NDAWG/3/2005

Methods for Assessment of Total Dose in the Radioactivity in Food and the Environment Report

Bill Camplin, Marcus Grzechnik and Carol Smedley, CEFAS

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1 Introduction

The Euratom Directive setting the standards for regulation of ionising radiation in the European Community specifies dose limits for the public (Council of the European Communities, 1996). The Basic Safety Standards (BSS) set a main limit on effective dose of 1 mSv/y and require that the total of contributions to exposure of the population as a whole should be regularly assessed (Articles 13 and 14). The BSS also require that the competent authorities ensure that dose assessments be as realistic as possible for reference groups of the population and that steps be taken to identify the reference groups of the population. Dose assessment of the population should include assessment of external radiation and the intake of radionuclides and the characteristics of the reference groups should be specified (Article 45). In the UK the Environment Agencies have been directed to observe the requirements of the BSS with respect to assessing doses to the public.

An earlier National Dose Assessment Working Group paper considered the principles for assessment of retrospective doses, ie, those that have already been received (Allott, 2005). Such assessments are largely based on environmental monitoring data and are supplemented using models where monitoring data are inadequate or unavailable. This paper builds on these principles and considers the practical application of the assessment of total retrospective dose[*] to the public of the United Kingdom.

In the past, total doses have been calculated from the addition of doses due to liquid discharges with those from gaseous discharges and those from direct radiation. This approach has given comfort that dose limits were not being exceeded, but was not always realistic. This is because the people exposed to these sources generally occur as a number of discrete groups with little overlap of habits. Addition of doses in this way may therefore lead to a significant overestimation of total doses to unrealistic reference groups.

Various methods have been used to address the issue of total dose (Ministry of Agriculture, Fisheries and Food and Scottish Environment Protection Agency, 1998; Robinson CA, Mayall A, Attwood CA, Cabianca T, Dodd DH, Fayers CA, Jones KA and Simmonds JR, 1994; Hancox JJ, Stansby SJ and Thorne MC (2002); Camplin WC, Brownless GP, Round GD, Winpenny K and Hunt GJ (2002)). However the available habits data did not always provide sufficient information to support a realistic dose assessment.

The Radioactivity in Food and the Environment report series presents government monitoring data for the main sources of radioactive waste discharges to the UK environment. The report is published by the bodies responsible for regulation of sources of radioactive waste, the Environment Agency, the Environment and Heritage Service and the Scottish Environment Protection Agency, and by the Food Standards Agency which has UK-wide responsibility for food safety (Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency, 2004). Assessments of dose are made separately for the effects of gaseous and liquid discharges of waste. In this paper these separated dose estimates are referred to as the 'baseline' estimates. Assessments of direct radiation have been undertaken independently by the Health and Safety Executive.

In the last few years, integrated habits surveys have begun to be carried out around nuclear sites throughout the UK. These surveys provide information on ‘total’ habits that may lead to exposure of groups in the population to gaseous and liquid releases and doses from direct radiation. The results of these surveys contribute to the identification

[*] hereafter referred to as total dose

and characterisation of reference groups in the population and are designed to allow more realistic dose assessments to be made.

The integrated habits surveys now provide all relevant data for non-food pathways in addition to the site-specific occupancy and food consumption data that previous studies used to collect. A review of the methods for assessing total retrospective dose was therefore carried out into ways of using the integrated habit data to provide a more realistic assessment of total retrospective dose. Members of the NDAWG Working Group on retrospective dose, CEFAS and the RIFE team considered the approaches that could be used in assessments and proposed five options for further consideration.

In summary this paper:

- Gives a brief review of existing baseline dose assessment methods in RIFE;
- Details 5 options for assessing total dose;
- Gives results of calculations for trial sites: Aldermaston, Hartlepool and Sellafield;
- Determines criteria for comparing the options;
- Ranks the options and draws conclusions.

The outcome of this work has now been incorporated in the RIFE series in the report for 2003 (Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency, 2004).

2 Options for determining total dose

2.1 Baseline estimates in the RIFE report series

The RIFE reports give details of the methods and data used to determine individual doses for members of the public. In summary, the key points relating to the baseline estimates are as follows:

- Doses are assessed for the effects of radioactive waste disposal from the main sources in the UK.
- The effects of gaseous and liquid sources are considered separately because the environmental data and the individuals affected naturally fall into two separate groups. Direct radiation is not included.
- For gaseous sources, the main pathways considered are ingestion of terrestrial foodstuffs such as milk and vegetables, and exposure due to inhalation and external relation from the plume and activity deposited from the plume. Doses are determined for several age groups.
- Terrestrial foodchain doses are largely determined by combining the results of measurement of concentrations in samples with generic consumption rates typical of high rate consumers determined from national surveys. The summation across food groups is determined by the so-called Top-Two method. That is 97.5^{th} and 50^{th} percentile consumption rates are used to calculate doses from all food groups. From this the two food groups that give the highest dose are taken to be consumed at 97.5^{th} percentile rates, while the remainder are consumed at 50^{th} percentile rates. The top-two approach is based on the observation that only a very small percentage of the population were critical rate consumers in more than two food groups and that consuming more than two foods at the 97.5^{th} percentile would result in unrealistically high total calorific intakes.
- Doses from plume related pathways and the associated deposited activity are calculated for a few sites where these pathways are known to be important. Models are used to determine concentrations and dose rates. Inhalation and occupancy data are characteristic of general values judged to be representative of the most exposed.

- For liquid sources, the main pathways considered are ingestion of fish and shellfish and external exposure above contaminated beaches and other substrates. Consumption and occupancy rates have been shown to vary considerably from site to site for these pathways from habits surveys. In view of this and the fact that doses from consumption of terrestrial foodstuffs tend to be relatively small, the doses are assessed on a more realistic basis using site-specific consumption and occupancy rates. Doses are determined for adults only because children tend to eat little seafood and doses to children are invariably less than those adults.
- Where appropriate other less prevalent pathways are also considered, for example ingestion of drinking water, inadvertent ingestion of water and sediments and handling of fishermen's nets.

