLs. The values presented here are intended for use as convenient reference levels against which the results of environmental monitoring can be compared.

Generalised derived limits are calculated using deliberately cautious assumptions and are based on the assumption that the level of environmental contamination is uniform over a year. If a measured environmental concentration exceeds about 10% of the GDL then the doses should be examined more closely, taking account of site-specific factors and the length of time the measured level is likely to be maintained. More detailed practical guidance on the application of the GDLs presented here is given in a companion paper.

This paper replaces that published as *Documents of the NRPB*, **7**, No. 1 (1996) which superseded NRPB-GS8 and NRPB-GS10. This was necessary as the dose coefficients used there were taken from the draft Basic Safety Standards of the International Atomic Energy Agency and some of these dose coefficients were modified prior to publication of the final document and ICRP Publication 72. In Publication 72, ICRP also gives recommendations on the default lung absorption types to be assumed in the absence of specific information. These recommendations are adopted here and in some cases lead to differences in the lung type used.

PREPARED BY C A ATTWOOD, J G TITLEY, J R SIMMONDS AND C A ROBINSON

INTRODUCTION

1 The Board has previously published generalised derived limits (GDLs) for radioisotopes of a range of elements[1,2] and these have found wide application. The 1990 recommendations of the International Commission on Radiological Protection (ICRP), published in Publication 60[3], introduced the concepts of effective dose and dose constraint. The Board has published guidance on the ICRP recommendations[4] and has considered their implications on public exposure[5]. Further, the implications of the ICRP recommendations on GDLs were discussed and it was noted that revised GDLs would be required[5]. Revised GDLs were subsequently published[6]; however, the dose coefficients used were taken from the draft Basic Safety Standards of the International Atomic Energy Agency (IAEA) and some of the dose coefficients were modified prior to publication of the final Basic Safety Standards[7] and ICRP Publication 72[8]. In Publication 72, ICRP also gives recommendations on the default lung absorption types to be assumed in the absence of specific information. These recommendations are adopted here and in some cases lead to differences in the lung type used.

2 Derived limits (DLs) are convenient reference levels against which the results of monitoring can be compared; they may be set for such quantities as dose rate in a workplace, or contamination of air or other environmental materials. They are related to the primary dose criteria by a defined model and are calculated such that compliance with them would ensure virtual certainty of compliance with the appropriate dose criteria. Generalised derived limits are intended for general application, as opposed to derived limits which are developed for specific situations for defined groups of individuals; GDLs are directly measurable quantities, such as concentrations in environmental materials (eg milk and other foods, grass and soil), and are calculated for single radionuclides. Measured values may include contributions from a number of sources and from past operations. As discussed elsewhere[5], the dose limit for members of the public covers public exposures from controlled sources and the Board recommends that exposures arising from past controlled releases should also be included in any comparison with the dose limit. This recommendation was accepted by the government in the recent White Paper on radioactive waste management policy[9]. Therefore, it is appropriate for doses resulting from measurements to be compared with the overall dose limit for members of the public[5] of 1 mSv y^{-1} and this is the basis for the GDLs presented here. Where appropriate, GDLs will also be estimated so that the annual equivalent dose to the lens of the eye and the skin do not exceed the recommended dose limits for the public of 15 and 50 mSv, respectively[5]. However, these organ-specific dose limits are rarely limiting in determining GDLs in environmental materials. Derived quantities for discharges of radionuclides to the environment are clearly related to the current operation of a single controlled source and should therefore be based on the appropriate dose constraint[5]. Generalised derived constraints[5] (GDCs) will therefore be developed for discharges of radionuclides to the environment based on the upper value of the constraint on effective dose for members of the public of 0.3 mSv y^{-1} recommended by the Board[5].

3 This report contains values of GDLs for a range of environmental materials for radioisotopes of seven elements that have all been considered in previous publications on GDLs[1,2,6]. The GDLs have been calculated using effective dose as defined in ICRP Publication 60[3]. The values for age-dependent dose coefficients (previously known as dose

per unit intakes) from inhalation and ingestion are as given elsewhere[8]. The opportunity has also been taken to review the data and methods used to calculate GDLs and this has led to some additional changes to the GDLs from those published previously. The dietary intakes used in the calculations have been revised to take account of recent survey data, and other parameters have been reviewed and changed as appropriate. In addition, there have been changes in the GDLs considered. There are now GDLs for sea washed land and sewage sludge, media that were not considered previously. The contamination of sea washed land is of interest because of the effects of controlled releases of radionuclides to sea. Also, small quantities of radionuclides are discharged from hospitals and other small users of radioactivity to the sewerage system, hence the inclusion of a GDL for sewage sludge. The GDL for surface contamination, calculated previously, assumed a fresh deposit of radionuclides sustained for a year. It is difficult to see a practical application for such GDLs and their unrealistic nature could lead to their misuse and misinterpretation. Therefore GDLs for surface contamination are no longer included. It is also no longer considered appropriate to present GDLs for seawater. This is because it is better to measure radioactivity in media, such as seafood and sediments, that more directly relate to the exposure of people. The GDLs presented here replace all those given previously[1,2,6]. A companion paper[10] gives more detailed practical guidance on the application of GDLs and their comparison with measurements. In future, further reports will give GDLs for radioisotopes of additional elements and also GDCs for discharges into the environment.

BASIS FOR THE REVISED GDLs

4 Generalised derived limits are intended for general application as environmental reference levels. They can be used as simple screening values for low levels of radionuclides in the environment and are calculated using a set of standardised and deliberately cautious assumptions concerning the habits of the hypothetically exposed group. The GDLs are based on the assumption that the level of environmental contamination is reasonably uniform over a year and they do not relate to transient conditions. For example, they should not be used in connection with single, short-term releases of radionuclides into the environment.

5 As outlined above and discussed elsewhere[5], GDLs are based on an effective dose limit of 1 mSv y^{-1}. The supplementary limits on the lens of the eye and the skin were also considered in calculating GDLs but, for the radioisotopes and GDLs included in this report, their values were never limiting so only the effective dose was relevant.

6 The GDLs are based on the dose to the most restrictive age group, taking into account variations in dose coefficients and dietary and other habits with age. As previously[1,2,6], the age groups considered are infants (1 year old), children (10 years old) and adults (assumed to be 20 years old). In addition, for GDLs in milk or where the ingestion of milk could be the dominant pathway, calculations are also performed for infants on a milk diet in the first year of life based on dose coefficients for a 3 month old. For some elements enhanced absorption at this stage of development leads to more restrictive GDLs. The use of the ingestion dose coefficient for a 3 month old, together with a milk intake more

applicable to an older infant to represent the first year of life, will lead to a cautious estimate of the GDL. This is particularly the case for radioisotopes where there is a marked reduction in the dose coefficient between 3 and 12 months. It is not considered appropriate to use the 3 month old dose coefficient for intakes of other foods as they are generally only consumed by older infants for whom a lower dose coefficient usually applies. Although data on dose coefficients are available for additional age groups[8], the ages considered here are thought to cover the range and to be adequate for the purposes of calculating GDLs. For calculating doses from intakes of radionuclides the lifetime of an

TABLE 1 *Dose coefficients for intake by ingestion*

		Committed effective dose per unit intake (Sv Bq^{-1})			
Nuclide	f_1[a]	Infant (3 months)	Infant (1 y)	Child (10 y)	Adult (20 y)
^{89}Sr	3.0 10^{-1}	3.6 10^{-8}	1.8 10^{-8}	5.8 10^{-9}	2.6 10^{-9}
^{90}Sr	3.0 10^{-1}	2.3 10^{-7}	7.3 10^{-8}	6.0 10^{-8}	2.8 10^{-8}
^{103}Ru	5.0 10^{-2}	7.1 10^{-9}	4.6 10^{-9}	1.5 10^{-9}	7.3 10^{-10}
^{106}Ru	5.0 10^{-2}	8.4 10^{-8}	4.9 10^{-8}	1.5 10^{-8}	7.0 10^{-9}
^{125}I	1.0	5.2 10^{-8}	5.7 10^{-8}	3.1 10^{-8}	1.5 10^{-8}
^{129}I	1.0	1.8 10^{-7}	2.2 10^{-7}	1.9 10^{-7}	1.1 10^{-7}
^{131}I	1.0	1.8 10^{-7}	1.8 10^{-7}	5.2 10^{-8}	2.2 10^{-8}
^{132}I	1.0	3.0 10^{-9}	2.4 10^{-9}	6.2 10^{-10}	2.9 10^{-10}
^{133}I	1.0	4.9 10^{-8}	4.4 10^{-8}	1.0 10^{-8}	4.3 10^{-9}
^{134}I	1.0	1.1 10^{-9}	7.5 10^{-10}	2.1 10^{-10}	1.1 10^{-10}
^{135}I	1.0	1.0 10^{-8}	8.9 10^{-9}	2.2 10^{-9}	9.3 10^{-10}
^{134}Cs	1.0	2.6 10^{-8}	1.6 10^{-8}	1.4 10^{-8}	1.9 10^{-8}
^{136}Cs	1.0	1.5 10^{-8}	9.5 10^{-9}	4.4 10^{-9}	3.0 10^{-9}
^{137}Cs	1.0	2.1 10^{-8}	1.2 10^{-8}	1.0 10^{-8}	1.3 10^{-8}
^{238}Pu	5.0 10^{-4}	4.0 10^{-6}	4.0 10^{-7}	2.4 10^{-7}	2.3 10^{-7}
^{239}Pu	5.0 10^{-4}	4.2 10^{-6}	4.2 10^{-7}	2.7 10^{-7}	2.5 10^{-7}
^{240}Pu	5.0 10^{-4}	4.2 10^{-6}	4.2 10^{-7}	2.7 10^{-7}	2.5 10^{-7}
^{241}Pu	5.0 10^{-4}	5.6 10^{-8}	5.7 10^{-9}	5.1 10^{-9}	4.8 10^{-9}
^{242}Pu	5.0 10^{-4}	4.0 10^{-6}	4.0 10^{-7}	2.6 10^{-7}	2.4 10^{-7}
^{241}Am	5.0 10^{-4}	3.7 10^{-6}	3.7 10^{-7}	2.2 10^{-7}	2.0 10^{-7}
^{242}Am	5.0 10^{-4}	5.0 10^{-9}	2.2 10^{-9}	6.4 10^{-10}	3.0 10^{-10}
^{243}Am	5.0 10^{-4}	3.6 10^{-6}	3.7 10^{-7}	2.2 10^{-7}	2.0 10^{-7}
^{242}Cm	5.0 10^{-4}	5.9 10^{-7}	7.6 10^{-8}	2.4 10^{-8}	1.2 10^{-8}
^{243}Cm	5.0 10^{-4}	3.2 10^{-6}	3.3 10^{-7}	1.6 10^{-7}	1.5 10^{-7}
^{244}Cm	5.0 10^{-4}	2.9 10^{-6}	2.9 10^{-7}	1.4 10^{-7}	1.2 10^{-7}

Note

(a) The gut transfer factors (f_1) for each nuclide given are the same for all age groups with the following exceptions:

Isotopes of Sr	3 month old: 6.0 10^{-1}	1 y and 10 y old: 4.0 10^{-1}
Isotopes of Ru	3 month old: 1.0 10^{-1}	
Isotopes of Am, Pu, Cm	3 month old: 5.0 10^{-3}	

individual is taken to be 70 years. Although this is slightly shorter than the average lifetime of individuals in the UK, its use is sufficiently cautious because intakes and risks decrease in old age.

7 The values of the effective dose coefficients for intake by inhalation and ingestion are as described elsewhere[8]. They have been calculated for each age group considered using the most recent age-dependent dosimetric models. Tables 1 and 2 give the values for the effective dose coefficients used in this report for intake by ingestion and inhalation, respectively. The recommended[8] default absorption types for particulate aerosols were used to select the appropriate inhalation dose coefficients for the GDL calculations.

TABLE 2 *Dose coefficients for intake by inhalation*

			Commited effective dose per unit intake (Sv Bq^{-1})		
Nuclide	f_1	Type[a]	Infant (1 y)	Child (10 y)	Adult (20 y)
^{89}Sr	1.0 10^{-1}	M	2.4 10^{-8}	9.1 10^{-9}	6.1 10^{-9}
^{90}Sr	1.0 10^{-1}	M	1.1 10^{-7}	5.1 10^{-8}	3.6 10^{-8}
^{103}Ru	5.0 10^{-2}	M	8.4 10^{-9}	3.5 10^{-9}	2.4 10^{-9}
^{106}Ru	5.0 10^{-2}	M	1.1 10^{-7}	4.1 10^{-8}	2.8 10^{-8}
^{125}I	1.0	F	2.3 10^{-8}	1.1 10^{-8}	5.1 10^{-9}
^{129}I	1.0	F	8.6 10^{-8}	6.7 10^{-8}	3.6 10^{-8}
^{131}I	1.0	F	7.2 10^{-8}	1.9 10^{-8}	7.4 10^{-9}
^{132}I	1.0	F	9.6 10^{-10}	2.2 10^{-10}	9.4 10^{-11}
^{133}I	1.0	F	1.8 10^{-8}	3.8 10^{-9}	1.5 10^{-9}
^{134}I	1.0	F	3.7 10^{-10}	9.7 10^{-11}	4.5 10^{-11}
^{135}I	1.0	F	3.7 10^{-9}	7.9 10^{-10}	3.2 10^{-10}
^{134}Cs	1.0	F	7.3 10^{-9}	5.3 10^{-9}	6.6 10^{-9}
^{136}Cs	1.0	F	5.2 10^{-9}	2.0 10^{-9}	1.2 10^{-9}
^{137}Cs	1.0	F	5.4 10^{-9}	3.7 10^{-9}	4.6 10^{-9}
^{238}Pu	5.0 10^{-4}	M	7.4 10^{-5}	4.4 10^{-5}	4.6 10^{-5}
^{239}Pu	5.0 10^{-4}	M	7.7 10^{-5}	4.8 10^{-5}	5.0 10^{-5}
^{240}Pu	5.0 10^{-4}	M	7.7 10^{-5}	4.8 10^{-5}	5.0 10^{-5}
^{241}Pu	5.0 10^{-4}	M	9.7 10^{-7}	8.3 10^{-7}	9.0 10^{-7}
^{242}Pu	5.0 10^{-4}	M	7.3 10^{-5}	4.5 10^{-5}	4.8 10^{-5}
^{241}Am	5.0 10^{-4}	M	6.9 10^{-5}	4.0 10^{-5}	4.2 10^{-5}
^{242}Am	5.0 10^{-4}	M	5.9 10^{-8}	2.4 10^{-8}	1.7 10^{-8}
^{243}Am	5.0 10^{-4}	M	6.8 10^{-5}	4.0 10^{-5}	4.1 10^{-5}
^{242}Cm	5.0 10^{-4}	M	1.8 10^{-5}	7.3 10^{-6}	5.2 10^{-6}
^{243}Cm	5.0 10^{-4}	M	6.1 10^{-5}	3.1 10^{-5}	3.1 10^{-5}
^{244}Cm	5.0 10^{-4}	M	5.7 10^{-5}	2.7 10^{-5}	2.7 10^{-5}

Note

(a) Absorption types M (moderate) and F (fast) describing absorption from the respiratory tract.

8 As presented here, GDLs relate the concentration of a single radionuclide in a single environmental material to the dose limit for members of the public. In practice, people are likely to be exposed to a number of radionuclides in a variety of materials. In comparing environmental measurements with GDLs it is therefore necessary to take account of all possible sources of contamination to ensure that the appropriate dose limit is not exceeded, as discussed later.

REVISED GDLs

9 The general approach and formulae used to calculate the GDLs are given in Appendix A. The principles and methods of calculation are generally the same as used previously[1,2,6]. The data on occupancy and rates of intake of air, water, terrestrial and aquatic foods have been reviewed and the values used to calculate GDLs are presented in Appendix B. The intake data for foods are based on a number of recent national surveys[11] and update and replace those used previously. One major change from previous GDL calculations is that account has been taken of the reduction in external irradiation doses during the time spent indoors; the factors and occupancies adopted are given in Appendix B. In addition, the environmental models used in the calculation of GDLs are discussed in Appendix B. Appendix C discusses the limiting age groups and exposure pathways for relevant GDLs and also outlines differences between the new GDLs and those published previously.

10 Generalised derived limits for terrestrial foods and other terrestrial and aquatic materials are given in Tables 3, 4 and 5, respectively. In each case the GDL is based on the most restrictive age group, which is indicated. Not all GDLs are presented for each radionuclide as values are only given when the particular GDL is relevant to the radionuclide. For example, a GDL in air is inappropriate for isotopes of strontium, iodine and caesium because this GDL is based on inhalation only and for these elements other exposure pathways are of much greater relative importance. Similarly, GDLs in grass are only appropriate for those radioisotopes for which foods derived from grazing animals are important contributors to dose; this does not apply to isotopes of plutonium, americium and curium. In addition, GDLs are not given for some short-lived radioisotopes in materials where time is required for mixing which results in significant radioactive decay. Such GDLs are for well-mixed soil and sea washed land, together with marine and freshwater sediment. The situation of continuous input of short-lived radionuclides to such media is included in the GDCs for discharge to the environment which will be considered in future reports.

11 Many of the GDLs given in Tables 3, 4 and 5 are the same as, or similar to, the previous values[1,2]. Where there are differences between the old and new GDLs they are often due to a combination of factors as discussed in Appendix C. The most important reasons are differences in the dose coefficients for particular radionuclides and changes to the habit data, notably food intakes. In addition, external exposures are lower, as account is now taken of the reduction in external dose during the time spent indoors; previously, people were assumed to be outdoors 100% of the time.

Text continues on page 13

TABLE 3 *Generalised derived limits for terrestrial foods*

Foodstuff[a]	Generalised derived limit[b] ($Bq\,kg^{-1}$)													
	^{89}Sr	^{90}Sr	^{103}Ru	^{106}Ru	^{125}I	^{129}I	^{131}I	^{132}I	^{133}I	^{134}I	^{135}I	^{134}Cs	^{136}Cs	^{137}Cs
Domestic fruit	2 10^3 i	3 10^2 c	6 10^3 i	6 10^2 i	5 10^2 i	1 10^2 c	2 10^2 i	1 10^4 i	6 10^2 i	4 10^4 i	3 10^3 i	7 10^2	3 10^3 i	1 10^3
Potatoes and other root vegetables	1 10^3 i	2 10^2 c	5 10^3 i	5 10^2 i	3 10^2 c	6 10^1 c	1 10^2 i	9 10^3 i	5 10^2 i	3 10^4 i	2 10^3 i	4 10^2	2 10^3 i	6 10^2
Green and other domestic vegetables	4 10^3 i	4 10^2	1 10^4 i	1 10^3 i	8 10^2	1 10^2	4 10^2 i	3 10^4 i	2 10^3 i	9 10^4 i	7 10^3 i	7 10^2	4 10^3	1 10^3
Pig meat	7 10^3 c	7 10^2 c	3 10^4 c	3 10^3 c	1 10^3 c	2 10^2 c	8 10^2 c	6 10^4 c	4 10^3 c	2 10^5 c	2 10^4 c	1 10^3	8 10^3	2 10^3
Cattle meat	6 10^3 i	6 10^2 c	2 10^4 i	2 10^3 i	1 10^3 c	2 10^2 c	6 10^2 i	4 10^4 i	2 10^3 i	1 10^5 i	1 10^4 i	1 10^3	7 10^3	2 10^3
Sheep meat	2 10^4	1 10^3	5 10^4	6 10^3	3 10^3	4 10^2	2 10^3	1 10^5	8 10^3 i	4 10^5	4 10^4 i	2 10^3	1 10^4	3 10^3
Offal	1 10^4 i	2 10^3 c	4 10^4 i	4 10^3 i	3 10^3 i	5 10^2	1 10^3 i	8 10^4 i	4 10^3 i	2 10^5 i	2 10^4 i	3 10^3	2 10^4	4 10^3
Poultry	1 10^4 i	1 10^3 c	4 10^4 i	4 10^3 i	2 10^3 c	3 10^2	1 10^3 i	8 10^4 i	4 10^3 i	2 10^5 i	2 10^4 i	2 10^3	1 10^4	3 10^3
Milk[c] ($Bq\,l^{-1}$)	8 10^1	1 10^1	4 10^2	3 10^1	5 10^1 i	1 10^1 i	2 10^1	1 10^3	6 10^1	3 10^3	3 10^2	1 10^2	2 10^2	1 10^2
Milk products	1 10^3 i	3 10^2 i	5 10^3 i	5 10^2 i	4 10^2 i	1 10^2 i	1 10^2 i	9 10^3 i	5 10^2 i	3 10^4 i	2 10^3 i	9 10^2	2 10^3 i	1 10^3
Eggs	4 10^3 i	8 10^2 c	1 10^4 i	1 10^3 i	1 10^3 i	3 10^2 c	4 10^2 i	3 10^4 i	2 10^3 i	9 10^4 i	7 10^3 i	2 10^3	7 10^3 i	3 10^3
Cereals	2 10^3 i	2 10^2 c	7 10^3 i	7 10^2 i	4 10^2 c	7 10^1 c	2 10^2 i	1 10^4 i	8 10^2 i	4 10^4 i	4 10^3 i	5 10^2	3 10^3 c	8 10^2