The results for calculations of dose for 2002 are given in Table 1 for the main sites in the UK. These data were the most up-to-date data available at the time of writing this paper. Where data are available for direct radiation from industry assessments provided by HSE (HSE, 2004), these are included in the table. The simple addition of these doses at each site is also provided as an estimate of the upper limit of the combined effects from all major sources. These sums will overestimate the actual doses received unless the people in the potential critical groups coincide which generally they do not. Establishing a method to obtain more realistic estimates of total dose is the task set for the rest of this paper.

2.2 The 5 new options

A wide number of options for determining total dose are possible, each with its own strengths and weaknesses. The most basic approach is simply to determine doses to each individual with the benefit of individual related consumption and occupancy data at each site. A dose representing the total dose for comparison with limits can then be derived by selecting those doses at the higher end of the spectrum observed.

This basic approach requires all the habits data to be used and does not lend itself to reproduction by others. Therefore 4 other options were proposed to overcome this problem and to present benefits of one kind or another for consideration and comparison. In each case there was a degree of arbitrariness in the choices made in the derivation of data, for example in the categorisation of pathways. There was no wholly 'correct' method. Indeed there were other options that could have been considered. The five options that were chosen are listed below and described further in Table 2. The benefits, and disbenefits, are considered in a set of trial calculations in Section 3.

A. INDIVIDUAL	Full calculation of dose to each individual in habits survey; dose for comparison with limit derived by cut-off method
B. INDIVIDUAL PLUS	Take the mean consumption and occupancy rates of high dose individuals from Option A and apply derived rates in future years to determine total dose
C. CONSTRUCT	Take the mean consumption and occupancy rates of all individuals with high rates and apply derived data in future years to determine total dose
D. TOP-TWO	Derive high and average consumption and occupancy rates for each pathway and use Top-Two method to determine total dose

E. PROFILING	Derive consumption and occupancy rates for each pathway for individuals who exhibit high rates for one of the pathways – a profile; build other profiles by repeating for other pathways and determine total dose as being the highest dose for any profile

In each case:

- Use was made of the outcome of an up-to date site specific habits survey.
- Children aged 1y and 10y were considered as well as adults by using generic child to adult ratios of consumption and occupancy.
- Direct radiation was considered as a separate add-on to the dose from food, gaseous plume related pathways and intertidal external radiation pathways.
- High consumption and occupancy rates and doses for comparison with the dose limit were defined using the cut-off method (Hunt et al, 1982). This method related the maximum rate observed or calculated to the minimum by a fixed amount representing the uncertainty in dosimetric factors. The approach was based on the ICRP homogeneity principle.

The scope of the occupancy and habits data derived for each option is summarised in Table 3. Examples of the data are given for a single site, Sellafield, in Appendix 1.

3. Trial calculations

The 5 options have been applied to concentration and dose rate data from the RIFE report for 2002 (Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency, 2003) as trial calculations for the purposes of testing the options and informing the subsequent ranking exercise. The calculations were performed for 3 sites: Aldermaston, Hartlepool and Sellafield. These were selected as being representative of the range of sites found in the UK. The assessments were not intended to provide a definitive assessment of dose but are set up purely for the purposes of providing experience and outputs to enable a comparison of options.

The generic and site-specific assumptions used in the assessments are provided in Appendix 2. The key features were as follows:

- The main pathways considered were food and external exposure over contaminated substrates such as intertidal areas. Monitoring data for 2002 from RIFE were used. Natural radioactivity was excluded where possible. Some data were based on Limit of Detection values. This approach was cautious.
- At Sellafield model predictions of doses due to gaseous discharges were used to extend the scope of the assessment for pathways involving inhalation of activity and external irradiation from the plume and deposited activity. This should be done for other sites in a complete assessment.
- No consideration of direct radiation was made at this stage.

A summary of results of doses to adults is shown in Table 4 along with those from the baseline methods published in RIFE (Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency, 2003).

Taking into account the different approaches used, each of the new methods agreed reasonably well with the RIFE data and it was difficult to draw distinct comparisons on the basis of dose alone. However some preliminary observations were made. Options A and B gave the most realistic dose because they reflect individuals' habits most directly. Method E approximated these doses most closely but was slightly more conservative

than A and B, giving generally higher doses. Method E was also closer to the RIFE baseline doses at two out of the three sites presented.

Tables 5 and 6 show the doses that were obtained when calculations were conducted for the 10 year-old and 1 year-old age groups respectively. Similar trends were noted in the doses to children, with method E more conservative than methods A and B. Large differences in the Sellafield predictions for children compared to RIFE data were due to the importance of seafood pathways.

Further details of the dose results for Sellafield are given in Appendix 3 as examples of the distribution of dose between pathways and radionuclides. Common features (pathways, nuclides) were often observed for each option.

4. Ranking of options

The main features that were used to rank the options were:

Reproducibility – can others easily use the approach and reassess doses.
Rigour and realism – how good is the match with reality.
Transparency – a measure of the ease of others to understand how the calculations had been performed and what they mean.
Homogeneity – is the group receiving the dose relatively homogeneous with respect to age, diet and those aspects that affect the dose received. This feature has been recommended as being one to use when defining a critical group. It is not a necessary requirement when determining the dose for comparison with limits.

The ranking operation began with a qualitative comparison of the characteristics of each option and this is presented in Table 7. From this analysis, the pros (+) and cons (-) of each option may be concisely summarised as:

A INDIVIDUAL
- **+** Most rigorous and realistic for assessing dose.
- **-** Difficult to present and for others to produce an assessment; potentially inhomogeneous

B INDIVIDUAL PLUS
- **+** Easy to reproduce and present
- **-** Less rigorous and potentially inhomogeneous

C CONSTRUCT
- **+** Easy to reproduce
- **-** Not easy to explain, potentially a very large critical group which will not actually exist

D TOP-TWO
- **+** High homogeneity
- **-** Not fully scientifically robust, critical group does not actually exist, data manipulation difficult to explain

E PROFILING
- **+** Critical group based on dominant pathway, therefore homogeneity criteria more likely to be met, easy to present and replicate
- \- Chance of overestimating dose because of unrealistically small number in group

A working group was formed to make a judgement on these features comprising RIFE co-authors (CEFAS, Environment Agency, Food Standards Agency and SEPA), operators (BNFL) and NRPB. In this case, ranking was performed using a paired comparison technique resulting in a quantitative measure of relative suitability of the option in relation to the features. For example if the group decided that option A exhibited better

rigour and realism when compared with option E, then A was awarded one point and E none. The option which was found to be awarded the highest number of points was taken to be best of the options in terms of the features considered.

The results of the ranking are presented in Table 8. Option E, which involved setting up profiles for each potential critical group was of the highest rank and was therefore selected as the method for making total retrospective dose assessments.

5. Future directions for assessment of total dose from monitoring data

The main direction for further work has been to apply the profiling method E to sites for which integrated habits survey results are available. This has begun in the RIFE report for 2003 where an assessment of total dose is presented for 7 sites: Aldermaston and Burghfield, Cardiff, Dounreay, Hartlepool, Sellafield and Winfrith. Further sites will be added in future reports. Publication of the results of the assessments of total doses to the groups around nuclear sites in the UK meets the BSS requirement to keep records of doses received by reference groups in the population.

These assessments have been developed to include direct radiation from sites with the benefit of data provided by the Health and Safety Executive. They have also incorporated further pathways modelled to allow for the absence of monitoring data where it may be important in determining total dose.

There are two main aims for further work. Firstly it will be necessary to periodically check the results of the application of the profiling option against the more rigorous approach of calculating dose to individuals, Option A. Secondly there remain a number of issues that relate more generally to the assessment of monitoring data and not to just the assessment of total dose. For example we have yet to deal adequately with the interpretation of 'less than' results for some radionuclides in key foodstuffs. These factors result in the current approach tending to provide a cautious estimate of dose and a tension therefore remains with the aim, as stated in the Euratom Basic Safety Standards, of ensuring that estimates of dose to the population are made as realistic as possible.

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Table 1 Results of assessments of dose for separate sources, 2002 (microsieverts)

Site	Liquid wastes	Gaseous wastes	Direct radiation	Total dose expressed as simple sum
Aldermaston	<5	<5	0	<10
Amersham	7	6	240	250
Berkeley and Oldbury	8	13	23	44
Bradwell	19	6	220	250
Capenhurst	11	<5	ND	ND
Cardiff	31	13	0	44
Chapelcross	39	55	<100	<190
Derby	<5	ND	0	ND
Devonport	<5	ND	ND	ND
Dounreay	9	32	<10	<51
Drigg	<5	17	<80	<100
Dungeness	7	120	560	690
Faslane	<5	ND	ND	ND
Hartlepool	<5	<5	<20	<30
Harwell	11	<5	14	30
Heysham	66	<5	<20	<91
Hinkley Point	15	5	<20	<40
Hunterston	17	9	43	69
Rosyth	<5	ND	ND	ND
Sellafield	610	38	19	670
Sizewell	<5	53	28	<86
Springfields	120	<5	0	<130
Torness	5	7	<20	<32
Trawsfynydd	28	8	10	46
Winfrith	7	<5	0	<12
Wylfa	16	<5	5	<26

Notes
1. Data rounded to 2 significant figures.
2. Data for liquid and gaseous sources taken for group with highest dose from RIFE (2003). Data for direct radiation taken from HSE (2004).
3. Sellafield dose from liquid wastes includes a contribution of 420 microsieverts from the legacy of past discharges of natural radionuclides from Whitehaven.
4. Zero entries indicate dose which is indistinguishable from background
5. ND means not determined

Table 2 Description of 5 options for determining total dose

Option and short name	***Description***	***Process***
A. INDIVIDUAL	Full calculation of dose to each individual in habits survey; dose for comparison with limit derived by cut-off method. Use same habits data until new survey is undertaken	• Combine the data from the most recent site-specific habits survey with concentration and dose rate data to determine doses to each individual • Select individuals with doses above 1/3 of the maximum dose • Average the doses to these individuals *NB: Alternatively, percentiles may be taken from the distribution of calculated doses.*
B. INDIVIDUAL PLUS	As A, but in year 1, derive average rates of consumption and occupancy by the critical group and apply these to future years	• In year 1, combine the data from the most recent site-specific habits survey with concentration and dose rate data to determine doses to each individual • Select individuals with doses above 1/3 of the maximum dose • Average the consumption and occupancy habits in each pathway for these individuals, including zero habits • Use this derived set of habits data to determine doses by summation over all pathways until a new survey is available
C. CONSTRUCT	In year 1, construct a secondary habits dataset made up of all those individuals with habits rates defined to be critical ones, then average the rates and apply these to future years	• For each pathway, determine those individuals who have consumption and occupancy rates above 1/3 the maximum rate • Construct a secondary database of all such individuals and their rates for all pathways • Average the rates excluding zeros • Use this derived set of habits data to determine doses by summation over all pathways until a new survey is available
D. TOP-TWO	In year 1, derive critical and average rates for each pathway and apply these to future years. Determine doses using the Top-two method previously adopted for terrestrial pathways	• For each pathway determine critical consumption and occupancy rates by averaging those rates higher than 1/3 the maximum rate. Apply these until a new survey is available • Divide critical rates by three to obtain average rates. This simplifying assumption has been chosen to correspond to observations made with national habits survey data. Other group specific factors could be used. • Calculate doses for all sets of rate combinations that include two critical rates and the remainder as averages • Use the set of habits which gives rise to the highest dose for comparison with the dose limit