TABLE 3 (*continued*)

Foodstuff[a]	Generalised derived limit[b] ($Bq\,kg^{-1}$)										
	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am	^{242}Am	^{243}Am	^{242}Cm	^{243}Cm	^{244}Cm
Domestic fruit	$6\ 10^{1}$	$5\ 10^{1}$	$5\ 10^{1}$	$3\ 10^{3}$	$6\ 10^{1}$	$7\ 10^{1}$	$1\ 10^{4}$ i	$7\ 10^{1}$	$4\ 10^{2}$ i	$9\ 10^{1}$ i	$1\ 10^{2}$ i
Potatoes and other root vegetables	$3\ 10^{1}$	$3\ 10^{1}$	$3\ 10^{1}$	$2\ 10^{3}$	$3\ 10^{1}$	$4\ 10^{1}$	$1\ 10^{4}$ i	$4\ 10^{1}$	$3\ 10^{2}$ i	$5\ 10^{1}$	$6\ 10^{1}$
Green and other domestic vegetables	$5\ 10^{1}$	$5\ 10^{1}$	$5\ 10^{1}$	$3\ 10^{3}$	$5\ 10^{1}$	$6\ 10^{1}$	$3\ 10^{4}$ i	$6\ 10^{1}$	$9\ 10^{2}$ i	$8\ 10^{1}$	$1\ 10^{2}$
Pig meat	$1\ 10^{2}$	$1\ 10^{2}$	$1\ 10^{2}$	$5\ 10^{3}$	$1\ 10^{2}$	$1\ 10^{2}$	$6\ 10^{4}$ c	$1\ 10^{2}$	$2\ 10^{3}$ c	$2\ 10^{2}$	$2\ 10^{2}$
Cattle meat	$1\ 10^{2}$	$9\ 10^{1}$	$9\ 10^{1}$	$5\ 10^{3}$	$9\ 10^{1}$	$1\ 10^{2}$	$5\ 10^{4}$ i	$1\ 10^{2}$	$1\ 10^{3}$ i	$1\ 10^{2}$	$2\ 10^{2}$
Sheep meat	$2\ 10^{2}$	$2\ 10^{2}$	$2\ 10^{2}$	$8\ 10^{3}$	$2\ 10^{2}$	$2\ 10^{2}$	$1\ 10^{5}$	$2\ 10^{2}$	$3\ 10^{3}$	$3\ 10^{2}$	$3\ 10^{2}$
Offal	$2\ 10^{2}$	$2\ 10^{2}$	$2\ 10^{2}$	$1\ 10^{4}$	$2\ 10^{2}$	$3\ 10^{2}$	$8\ 10^{4}$ i	$3\ 10^{2}$	$2\ 10^{3}$ i	$3\ 10^{2}$	$4\ 10^{2}$
Poultry	$1\ 10^{2}$	$1\ 10^{2}$	$1\ 10^{2}$	$7\ 10^{3}$	$1\ 10^{2}$	$2\ 10^{2}$	$8\ 10^{4}$ i	$2\ 10^{2}$	$2\ 10^{3}$ i	$2\ 10^{2}$	$3\ 10^{2}$
Milk[c] ($Bq\,l^{-1}$)	$7\ 10^{-1}$	$7\ 10^{-1}$	$7\ 10^{-1}$	$5\ 10^{1}$	$7\ 10^{-1}$	$8\ 10^{-1}$	$6\ 10^{2}$	$8\ 10^{-1}$	$5\ 10^{0}$	$9\ 10^{-1}$	$1\ 10^{0}$
Milk products	$6\ 10^{1}$ i	$5\ 10^{1}$ i	$5\ 10^{1}$ i	$3\ 10^{3}$	$6\ 10^{1}$ i	$6\ 10^{1}$ i	$1\ 10^{4}$ i	$6\ 10^{1}$ i	$3\ 10^{2}$ i	$7\ 10^{1}$ i	$8\ 10^{1}$ i
Eggs	$2\ 10^{2}$ i	$2\ 10^{2}$ i	$2\ 10^{2}$ i	$8\ 10^{3}$	$2\ 10^{2}$ i	$2\ 10^{2}$ i	$3\ 10^{4}$ i	$2\ 10^{2}$ i	$9\ 10^{2}$ i	$2\ 10^{2}$ i	$2\ 10^{2}$ i
Cereals	$4\ 10^{1}$	$4\ 10^{1}$	$4\ 10^{1}$	$2\ 10^{3}$	$4\ 10^{1}$	$5\ 10^{1}$	$2\ 10^{4}$ i	$5\ 10^{1}$	$4\ 10^{2}$ i	$7\ 10^{1}$	$8\ 10^{1}$

Notes

(a) The GDLs for food products are expressed as fresh mass.

(b) The GDLs apply to uniform conditions over a year and are based on the limiting age group, which is for adults for all foods, except milk, or as indicated by:

i infants aged 1 year   c children aged 10 years

(c) For milk the limiting age group is for infants in the first year of life (age 3 months), except where indicated.

TABLE 4 *Generalised derived limits for the terrestrial environment*

Material	Generalised derived limit[a] (Bq kg^{-1})													
	^{89}Sr	^{90}Sr	^{103}Ru	^{106}Ru	^{125}I	^{129}I	^{131}I	^{132}I	^{133}I	^{134}I	^{135}I	^{134}Cs	^{136}Cs	^{137}Cs
Air[b] (Bq m^{-3})	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Well-mixed soil[c,d]	—	$4\ 10^{2}$ c	—	$7\ 10^{3}$	—	$4\ 10^{2}$ c	—	—	—	—	—	$6\ 10^{2}$	—	$1\ 10^{3}$
Grass[d]	$9\ 10^{3}$ i	$2\ 10^{3}$ f	—	—	$2\ 10^{3}$ i	$6\ 10^{2}$ i	$7\ 10^{2}$ i	$5\ 10^{4}$ i	$3\ 10^{3}$ i	$2\ 10^{5}$ i	$1\ 10^{4}$ i	$2\ 10^{3}$	$8\ 10^{3}$ i	$3\ 10^{3}$
Sewage sludge[c,e]	$7\ 10^{4}$ i	$6\ 10^{2}$ i	$7\ 10^{4}$	$3\ 10^{4}$	$2\ 10^{4}$ i	$4\ 10^{2}$ i	—	—	—	—	—	$2\ 10^{3}$	—	$1\ 10^{3}$
Sea washed pasture[c,d]	—	$2\ 10^{3}$ f	—	$2\ 10^{4}$	—	$6\ 10^{2}$ i	—	—	—	—	—	$1\ 10^{3}$	—	$2\ 10^{3}$

Material	Generalised derived limit[a] (Bq kg^{-1})										
	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am	^{242}Am	^{243}Am	^{242}Cm	^{243}Cm	^{244}Cm
Air[b] (Bq m^{-3})	$3\ 10^{-3}$	$3\ 10^{-3}$	$3\ 10^{-3}$	$2\ 10^{-1}$	$3\ 10^{-3}$	$3\ 10^{-3}$	$8\ 10^{0}$ c	$3\ 10^{-3}$	$2\ 10^{-2}$ c	$4\ 10^{-3}$	$5\ 10^{-3}$
Well-mixed soil[c,d]	$5\ 10^{3}$	$5\ 10^{3}$	$5\ 10^{3}$	$2\ 10^{5}$	$5\ 10^{3}$	$5\ 10^{3}$	—	$3\ 10^{3}$	—	$5\ 10^{3}$	$8\ 10^{3}$
Grass[d]	—	—	—	—	—	—	—	—	—	—	—
Sewage sludge[c,e]	$4\ 10^{3}$	$3\ 10^{3}$	$3\ 10^{3}$	$1\ 10^{5}$	$3\ 10^{3}$	$4\ 10^{3}$	—	$2\ 10^{3}$	$4\ 10^{5}$ i	$4\ 10^{3}$	$8\ 10^{3}$
Sea washed pasture[c,d]	$2\ 10^{4}$	$2\ 10^{4}$	$2\ 10^{4}$	$6\ 10^{5}$	$2\ 10^{4}$	$2\ 10^{4}$	—	$1\ 10^{4}$	—	$1\ 10^{4}$	$3\ 10^{4}$

Notes

(a) The GDLs apply to uniform conditions over a year and are based on the limiting age group, which is for adults except where indicated by:

f infants in the first year of life on an all-milk diet i infants aged 1 year c children aged 10 years

(b) The GDLs for air are based on the inhalation pathway only.
(c) The GDLs for ^{241}Pu are calculated on the assumption of ingrowth of ^{241}Am.
(d) The GDLs are expressed as dry mass.
(e) The GDLs for sewage sludge considered two possibilities: exposure at the sewage treatment plant and the effects of application of sewage sludge to agricultural land. With the exception of isotopes of Ru, sewage sludge applied to land is the critical pathway. The GDLs for sewage sludge are expressed as wet mass.

TABLE 5 *Generalised derived limits for the aquatic environment*

Material	Generalised derived limit[a] ($Bq\ kg^{-1}$)													
	^{89}Sr	^{90}Sr	^{103}Ru	^{106}Ru	^{125}I	^{129}I	^{131}I	^{132}I	^{133}I	^{134}I	^{135}I	^{134}Cs	^{136}Cs	^{137}Cs
Marine fish[b]	$4\ 10^{3}$	$4\ 10^{2}$	$1\ 10^{4}$	$1\ 10^{3}$	$7\ 10^{2}$	$9\ 10^{1}$	$5\ 10^{2}$	$3\ 10^{4}$	$2\ 10^{3}$	$9\ 10^{4}$	$1\ 10^{4}$	$5\ 10^{2}$	$3\ 10^{3}$	$8\ 10^{2}$
Freshwater fish[b]	$2\ 10^{4}$	$2\ 10^{3}$	$7\ 10^{4}$	$7\ 10^{3}$	$3\ 10^{3}$	$5\ 10^{2}$	$2\ 10^{3}$	$2\ 10^{5}$	$1\ 10^{4}$	$5\ 10^{5}$	$5\ 10^{4}$	$3\ 10^{3}$	$2\ 10^{4}$	$4\ 10^{3}$
Crustaceans[b]	$2\ 10^{4}$	$2\ 10^{3}$	$7\ 10^{4}$	$7\ 10^{3}$	$3\ 10^{3}$	$5\ 10^{2}$	$2\ 10^{3}$	$2\ 10^{5}$	$1\ 10^{4}$	$5\ 10^{5}$	$5\ 10^{4}$	$3\ 10^{3}$	$2\ 10^{4}$	$4\ 10^{3}$
Molluscs[b]	$2\ 10^{4}$	$2\ 10^{3}$	$7\ 10^{4}$	$7\ 10^{3}$	$3\ 10^{3}$	$5\ 10^{2}$	$2\ 10^{3}$	$2\ 10^{5}$	$1\ 10^{4}$	$5\ 10^{5}$	$5\ 10^{4}$	$3\ 10^{3}$	$2\ 10^{4}$	$4\ 10^{3}$
Freshwater sediment[c,d]	—	$3\ 10^{6}$ c	—	$8\ 10^{4}$ c	—	$9\ 10^{5}$ c	—	—	—	—	—	$9\ 10^{3}$ c	—	$2\ 10^{4}$ c
Marine sediment[c,d]	—	$3\ 10^{6}$	—	$2\ 10^{4}$	—	$6\ 10^{5}$	—	—	—	—	—	$2\ 10^{3}$	—	$5\ 10^{3}$
Freshwater[c,e] ($Bq\ l^{-1}$)	$2\ 10^{2}$ i	$2\ 10^{1}$	—	$1\ 10^{1}$ c	$4\ 10^{1}$ c	$5\ 10^{0}$	—	—	—	—	—	$1\ 10^{0}$	—	$2\ 10^{0}$
Drinking water ($Bq\ l^{-1}$)	$2\ 10^{2}$ i	$5\ 10^{1}$ c	$8\ 10^{2}$ i	$8\ 10^{1}$ i	$7\ 10^{1}$ i	$2\ 10^{1}$ c	$2\ 10^{1}$ i	$2\ 10^{3}$ i	$9\ 10^{1}$ i	$5\ 10^{3}$ i	$4\ 10^{2}$ i	$9\ 10^{1}$	$4\ 10^{2}$ i	$1\ 10^{2}$

TABLE 5 (*continued*)

Material	Generalised derived limit[a] ($Bq\ kg^{-1}$)										
	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am	^{242}Am	^{243}Am	^{242}Cm	^{243}Cm	^{244}Cm
Marine fish[b]	$4\ 10^{1}$	$4\ 10^{1}$	$4\ 10^{1}$	$2\ 10^{3}$	$4\ 10^{1}$	$5\ 10^{1}$	$3\ 10^{4}$	$5\ 10^{1}$	$8\ 10^{2}$	$7\ 10^{1}$	$8\ 10^{1}$
Freshwater fish[b]	$2\ 10^{2}$	$2\ 10^{2}$	$2\ 10^{2}$	$1\ 10^{4}$	$2\ 10^{2}$	$3\ 10^{2}$	$2\ 10^{5}$	$3\ 10^{2}$	$4\ 10^{3}$	$3\ 10^{2}$	$4\ 10^{2}$
Crustaceans[b]	$2\ 10^{2}$	$2\ 10^{2}$	$2\ 10^{2}$	$1\ 10^{4}$	$2\ 10^{2}$	$3\ 10^{2}$	$2\ 10^{5}$	$3\ 10^{2}$	$4\ 10^{3}$	$3\ 10^{2}$	$4\ 10^{2}$
Molluscs[b]	$2\ 10^{2}$	$2\ 10^{2}$	$2\ 10^{2}$	$1\ 10^{4}$	$2\ 10^{2}$	$3\ 10^{2}$	$2\ 10^{5}$	$3\ 10^{2}$	$4\ 10^{3}$	$3\ 10^{2}$	$4\ 10^{2}$
Freshwater sediment[c,d]	$4\ 10^{5}$ c	$3\ 10^{5}$ c	$3\ 10^{5}$ c	$1\ 10^{7}$ c	$4\ 10^{5}$ c	$3\ 10^{5}$ c	—	$7\ 10^{4}$ c	—	$1\ 10^{5}$ c	$6\ 10^{5}$ c
Marine sediment[c,d]	$1\ 10^{5}$	$9\ 10^{4}$	$9\ 10^{4}$	$3\ 10^{6}$	$9\ 10^{4}$	$9\ 10^{4}$	—	$2\ 10^{4}$	—	$3\ 10^{4}$	$2\ 10^{5}$
Freshwater[c,e] ($Bq\ l^{-1}$)	$1\ 10^{1}$	$1\ 10^{1}$	$1\ 10^{1}$	$4\ 10^{2}$	$1\ 10^{1}$	$1\ 10^{1}$	—	$4\ 10^{0}$	$2\ 10^{2}$ c	$5\ 10^{0}$	$6\ 10^{0}$ c
Drinking water ($Bq\ l^{-1}$)	$7\ 10^{0}$	$7\ 10^{0}$	$7\ 10^{0}$	$3\ 10^{2}$	$7\ 10^{0}$	$8\ 10^{0}$	$2\ 10^{3}$ i	$8\ 10^{0}$	$5\ 10^{1}$ i	$1\ 10^{1}$	$1\ 10^{1}$ i

Notes

(a) The GDLs apply to uniform conditions over a year and are based on the limiting age group, which is for adults, except where indicated by:

i infants aged 1 year   c children aged 10 years

(b) The GDLs for aquatic foodstuffs are for the edible fraction and are expressed as fresh mass.
(c) The GDLs for ^{241}Pu are calculated on the assumption of ingrowth of ^{241}Am.
(d) The GDLs for sediment are expressed as dry mass.
(e) The GDLs for freshwater include activity in the dissolved and suspended fractions.

INVESTIGATION LEVELS AND SITE-SPECIFIC ASSESSMENTS

12 Generalised derived limits are intended for screening purposes and have been calculated in such a way that the resultant doses are expected to be overestimated in most circumstances. However, it is possible that some underestimation may occur under particular conditions, for example, where additional pathways are possible. It has, therefore, been recommended that an implied dose of 0.1 $mSv\,y^{-1}$ is a reasonable level at which to trigger further investigation[5]. This corresponds to 10% of the GDL for environmental materials and if this is exceeded the situation should be examined more closely, taking account of site-specific factors, the source of the activity, and the length of time the situation is likely to persist. A single measurement in excess of 10% of the GDL does not, of course, necessarily imply that the effective dose of 0.1 $mSv\,y^{-1}$ will be exceeded. Factors to be considered in site-specific calculations are discussed in a companion paper[10], where advice is also given on the interpretation of environmental measurements for comparison with GDLs and how the GDLs should be applied in particular situations.

13 In practice, people will be exposed to more than one radionuclide and from more than one environmental medium. Account must be taken of exposures from all relevant exposure pathways and radionuclides that contribute significantly to the total effective dose for comparison with the dose limit. When interpreting the results of environmental measurements, therefore, it is necessary to give due consideration to all relevant modes of exposure. This can be done by summing proportions of the relevant GDLs or, if necessary, the doses from each route and radionuclide can be calculated and the sum compared with the dose limit. For example, in a particular area both green vegetables and root crops could be grown and found to contain ^{134}Cs, ^{137}Cs, ^{90}Sr and ^{129}I. The measured concentrations can be expressed as a percentage of the relevant GDL and the eight resulting percentages summed. If this sum exceeds 10% then further investigation is required.

CONCLUSIONS

14 Revised GDLs for the most significant radioisotopes of strontium, ruthenium, iodine, caesium, plutonium, americium and curium are presented in this report. They are based on an annual effective dose limit for members of the public of 1 mSv and take account of the 1990 recommendations of ICRP, including the definition of effective dose[3]. In calculating the GDLs revised dosimetric models have been used and the opportunity has been taken to review, and revise if appropriate, the data and methods used. Values are specified for a range of materials from the terrestrial and aquatic environments. In each case the GDL presented is the most restrictive of those calculated for the age groups considered.

15 If environmental contamination exceeds about 10% of the GDL the doses to the most exposed group should be examined more closely, taking into account site-specific factors and the likely duration of the situation.

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16 The calculation of GDLs was carried out under formal quality assurance procedures. Mr N Green and Dr K R Smith acted as QA managers for the work. Dr B T Wilkins and Mr C Fayers also made a valuable contribution to the project.

REFERENCES

1 NRPB. Revised generalised derived limits for radioisotopes of strontium, iodine, caesium, plutonium, americium and curium. Chilton, NRPB-GS8 (1987).

2 NRPB. Generalised derived limits for radioisotopes of ruthenium. Chilton, NRPB-GS10 (1989).

3 ICRP. 1990 recommendations of the International Commission on Radiological Protection. ICRP Publication 60. *Ann. ICRP*, **21**, Nos 1–3 (1991).

4 NRPB. Statement by the National Radiological Protection Board: 1990 recommendations of the International Commission on Radiological Protection. *Doc. NRPB*, **4**, No. 1, 1–5 (1993).

5 NRPB. Public exposure: guidance on the 1990 recommendations of ICRP. *Doc. NRPB*, **4**, No. 2, 27–41 (1993).

6 NRPB. Generalised derived limits for radioisotopes of strontium, ruthenium, iodine, caesium, plutonium, americium and curium. *Doc. NRPB*, **7**, No. 1, 1–34 (1996).

7 IAEA. International basic safety standards for protection against ionizing radiation and for the safety of radiation sources. Vienna, IAEA, Safety Series No. 115 (1996).

8 ICRP. Age-dependent doses to members of the public from intake of radionuclides: Part 5. Compilation of ingestion and inhalation dose coefficients. ICRP Publication 72. *Ann. ICRP*, **26**, No. 1 (1996).

9 White Paper: Review of radioactive waste management policy. London, HMSO, Cm 2919 (1995).

10 NRPB. Application of generalised derived limits. *Doc. NRPB*, **9**, No. 1, 35–60 (1998).

11 Byrom, J, Robinson, C, Simmonds, J R, Walters, B, and Taylor, R R. Food consumption rates for use in generalised radiological dose assessments. *J. Radiol. Prot.*, **15**, No. 4, 335–41 (1995).