E. PROFILING	In year 1, derive profiles of habits rates that correspond to high consumers for each pathway and apply these to future years. Calculate doses for each profile and select the highest dose.	• Starting with the first pathway, use the cut-off method to determine critical individuals. Average the consumption and occupancy rates of each of these individuals and assign the habits rates determined as 'Profile A' • Repeat for the second pathway (Profile B), and subsequent pathways. Use these data until a new survey is available • Use the habits profiles to calculate doses • Use the set of habits which gives rise to the highest dose for comparison with the dose limit

Table 3 Summary of scope of derived adult consumption and occupancy data for a single site

Option and short name	*Derived data scope*
A. INDIVIDUAL	Matrix of ~ 20 pathways by several hundred individuals
B. INDIVIDUAL PLUS	Single row of ~ 20 pathways
C. CONSTRUCT	Single row of ~ 20 pathways
D. TOP-TWO	Double row of ~ 20 pathways; high and average rates
E. PROFILING	Square matrix of ~ 20 by ~ 20 pathways

Table 4 Doses to adults (µSv, 2 sig figs) obtained using various methods at the three sites

	Aldermaston	***Hartlepool***	***Sellafield***
RIFE aquatic	3.5	3.0	240
RIFE terrestrial	2.1	0.36	15
A (INDIVIDUAL) & B (INDV PLUS)	2.3	1.8	250
C (CONSTRUCT)	6.0	2.4	220
D (TOP-TWO)	5.6	3.0	310
E (PROFILING)	4.2	1.9	260

Table 5 Doses to 10 year-olds (µSv, 2 sig figs) obtained using various methods at the three sites

	Aldermaston	***Hartlepool***	***Sellafield***
RIFE aquatic	none	None	none
RIFE terrestrial	1.6	0.46	19
A (INDIVIDUAL) & B (INDV PLUS)	1.1	0.42	84
C (CONSTRUCT)	3.4	0.77	100
D (TOP-TWO)	3.2	0.99	120
E (PROFILING)	2.1	0.44	88

Table 6 Doses to 1 year-olds (µSv, 2 sig figs) obtained using various methods at the three sites

	Aldermaston	***Hartlepool***	***Sellafield***
RIFE aquatic	none	none	none
RIFE terrestrial	2.1	0.13	33
A (INDIVIDUAL) & B (INDV PLUS)	1.5	0.18	30
C (CONSTRUCT)	1.9	0.31	49
D (TOP-TWO)	1.9	0.33	60
E (PROFILING)	1.6	0.23	38

Table 7 Comparison of Options according to criteria of Reproducibility, Rigour and Realism, Transparency and Homogeneity

Option	*Reproducibility*	*Rigour and realism*	*Transparency*	*Homogeneity*
A. INDIVIDUAL DOSE	Full reproducibility would require large amount of 'raw' individual habits data to be made available. Determination of 'critical group' using monitoring data and individual dose calculation is therefore more difficult for others to reproduce.	Most rigorous and realistic method available for assessing doses.	Presentation is difficult. It is not easy to present summary habits and state in summary form what the critical group actually represents (e.g. high fish consumers, local inhabitants). In fact, the calculated dose could include 2 or 3 sub-critical groups.	In principle there is likely to be greater inhomogeneity with respect to habits which does not conform to ICRP principles. This may be circumvented by attempting to pre-select individuals with similar habits (e.g. terrestrial groups, aquatic groups).
B. INDIVIDUAL DOSE PLUS	Easy to present habits which have been used to calculate critical dose and thus allow others to reconstruct dose.	Similar to A but individuals are selected to the critical group based on dose in the year in which the survey is undertaken. It is possible that this selection will not accurately reflect changes in concentrations and dose rates in future years.	The averaging of habits for the selected critical group provides some potential to relate this to a group of people (eg high fish/shellfish consumers or fishermen).	As A
C. CONSTRUCT	As B	Large group selected without rigorous attention to relative importance of pathways	Construction of the critical group is not easy to explain. One set of habit data presented, but may be difficult to assign a real group of people to these habits.	The critical group could potentially consist of a large number of individuals. It is therefore unlikely to meet ICRP homogeneity principle. This may be circumvented by attempting to pre-select individuals with similar habits (e.g. subdivision into terrestrial groups, aquatic groups, near site groups).

D. TOP-TWO	Critical group dose based on small set of habit data enabling others to make assessments based on this data	Reverting to an old, not fully justified approach in terms of top two foods. The extension of this concept to all top-two pathways is arbitrary.	Manipulation of data not easy to explain. The critical combination of habits would not represent real individuals and would be difficult to explain	High rate pathways are limited. Likelihood is that homogeneity is therefore protected.
E. PATHWAY / HABIT PROFILING	As D	Realism is increased as the critical group actually exists.	Selection of the potential critical group by a single pathway allows presentation to be simplified.	Key pathway is automatically defined to be homogeneous

Table 8 Results of ranking options using paired comparisons

Score	Feature				
Option	**Reproducibility**	**Rigour and realism**	**Transparency**	**Homogeneity**	**Total**
A Individual	0	4	2	1.5	7.5
B Individual plus	3.5	2	3	1.5	10
C Construct	3.5	1	1	0	5.5
D Top-two	1.5	0	0	3	4.5
E Profiling	1.5	3	4	4	12.5

Appendix 1 Derived adult consumption and occupancy rates at Sellafield

Option A INDIVIDUAL

A matrix of 27 pathways by 664 individuals. Data not presented in this paper.

Option B INDIVIDUAL PLUS

Pathway	Sea Fish	Freshwater Fish	Crustacea	Mollusca	Cattle Meat	Domestic Fruit	Eggs	Game	Green Vegetables	Honey	Milk	Mushrooms	Offal	Other Domestic Vegetables	Pig Meat	Potatoes	Poultry	Root vegetables	Sheep Meat	Wild fruit and nuts	Distance band 1 (0-0.25km)	Distance band 2 (0.25-0.5km)	Distance band 3 (0.5-1km)	Coal and Sand (Gamma ext)	Saltmarsh (Gamma ext)	Sand, Sand and Stones (Gamma ext)	Sand and Mud (Gamma ext)
Cons (kg or l/y) and occ (h/y)	28.7	0.0	17.3	31.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	380

Option C CONSTRUCT

Pathway	Cons (kg or l/y) and occ (h/y)
Sea Fish	21.8
Freshwater Fish	0.2
Crustacea	12.2
Mollusca	15.0
Cattle Meat	46.3
Domestic Fruit	10.7
Eggs	11.1
Game	11.8
Green Vegetables	20.3
Honey	3.5
Milk	210.0
Mushrooms	0.8
Offal	0.0
Other Domestic Vegetables	12.9
Pig Meat	0.0
Potatoes	75.6
Poultry	3.8
Root vegetables	20.0
Sheep Meat	9.3
Wild fruit and nuts	1.2
Distance band 1 (0-0.25km)	7910
Distance band 2 (0.25-0.5km)	6100
Distance band 3 (0.5-1km)	5810
Coal and Sand (Gamma ext)	160
Saltmarsh (Gamma ext)	400
Sand, Sand and Stones (Gamma ext)	320
Sand and Mud (Gamma ext)	600

Option D TOP-TWO

Pathway	Critical cons (kg or l/y) and occ (h/y)		Average cons (kg or l/y) and occ (h/y)	
Sea Fish	41.3		13.8	
Freshwater Fish	0.2		0.1	
Crustacea	27.0		9.0	
Mollusca	33.7		11.2	
Cattle Meat	46.3		15.4	
Domestic Fruit	32.1		10.7	
Eggs	13.1		4.4	
Game	25.7		8.6	
Green Vegetables	35.8		11.9	
Honey	5.0		1.7	
Milk	260.0		86.7	
Mushrooms	2.1		0.7	
Offal	0		0	
Other Domestic Vegetables	38.4		12.8	
Pig Meat	0.0		0.0	
Potatoes	109.4		36.5	
Poultry	6.6		2.2	
Root vegetables	30.9		10.3	
Sheep Meat	23.6		7.9	
Wild fruit and nuts	3.4		1.1	
Distance band 1 (0-0.25km)	7910		2640	
Distance band 2 (0.25-0.5km)	7010		2340	
Distance band 3 (0.5-1km)	6090		2030	
Coal and Sand (Gamma ext)	160		50	
Saltmarsh (Gamma ext)	400		130	
Sand, Sand and Stones (Gamma ext)	640		210	
Sand and Mud (Gamma ext)	870		290	