Appendix A

PRINCIPLES AND METHODS OF CALCULATING GDLs FOR ENVIRONMENTAL MATERIALS

Introduction

Generalised derived limits (GDLs) have been calculated for twelve materials which are important for, and relevant to, monitoring and control in the aquatic and terrestrial environments. The twelve GDLs can be divided into two groups, GDLs for materials which give rise to doses over a single exposure pathway and GDLs for materials which give rise to doses over multiple exposure pathways. Five environmental materials are considered to give rise to doses over a single exposure pathway: air, terrestrial and marine foods, drinking water and freshwater fish. Seven environmental materials are considered to give rise to doses over multiple exposure pathways: well-mixed soil, sea washed pasture, grass, freshwater, marine sediments, freshwater sediments and sewage sludge. The GDLs are presented for a total of twenty-five radionuclides. However, it is inappropriate to consider all the radionuclides in all the materials for various reasons, as discussed in the main report.

Some of the radionuclides considered are likely to have radioactive decay products (progeny) and these may need to be taken into account when determining GDLs. Progeny ingrowth only needs to be considered explicitly if sufficient time is likely to elapse for ingrowth to occur. Some radionuclides, such as ^{106}Ru, ^{137}Cs and ^{243}Am, have very-short-lived progeny and can be assumed to be in secular equilibrium for determining all GDLs. For the materials which give rise to doses over a single exposure pathway, the ingestion or inhalation can occur without a significant delay and so other progeny ingrowth does not need to be considered explicitly. However, for materials which give rise to doses over multiple exposure pathways, such as soil and sediments, exposure may continue to occur sometime into the future; in these cases ingrowth of longer lived progeny may need to be considered explicitly.

GDLs for materials which give rise to doses over a single exposure pathway

This group comprises GDLs for air, terrestrial foods, marine foods, drinking water and freshwater fish. The GDLs for three age groups, infants (1 year old), children (10 years old) and adults (assumed to be 20 years old), were calculated and the most restrictive of these are presented in Tables 3, 4 and 5 of the main text. An additional age group is considered in calculating GDLs for milk, unweaned infants in the first year of life (3 months old). The GDLs for single exposure pathways, ingestion or inhalation, are calculated using equation A1.

$$\mathrm{GDL_m} = \frac{D}{H_e\, I_m} \qquad \text{(A1)}$$

where $\mathrm{GDL_m}$ = GDL for a particular material (m), and age group exposed (Bq kg^{-1}, Bq l^{-1} or Bq m^{-3}),

D = effective dose limit of 10^{-3} Sv y^{-1},

H_e = dose coefficient for inhalation or ingestion (Sv Bq^{-1}),

I_m = annual intake of the material (m), by each age group (kg y^{-1}, l y^{-1} or m^3 y^{-1}).

GDLs for materials which give rise to doses over multiple exposure pathways

The GDLs which fall in to this group are grass, well-mixed soil, marine and freshwater sediments, sea washed pastures, freshwater and sewage sludge. Ingrowth of ^{241}Am progeny from ^{241}Pu has been taken into account in the derivation of these GDLs. Although the maximum possible activity concentration of ingrown ^{241}Am is 30 times lower than that of the parent ^{241}Pu, the ingestion and inhalation dose coefficients of ^{241}Am are a factor of 50 and 70 times higher, respectively, than those of ^{241}Pu. Therefore ingrowth of ^{241}Am will lead to higher doses than ^{241}Pu and a more restrictive GDL. The GDL for ^{241}Pu was therefore calculated as the GDL for ^{241}Am multiplied by 30.

Pathways considered in the calculation of multiple exposure GDLs are summarised in Table A1. The GDLs for three age groups, infants (1 year old), children (10 years old)

TABLE A1 *Pathways considered for multiple exposure GDLs*

GDL	Exposure pathways
Well-mixed soil	External exposure from well-mixed soil Inadvertent ingestion of well-mixed soil Inhalation of resuspended well-mixed soil Ingestion of plant products from well-mixed soil Ingestion of animal products from well-mixed soil
Grass	Ingestion of animal products
Marine and freshwater sediments	External exposure from sediment Inadvertent ingestion of sediment Inhalation of resuspended sediment
Freshwater	*Aquatic exposure pathways* Ingestion of river water Ingestion of freshwater fish External exposure from shoreline sediment Inhalation of resuspended shoreline sediment
	Exposure pathways from soil irrigation External exposure from irrigated soil Inadvertent ingestion of irrigated soil Inhalation of resuspended irrigated soil Ingestion of plant products from irrigated soil
Sewage sludge	*Exposure at sewage works* External exposure from sludge tanks Inhalation of resuspended sewage sludge Inadvertent ingestion of sewage sludge
	Exposure pathways associated with conditioning of soil with sewage sludge External exposure from conditioned soil Inadvertent ingestion of conditioned soil Inhalation of resuspended conditioned soil Ingestion of cereal products from conditioned soil Ingestion of animal products from conditioned soil
Sea washed pasture	External exposure from sea washed pasture Inadvertent ingestion of soil Inhalation of resuspended soil Ingestion of animal products from sea washed pasture

and adults (20 years old), were calculated and the most restrictive of these are presented in Tables 4 and 5 of the main text. For each environmental material, the GDL was calculated by summing the contributions from all the significant exposure pathways and is given by equation A2.

$$\frac{1}{\mathrm{GDL_m}} = \sum_{i=1}^{n} \frac{1}{\mathrm{GDL}_{\mathrm{m}i}} \tag{A2}$$

where $\mathrm{GDL_m}$ = GDL for the material (m), and exposed age group, summed over all exposure pathways (i) (Bq $\mathrm{kg^{-1}}$ or Bq $\mathrm{l^{-1}}$),

$\mathrm{GDL}_{\mathrm{m}i}$ = GDL for the material (m), age group and particular exposure pathway (i) (Bq $\mathrm{kg^{-1}}$ or Bq $\mathrm{l^{-1}}$),

n = number of exposure pathways considered.

Four major exposure pathways were considered: external gamma irradiation from contaminated materials, internal exposure from inhalation of resuspended material, internal exposure from inadvertent ingestion of the material, and internal irradiation from ingestion of foods or drinking water. The GDLs for sewage sludge and freshwater include pathways arising from conditioning and irrigation of land, respectively. These applications were modelled as a surface deposit using dynamic foodchain and soil models, as outlined in Appendix B. The methods for estimating GDLs for the main exposure pathways are outlined below.

External gamma exposure

The external dose is dependent on the energy and frequency of emissions, the properties of the materials, shielding and occupancy. The external dose model and effective external dose rates 1 m above various materials, together with occupancies, shielding and physical properties of the materials, are described in Appendix B. The external gamma components of the multiple pathway GDLs are given by equations A3 and A4.

$$\mathrm{GDL_{ex}} = \frac{D}{E} \tag{A3}$$

where $\mathrm{GDL_{ex}}$ = GDL for external gamma exposure for each age group (Bq $\mathrm{kg^{-1}}$),

D = effective dose limit of 10^{-3} Sv $\mathrm{y^{-1}}$,

E = effective dose from external irradiation from a unit activity concentration in the materials for each age group (Sv $\mathrm{y^{-1}}$ per Bq $\mathrm{kg^{-1}}$).

For soils, E is given by

$$E = G\,(F_{\mathrm{ind}}\,T_{\mathrm{ind}} + F_{\mathrm{out}}\,T_{\mathrm{out}}) \tag{A4}$$

where G = external effective dose 1 m above the materials, integrated over 1 year (Sv $\mathrm{y^{-1}}$ per Bq $\mathrm{kg^{-1}}$),

F_{ind} = fraction of a year spent indoors (dimensionless),

T_{ind} = indoor location factor (dimensionless),

F_{out} = fraction of a year spent outdoors (dimensionless),

T_{out} = outdoor location factor (dimensionless).

The term location factor is defined as the ratio of the dose received in the protected location (indoors or outdoors) to that received outdoors over undisturbed pasture for the period during which the person is in that location. The term location factor therefore describes the shielding offered at a particular location compared with a situation where no shielding is available.

For sea washed pasture, sewage sludge in tanks, freshwater and marine sediments, E is derived from the product of external effective dose 1 m above the materials, integrated over 1 year, and the fraction of the year spent above the materials.

Inhalation of resuspended materials

Two pathways have been defined for the inhalation of resuspended materials: ambient resuspension, which gives rise to low, but persistent levels of resuspended material, and mechanical resuspension by ploughing of agricultural land, which gives rise to enhanced, local levels of resuspended material. The mechanical resuspension component of inhalation exposure has been calculated for soils, on the assumption that only adults are exposed. The GDL for inhalation of resuspended materials is given by equation A5.

$$\mathrm{GDL_{inh}} = \frac{D}{(O_{\mathrm{mech}}\, L_{\mathrm{mech}} + O_{\mathrm{wind}}\, L_{\mathrm{wind}})\, H_{\mathrm{e(inh)}}\, B} \qquad \text{(A5)}$$

where $\mathrm{GDL_{inh}}$ = GDL for inhalation of resuspended materials (Bq $\mathrm{kg^{-1}}$),
D = effective dose limit of 10^{-3} Sv $\mathrm{y^{-1}}$,
$H_{\mathrm{e(inh)}}$ = dose coefficient for inhalation (Sv $\mathrm{Bq^{-1}}$),
B = breathing rate ($\mathrm{m^3\,h^{-1}}$),
O_{mech} = occupancy in air containing mechanically disturbed soil (h $\mathrm{y^{-1}}$) (adults only),
L_{mech} = concentration of soil in air due to mechanical disturbance (kg $\mathrm{m^{-3}}$),
O_{wind} = occupancy above materials for ambient resuspension (h $\mathrm{y^{-1}}$),
L_{wind} = concentration in air due to ambient resuspension (kg $\mathrm{m^{-3}}$).

Inadvertent ingestion

The third exposure pathway considered was inadvertent ingestion. This pathway was not considered in the GDLs calculated in NRPB-GS8[1] and NRPB-GS10[2]. Inadvertent ingestion as described by equation A6 was included in the calculation of GDLs for marine sediment, freshwater sediment, sea washed pasture, well-mixed soil and farmland treated with sewage sludge and freshwater irrigation.

$$\mathrm{GDL_a} = \frac{D}{I_{\mathrm{a}}\, H_{\mathrm{e(ing)}}\, O_{\mathrm{m}}} \qquad \text{(A6)}$$

where $\mathrm{GDL_a}$ = GDL for inadvertent ingestion of materials for each age group (Bq $\mathrm{kg^{-1}}$),
D = effective dose limit of 10^{-3} Sv $\mathrm{y^{-1}}$,
I_{a} = inadvertent ingestion rate for each age group (kg $\mathrm{h^{-1}}$),
$H_{\mathrm{e(ing)}}$ = dose coefficient for ingestion (Sv $\mathrm{Bq^{-1}}$),
O_{m} = number of hours per year exposed to the particular material for each age group (h $\mathrm{y^{-1}}$).

In some cases, eg well-mixed soil, 100% occupancy of the area is assumed and allowance only has to be made for the time spent indoors. In these cases, I_{a} is replaced by the annual inadvertent ingestion rate (kg $\mathrm{y^{-1}}$) taking into account indoor occupancy (see Appendix B) and O_{m} is no longer required.

Ingestion of food products

The fourth pathway considered was ingestion of foods produced on contaminated soils. The GDLs for grass, well-mixed soil, sea washed pasture and farmland treated with sewage sludge and irrigated with freshwater have contributions from food ingestion. The GDLs for actinides in grass were not considered because transfer to animal food products is not the most important exposure pathway.

The GDLs for each foodstuff produced on well-mixed soil and sea washed pasture are given by equation A7.

$$\mathrm{GDL_f} = \frac{D}{I_\mathrm{f}\, H_{\mathrm{e(ing)}}\, C_\mathrm{sf}} \tag{A7}$$

where $\mathrm{GDL_f}$ = GDL for the ingestion of foods (f), grown on contaminated soil for each age group (Bq kg^{-1} or Bq l^{-1}),

D = effective dose limit of 10^{-3} Sv y^{-1},

I_f = food ingestion rate (kg y^{-1} or l y^{-1}),

$H_{\mathrm{e(ing)}}$ = dose coefficient for ingestion (Sv Bq^{-1}),

C_sf = concentration factor relating the radionuclide activity concentration in soil to the radionuclide activity concentration in food (Bq kg^{-1} or Bq l^{-1} in food per Bq kg^{-1} in the soil).

The GDLs for foodstuffs derived from land treated with sewage sludge or irrigated with freshwater used activity concentrations predicted by dynamic foodchain models following deposition of the radionuclides. The modelling approach adopted is described in Appendix B.

The GDLs for each foodstuff produced on grass were derived from equation A8.

$$\mathrm{GDL_{f(grass)}} = \frac{\mathrm{GDL_f}}{I_\mathrm{a}\, C_{\mathrm{f(p-a)}}} \tag{A8}$$

where $\mathrm{GDL_{f(grass)}}$ = GDL for each foodstuff (f) produced on contaminated grass for each age group (Bq kg^{-1} or Bq l^{-1}),

$\mathrm{GDL_f}$ = GDL for each foodstuff (Bq kg^{-1} or Bq l^{-1}),

$C_{\mathrm{f(p-a)}}$ = fraction of the daily activity intake via grazing animal diet transferred to a unit mass of foodstuff (Bq kg^{-1} or Bq l^{-1} of foodstuff per Bq d^{-1} ingested),

I_a = amount eaten per animal per day (kg d^{-1}).

Aquatic exposure from freshwater

The GDL for freshwater (expressed as whole water, for both dissolved and suspended fractions) had a unique method of derivation. The GDL is divided into two main components: exposure associated with aquatic exposure pathways and exposure due to irrigation. Exposure due to irrigation was modelled as described in Appendix B. The GDLs from aquatic exposure pathways were derived from the GDLs calculated for each exposure pathway using equation A9:

$$\mathrm{GDL_{fwaq}} = \frac{\mathrm{GDL_{aqex}}}{C_\mathrm{f}} \tag{A9}$$

where GDL_{fwaq} = GDL for dissolved fraction of, or filtered, freshwater ($Bq\,l^{-1}$),
GDL_{aqex} = GDL for the aquatic exposure pathways: ingestion of freshwater fish, inhalation of and external exposure from shoreline sediment ($Bq\,kg^{-1}$),
C_f = concentration factor between environmental material or fish and filtered freshwater ($Bq\,kg^{-1}$ per $Bq\,l^{-1}$).

For the pathways associated with sediment (external exposure and inhalation), the concentration factor used was the element-dependent sediment water distribution coefficient (K_d). For the GDL associated with the consumption of fish, the element-dependent freshwater fish concentration factor was used. These values are given in Table B9. The GDL for freshwater expressed in terms of unfiltered water (ie dissolved and solid phase) was derived using equation A10:

$$GDL_{fwater} = GDL_{fwaq}(1 + K_d S) \qquad \text{(A10)}$$

where GDL_{fwater} = GDL for freshwater (dissolved and suspended fraction) ($Bq\,l^{-1}$),
K_d = sediment water distribution coefficient ($Bq\,kg^{-1}$ per $Bq\,l^{-1}$),
S = freshwater suspended sediment load ($5\;10^{-5}\,kg\,l^{-1}$).

REFERENCES

1 NRPB. Revised generalised derived limits for radioisotopes of strontium, iodine, caesium, plutonium, americium and curium. Chilton, NRPB-GS8 (1987).

2 NRPB. Revised generalised derived limits for radioisotopes of ruthenium. Chilton, NRPB-GS10 (1989).

Appendix B

ENVIRONMENTAL MODELS AND HABIT DATA

Habit data

Generalised habit data for radiological protection purposes have been reviewed and updated since publication of NRPB-GS8[1] and NRPB-GS10[2]. The revised habit data are discussed in detail elsewhere[3], but the main developments are outlined here for ease of reference. The habit data used to calculate generalised derived limits (GDLs) are those considered appropriate for critical groups, ie people in the population who are representative of those who receive the highest radiation exposures. The terrestrial food ingestion rates given in Table B1 have been revised to take account of recent national surveys of diet and have been agreed by the Ministry of Agriculture, Fisheries and Food and the Board[4]. The 97.5th percentile of the national distribution of intake has been used to represent the critical group habits. Generalised critical group intakes of marine foods, and occupancies of intertidal areas, beaches and river banks, are based on a review of site-specific surveys conducted by MAFF[5] and on behalf of Her Majesty's Inspectorate of Pollution[6], now part of the Environment Agency. These data are given in Tables B2 and B3 and are discussed further elsewhere[3]. A 2000 h y^{-1} occupancy for adults was assumed for the sewage works and represents a working year. An effective occupancy of 1000 h y^{-1} was assumed for plant operators close enough to sewage tanks to receive an external dose.

Inhalation rates have been revised to be consistent with the revision of the ICRP model of the respiratory tract[7]. No additional information on water intake is available since

TABLE B1 *Critical group food intake rates*

Food group	Critical group intakes (kg y^{-1}) Infant (1 y)	Child (10 y)	Adult (20 y)
Domestic fruit	35	50	75
Potatoes and root vegetables	45	95	130
Green and other domestic vegetables[a]	15	35	80
Pig meat	5.5	25	40
Cattle meat	10	30	45
Sheep meat	3.0	10	25
Offal	5.5	10	20
Poultry	5.5	15	30
Milk[b] (l y^{-1})	320	240	240
Milk products	45	45	60
Eggs	15	20	25
Cereals	30	75	100

Notes

(a) Intakes summed over green vegetables and other domestic vegetables including legumes.

(b) The GDL for milk, consumed by infants in the first year of life, assumed a milk intake of 350 l y^{-1}.

TABLE B2 *Critical group intake rates of aquatic foods*

	Critical group intakes (kg y^{-1})		
Food group	Infant (1 y)	Child (10 y)	Adult (20 y)
Freshwater fish	1	5	20
Marine fish	5	20	100
Crustaceans	1	5	20
Molluscs	1	5	20

TABLE B3 *Occupancies above marine and freshwater sediment and sea washed pasture*

	Occupancy (h y^{-1})		
Substrate	Infant (1 y)	Child (10 y)	Adult (20 y)
Marine sediment	30	300	2000
Freshwater sediment	30	500	500
Sea washed pasture	30	300	2000

previous GDL publications[1,2] and the drinking water intakes used are unchanged. Table B4 gives the inhalation and water intake rates used in the calculations.

Inadvertent ingestion rates of soil and sediment have been derived and are presented in Table B5. Annual critical ingestion rates for soil and sediments are given which take account of time spent outdoors during the course of the year. Hourly inadvertent ingestion rates are also given for use with an occupancy value for time spent on an area of soil or sediment. For example, the hourly ingestion rate (kg h^{-1}) was used in conjunction with occupancy (h y^{-1}) on intertidal sediment. The adult inadvertent ingestion rates were assumed to apply also to people working at a sewage treatment works.

The proportion of time spent indoors and outdoors is necessary for the calculation of external dose in order to account for the shielding effect of buildings. These proportions are given in Table B6, and are discussed in more detail elsewhere[3].

TABLE B4 *Critical group inhalation and water intake rates*

	Infant (1 y)	Child (10 y)	Adult (20 y)
Inhalation rate (m^3 y^{-1})	1900	5500	7300
Drinking water (l y^{-1})	260	350	600

TABLE B5 *Critical group inadvertent ingestion rates*

	Infant (1 y)	Child (10 y)	Adult (20 y)
Inadvertent ingestion rate whilst occupying a substrate (kg h^{-1})	$5\ 10^{-5}$	$1\ 10^{-5}$	$5\ 10^{-6}$
Annual inadvertent ingestion rate accounting for indoor occupancy (kg y^{-1})	$4.4\ 10^{-2}$	$1.8\ 10^{-2}$	$8.3\ 10^{-3}$

TABLE B6 *Occupancies associated with external exposure from contaminated farmland*

	Occupancy (%)		
	Infant (1 y)	Child (10 y)	Adult (20 y)
Indoor	90	80	50
Outdoor	10	20	50

For the pathways associated with inhalation of resuspended material, the air concentrations of resuspended material are assumed to be the same indoors as those outdoors and are therefore not affected by indoor occupancy. Breathing rates were combined with occupancies above various media. Adults were assumed to receive an additional inhalation dose due to mechanical resuspension of soil. An exposure time of 300 h y^{-1} for ploughing was assumed for this purpose.

Environmental models

Equilibrium transfer factors for terrestrial foods

Simple equilibrium foodchain transfer models were used to determine the concentration of radionuclides in foods for the GDLs for well-mixed soil, sea washed pasture and grass. Concentration factors relating the radionuclide activity concentration in soil to radionuclide activity concentration in plant and animal foodstuffs were calculated using equations B1 and B2, respectively:

$$C_{sf} = \frac{A_p}{A_s} \qquad \text{(B1)}$$

$$C_{sf} = C_{f(p-a)}(C_{f(s-p)} I_p + I_s) \qquad \text{(B2)}$$

where C_{sf} = concentration factor relating the activity concentration in the food to the activity concentration in the soil (Bq kg^{-1} or Bq l^{-1} per Bq kg^{-1} dry mass soil),

A_p = activity concentration in the plant (Bq kg^{-1} fresh mass),

A_s = activity concentration in the soil (Bq kg^{-1} dry mass),

$C_{f(s-p)}$ = equilibrium concentration factor relating the activity concentration in food crops to the activity concentration in soil (Bq kg^{-1} fresh mass plant per Bq kg^{-1} dry mass soil),

$C_{f(p-a)}$ = equilibrium concentration factor for the transfer of activity to animal products arising from a daily intake of activity in the animal diet (Bq kg^{-1} or Bq l^{-1} per Bq d^{-1}),

I_p = animal food intake (kg d^{-1} fresh mass),

I_s = intake of soil by cattle or sheep (kg d^{-1} dry mass).