Option E PROFILING

Consumption (kg or l/y) and occupancy (h/y) rate	***Pathway***	Sea Fish	Freshwater Fish	Crustacea	Mollusca	Cattle Meat	Domestic Fruit	Eggs	Game	Green Vegetables	Honey	Milk	Mushrooms	Offal	Other Domestic Vegetables	Pig Meat	Potatoes	Poultry	Root vegetables	Sheep Meat	Wild fruit and nuts	Distance band 1 (0-0.25km)	Distance band 2 (0.25-0.5km)	Distance band 3 (0.5-1km)	Coal and Sand (Gamma ext)	Saltmarsh (Gamma ext)	Sand, Sand & Stones (Gamma ext)	Sand and Mud (Gamma ext)
Profile																												
Sea Fish		41.3	0.0	11.6	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	20	190
Freshwater Fish		1.4	0.2	0.0	0.0	0.0	0.0	1.2	0.3	0.0	0.0	0.0	0.1	0.0	0.0	0.0	33.3	2.0	0.0	0.0	0.0	0	0	0	0	0	10	20
Crustacea		43.4	0.0	27.0	17.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	60
Mollusca		23.6	0.0	17.0	33.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	400
Cattle Meat		0.1	0.0	0.0	0.0	46.3	1.4	5.2	0.1	0.1	0.0	113.9	0.2	0.0	2.0	0.0	28.8	2.4	2.8	6.4	0.5	820	460	430	0	0	0	0
Domestic Fruit		0.0	0.0	0.0	0.0	0.0	32.1	6.4	0.0	15.3	1.5	0.0	0.1	0.0	25.5	0.0	65.9	3.1	21.4	1.6	0.3	0	0	0	0	0	0	20
Eggs		0.6	0.0	0.0	0.0	10.9	4.8	13.1	0.0	6.2	0.0	92.0	0.2	0.0	4.7	0.0	30.2	1.9	6.0	3.1	0.8	820	630	500	0	0	10	0
Game		0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0	0	0	0	0	0	0	0
Green Vegetables		1.2	0.0	0.0	0.0	0.0	17.8	11.7	0.0	35.8	0.0	0.0	0.3	0.0	26.3	0.0	81.3	0.7	31.4	1.5	0.6	0	0	70	0	0	0	0
Honey		0.0	0.0	0.0	0.0	0.0	42.1	0.0	0.0	3.5	5.0	0.0	0.0	0.0	12.9	0.0	12.3	2.8	19.0	0.0	0.7	0	0	0	0	0	0	80
Milk		0.4	0.0	0.0	0.0	12.7	1.7	4.8	0.0	0.7	0.0	260.0	0.0	0.0	0.2	0.0	16.4	0.9	3.6	2.0	0.4	1360	590	0	0	0	20	0
Mushrooms		0.0	0.0	0.0	0.1	0.0	11.1	6.6	0.0	12.0	0.1	46.1	2.1	0.0	7.6	0.0	35.3	0.6	15.1	1.7	1.3	0	0	1620	0	0	10	0
Offal		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0
Other Domestic Vegetables		0.0	0.0	0.0	0.0	0.0	21.4	9.3	0.0	32.8	0.0	0.0	0.2	0.0	38.4	0.0	93.2	1.0	35.0	2.3	0.1	0	0	110	0	0	0	0
Pig Meat		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0
Potatoes		0.6	0.0	0.0	0.0	10.5	5.5	6.4	0.0	10.5	0.0	43.1	0.2	0.0	9.6	0.0	109.4	2.4	11.4	0.9	0.3	0	400	30	0	0	0	0
Poultry		0.2	0.0	0.0	0.0	17.7	10.2	6.2	3.4	2.5	0.3	57.8	0.3	0.0	6.9	0.0	31.9	6.6	6.4	6.3	0.6	690	530	500	0	0	0	10
Root vegetables		0.8	0.0	0.0	0.0	4.5	16.5	7.8	0.0	25.5	0.3	29.6	0.2	0.0	19.8	0.0	65.4	1.0	30.9	1.0	1.2	0	0	50	0	0	0	10
Sheep Meat		0.0	0.0	0.0	0.0	49.8	5.4	8.9	0.5	0.3	0.0	139.0	0.4	0.0	2.4	0.0	1.5	3.9	1.9	23.6	2.0	0	2130	2020	0	0	0	0
Wild fruit and nuts		0.1	0.0	0.0	0.0	7.3	3.7	10.0	0.2	8.7	0.0	8.0	0.4	0.0	3.7	0.0	36.0	1.0	10.9	2.0	3.4	0	1110	1810	0	0	0	0
Distance band 1 (0-0.25km)		0.3	0.0	0.0	0.0	18.9	0.0	9.5	0.0	0.0	0.0	221.3	0.0	0.0	0.0	0.0	4.2	1.8	0.0	0.0	0.3	7910	0	0	0	0	0	0
Distance band 2 (0.25-0.5km)		0.0	0.0	0.0	0.0	28.3	7.8	12.4	0.0	0.0	0.0	219.0	0.1	0.0	0.0	0.0	66.2	2.2	2.0	14.2	1.8	0	7010	0	0	0	0	0
Distance band 3 (0.5-1km)		0.7	0.0	0.0	0.0	5.6	1.2	3.8	0.2	0.1	0.0	6.1	0.6	0.0	2.6	0.0	0.5	1.0	0.3	1.5	1.0	0	0	6090	0	0	0	0
Coal and Sand (Gamma ext)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	160	0	0	0
Saltmarsh (Gamma ext)		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	400	0	0
Sand, Sand and Stones (Gamma ext)		4.0	0.0	0.3	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	640	50
Sand and Mud (Gamma ext)		21.8	0.0	0.8	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	40	870

Appendix 2 Assumptions for trial assessments

1. General assumptions and data
2. Aldermaston and Burghfield assumptions and data
3. Hartlepool assumptions and data
4. Sellafield assumptions and data

1. General assumptions and data

- Consumption and occupancy rates were interpreted in terms of the groups of pathways indicated below. Generally concentrations and dose rates do not vary a great deal within each group. Where this was not the case further rules were specified.

- Average rates were defined to be 1/3 critical rates where they were used (in the Top-two method). This simple relationship was derived from consideration of national data. The use of site-specific surveys to define average rates is not satisfactory because such surveys are targeted at high rate consumers and do not attempt to take representative samples of the norm.

- Gaseous plume external radiation and inhalation pathways were only considered for Sellafield in this paper. Consideration of these pathways will be extended to other sites where they are likely to make a significant contribution to dose.

- Direct radiation data were not included at this stage. HSE data will be incorporated in subsequent assessments.

- We have assumed that the sampling programme was adequate to provide data for the most important foodstuffs. As was the case for baseline RIFE calculations, there were consumption data for which there were no measurements of concentrations in food.

- Radionuclide concentrations and dose rates were largely those used in RIFE (2003) dose calculations. They were therefore subject to the selection and other rules specified therein. In addition, there were occasions where the groups used for integration calculations did not marry simply to the concentrations and dose rates used in RIFE (2003). For example, crabs and lobsters were considered separately at Sellafield in RIFE (2003). The approach used for the integrated calculations was to simplify the assessment. Where this has been done, the specific assumptions are stated in the following sections for each site.

- The monitoring data included Limit of Detection (LoD) values. This paper has followed the approach used in the baseline assessments in RIFE; values at LoD were assumed as positively detected values. This approach was cautious and some of the results of the assessment can provide a misleading view of important radionuclides and pathways.

  Child doses were calculated by applying a generic child/adult ratio to the adult consumption and occupancy rate for each group. Site specific child data were not used because there were few such data. The ratios are given below and were derived from Smith and Jones (2003) and Byrom et al (1995). A non-zero consumption rate of fish and shellfish for 1 y old children has been adopted because there was limited evidence from the site-specific surveys that such consumption should be allowed for in assessments in order to ensure that doses are not underestimated.