The element-dependent equilibrium concentration factors between soil and plant, and between animal diet and animal products, were taken from NRPB-R273[8] and are given in Tables B7 and B8, respectively. The intakes of food and soil by grazing animals were 1.5 kg and 0.3 kg d^{-1}, respectively, for sheep and 13 kg of food and 0.52 kg d^{-1} of soil for cattle[8].

Aquatic environment distribution and transfer coefficients

Element-dependent freshwater to sediment distribution coefficients and fish concentration factors used in the derivation of the freshwater GDL are given in Table B9.

External exposure model

External exposure pathways were included in the GDLs for well-mixed soil, sea washed pasture, marine and freshwater sediment, freshwater and sewage sludge. Doses from external irradiation were estimated using an external dose model[9], which predicts the effective dose rate 1 m above an infinite area of contaminated material. External irradiation was modelled for a unit activity concentration of each radionuclide well mixed to a depth of 0.3 m in soil, sea washed pasture, and freshwater and marine sediment. External irradiation

TABLE B7
Element-dependent concentration factors for the uptake of activity from soil to plant

Element	Concentration factor, C_f (Bq kg^{-1} food per Bq kg^{-1} soil)				
	Food type				
	Domestic fruit	Potatoes and root vegetables	Green vegetables	Cereals	Pasture
Sr	$4\ 10^{-2}$	$1\ 10^{-1}$	$3\ 10^{-1}$	$2\ 10^{-1}$	$5\ 10^{-2}$
Ru	$2\ 10^{-3}$	$1\ 10^{-2}$	$1\ 10^{-2}$	$1\ 10^{-2}$	$1\ 10^{-2}$
I	$4\ 10^{-2}$	$2\ 10^{-2}$	$2\ 10^{-2}$	$2\ 10^{-2}$	$2\ 10^{-2}$
Cs	$2\ 10^{-2}$	$5\ 10^{-3}$	$7\ 10^{-3}$	$1\ 10^{-2}$	$3\ 10^{-2}$
Pu	$3\ 10^{-4}$	$5\ 10^{-5}$	$1\ 10^{-5}$	$2\ 10^{-5}$	$1\ 10^{-4}$
Am	$8\ 10^{-4}$	$8\ 10^{-5}$	$5\ 10^{-5}$	$5\ 10^{-5}$	$1\ 10^{-4}$
Cm	$8\ 10^{-4}$	$3\ 10^{-5}$	$5\ 10^{-5}$	$2\ 10^{-5}$	$1\ 10^{-3}$

TABLE B8
Element-dependent equilibrium transfer factors for the uptake of activity from animal intakes to animal products

Element	Equilibrium transfer factor, C_f (Bq kg^{-1} or Bq l^{-1} food per Bq d^{-1} of animal intake)					
	Animal product					
	Cattle meat	Sheep meat	Cattle offal	Sheep offal	Milk	Milk products
Sr	$3\ 10^{-4}$	$3\ 10^{-3}$	$3\ 10^{-4}$	$3\ 10^{-3}$	$2\ 10^{-3}$	$2.2\ 10^{-2}$
Ru	$1\ 10^{-3}$	$1\ 10^{-2}$	$1\ 10^{-3}$	$1\ 10^{-2}$	$1\ 10^{-6}$	$1.1\ 10^{-5}$
I	$2\ 10^{-3}$	$5\ 10^{-2}$	$2\ 10^{-3}$	$5\ 10^{-2}$	$5\ 10^{-3}$	$5.5\ 10^{-2}$
Cs	$3\ 10^{-2}$	$5\ 10^{-1}$	$3\ 10^{-2}$	$5\ 10^{-1}$	$5\ 10^{-3}$	$5.5\ 10^{-2}$
Pu	$1\ 10^{-4}$	$4\ 10^{-4}$	$2\ 10^{-2}$	$3\ 10^{-2}$	$1\ 10^{-6}$	$1.1\ 10^{-5}$
Am	$1\ 10^{-4}$	$4\ 10^{-4}$	$2\ 10^{-2}$	$3\ 10^{-2}$	$1\ 10^{-6}$	$1.1\ 10^{-5}$
Cm	$1\ 10^{-4}$	$4\ 10^{-4}$	$2\ 10^{-2}$	$3\ 10^{-2}$	$1\ 10^{-6}$	$1.1\ 10^{-5}$

TABLE B9
Element-dependent fish concentration factors and sediment water distribution coefficients for freshwater

Element	Fish concentration factor, C_f (Bq kg^{-1} per Bq l^{-1})	Distribution coefficient, K_d (Bq kg^{-1} per Bq l^{-1})
Sr	$6.0\ 10^{1}$	$2.0\ 10^{3}$
Ru	$1.0\ 10^{1}$	$7.0\ 10^{3}$
I	$2.0\ 10^{1}$	$3.0\ 10^{2}$
Cs	$2.0\ 10^{3}$	$2.0\ 10^{3}$
Pu	$3.5\ 10^{0}$	$1.0\ 10^{5}$
Am	$2.5\ 10^{1}$	$4.0\ 10^{5}$
Cm	$2.5\ 10^{1}$	$4.0\ 10^{5}$

was also calculated for sewage sludge tanks, containing uniformly contaminated sludge to a depth of 1 m. The physical properties assumed for each material are summarised in Table B10. The external doses per unit activity concentration in well-mixed materials integrated over 1 year are shown in Table B11. External irradiation of individuals will be influenced by the degree of shielding. For the well-mixed soil GDL, individuals were assumed to spend time inside buildings as indicated in Table B6. Location factors for the reduction in gamma doses to people indoors and outdoors were assumed to be 0.1 and 1.0, respectively[3].

Characteristic	Soil	Sediment	Sewage sludge
Depth (m)	0.3	0.3	1.0
Dry bulk density ($kg\,m^{-3}$)	1250	1500	50
Wet bulk density ($kg\,m^{-3}$)	1500	1700	1000

TABLE B10 *Depth and density assumed for the generic soil, sediment and sewage sludge*

Parent nuclide	Effective gamma dose rates ($Sv\,y^{-1}$ per $Bq\,kg^{-1}$) Well-mixed soil	Well-mixed sediments	Sewage sludge in tanks
^{89}Sr	—	—	$3.1\ 10^{-11}$
^{90}Sr	$1.5\ 10^{-14}$	$1.2\ 10^{-14}$	$5.7\ 10^{-14}$
^{103}Ru	—	—	$1.3\ 10^{-7}$
^{106}Ru	$2.0\ 10^{-7}$	$2.2\ 10^{-7}$	$2.7\ 10^{-7}$
^{125}I	—	—	$3.5\ 10^{-9}$
^{129}I	$2.5\ 10^{-9}$	$2.2\ 10^{-9}$	$1.2\ 10^{-8}$
^{134}Cs	$1.9\ 10^{-6}$	$2.0\ 10^{-6}$	$2.4\ 10^{-6}$
^{137}Cs	$7.8\ 10^{-7}$	$8.4\ 10^{-7}$	$1.0\ 10^{-6}$
^{238}Pu	$2.9\ 10^{-11}$	$2.5\ 10^{-11}$	$1.1\ 10^{-10}$
^{239}Pu	$5.5\ 10^{-11}$	$5.6\ 10^{-11}$	$1.3\ 10^{-10}$
^{240}Pu	$3.6\ 10^{-11}$	$3.3\ 10^{-11}$	$1.3\ 10^{-10}$
^{242}Pu	$8.0\ 10^{-10}$	$8.6\ 10^{-10}$	$1.2\ 10^{-9}$
^{241}Am	$9.6\ 10^{-9}$	$9.4\ 10^{-9}$	$3.8\ 10^{-8}$
^{243}Am	$1.9\ 10^{-7}$	$2.0\ 10^{-7}$	$4.4\ 10^{-7}$
^{242}Cm	—	—	$7.3\ 10^{-11}$
^{243}Cm	$1.3\ 10^{-7}$	$1.3\ 10^{-7}$	$2.5\ 10^{-7}$
^{244}Cm	$2.5\ 10^{-10}$	$2.7\ 10^{-10}$	$4.3\ 10^{-10}$

TABLE B11 *Integrated effective gamma dose rates per unit activity concentration above well-mixed soil, sediments and sewage sludge*

Resuspension model

Inhalation of resuspended materials is included as a pathway in GDLs for well-mixed soil, sea washed pasture, marine and freshwater sediment, sewage sludge and freshwater. Inhalation of resuspended materials used a dust loading approach throughout. Resuspension of materials was assumed to occur by two processes, wind driven resuspension and mechanical disturbance. Wind driven resuspension was assumed for soils and sediments. All age groups were assumed to be exposed continuously to an airborne dust concentration[10] of $10^{-7}\,kg\,m^{-3}$. Resuspension of sewage sludge as liquid droplets from stirring processes assumed an air concentration[11] of $10^{-7}\,kg\,m^{-3}$. Mechanical resuspension of soil was assumed to occur during ploughing, and was therefore included in the GDLs for well-mixed soil, conditioning of soil with sewage sludge and irrigation of land with freshwater. Adults only were assumed to be exposed for $300\,h\,y^{-1}$ at an airborne dust concentration[10] of $10^{-5}\,kg\,m^{-3}$.

Treatment of agricultural land

Conditioning with sewage sludge

Sewage sludge can be applied to agricultural land as a soil conditioner. This gives rise to possible routes of exposure to man, and therefore needs to be considered in the derivation of the GDL for sewage sludge. The sewage sludge GDL considered the conditioning of pasture and arable land used for cereals, and resulting exposure from treated soil and ingestion of animal products and crops. Conditioning of pasture was assumed to occur annually in early spring, approximately 1 month before grazing animals were allowed on to the pasture. It was further assumed that the grass grew after the application, and that there was no direct contamination of the grass by radionuclides in the sludge. For cereals, it was assumed that sewage sludge was applied to bare soil, and ploughed in before seeding. For both pasture and cereals it was assumed that the agricultural land was treated every year for 50 years with sewage sludge from the same source. The dynamic foodchain model FARMLAND[8] was used to predict the activity concentrations in cattle meat, offal, milk, sheep meat, sheep offal and cereals in the 50th year, per unit deposit (Table B12). The activity concentrations in the animal and plant products were scaled by the application rate of sewage sludge using equation B3.

$$A_{\rm f} = A_{\rm f(u)}\, R_{\rm s} \qquad \text{(B3)}$$

where $A_{\rm f}$ = food product activity concentration in the 50th year from conditioning of farmland with sewage sludge (Bq kg^{-1} per Bq kg^{-1} of sludge),

$A_{\rm f(u)}$ = food product activity concentration in the 50th year per unit deposition (Bq kg^{-1} per Bq m^{-2} y^{-1}) (Table B12),

$R_{\rm s}$ = soil conditioning rate with sewage sludge (kg m^{-2} y^{-1}).

The conditioning rate for sewage sludge[12] was assumed to be 8 kg m^{-2} and the sewage sludge activity concentration was 1 Bq kg^{-1}.

Soil activity concentrations from surface deposition were estimated by use of the soil part of the FARMLAND model[8]. The following assumptions were made. For exposure from inhalation of ambient resuspended soil and inadvertent ingestion of soil only the top 0.01 m

TABLE B12 *Activity concentrations in foods for a surface deposit predicted for the 50th year by the foodchain model (sewage sludge application to land)*

	50th year activity concentration in foods from a surface deposit of sewage sludge (Bq kg^{-1} or Bq l^{-1} per Bq m^{-2} y^{-1})					
Nuclide	Grain	Cow meat	Cow liver	Cow milk	Sheep meat	Sheep liver
^{89}Sr	9.0 10^{-5}	2.2 10^{-5}	2.2 10^{-5}	1.1 10^{-4}	2.4 10^{-5}	2.4 10^{-5}
^{90}Sr	1.1 10^{-2}	7.2 10^{-4}	7.2 10^{-4}	3.4 10^{-3}	4.7 10^{-4}	4.7 10^{-4}
^{106}Ru	3.0 10^{-5}	4.7 10^{-5}	4.7 10^{-5}	8.8 10^{-8}	1.0 10^{-4}	1.0 10^{-4}
^{125}I	1.0 10^{-5}	7.4 10^{-5}	7.4 10^{-5}	1.2 10^{-4}	2.4 10^{-4}	2.4 10^{-4}
^{129}I	1.9 10^{-3}	9.9 10^{-4}	9.9 10^{-4}	1.5 10^{-3}	8.3 10^{-3}	8.3 10^{-3}
^{134}Cs	6.2 10^{-5}	4.6 10^{-3}	4.6 10^{-3}	9.2 10^{-4}	1.0 10^{-2}	1.0 10^{-2}
^{137}Cs	5.7 10^{-4}	8.3 10^{-3}	8.3 10^{-3}	1.6 10^{-3}	2.3 10^{-2}	2.3 10^{-2}
^{238}Pu	2.3 10^{-6}	2.0 10^{-5}	2.4 10^{-3}	1.4 10^{-6}	3.5 10^{-5}	2.5 10^{-3}
^{239}Pu	2.7 10^{-6}	2.1 10^{-5}	2.6 10^{-3}	1.5 10^{-6}	3.7 10^{-5}	2.6 10^{-3}
^{240}Pu	2.7 10^{-6}	2.1 10^{-5}	2.5 10^{-3}	1.5 10^{-6}	3.7 10^{-5}	2.6 10^{-3}
^{242}Pu	2.7 10^{-6}	2.1 10^{-5}	2.6 10^{-3}	1.5 10^{-6}	3.7 10^{-5}	2.6 10^{-3}
^{241}Am	5.3 10^{-6}	2.6 10^{-5}	3.1 10^{-3}	1.9 10^{-6}	3.8 10^{-5}	2.7 10^{-3}
^{243}Am	5.5 10^{-6}	2.6 10^{-5}	3.2 10^{-3}	1.9 10^{-6}	3.8 10^{-5}	2.8 10^{-3}
^{242}Cm	3.7 10^{-8}	4.6 10^{-7}	5.5 10^{-5}	3.3 10^{-8}	2.2 10^{-6}	1.6 10^{-4}
^{243}Cm	1.6 10^{-6}	2.1 10^{-5}	2.5 10^{-3}	1.5 10^{-6}	3.4 10^{-5}	2.4 10^{-3}
^{244}Cm	1.3 10^{-6}	1.9 10^{-5}	2.3 10^{-3}	1.3 10^{-6}	3.2 10^{-5}	2.3 10^{-3}

of the soil profile was involved, while for inhalation of mechanically resuspended soil the top 0.3 m of the soil was subject to resuspension. Activity concentrations in the top 0.01 m of soil were obtained for surface deposition for 50 years on to an undisturbed soil profile. Activity concentrations in the top 0.3 m of the soil were obtained for surface deposition for 50 years on to well-mixed soil. External doses from conditioned soil were modelled for the exposed group occupying undisturbed soil contaminated by surface deposition of radionuclides in sewage sludge.

Activity concentrations in the soil and external doses per unit deposit are given in Table B13. The activity concentrations in the soil and external doses were scaled by the application rate of sewage sludge using equations B4 and B5.

$$S_a = S_{a(u)} R_s \quad \text{(B4)}$$

$$D_{ext} = D_{ext(u)} R_s \quad \text{(B5)}$$

where S_a = soil activity concentration in the 50th year from conditioning of farmland with sewage sludge (Bq kg^{-1} per Bq kg^{-1} of sludge),

$S_{a(u)}$ = soil activity concentration in the 50th year per unit deposition (Bq kg^{-1} per Bq m^{-2} y^{-1}),

D_{ext} = external dose in the 50th year from conditioning of farmland with sewage sludge (Sv y^{-1} per Bq kg^{-1} of sludge),

$D_{ext(u)}$ = external dose in the 50th year per unit deposition (Sv y^{-1} per Bq m^{-2} y^{-1}),

R_s = soil conditioning rate with sewage sludge (kg m^{-2} y^{-1}).

TABLE B13
Activity concentrations and external dose rates in the 50th year above soil per unit deposit

	50th year activity concentration (Bq kg^{-1} per Bq m^{-2} y^{-1})		Effective dose rate in 50th year (Sv y^{-1} per Bq m^{-2} y^{-1})	
Nuclide	In top 0.3 m of well-mixed soil	In top 0.01 m of undisturbed soil	Above well-mixed soil	Above undisturbed soil
^{89}Sr	5.3 10^{-4}	1.5 10^{-2}	6.6 10^{-14}	3.1 10^{-13}
^{90}Sr	6.8 10^{-2}	1.6 10^{-1}	1.0 10^{-15}	1.3 10^{-15}
^{106}Ru	3.8 10^{-3}	8.6 10^{-2}	1.1 10^{-9}	4.9 10^{-9}
^{125}I	6.3 10^{-4}	1.8 10^{-2}	2.1 10^{-12}	3.0 10^{-11}
^{129}I	1.1 10^{-1}	3.3 10^{-1}	2.8 10^{-10}	4.8 10^{-10}
^{134}Cs	7.8 10^{-3}	1.4 10^{-1}	1.7 10^{-8}	6.7 10^{-8}
^{137}Cs	6.9 10^{-2}	3.0 10^{-1}	5.5 10^{-8}	1.1 10^{-7}
^{238}Pu	9.4 10^{-2}	3.2 10^{-1}	2.8 10^{-12}	5.2 10^{-12}
^{239}Pu	1.1 10^{-1}	3.3 10^{-1}	6.1 10^{-12}	1.1 10^{-11}
^{240}Pu	1.1 10^{-1}	3.3 10^{-1}	4.1 10^{-12}	6.7 10^{-12}
^{242}Pu	1.1 10^{-1}	3.3 10^{-1}	9.0 10^{-11}	1.5 10^{-10}
^{241}Am	1.1 10^{-1}	3.3 10^{-1}	1.0 10^{-9}	2.0 10^{-9}
^{243}Am	1.1 10^{-1}	3.3 10^{-1}	2.2 10^{-8}	4.0 10^{-8}
^{242}Cm	1.7 10^{-3}	4.5 10^{-2}	7.5 10^{-14}	8.1 10^{-13}
^{243}Cm	6.7 10^{-2}	3.0 10^{-1}	8.6 10^{-9}	1.9 10^{-8}
^{244}Cm	5.3 10^{-2}	2.9 10^{-1}	1.4 10^{-11}	3.0 10^{-11}

Irrigation with freshwater

Freshwater can be applied to agricultural land for irrigation, and this route therefore needs to be considered in the derivation of the GDL for freshwater. The pathways considered were due to irrigation of vegetables and cereals only, and included exposure from the treated soil. It was assumed that irrigation occurred over the 120 day period of crop growth up to harvest, and that irrigation occurred every year for 50 years using freshwater from the same source. The dynamic foodchain model FARMLAND[8] was used to predict the activity concentrations in root vegetables, green vegetables and cereals in the 50th year per unit deposit on to the soil (Table B13). The activity concentrations in the animal and plant products per unit deposition were scaled by the application rate of freshwater using equation B3. Sewage sludge parameters were substituted by a freshwater unit activity concentration and an application rate[13], assumed to be 1 $Bq\,l^{-1}$ and 100 $kg\,m^{-2}\,y^{-1}$, respectively.

Soil activity concentrations from surface deposition were estimated by use of the soil part of the FARMLAND model[8]. In this case, the following assumptions were made. For exposure from inadvertent ingestion of soil and inhalation of both ambient and mechanically resuspended soil, the top 0.3 m of the soil was involved. Activity concentrations in the top 0.3 m of the soil were obtained for surface deposition for 50 years on to well-mixed soil. External doses from conditioned soil were modelled for the exposed group occupying well-mixed soil contaminated by surface deposition of radionuclides in freshwater.

Activity concentrations in the soil and external doses per unit deposit are given in Table B14. The activity concentrations in the soil and external doses per unit deposition

TABLE B14
Activity concentrations in foods for a surface deposit predicted for the 50th year by the foodchain model per unit deposit (for irrigation)

Nuclide	50th year activity concentration in foods from a surface deposit of irrigation water ($Bq\,kg^{-1}$ per $Bq\,m^{-2}\,y^{-1}$)		
	Green vegetables	Root vegetables	Cereals
^{89}Sr	$8.5\ 10^{-3}$	$5.4\ 10^{-5}$	$4.8\ 10^{-3}$
^{90}Sr	$2.7\ 10^{-2}$	$3.0\ 10^{-4}$	$1.8\ 10^{-2}$
^{106}Ru	$9.8\ 10^{-3}$	$2.0\ 10^{-5}$	$5.4\ 10^{-4}$
^{125}I	$9.9\ 10^{-3}$	$7.1\ 10^{-3}$	$3.0\ 10^{-2}$
^{129}I	$1.5\ 10^{-2}$	$1.2\ 10^{-2}$	$5.0\ 10^{-2}$
^{134}Cs	$1.3\ 10^{-2}$	$1.1\ 10^{-2}$	$4.7\ 10^{-2}$
^{137}Cs	$1.3\ 10^{-2}$	$1.2\ 10^{-2}$	$4.9\ 10^{-2}$
^{238}Pu	$1.0\ 10^{-2}$	$3.6\ 10^{-7}$	$5.2\ 10^{-4}$
^{239}Pu	$1.0\ 10^{-2}$	$4.1\ 10^{-7}$	$5.2\ 10^{-4}$
^{240}Pu	$1.0\ 10^{-2}$	$4.1\ 10^{-7}$	$5.2\ 10^{-4}$
^{242}Pu	$1.0\ 10^{-2}$	$4.1\ 10^{-7}$	$5.2\ 10^{-4}$
^{241}Am	$1.0\ 10^{-2}$	$6.4\ 10^{-7}$	$5.2\ 10^{-4}$
^{243}Am	$1.0\ 10^{-2}$	$6.6\ 10^{-7}$	$5.2\ 10^{-4}$
^{242}Cm	$9.3\ 10^{-3}$	$4.9\ 10^{-8}$	$4.8\ 10^{-4}$
^{243}Cm	$1.0\ 10^{-2}$	$1.7\ 10^{-7}$	$5.2\ 10^{-4}$
^{244}Cm	$1.0\ 10^{-2}$	$1.5\ 10^{-7}$	$5.2\ 10^{-4}$

were scaled by the application rate of freshwater using equations B4 and B5, with the substitution of sewage sludge parameters by the freshwater unit activity concentration and application rates given above.

REFERENCES

1 NRPB. Revised generalised derived limits for radioisotopes of strontium, iodine, caesium, plutonium, americium and curium. Chilton, NRPB-GS8 (1987).

2 NRPB. Revised generalised derived limits for radioisotopes of ruthenium. Chilton, NRPB-GS10 (1989).

3 Robinson, C A. Generalised habit data for radiological assessments. Chilton, NRPB-M636 (1996).

4 Byrom, J, Robinson, C, Simmonds, J R, Walters, B, and Taylor, R R. Food consumption rates for use in generalised radiological dose assessments. *J. Radiol. Prot.*, **15**, No. 4, 335–41 (1995).

5 MAFF DFR, Lowestoft. Personal communications (1992–1994).

6 Research Surveys of Great Britain Ltd. Use of the Cumbrian coastal area. London, Department of the Environment, DOE/HMIP/RR/91/057 (1991).

7 ICRP. Human respiratory tract model of radiological protection. ICRP Publication 66, *Ann. ICRP*, **24**, Nos 1–3 (1994).

8 Brown, J, and Simmonds, J R. FARMLAND: a dynamic model for the transfer of radionuclides through terrestrial foodchains. Chilton, NRPB-R273 (1995) (London, TSO).

9 Carey, A D, Jones, J A, and Mobbs, S F. GRANIS: a model for the assessment of external photon irradiation from contaminated media of infinite lateral extent. Chilton, NRPB (to be published).

10 Simmonds, J R, Lawson, G, and Mayall, A. Methodology for assessing the radiological consequences of routine releases of radionuclides to the environment. Luxembourg, EC, EUR15760 EN (1995).

11 Northrop, R, Carnow, B, Wadden, R, Rosenburg, S, Neal, A, Sheaff, L, Holden, J, Meyer, S, and Scheff, P. Health effects of aerosols emitted from an activated sludge plant. IN *Waste Water Aerosols and Disease*. Proceedings of a symposium. Cincinnati, Environmental Protection Agency, Publication EPA-600/9-80-028 (1980).

12 WRC. The agricultural value of sewage sludge. A farmers' guide. Guidance leaflet produced by WRC, ADAS and MAFF. Medmenham, Water Research Centre.

13 MAFF. Survey of irrigation of outdoor crops in 1990, England and Wales. Guildford, Government Statistical Service, MAFF Stats 157 (1991).

Appendix C

IMPORTANT EXPOSURE PATHWAYS FOR GDLs

Introduction

Details of the limiting exposure pathways and age groups for the generalised derived limits (GDLs) presented in the main report are discussed in this appendix in the light of habit and environmental data used in the calculations. In addition, the differences between the GDLs presented here and those published previously are discussed.

Single exposure pathway GDLs

Inhalation of air

The GDLs for air were only calculated for radioisotopes of plutonium, americium and curium. The GDL is inappropriate for radioisotopes of strontium, ruthenium, caesium and iodine because of the much greater importance of other exposure pathways for these radioisotopes.

Adults are the limiting group for all radionuclides except ^{242}Am and ^{242}Cm where 10 year old children are limiting. The dose coefficients for intakes by inhalation are greater for ^{242}Am and ^{242}Cm in children than in adults.

Terrestrial foods

The GDLs for terrestrial foods were calculated for twenty-five radionuclides for the three main age groups, infants (1 year old), children (10 years old), and adults (assumed to be 20 years old). An additional age group was considered for the GDL for milk to take account of infants in the first year of life whose diet was assumed to consist entirely of milk (3 months old). Table 3 of the main text indicates the limiting age group for each terrestrial food GDL and a number of trends are worthy of discussion. Infants in the first year of life generally constitute the limiting group for the ingestion of milk. The reasons for this are two-fold. For radionuclides other than ^{125}I and ^{129}I dose coefficients for ingestion by 3 month old infants are higher than the corresponding values for 1 year olds to take account of the higher gut transfer factor appropriate for infants on an all-milk diet. The milk intake rate of 350 l y^{-1} for infants in the first year of life is also the highest and 1 year old infants are the limiting age group for the GDLs for ^{125}I and ^{129}I only. Adults dominate the GDLs for ^{134}Cs and ^{137}Cs across all foods considered except milk. Children (10 years old) and infants (1 year old) tend to restrict the GDLs for isotopes of strontium, ruthenium and iodine, whereas adults are more likely to dominate GDLs for the actinides. The importance of milk, milk products, eggs and pig meat in the diets of infants and children is reflected in the pattern of limiting age groups.

Drinking water

Children (10 years old) and infants (1 year old) are the limiting group for isotopes of strontium, ruthenium and iodine. Infants are also limiting for the GDLs in drinking water for ^{136}Cs, ^{242}Am, ^{242}Cm and ^{244}Cm. Although the drinking water intakes of infants (260 l y^{-1}) and children (350 l y^{-1}) are considerably less than that for adults (600 l y^{-1}), this is offset by higher child and infant dose coefficients for ingestion. The remaining GDLs are limited by the adult age group.

Aquatic foods

The GDLs for marine fish, crustaceans, molluscs and freshwater fish are limited by the adult age group for all radionuclides. This is a function of the higher adult critical group intakes of these foods, as shown in Table B2.

Multiple exposure pathway GDLs

Grass

The GDL for grass is presented for radioisotopes of strontium, caesium and iodine only, because foodstuffs derived from grazing animals are important contributors to doses from these elements. The foodstuffs considered for this GDL were cattle meat, sheep meat, offal, milk and milk products. The GDL for grass was calculated for the main age groups and for infants in the first year of life, due to the potential importance of milk ingestion to this GDL.

For ^{89}Sr and iodine isotopes milk products and milk account for 60% and 38% of the GDL, respectively, and infants (1 year old) are the limiting age group. For ^{90}Sr infants in the first year of life consuming only milk are the limiting age group. Adults are the limiting group for ^{134}Cs and ^{137}Cs where milk products contribute 33% and sheep meat 27% of the GDLs. For ^{136}Cs infants are the limiting age group and 80% of the GDL is due to ingestion of milk and milk products.

Well-mixed soil

This GDL applies to deposits of radionuclides in soil well mixed to a depth of 0.3 m by natural weathering or farming activities. The GDL for well-mixed soil is not relevant for radionuclides with a half-life less than about 1 year, and has therefore only been presented for 14 radionuclides.

The dominant pathways in the GDLs for well-mixed soil vary, depending on radionuclide. Ingestion of foods (root vegetables, green vegetables and cereals) contributes 99% of the GDLs for ^{90}Sr and ^{129}I which are limited by the child (10 years old) age group. External irradiation accounts for between 54% and 83% of the GDLs for ^{106}Ru, ^{134}Cs and ^{137}Cs and the adult age group is limiting for these radionuclides. Dietary intake is also an important contributor to these GDLs. External irradiation and inhalation of resuspended soil contribute 80% of the GDLs for ^{243}Am and ^{243}Cm. For the remaining actinides, inhalation of resuspended soil by mechanical disturbance contributes between 68% and 73% to the GDLs, which are therefore limited by the adult age group.

Sea washed pasture

This GDL is intended for coastal land which is occasionally inundated by spring high tides. Contamination of the land can result from authorised discharges of radionuclides to the marine environment.

The GDLs for ^{90}Sr and ^{129}I are dominated by the milk ingestion pathway. For ^{90}Sr infants in the first year of life consuming milk only are limiting, while for ^{129}I other foods also contribute and the GDL is limited by infants on a mixed diet. External exposure accounts for 97% of the GDL for ^{106}Ru which relates to adults. For ^{134}Cs and ^{137}Cs external irradiation and terrestrial foods are the dominant exposure pathways. These pathways each contribute around 50% to the overall GDL for ^{134}Cs, while for ^{137}Cs the ingestion of terrestrial foods provides 64% and external exposure 36% of the GDL. For the radioisotopes of plutonium and for ^{241}Am and ^{244}Cm the GDL is dominated by the consumption of terrestrial foods (around 80%), largely due to offal ingestion. For ^{243}Am and ^{243}Cm external irradiation and ingestion of terrestrial foods are the main exposure pathways, each contributing around 45% to the overall GDL.

Shoreline sediment

These GDLs apply to deposits of radionuclides in sediments well mixed to a depth of 0.3 m by natural scour, wave action and biological activities. The GDLs for freshwater and marine sediments are not relevant for radionuclides with a half-life less than about 1 year. Therefore GDLs have only been presented for 14 radionuclides.

Marine sediment

Inadvertent ingestion accounts for 98% and 69% of the GDLs for ^{90}Sr and ^{129}I, respectively. The external pathway accounts for between 82% and 99% of the GDLs for ^{106}Ru, ^{134}Cs, ^{137}Cs, ^{243}Am and ^{243}Cm. The GDLs for ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{242}Pu are dominated by the inhalation of resuspended sediment (77%) with inadvertent ingestion contributing about 23% of the GDL. For ^{241}Am and ^{241}Pu inhalation of resuspended sediment contributes 62% of the GDL with a further 18% coming from external radiation. In all cases the limiting age group was adults, a function of the 2000 h y^{-1} occupancy assumed for marine sediments.

Freshwater sediment

The exposure pathways dominating the freshwater sediment GDLs are similar to those for marine sediment; however, 10 year old children are limiting for all radionuclides because of the higher inadvertent ingestion rate assumed for children than for adults. An occupancy of 500 h y^{-1} over freshwater sediments was assumed for both adults and children.

Freshwater

This GDL is intended for the monitoring of freshwater from inland rivers and lakes. The GDL for freshwater accounts for the activity dissolved in solution and associated with suspended sediment, and is expressed as Bq l^{-1} of whole water (dissolved and suspended). The GDL takes into account exposure from ingestion of fish and drinking water and external irradiation and inhalation of resuspended sediments. In addition, pathways associated with the irrigation of agricultural land with freshwater were also considered.

For isotopes of strontium and iodine, ingestion of drinking water, freshwater fish and terrestrial foods are the most important contributors to the GDL. External irradiation from shoreline sediments accounts for about 93% of the freshwater GDL for ^{106}Ru. Ingestion of freshwater fish contributes between 70% and 80% of the GDL for ^{134}Cs and ^{137}Cs, a reflection of the high fish concentration factor for caesium (2000 Bq kg^{-1} per Bq l^{-1}, Table B9). External irradiation from shoreline sediments also makes an important contribution (about 20%) to the freshwater GDLs for caesium isotopes, which are limited by adults.

Inhalation of resuspended shoreline sediment is the most important exposure pathway for the GDLs for isotopes of plutonium and ^{241}Am, contributing about 40% of the total. The ingestion of drinking water and terrestrial foods is also significant, contributing around 30% and 25%, respectively, to the GDLs for ^{238}Pu, ^{239}Pu, ^{240}Pu and ^{242}Pu. Freshwater GDLs for ^{242}Cm and ^{244}Cm are dominated by the inhalation of resuspended shoreline sediments. External irradiation from shoreline sediment accounts for about 75% of the freshwater GDLs for ^{243}Am and ^{243}Cm.

Sewage sludge

This GDL is intended for the monitoring of sewage sludge which has become contaminated by previous authorised discharges to sewers, and is presented for wet sewage sludge (Bq kg^{-1}). Two main exposure situations were considered in the calculation of the GDL. The first exposure situation considered sewage sludge at a treatment works (adults only), and the second considered exposures due to the conditioning of agricultural land with sludge (all age groups). The sewage sludge GDL has been calculated on the basis that the groups of people exposed in the two situations are not the same, therefore simply to sum exposure over all the pathways was considered inappropriate. The most restrictive value arising from the two exposure situations has been presented as the GDL for sewage sludge.

The most restrictive GDL was due to conditioning of agricultural land for all the radionuclides considered, except ^{106}Ru and ^{103}Ru, where exposure at the sewage works is limiting. Of these, ^{103}Ru has a relatively short half-life and was not considered for application to agricultural land; exposure at the sewage treatment works is therefore the only exposure route considered. External exposure from contaminated sludge in holding tanks is the most important exposure pathway for both ruthenium isotopes. For the remaining isotopes a combination of exposure routes associated with agricultural land was important. Consumption of terrestrial food accounts for 99% of the GDLs for strontium and iodine isotopes. For ^{134}Cs and ^{137}Cs external irradiation from land treated with sewage sludge contributes about 60% of the GDL and around 40% comes from terrestrial foods. For ^{243}Am and ^{243}Cm external exposure accounts for between 35% and 40% of the GDL, inhalation of resuspended soil contributes 38% and ingestion of terrestrial foods the remainder. For ^{241}Am, ^{244}Cm and the remaining isotopes of plutonium two pathways, inhalation of resuspended soil (60% – 70%) and ingestion of terrestrial foods (25% – 35%), particularly offal, are the most important. For ^{242}Cm, the limiting pathways were inhalation and ingestion of soil, each accounting for 44% of the GDL.

Differences between the new GDLs and those published previously

Differences between the new GDLs presented in Tables 3, 4 and 5 of the main text and those published in NRPB-GS8[1] and NRPB-GS10[2] are likely to be of interest to those involved in the monitoring and control of activity in the terrestrial and aquatic environments.

Single exposure pathways

The differences between the current and previous GDLs for single exposure pathways can be explained by two major factors: revision of dose coefficients for ingestion and inhalation[3] and changes in the critical group intake rates of various materials[4,5]. In addition, the GDL for ^{241}Pu in terrestrial and aquatic foods and drinking water was derived without consideration of the ingrowth of ^{241}Am, resulting in a less restrictive GDL than reported previously[1].

Multiple exposure pathways

The differences between GDLs arising from doses over multiple exposure pathways can be explained by a number of factors. As discussed for single exposure pathway GDLs, revision of dose coefficients for ingestion and inhalation and estimates of critical group intake rates of various materials has occurred. In addition, revisions have been made to the model used to estimate external dose[6]. A new pathway (inadvertent ingestion of materials) has been included in GDLs for well-mixed soil and sediment. For radionuclides where food ingestion pathways were limiting (^{90}Sr, ^{106}Ru and ^{129}I), changes in food intake rates are the main reasons for changes in the well-mixed soil GDLs. However, changes to the dose coefficients[3] and concentration factors for the uptake of activity from soil to foods also contribute[7]. For ^{134}Cs and ^{137}Cs the external irradiation pathway was limiting for the GDLs for well-mixed soil and sediments presented in this publication and those published previously. The well-mixed soil GDLs for ^{134}Cs and ^{137}Cs were affected by the introduction of location factors for shielding by buildings. The inhalation of resuspended material was the limiting exposure pathway for the actinides considered in this publication and previously. The GDLs calculated previously used a resuspension factor to link air concentrations to the activity in soil. The current calculations account for occupancy over the substrate of interest and replace the resuspension factor by a process driven dust loading.

Freshwater GDLs published previously did not account for exposure from irrigation of farmland. Differences between some GDLs for freshwater and those published previously are attributable to the contribution to doses from foods produced on irrigated soil, external exposure pathways and inhalation of resuspended soil.

REFERENCES

1 NRPB. Revised generalised derived limits for radioisotopes of strontium, iodine, caesium, plutonium, americium and curium. Chilton, NRPB-GS8 (1987).

2 NRPB. Revised generalised derived limits for radioisotopes of ruthenium. Chilton, NRPB-GS10 (1989).

3 ICRP. Age-dependent doses to members of the public from intake of radionuclides: Part 5. Compilation of ingestion and inhalation dose coefficients. ICRP Publication 72. *Ann. ICRP*, **26**, No. 1 (1996).

4 Robinson, C A. Generalised habit data for radiological assessments. Chilton, NRPB-M636 (1996).

5 Byrom, J, Robinson, C, Simmonds, J R, Walters, B, and Taylor, R R. Food consumption rates for use in generalised radiological dose assessments. *J. Radiol. Prot.*, **15**, No. 4, 335–41 (1995).

6 Carey, A D, Jones, J A, and Mobbs, S F. GRANIS: a model for the assessment of external photon irradiation from contaminated media of infinite lateral extent. Chilton, NRPB (to be published).

7 Brown, J, and Simmonds, J R. FARMLAND: a dynamic model for the transfer of radionuclides through terrestrial foodchains. Chilton, NRPB-R273 (1995) (London, TSO).

APPLICATION OF GENERALISED DERIVED LIMITS

ABSTRACT

This document is intended for use by those who are required to make measurements of radionuclides in environmental materials and assess their radiological significance. It sets out the place of generalised derived limits (GDLs) within the overall framework of an environmental measurement and assessment programme. The GDLs are environmental reference levels against which the results of monitoring can be compared; they can be applied to circumstances where exposure is continuous throughout the year, but they do *not* apply to transient situations such as the aftermath of an accident.

The calculation of GDLs has been based on information considered appropriate for the UK. Consequently, the resultant values may not be applicable to other countries. However, the overall approach to the calculations and the practical advice in this document are of more general utility.

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INTRODUCTION

1 Generalised derived limits (GDLs) are convenient reference levels against which the results of monitoring may be compared; they enable a preliminary assessment to be made of the radiological impact of environmental contamination on members of the public[1]. The Board has published GDLs for radioisotopes of strontium, ruthenium, iodine, caesium, plutonium, americium and curium elsewhere in this issue[1]; values for important radioisotopes of other elements will be published in the future. This paper contains practical guidance that can be applied to the GDLs for any radionuclide; advice on the radionuclides considered so far is used for illustration and example.

2 This document is intended for use by those who are required to make measurements of radionuclides in environmental materials and assess their radiological significance. It sets out the place of GDLs within the overall framework of an environmental measurement and assessment programme. Factors governing the choice of the most appropriate material to sample and the selection of the relevant GDL are discussed. The use of GDLs in situations where a number of different radionuclides are present in the environment and the action required if the GDL screening level is exceeded are explained.

3 The GDLs are calculated using information that is considered appropriate for the UK. Consequently, the published values may not be applicable to other countries. However, the overall approach to the calculations[1] and the advice given here are of more general utility.

BASIS OF THE GDLs

4 Measured activity concentrations in environmental materials often contain contributions from more than one origin, or from discharges that have occurred over a number of years. Consequently, dose estimates that are based on such measurements should be compared with the appropriate dose limit[1,2]. They should not be compared with any dose constraints, because these apply only to a single source or site and are prospective upper bounds on the process of optimisation of radiological protection. The GDLs are therefore related to an annual dose limit of 1 mSv for members of the public, a value that has been recommended by the Board[2] and subsequently endorsed by the UK government[3*]; they are derived using a defined model and are calculated using deliberately cautious assumptions such that compliance with the GDL will ensure virtual certainty of compliance with the dose limit.

5 Since GDLs are directly related to the dose limit for members of the public, they are only appropriate for those sources of exposure to which the dose limit applies. Thus, they relate to levels of radionuclides in the environment which result from the combined effects of past and present controlled releases. Since the limit is given in terms of an annual dose, the calculation of GDLs is based on the assumption that exposure continues for the whole year. The GDLs are not appropriate for assessing transient exposure situations. Strictly, they do *not* apply to accidental releases of radionuclides into the environment, for which comparisons with the dose limit are inappropriate[2]. However, in the longer term after an accident, when the original deposit has reached near-equilibrium in the environment, the

*The current statutory dose limit for members of the public is 5 mSv y^{-1}. However, guidance issued by government departments is based on 1 mSv y^{-1}.