Group	*Ratio child/adult*	
	10y	1y
Sea Fish	0.20	0.05
Freshwater Fish	0.25	0.05
Crustacea	0.25	0.05
Mollusca	0.25	0.05
Cattle Meat	0.67	0.22
Domestic Fruit	0.67	0.47
Eggs	0.80	0.60
Game	0.50	0.14
Green Vegetables	0.44	0.22
Honey	0.79	0.79
Milk	1.0	1.3
Mushrooms	0.45	0.15
Offal	0.50	0.28
Other Domestic Veg	0.50	0.20
Pig Meat	0.63	0.14
Potatoes	0.71	0.29
Poultry	0.50	0.18
Root Vegetables	0.50	0.38
Sheep Meat	0.40	0.12
Wild fruit and nuts	0.49	0.11
Gamma External	0.50	0.03
Plume pathways	1.0	1.0

'Gamma external' pathways were those associated with liquid discharges and exposure over substrates such as intertidal areas and river banks.

'Plume pathways' were those related to gaseous discharges i.e. inhalation of activity in a plume, inhalation of activity resuspended from deposits to ground, and external radiation from the plume and from deposits on the ground.

- Intertidal external pathways were normally simplified and grouped into 3:

  Gamma external sand
  Gamma external sand and mud
  Gamma external mud or saltmarsh

  Sellafield was an exception because of the higher levels of dose rate observed. In this case activities in Whitehaven harbour were additionally considered over sand and coal. Beta doses were not calculated because their contribution to effective dose was relatively small and their consideration alongside the skin dose limit was not limiting for routine releases of activity to the environment.

2. Aldermaston and Burghfield assumptions and data

- Consumption and occupancy rates were sourced from the Aldermaston/Burghfield habits survey conducted in 2002.

- Game = Rabbits & Hares + Venison.

- Wild fruit and nuts = wild free foods.

- Occupancy on the bankside of River Kennett was taken to represent occupancy on the Thames. A dose rate of 0.013 µGy hr^{-1} was applied after background was removed (as in RIFE (2003)).

- No freshwater fish consumption from the Thames catchment was observed in the habits survey. In RIFE it is assumed that a nominal rate of 1 kg/y should be assessed.

3. Hartlepool assumptions and data

- Consumption and occupancy rates were sourced from Hartlepool 2002 habits survey.
- Game = Rabbits & Hares + Wildfowl.
- Mushrooms = Wild Fungi.
- Gamma external was based on RIFE calculations of dose due to sediments at Seal Sands. This corresponded to an overall dose rate of 0.00067 µGy hr^{-1}.