GDL system can be used to provide a simple, preliminary assessment of the radiological consequences of widespread, low level contamination.

6 The assumption of annual exposure also implies that contamination of the material under consideration is relatively widespread. This can be illustrated by the calculation of GDLs in foodstuffs, for which it is implicitly assumed that concentrations are constant throughout the whole of the annual intake. To supply the amount of vegetables or fruit required by a single consumer, an area of 50–100 m^2 would be needed, which corresponds to a substantial garden. The provision of a year's supply of meat, offal or milk would require a larger area of land to sustain sheep or cattle. The area then required to provide sufficient food for a single person could be around a few hectares, ie the size of a smallholding.

7 Since GDLs relate to levels of radionuclides in the environment that arise from human activities, they do not apply to levels that occur naturally. Where a radionuclide may be of natural origin, as would be the case for ^{210}Po and ^{226}Ra for example, the GDL relates only to possible incremental concentrations resulting from human activity, and not the total. For such radionuclides, it is therefore necessary to have some estimate of the ambient levels in the area in order to assess the radiological impact of the practice under consideration.

8 Deliberately cautious assumptions are made in GDL calculations in order to make them generally applicable as screening levels. The hypothetically exposed individuals are assumed to be representative of those members of the public likely to receive the highest doses as a result of their habits (*the hypothetical critical group*). Thus, the ingestion rates assumed for foodstuffs are representative of people who consume higher than average amounts, the occupancy of beaches and riverbanks is consistent with the frequent use of such areas for occupational or leisure purposes, and high outdoor occupancy rates are used for both adults and children. The GDLs are also based on the most restrictive age group, taking into account variations in dose coefficients and dietary and other habits with age.

SINGLE AND MULTIPLE EXPOSURE PATHWAY GDLs

9 Radiation doses resulting from the presence of radionuclides in the environment arise by the following main pathways: external exposure, where the source of the activity is outside the body; internal exposure, which occurs after a radionuclide has been either ingested or inhaled. The exposure pathways of potential interest depend on the environmental material under consideration. For example, for individual foodstuffs, only one exposure pathway would be involved and so the relevant GDL would be termed 'single exposure pathway'. In the case of soil, which could be used to grow crops or to accommodate people or farm animals, more than one exposure pathway could be involved and so the relevant GDL would be termed 'multiple exposure pathway'. Where multiple exposure pathways are involved, the combination of cautious assumptions included in the calculations is unlikely to be applicable to all situations, particularly those where several exposure pathways contribute significantly to the resultant value of the GDL; the level of caution built in will depend on the radionuclide concerned. There are, however, some instances where a multiple exposure pathway GDL is dominated by one or two exposure pathways, and the combination of habits relating to these pathways might then be quite plausible.

10 There are some potential exposure pathways that are not included in GDL calculations which may require consideration in a site-specific assessment. An example would be the ingestion of foodstuffs found in the wild, such as berries and mushrooms. These are unlikely to be of general significance, but in particular circumstances their contribution may be worthy of evaluation as part of a rigorous dose assessment. This issue is discussed in more detail later (see paragraphs 56 and 57).

SAMPLING AND MEASUREMENT PROTOCOLS FOR COMPARISON WITH THE GDLs

11 The selection of the most appropriate material to sample depends on current knowledge about the situation. Ideally, the material sampled should be that directly responsible for the resultant exposure of man. Thus, for example, if the consumption of milk was the probable exposure pathway of interest, then milk would be sampled in preference to grass or soil. However, if information is lacking then a material such as soil that can give rise to all the possible exposure pathways would be more appropriate, at least for the purposes of a preliminary assessment. Soil would be of particular value for initial investigations where information on individual radionuclides was absent.

12 Information about the radionuclide of interest is a primary factor in deciding upon a sampling strategy, since this determines the exposure pathways of potential importance. The calculations used to derive the appropriate multiple exposure pathway GDL can be of assistance here, since they provide the contributions from each individual pathway to the GDL. The contributions relating to those radionuclides considered elsewhere in this issue[1] are set out in the appendix; corresponding data will accompany future advice for other radionuclides. In the absence of specific information, these data enable the exposure pathways of potential importance to be identified and thereby provide an indication of the most appropriate environmental materials to be sampled.

13 A sampling programme may be constrained by practical considerations. Taking animal products as an example, milk is relatively easy to obtain, but meat or offal are obviously more difficult; again, recourse to a material such as soil or grass might be a more practical option for the purposes of a first assessment. In the case of land contaminated with actinides, for which the resuspension pathway may be of importance, the costs and difficulties in installing high-volume air sampling equipment might be prohibitive, and an initial assessment would then be best served by the collection of soil samples.

14 There is also a need to ensure that the chosen programme provides data that are adequately representative of the situation under consideration. For example, it would generally be more appropriate to collect samples of milk from a bulk tank, which would then be representative of an entire herd, rather than an individual animal. In the case of sea washed land, the amount of sediment deposited is very dependent on altitude, and while single samples collected from areas of high deposition may be sufficient for an initial assessment, more extensive information might be required for rigorous evaluations. This topic is discussed further in paragraphs 24 and 25.

15 The number of samples that are collected may be affected by the subsequent analytical effort required. For example, some radionuclides such as ^{137}Cs can be readily and rapidly determined using gamma-ray spectrometry, a non-destructive technique, whereas others such as ^{90}Sr or isotopes of plutonium require dissolution and radiochemical isolation prior

to measurement. The former are amenable to a more comprehensive study, perhaps involving sampling over a wider area, or in a variety of materials, which in turn would include comparisons with more than one GDL. In the case of the latter, it would be more important to decide in advance upon which exposure pathways were likely to be of greatest importance, and therefore upon the optimum sampling strategy.

16 In all cases, the date of collection of the sample, the location of the collection point and the subsequent treatment of the sample should be recorded. The latter is of particular importance because inappropriate treatment can invalidate the resultant analytical data. Reported activity concentrations should relate to the date of collection of the sample and not to the date of measurement.

17 The sampling procedure employed and the subsequent treatment must take account of the assumptions used in the derivation of the GDL. Some of the more important considerations are set out below.

Foodstuffs

18 The consumption rates and transfer parameters used in the GDL calculations relate to the edible portion of the foods concerned. Thus, measurements should be performed on the edible fraction of food. In some cases, the identification of this fraction is straightforward. In others, a more cautious approach may be advisable. An example would be potatoes, where because of changes in dietary preferences in recent years, it would be more appropriate to determine concentrations in whole tubers rather than after peeling[4]. The measurement results are expressed in terms of fresh mass. Samples of foodstuffs should not be allowed to deteriorate before measurements begin.

19 Consumption rates refer to the mass of the processed food that is ingested, whereas transfer parameters and measurements generally refer to the fresh raw food. However, a recent assessment of the effects of food processing on radionuclide content indicated that, for critical group assessments, it would be reasonable to assume that domestic cooking processes did not give rise to any changes in the amount of activity ingested[5]. Generally, therefore, measurements can be made on the raw food.

Grass

20 The GDLs for grass have been derived for selected radionuclides that are readily transferred to animal products. The values are given in terms of dry mass; measurements should therefore be expressed on the same basis. This does not necessarily imply that samples should be dried prior to measurement, since some radionuclides such as isotopes of iodine are potentially volatile. In such cases, a separate portion of the sample should be used to determine a dry-to-fresh mass ratio; this can then be applied to the original measurement data. Grass would normally be cut to within 10 mm of the ground. Although not needed for a comparison with the GDLs, it is advisable to collect the grass from measured quadrats, typically 1–5 m^2 in area, and to determine the amount of grass collected. Information on the foliar density might be of use if a more rigorous assessment was subsequently required.

21 It should be noted that the GDLs for grass apply to conventional pasture. Some domesticated animals spend much of their time grazing on unmanaged land such as uplands or heaths. In this case, their diet may consist of a variety of plant species and may change during the year. The GDLs for grass have not been intended to apply to such situations. Emphasis should instead be placed on measurements on the animal products themselves.

Water

22 The GDLs are presented separately for drinking water and for freshwater. The former is based on the drinking water pathway only and is for comparison with measurements made on water in the form in which it will be consumed, ie following any treatment processes. In contrast, freshwater may be used in a variety of ways; it may also contain sediment suspended in the water column. In addition to direct consumption, the GDL for freshwater therefore includes other exposure pathways such as ingestion of freshwater fish, and pathways arising from exposure to sediment and from irrigation of land. Consequently, a different approach is required in which measurements of activity concentrations are made in both the aqueous phase and the particulate material. Samples should therefore be taken directly from the appropriate freshwater system and any suspended particulate material separated by filtration before any analytical work begins. This should not add to the analytical effort required, since the two phases would generally be separated prior to analysis for purely practical reasons. The suspended sediment load, ie the mass of sediment per unit volume of water, should be recorded, since this is required in the calculation of the final results. Moreover, it may be an important factor if a more rigorous assessment is subsequently required. For a given radionuclide, the quantity that should be compared with the GDL for freshwater is the total activity concentration in the original sample, ie taking account of any activity originating from suspended sediment.

Well-mixed soil and sea washed pasture

23 The GDL for well-mixed soil is calculated on the assumption that the activity is uniformly distributed to a depth of 300 mm in the soil. This represents an aged deposit that has been mixed by natural and agricultural processes. Samples should therefore be collected over this depth of soil and homogenised before any aliquots are taken for analysis. This procedure would be appropriate for cultivated agricultural or horticultural land, but not to land that had recently received a fresh surface deposit. The GDL for well-mixed soil would also not be applicable to areas of permanent pasture that had been established before deposition began. In this case, the GDLs for grass would be more appropriate (paragraph 20).

24 Separate GDLs have been calculated for sea washed pasture, and these are also based on a uniform distribution of activity to a depth of 300 mm. The sampling requirements are therefore the same as those for well-mixed soil. Interest in sea washed pastures mainly concerns the northwest coast of England, north Wales and southwest Scotland and arises because of discharges into the Irish Sea from the Sellafield nuclear fuel reprocessing plant. The distribution of radionuclide concentrations with depth in sea washed pastures and saltmarshes is not uniform; in practice, concentrations are highest at some depth in the soil, which is consistent with the marked decreases in discharges from Sellafield over the last 20 years[6]. The assumption of a uniform distribution with depth would then be cautious for all of the exposure pathways considered. The present approach is considered reasonable for the current situation in the UK, but it might not be appropriate in situations where discharges are increasing.

25 For both types of sample, the GDLs are expressed in terms of dry mass; the measurement data should be presented on the same basis. If potentially volatile radionuclides are thought to be present, then the samples should be treated in a manner similar to that described for grass.

Shoreline sediment

26 The GDLs for marine and freshwater sediment apply to shoreline sediment, including intertidal zones, but not to material that is permanently submerged. These GDLs are based on the premise that the material has been well mixed by physical and biological activities to a depth of 300 mm. However, obtaining sediment cores in unconsolidated material is not always straightforward, while in some instances the depth of the deposited sediment may be very much less than 300 mm. In these circumstances, a sample from the surface is all that can be reasonably achieved for the purposes of an initial evaluation. In such cases, the sampling details should be recorded. As in the case of soils, the GDLs are expressed in terms of dry mass, and the measurement data should be presented in the same form.

Sewage sludge

27 The GDLs are presented in terms of the wet mass of sewage sludge, since this is the form in which it is applied to agricultural land. The measurement data should be presented on the same basis. While it is more convenient to dry the sludge prior to beginning any measurements, if potentially volatile radionuclides are present consideration might need to be given to the generation of reliable data using the original material. Where appropriate, the ratio of the wet and dry mass of the sludge should be determined.

APPLICATION OF GDLs

28 The process of comparing measurement data with the appropriate GDL is illustrated in the figure. Before proceeding, it is advisable to check that the material was collected, processed and analysed in a manner suitable for comparison with the GDL. The reliability of the analytical data should also be assured. If the quality of the data is in doubt, then the analysis and, if necessary, the sample collection should be repeated.

Screening level

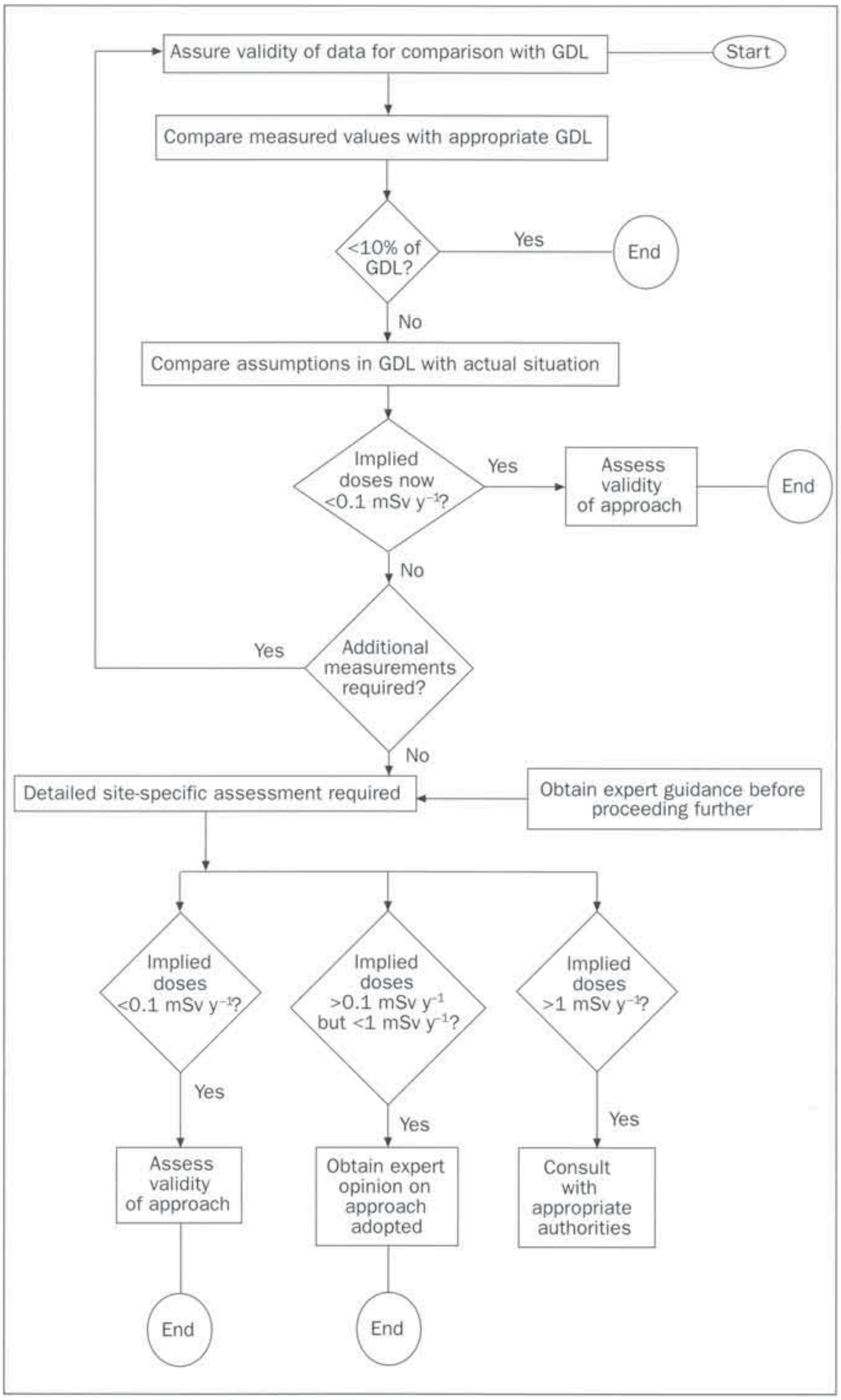
29 The Board recommends a screening level of 10% of the GDL, or the corresponding level of dose of 0.1 mSv y^{-1}, which if exceeded indicates the need for further investigation of the exposure pathways and likely critical group doses[1,2]. The action required in such cases is considered later in this paper (see paragraphs 45–58).

Terrestrial environment

30 Soil is a relatively easy material to collect and measure, and the GDL for well-mixed soil takes account of all of the most important exposure pathways arising from contamination in the terrestrial environment. It is particularly useful for radionuclides that require a great deal of analytical effort, because it allows the combination of exposures from more than one pathway to be taken into account. As noted earlier, this GDL is only applicable to soil samples taken from areas of tilled agricultural or horticultural land which have received deposits over a number of years, and not to samples from areas of permanent or sea washed pasture, or to semi-natural systems such as uplands or moorlands.

31 In the past, GDLs for well-mixed soil have erroneously been applied to sea washed pasture. The assumptions used in the calculation of GDLs for well-mixed soil include permanent occupancy of the contaminated land and the production of all foodstuffs. The former is clearly inappropriate for land that is periodically inundated by the sea, while the agriculture that sea washed land can support is limited. A GDL has now been calculated specifically for soil that originates from sea washed pasture, taking account of the

Application of the GDL system



appropriate occupancy factors and agriculture. Although termed 'pasture', this GDL can be applied to other intertidal land such as saltmarsh, but not to shoreline sediment, for which separate values have been derived.

32 A specific GDL has been developed for grass from permanent pasture which takes account specifically of exposure pathways from grazing animals. The GDLs for grass have deliberately been derived only for those radionuclides for which such exposure pathways are likely to be significant.

33 The GDLs for individual foods are valuable where the agricultural land use is known and food samples are easily obtained, and where the radionuclides are readily measurable. However, the availability of samples will vary with season, and a complete evaluation may therefore take some time. Activity concentrations in milk often provide the most useful basis for comparison with the GDLs, provided that the milk is produced in the area of concern. This is because cows are efficient integrators of deposited radioactivity, and milk is an easily obtained food sample, although seasonal grazing habits also need to be taken into account.

34 There are, however, occasions when measurements on the foodstuffs themselves may not be the best approach. One example would be radionuclides for which the more convenient analytical methods cannot achieve sufficiently low detection limits. For example, in the case of isotopes of ruthenium, the detection limits that can be achieved for milk using gamma-ray spectrometry approach the value of the screening level; lower limits could be achieved using radiochemistry, but the effort and expertise required are considerable. However, the transfer of ruthenium to milk is very small, and widespread contamination with ^{103}Ru and ^{106}Ru could result in other pathways becoming worthy of consideration. In such cases, measurements in other materials such as soil would be more useful. Not only are all potential exposure pathways taken into account, but the detection limits that can be achieved by gamma-ray spectrometry are then well below the relevant screening level.

35 In using single exposure pathway GDLs such as those for individual foodstuffs, it is important to remember that other pathways also contribute to the doses received by members of the public. For example, a person might consume more than one foodstuff produced within a contaminated area. Such possibilities merit consideration. For readily measurable radionuclides such as ^{137}Cs, it may be practicable to make measurements in each of the terrestrial foods grown in a contaminated area. The measured value in each food should then be expressed in terms of a percentage of the relevant GDL, ie the percentage of the GDL utilised. The sum of the percentages utilised can then be compared with the 10% screening level. This approach might not be suitable for radionuclides such as ^{90}Sr, which require radiochemical isolation prior to measurement. In such cases, measurements in well-mixed soil could be a better option. This is particularly so in the case of ^{90}Sr, because the ingestion pathway for vegetables and cereals is the dominant contributor (99%) to the GDL for well-mixed soil[1].

Marine environment

36 Generalised derived limits are not calculated for seawater because it is better to measure radionuclide concentrations in media such as sediment or seafoods that more directly relate to the exposure of people. The GDLs are presented for each radionuclide in marine fish, crustaceans and molluscs and, for radionuclides with halflives greater than a

year, in marine sediment. The GDL for marine sediment refers to material that has been deposited on the shoreline and so takes account of those pathways that are directly related to time spent at that location, ie external exposure, inhalation of resuspended material and the inadvertent ingestion of sediment. However, in contrast to the corresponding GDL for well-mixed soil, it does not include the ingestion of marine foodstuffs and so does not represent the combined exposures from all important pathways in the marine environment. In practical terms therefore, it is important to consider whether the ingestion of marine foods is important in a given situation, and if so to make appropriate measurements and comparisons with the GDLs. The overall impact can then be assessed in the same manner as that set out for multiple radionuclides (paragraph 44).

37 The relative importance of the ingestion and the sediment-dependent exposure pathways depends on the radionuclides concerned. For example, ^{137}Cs is readily transferred to fish, and following adsorption on to sediment would also give rise to external irradiation during occupancy of shoreline areas. In this case, ease of measurement means that a more extensive investigation would be relatively straightforward. However, similar considerations apply to isotopes of plutonium, which are taken up by molluscs as well as being strongly adsorbed by sediment, and here there would be no option but to make measurements in both materials. It would be imprudent to make broad extrapolations between measured concentrations in sediment and likely levels in marine foodstuffs: fish in particular are not confined to a given area, and moreover there is not a simple relationship between activity concentrations in sediment and those in such foodstuffs.

Freshwater environment

38 The GDL for freshwater takes account of the ingestion of fish, exposures to shoreline sediment and exposures arising from the irrigation of land in addition to the use of the water for drinking. A separate GDL specifically for drinking water is also provided; this GDL should not be applied to water that is used for any purpose in addition to drinking. As in the case of marine systems, the GDL for freshwater sediment refers to the shoreline and so takes account of the external exposure, resuspension and inadvertent ingestion which may take place during time spent there, but does not include the ingestion of freshwater fish.

39 In many cases, the simplest and most relevant approach would be to make measurements on freshwater and compare them with the corresponding GDL. Samples are relatively easy to collect and the GDL represents the sum of exposures arising from the freshwater environment. A more extensive measurement programme could be mounted for radionuclides that require little analytical effort. For example, if the consumption of freshwater fish was a possibility, then additional measurements would be prudent, since as in the case of the marine environment this foodstuff could have originated from a wide area. Equally, for some radionuclides such as ^{106}Ru, the dominant exposure pathways result from occupancy of the shoreline, and so sampling of the shoreline sediment itself would be the preferred approach.

40 There are instances where the inhalation of resuspended material could be the exposure pathway of interest, for example following irrigation of agricultural land. The problems of sampling airborne dust were noted earlier, and initially at least an evaluation based on freshwater itself could provide a simpler approach.

Sewage sludge

41 The primary form of control of discharges of radionuclides into sewerage systems is provided by generalised derived constraints (GDCs). However, a GDL for sewage sludge has also been calculated in order to allow exposures arising from combinations of discharges from more than one operator to be assessed. This GDL is intended for measurements of sludge at the sewerage plant. Two sets of circumstances were considered: exposures arising at the sewerage plant; exposures arising from the application of the sludge to agricultural land. The basis of the calculations is given elsewhere in this issue[1]; only the more restrictive values have been recommended for general use[1].

42 The table contains the results of both sets of calculations for the radionuclides considered so far[1]. In most cases the more restrictive values relate to the application of sludge to agricultural land, the two exceptions being ^{103}Ru and ^{106}Ru (see the appendix, Figure A7). For a given radionuclide the differences between the two sets of values are in some cases several orders of magnitude. On the basis of the published GDLs, undue restrictions could therefore be placed on operations at a sewerage plant if in practice the sludge was never intended for use as a soil treatment. Consequently, the values relating to exposures at the sewerage plant are presented formally here as a means of assessing the radiological impact on the workforce. This two-tier approach differs in concept to the derivation of GDLs for other materials.

43 The GDCs for discharges from individual facilities to sewerage and freshwater systems will be published in due course.

GDLs for sewage sludge following application to farmland and retention at the sewerage works (Bq kg^{-1} wet mass)

	Application to farmland		At sewerage works	
Nuclide	GDL	Limiting age group	GDL	Limiting age group
^{89}Sr	7 10^4	Infant	6 10^7	Adult
^{90}Sr	6 10^2	Infant	7 10^6	Adult
^{103}Ru	–	–	7 10^4	Adult
^{106}Ru	5 10^4	Adult	3 10^4	Adult
^{125}I	2 10^4	Infant	2 10^6	Adult
^{129}I	4 10^2	Infant	5 10^5	Adult
^{134}Cs	2 10^3	Adult	4 10^3	Adult
^{137}Cs	1 10^3	Adult	9 10^3	Adult
^{238}Pu	4 10^3	Adult	1 10^5	Adult
^{239}Pu	3 10^3	Adult	1 10^5	Adult
^{240}Pu	3 10^3	Adult	1 10^5	Adult
^{241}Pu	1 10^5	Adult	2 10^6	Adult
^{242}Pu	3 10^3	Adult	1 10^5	Adult
^{241}Am	4 10^3	Adult	8 10^4	Adult
^{243}Am	2 10^3	Adult	2 10^4	Adult
^{242}Cm	4 10^5	Infant	1 10^6	Adult
^{243}Cm	4 10^3	Adult	3 10^4	Adult
^{244}Cm	8 10^3	Adult	2 10^5	Adult

Treatment of multiple radionuclides and groups of materials

44 The dose limit applies to the sum of exposures from sources subject to the ICRP system of radiological protection for practices, taking account of both current and previous discharges. It is therefore necessary to ensure that all relevant radionuclides are taken into account when carrying out any assessment of radiological impact; this includes evaluations that make use of GDLs. The selection of the most appropriate material or groups of materials has been discussed already, but it is conceivable that more than one radionuclide may be involved. In such cases, it is not appropriate to assess radiological impact on the basis of individual comparisons with the 10% screening value. Instead, the overall impact should be assessed by calculating the percentage of the GDL utilised for each of the radionuclides of interest, ie the measured value expressed as a percentage of the appropriate GDL. These percentages should then be summed and the total compared with the screening value of 10%. A further investigation would be warranted if the total exceeded 10%, irrespective of whether this value was exceeded by any, or indeed none, of the individual values.

Action required if the screening level is exceeded

45 A single measurement in excess of the screening level does not necessarily imply that an effective dose of 0.1 mSv y^{-1} will be exceeded. Rather, it indicates that the applicability of the GDL to the situation in question deserves a more thorough appraisal. Since there is a degree of caution built in to the calculation of GDLs, a simple assessment of the actual situation will often be all that is required.

46 For situations involving more than one radionuclide, the process of determining the overall utilisation of the GDL (paragraph 44) will identify the radionuclides of primary importance. In the case of multiple exposure pathway GDLs, the next step is the identification of the most important exposure pathways, which are radionuclide-dependent. For those radionuclides that have been considered earlier in this issue[1], the contribution from each exposure pathway to these GDLs is given in the appendix.

47 The identification of the important exposure pathways enables the assumptions made in the calculation of the GDL to be elicited[1]. The applicability of these assumptions to a particular situation can then be evaluated (see the figure). The radionuclide-dependent parameters such as soil-to-plant transfer factors that were used in the calculation of GDLs were the best estimates currently used by the Board[7], and it is not generally necessary to consider these at an early stage. Instead, emphasis should be placed on radionuclide-independent parameters. Some of the more important factors are discussed below.

Land use

48 Information on land use may enable estimates of the potential contributions from foodstuffs to be refined. As an example, the GDLs for grass include all animal products, of which milk and milk products are the dominant contributors for most of the radionuclides considered (see the appendix). Consequently, if dairy animals are not given access to a given area, then the contributions from milk to the GDLs can be disregarded. Similarly, some of the crops considered in the calculation of GDLs for well-mixed soil might not be cultivated in the area under consideration.

Habit data

49 Generally, it is unlikely that suitable, representative data on the consumption rates of foodstuffs would be available for specific areas. Certain coastal areas are a notable

exception[8]. In view of the need for caution, GDLs have been calculated using higher than average rates appropriate for the UK generally, that have been agreed by the Board and the Ministry of Agriculture, Fisheries and Food[9]. However, for more realistic assessments the assumption that an individual consumes all foods at higher than average rates is implausible. Such assessments could reasonably be based on the premise that an individual might consume no more than two foodstuffs at higher than average rates and the remainder at average rates[10]. For assessment purposes, the two foodstuffs selected would be those that potentially contributed most to the estimated dose. Data on average consumption rates appropriate for the UK have been published[9]. It is worth noting also that the consumption of grain is taken into account in the calculation of GDLs, although for most people the grain in the diet comes from a very wide area. Consequently, if grain was identified as a potentially important contributor to the estimated dose, then the possibility of people achieving self-sufficiency in the production of grain from within the area of interest should be investigated.

50 Occupancy factors for use in general assessments have been published[11], and are the values used in the calculation of GDLs[1]. It is unlikely that site-specific occupancy factors will be available, although data in the use of intertidal areas in northwest England have been published[12,13]. It is worth noting, however, that the GDL for well-mixed soil is based on continuous occupancy, the time spent indoors being taken into account[1]. For radionuclides such as ^{137}Cs or ^{239}Pu, for which occupancy is an important factor in the calculation of the GDL, dose estimates could therefore be readily revised if it was known that the area under consideration was not permanently inhabited[1,11].

Ancillary measurements

51 For some GDLs, the ancillary measurements made on the samples are of value in a more site-specific assessment. For example, in the case of freshwater, the GDL has been calculated using a suspended sediment load of 50 mg l^{-1}. Some radionuclides are extensively sorbed on to sediment, and for actinides the inhalation of resuspended shoreline sediment is an important contributor to the GDL. The activity concentrations in the suspended sediment fraction alone may therefore merit evaluation. For shoreline sediment, the depth of sediment that could be sampled could be important for those radionuclides for which external irradiation contributes significantly to the GDL. This would not, however, be the case for those where resuspension and inadvertent ingestion are important, because the activity ingested or inhaled would come from the surface layer. In the case of sewage sludge, it would be useful to compare the actual rates and frequency of application with the values assumed in the calculation of the GDL[1]. In the case of grass, the activity concentrations observed in a sample may contain significant contributions from soil adhering to the foliage: factors such as animal husbandry and the quality of the grazing land affect the amount of soil resuspended on to foliage and the amount inadvertently ingested by the animal. Ingestion of soil-associated activity can be the dominant contributor to intakes of certain radionuclides, particularly actinides, although experimental evidence indicates that the availability of soil-associated radionuclides for uptake by animals is less than the values assumed in the calculation of GDLs[14]. Consequently, the amount of soil adhering to the grass and its influence on the observed activity concentrations could merit consideration. This factor could be of particular importance in the case of sea washed land.

52 If after an analysis of the applicability of the basic assumptions there is still a need for a more specific assessment, then two further factors merit consideration. These are:

(a) the extent of the contamination,

(b) whether additional measurements are required.

53 The extent of the contamination may not be sufficient to fulfil the criterion given earlier, ie that the predicted level of exposure continues over the whole year. Thus, for example, a contaminated area might not be large enough to produce the required amount of food. In addition, the measured levels of contamination might not be representative of the entire area.

54 Before a decision is taken on the need for further measurements, published measurement data should be examined to determine whether any relevant information is available. The exposure pathways of importance will have already been identified (paragraph 44), and so this examination should not be confined to the original material under consideration but extended to others that may be of more direct application to a dose assessment.

55 Additional measurements need not necessarily entail further sample collection and analysis. For some radionuclides in certain materials, external irradiation is an important contributor to the GDL. External irradiation has been taken into account in the calculation of GDLs for materials such as well-mixed soil, sea washed land and sediment. In the case of grass, this exposure pathway was not considered, although a person might spend some time on contaminated grassland, and this pathway might merit evaluation when a site-specific assessment is required. In recent years, equipment to measure external dose rates has become widely available as part of contingency planning for emergency response, and guidance on measurement protocols has been published[15]. Such equipment is portable and relatively cheap, and moreover a single measurement provides an estimate of dose rate that is representative of an area of around 10–20 m in diameter. Measurements can be made relatively quickly, and so a large area can be surveyed in a short time. For radionuclides for which this pathway could be of importance, such as ^{134}Cs and ^{137}Cs, it would therefore be straightforward to take account of external exposure by measurements of dose rate, combined with estimates of the time that people spent in the area under consideration. Such an evaluation would need to subtract the contribution to external dose rates due to the ambient background radiation. Background dose rates have been published for materials such as sands and sediments[16]. However, for inland soils the variability in background values across the UK is considerable[17], and the preferred option might be to make comparative measurements at a suitable control site.

56 In some cases, more extensive sampling of the original material is unavoidable if the extent of the contaminated area is to be defined. In the particular case of sea washed land, information on the distribution of activity with depth in the soil may be helpful. Alternatively, measurements could be made in other materials that would provide a more direct estimate of exposure. In the case of foodstuffs, it might also be appropriate at this stage to evaluate any additional minor pathways that are not considered in the calculation of the GDLs. An example would be the collection of food from the wild, such as mushrooms or berries. It should be recognised that a possible consequence of the compilation of information is that the limited data used in the original comparison with the GDL may form no part of the final evaluation.

57 If a more rigorous assessment is still indicated, then the introduction of a site-specific habit survey could be considered. The structure of such a programme should be based on the exposure pathways of interest, but in any case should focus on data that would be representative of a full year. The determination of site-specific radionuclide transfer parameters might also be necessary. It must be emphasised that the effort and resources involved in carrying out rigorous habit surveys and radioecological investigations can be substantial; a decision to undertake either type of study should not be made without expert guidance.

58 If a rigorous site-specific assessment implies that doses could approach 1 mSv y^{-1}, the dose limit for members of the public, it would be prudent to seek expert guidance on the assessment protocols adopted. Regulators might in any case require an independent opinion to be satisfied with this conclusion. If the estimated dose exceeded 1 mSv y^{-1}, then the situation should be discussed with the appropriate government departments or agencies.

CONCLUSIONS

59 Generalised derived limits are convenient reference levels against which the results of monitoring can be compared, but care is required in their use. Sampling and measurement procedures should be designed to produce reliable data that can be directly compared with the relevant GDL. The environmental material selected for study should be that which gives the most direct estimate of exposure, although in many cases a material that could give rise to more than one exposure pathway could be sufficient for the purposes of a preliminary assessment. The material selected may in any case be determined by practical constraints.

60 It is important to assess land use and the characteristics of each of the radionuclides of importance in the area in order to get a true picture of the doses received by members of the public. All relevant exposure pathways and radionuclides should be taken into account. The Board recommends a screening level of 10% of the GDL, or the corresponding level of dose of 0.1 mSv y^{-1}, which if exceeded indicates the need for further investigation. The screening level applies to the total utilisation of the GDL by all radionuclides and all exposure pathways; the 10% value does not apply to each individual component.

61 If the 10% value is exceeded, this does not necessarily imply that the resultant dose exceeds 0.1 mSv y^{-1}; rather, a more specific assessment is indicated, taking actual circumstances into account. The GDL system can be used to identify the radionuclides of importance, and the exposure pathways that merit consideration. These exposure pathways and the default assumptions made in the calculations can then be assessed in terms of their applicability to the situation under consideration. Since there is a degree of caution built into the calculation of the GDLs, in many cases inspection of the applicability of radionuclide-independent parameters such as occupancy factors or land use could be sufficient to demonstrate that no further action is required.

62 If a more extensive measurement programme is indicated, the availability of relevant published data should first be explored. Comprehensive habit surveys and radioecological investigations involve considerable effort and expense, and should not be undertaken without expert guidance.

63 It would be prudent to seek expert advice if an assessment gave implied doses that approached 1 mSv y^{-1}. Regulators might in any case require expert opinion to be satisfied with such a conclusion. Dose estimates in excess of 1 mSv y^{-1} should be discussed with the appropriate government departments or agencies.

REFERENCES

1 NRPB. Revised generalised derived limits for radioisotopes of strontium, ruthenium, iodine, caesium, plutonium, americium and curium. *Doc. NRPB*, **9**, No. 1, 1–34 (1998).

2 NRPB. Public exposure: guidance on the 1990 recommendations of ICRP. *Doc. NRPB*, **4**, No. 2, 27–41 (1995).

3 White Paper: Review of radioactive waste management policy. London, HMSO, Cm 2919 (1995).

4 Green, N, Wilkins, B T, and Poultney, S. Radionuclide distribution in potato tubers: implications for radiological assessments. Presented at an International Conference on Low-level Measurements of Radionuclides in Environmental and Biological Materials, Cherbourg, September 1996.

5 Green, N, and Wilkins, B T. The effects of food processing on the radionuclide content of food: implications for radiological assessments. *Radiat. Prot. Dosim.*, **67**, 281–6 (1996).

6 Hutchinson, S M, and Prandle, D. Siltation of the saltmarsh of the Dee Estuary derived from ^{137}Cs analysis of shallow cores. *Estuarine, Coastal Shelf Sci.*, **38**, 471–8 (1994).

7 Brown, J, and Simmonds, J R. FARMLAND: a dynamic model for the transfer of radionuclides through terrestrial foodchains. Chilton, NRPB-R273 (1995) (London, TSO).

8 Camplin, W C. Radioactivity in surface and coastal waters of the British Isles, 1994. Lowestoft, MAFF Directorate of Fisheries Research, Aquatic Environment Monitoring Report No. 45 (1995).

9 Byrom, J, Robinson, C A, Simmonds, J R, Walters, B, and Taylor, R R. Food intake rates for use in generalised radiological dose assessments. *J. Radiol. Prot.*, **15**, No. 4, 335–41 (1995).

10 Robinson, C A, Mayall, A, Attwood, C A, Cabianca, T, Dodd, D H, Fayers, C A, Jones, K A, and Simmonds, J R. Critical group doses around nuclear sites in England and Wales. Chilton, NRPB-R271 (1994) (London, TSO).

11 Robinson, C A. Generalised habit data for radiological assessments. Chilton, NRPB-M636 (1996).

12 Doddington, T C, Camplin, W C, and Caldwell, P. Investigation of external radiation exposure pathways in the Eastern Irish sea. Lowestoft, MAFF Directorate of Fisheries Research, Fisheries Research Data Report No. 22 (1990).

13 Research Surveys of Great Britain Ltd. The use of the Cumbrian coastal area. London, Department of the Environment, DOE/HMIP/RR/91/057 (1991).

14 Wilkins, B T, Cooke, A I, Green, N, Rimmer, D L, and Weekes, T E C. The availability of soil-associated radionuclides for uptake by grazing animals: implications for radiological assessments. *Radiat. Prot. Dosim.*, **69**, 111–16 (1997).

15 HMIP. Routine measurements of gamma ray air kerma rate in the environment. London, HMSO, Technical Guidance Note (Monitoring) M5 (1995).

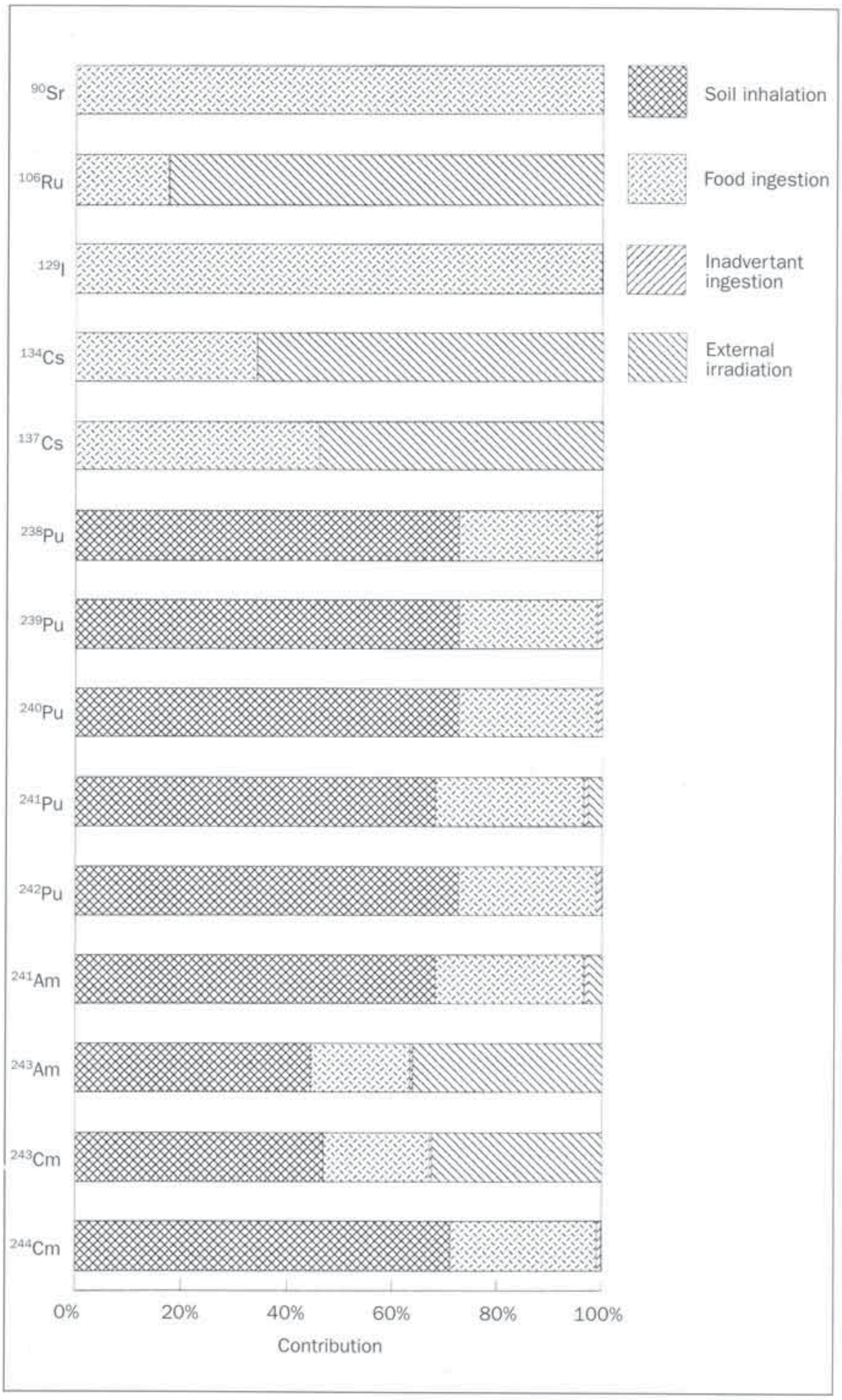
16 Camplin, W C. Radioactivity in surface and coastal waters of the British Isles, 1993. Lowestoft, MAFF Directorate of Fisheries Research, Aquatic Environment Monitoring Report No. 42 (1994).

17 Green, B M R, Lomas, P R, Bradley, E J, and Wrixon, A D. Gamma radiation levels outdoors in Great Britain. Chilton, NRPB-R191 (1989) (London, TSO).

Appendix

CONTRIBUTION OF INDIVIDUAL PATHWAYS TO THE MULTIPLE EXPOSURE PATHWAY GDLs FOR RADIOISOTOPES OF STRONTIUM, RUTHENIUM, IODINE, CAESIUM, PLUTONIUM, AMERICIUM AND CURIUM

FIGURE A1
Contribution of each exposure pathway to the GDL for well-mixed soil (%)



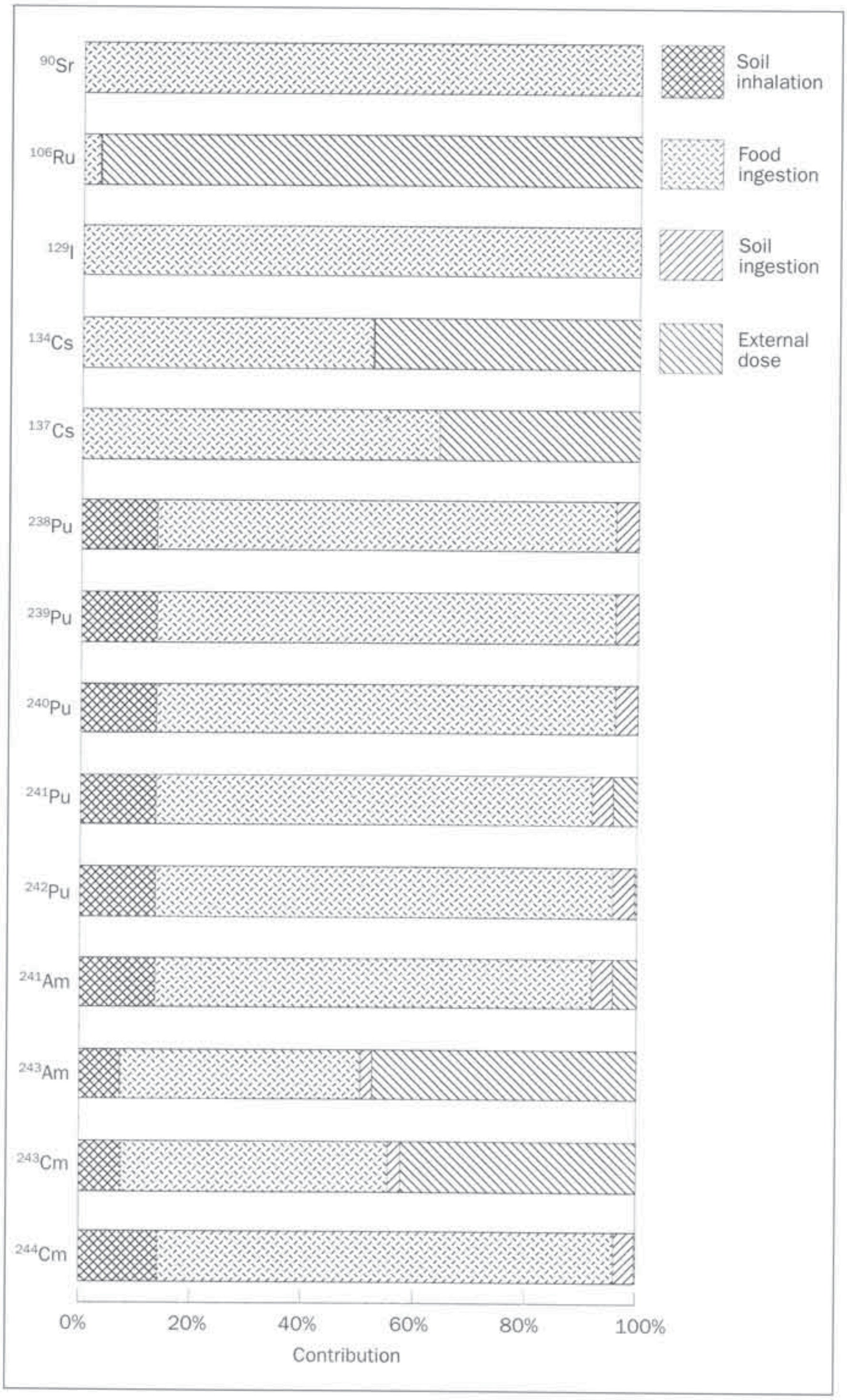
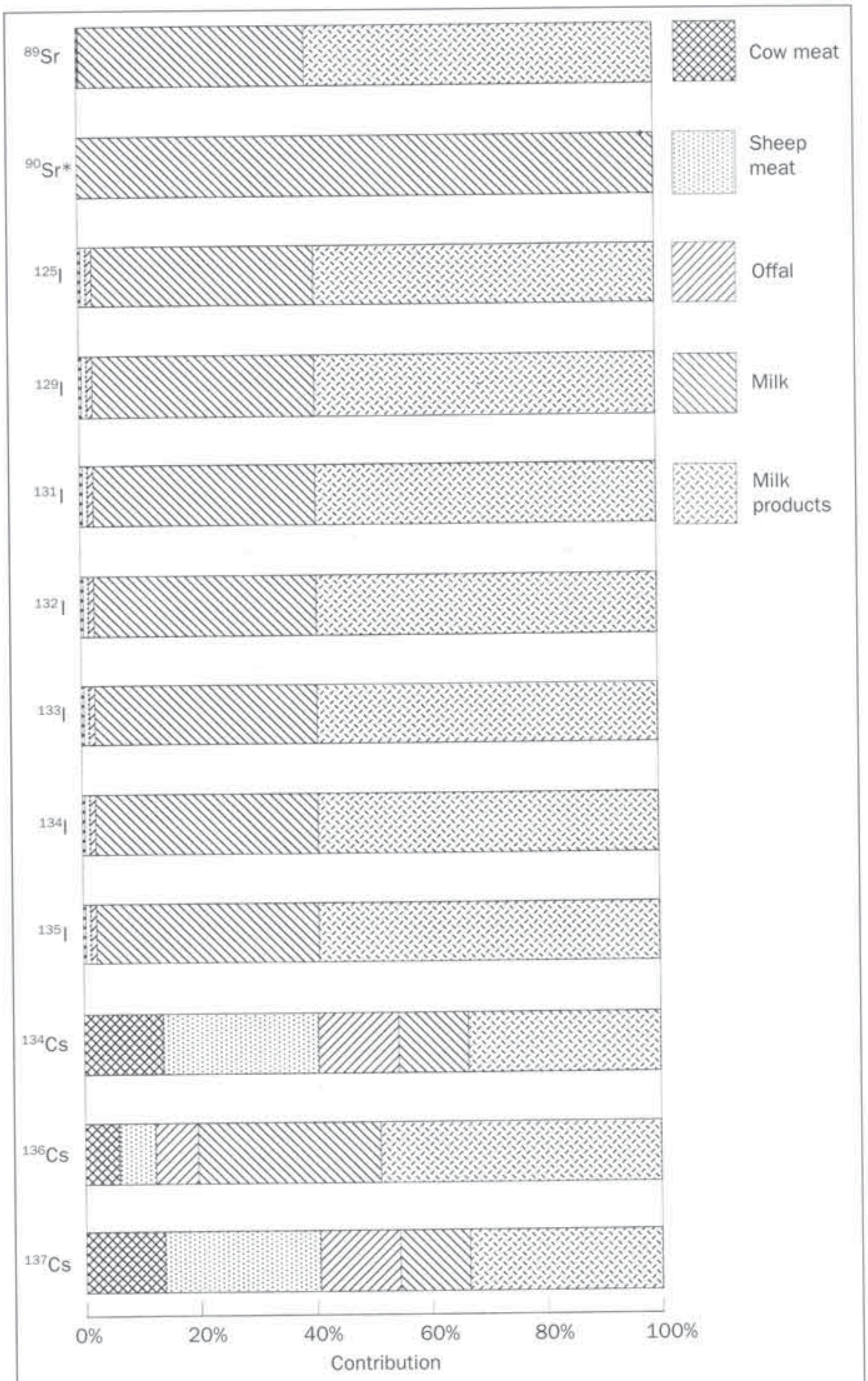


FIGURE A2

Contribution of each exposure pathway to the GDL for sea washed pasture (%)

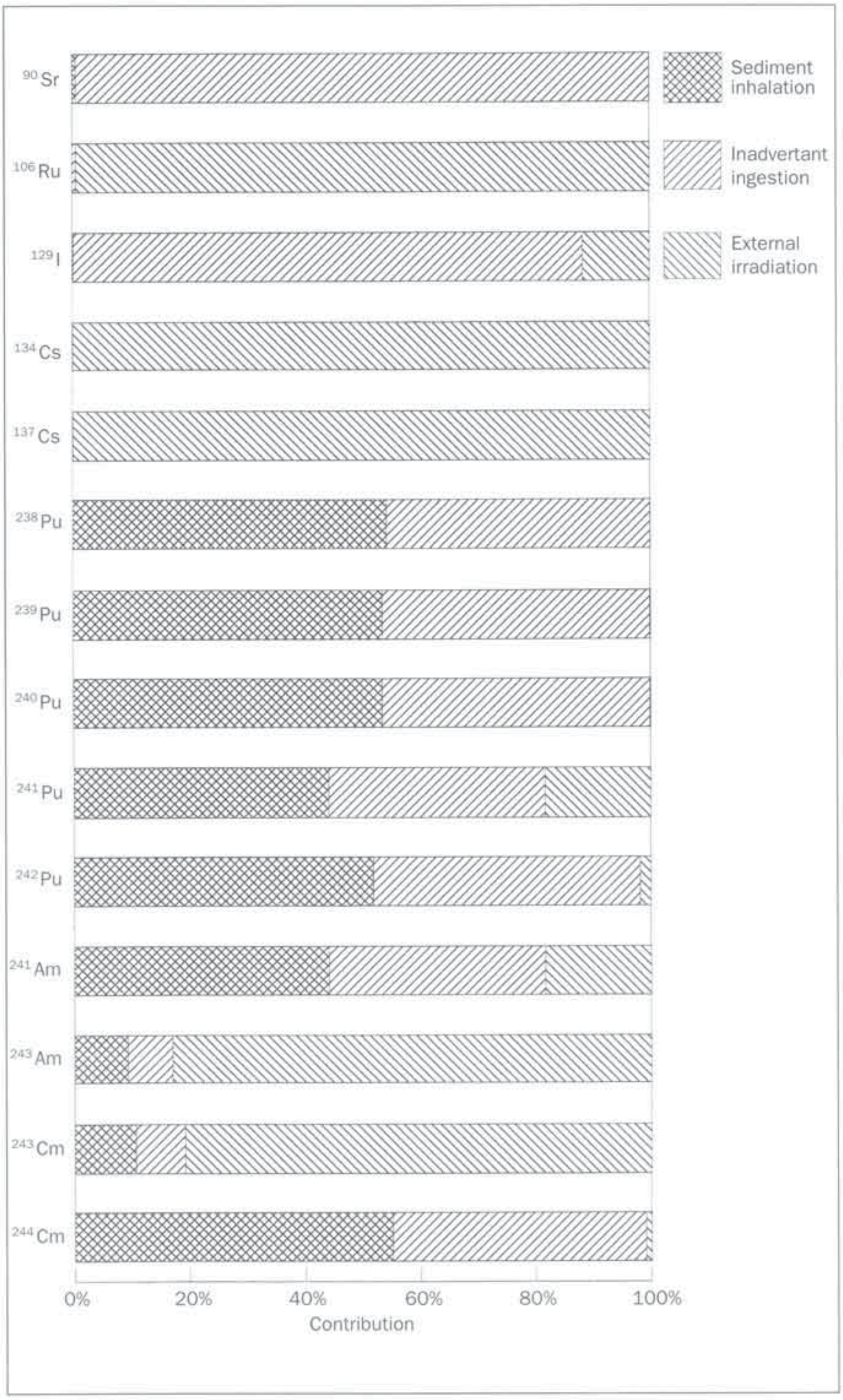
FIGURE A3
Contribution of each exposure pathway to the GDL for grass (%)

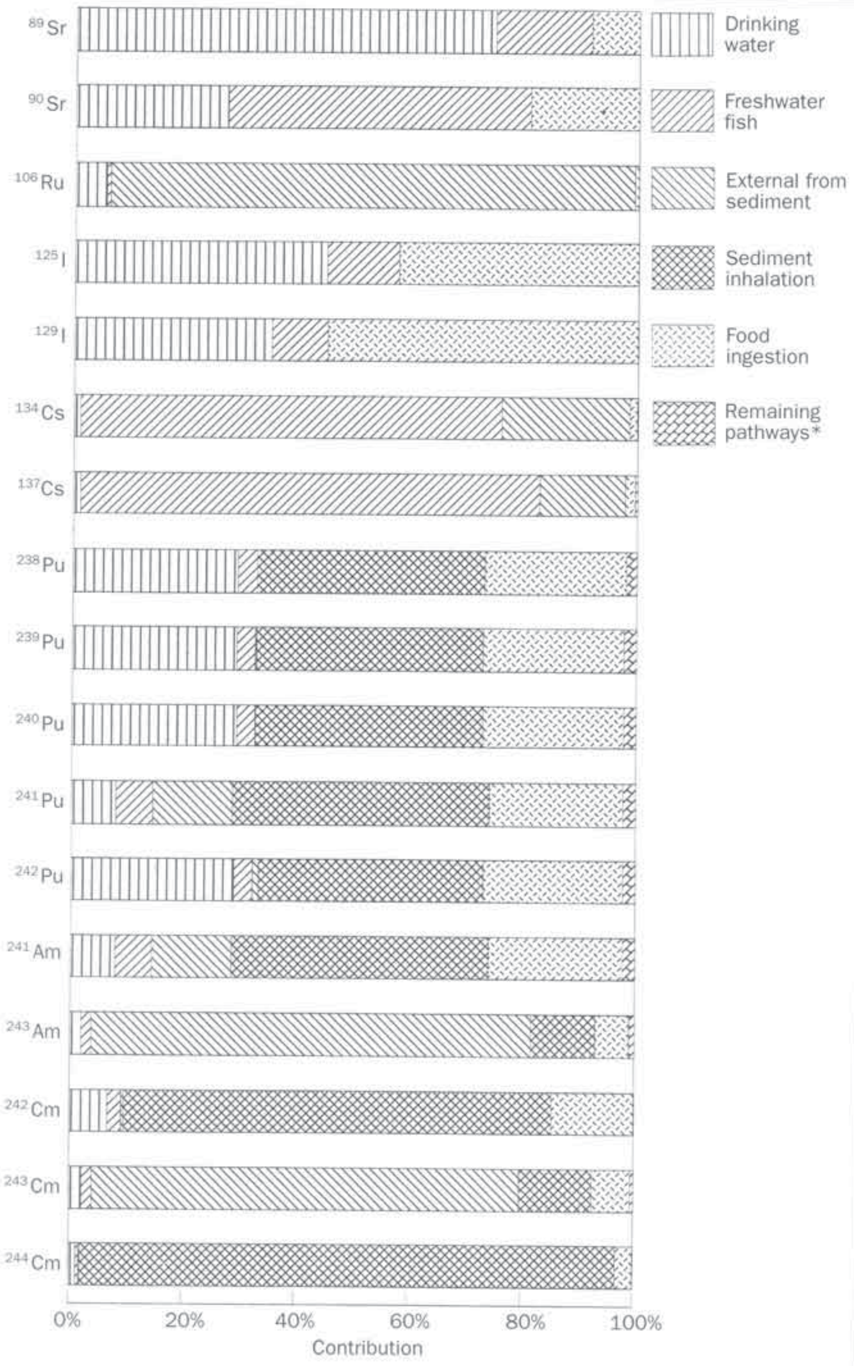


* The GDL for ^{90}Sr is limited by infants in the first year of life on an all-milk diet.

FIGURE A4
Contribution of each exposure pathway to the GDL for marine sediment (%)

FIGURE A5
Contribution of each exposure pathway to the GDL for freshwater sediment (%)

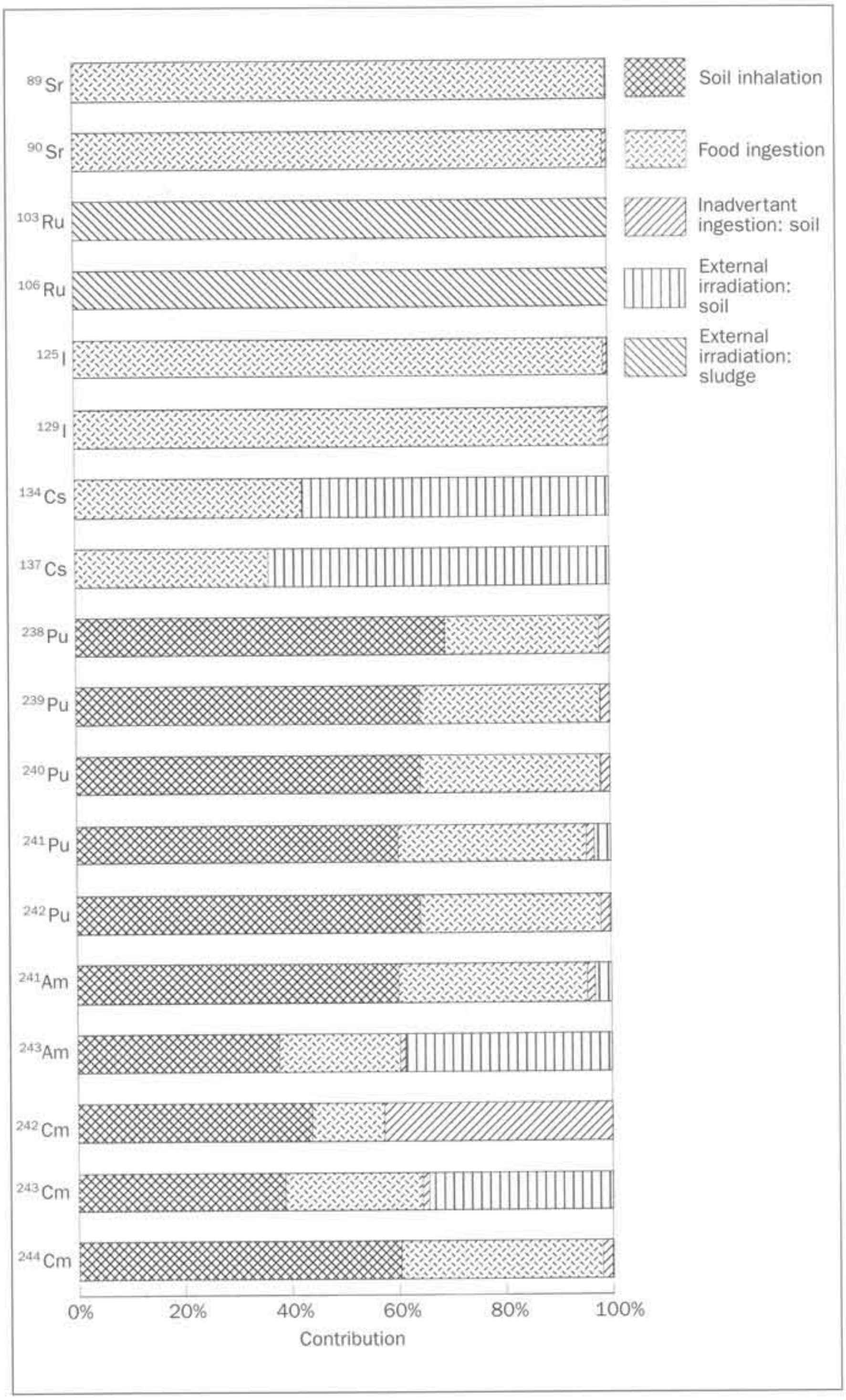




* Remaining exposure pathways are inhalation, inadvertant ingestion and external irradiation from irrigated soil, each contributing < 2% to the GDL.

FIGURE A6
Contribution of each exposure pathway to the GDL for freshwater (%)

FIGURE A7
Contribution of each exposure pathway to the GDL for sewage sludge (%)



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