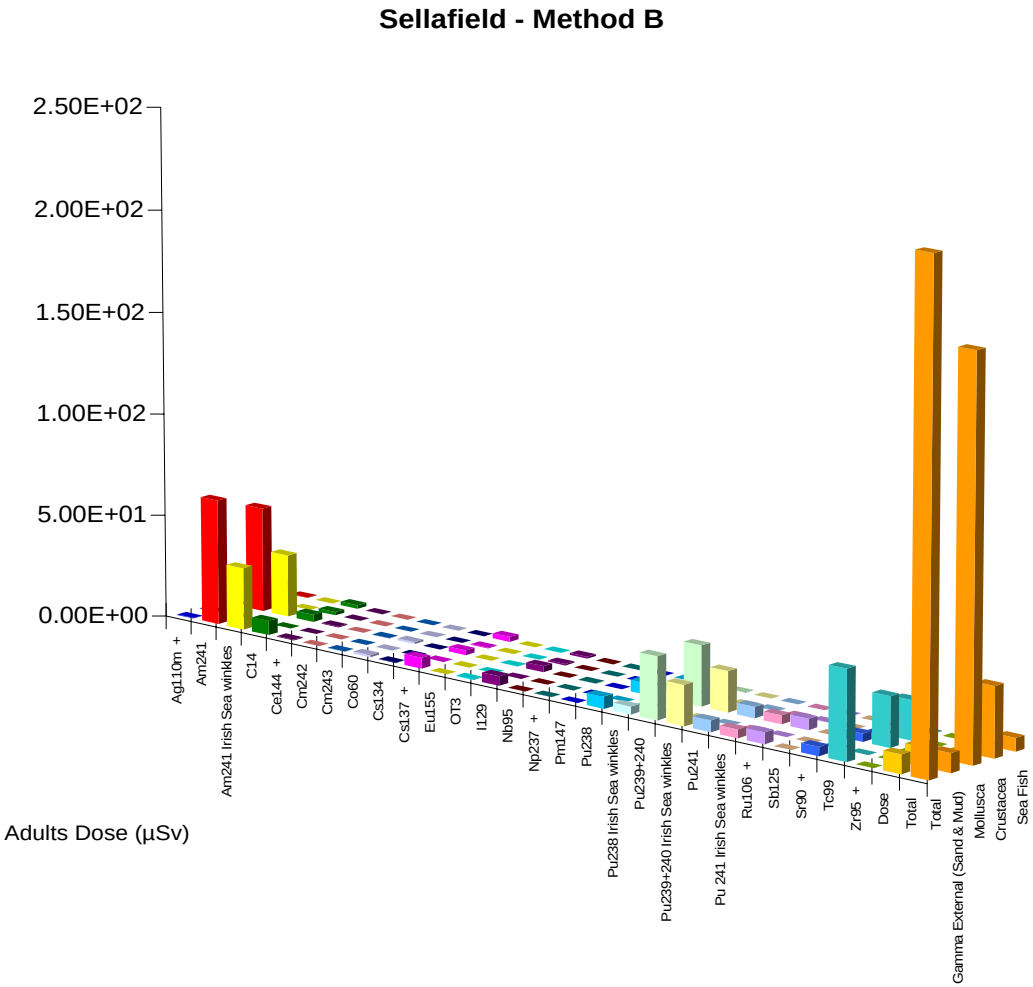
4. Sellafield assumptions and data

- Consumption and occupancy rates were sourced from 2003 Sellafield survey.
- No calculations for enhanced natural radioactivity were performed at this stage.
- Game = Wildfowl + Rabbits & Hares + Venison
- Irish Sea Winkles and Other Molluscs were assumed to be of equal proportions in diet. In practice this meant that concentrations of Am and Pu in the mollusc group were halved since there were dual entries for these nuclides to allow for different dose coefficients for winkles and other molluscs.
- Cod and Plaice were assumed to represent Sea Fish in equal proportions .
- Lobsters and Crabs were assumed to represent crustacea in equal proportions .
- External occupancy was represented by gamma dose rates as follows:
  1) Coal and Sand – 0.05 µGy hr^{-1}
  2) Saltmarsh – 0.12 µGy hr^{-1}
  3) Sand and Mud – 0.025 µGy hr^{-1}
  4) Sand + Sand & Stones - 0.025 µGy hr^{-1}
- A calculation of gaseous plume pathways was included in the Sellafield integrated dose. Dose rates were assigned to areas corresponding to 0-250 m, 250-500 m and 500-1000 m outside the site perimeter. The PC CREAM atmospheric plume model was used to calculate the dose rates (µSv/hr) to adults and children for an entire year (8760 hr/y). They were calculated at the middle of each of the areas, viz 125 m, 325 m and 750 m outside the perimeter fence. The occupancy data obtained in the habits survey of the region was then used to calculate doses based upon hours of occupancy per year in each of the three relevant regions. The occupancy rates for individuals in the habits dataset were taken as the sum of indoor and outdoor occupancy. The combined occupancy was adjusted using the generic factors given below to allow for the effects of shielding. These were the factors used for the baseline RIFE calculations for a residential type occupancy.

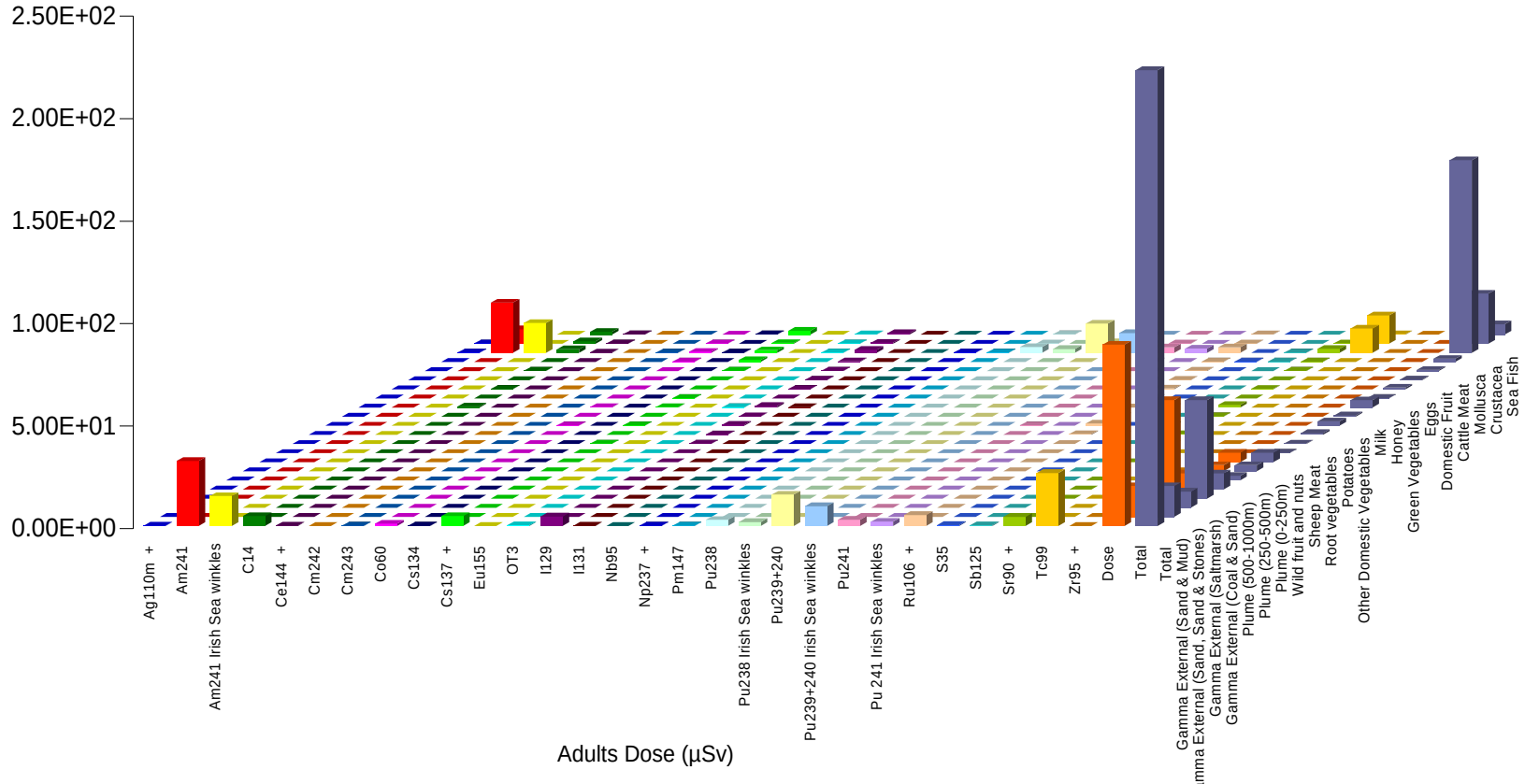
	Fraction of total time spent indoors	Fraction of outside dose rate received indoors Cloud gamma	Fraction of outside dose rate received indoors Deposited gamma
1 y	0.9	0.2	0.1
10 y	0.8	0.2	0.1
Adult	0.7	0.2	0.1

Appendix 3 Examples of results from trial calculations

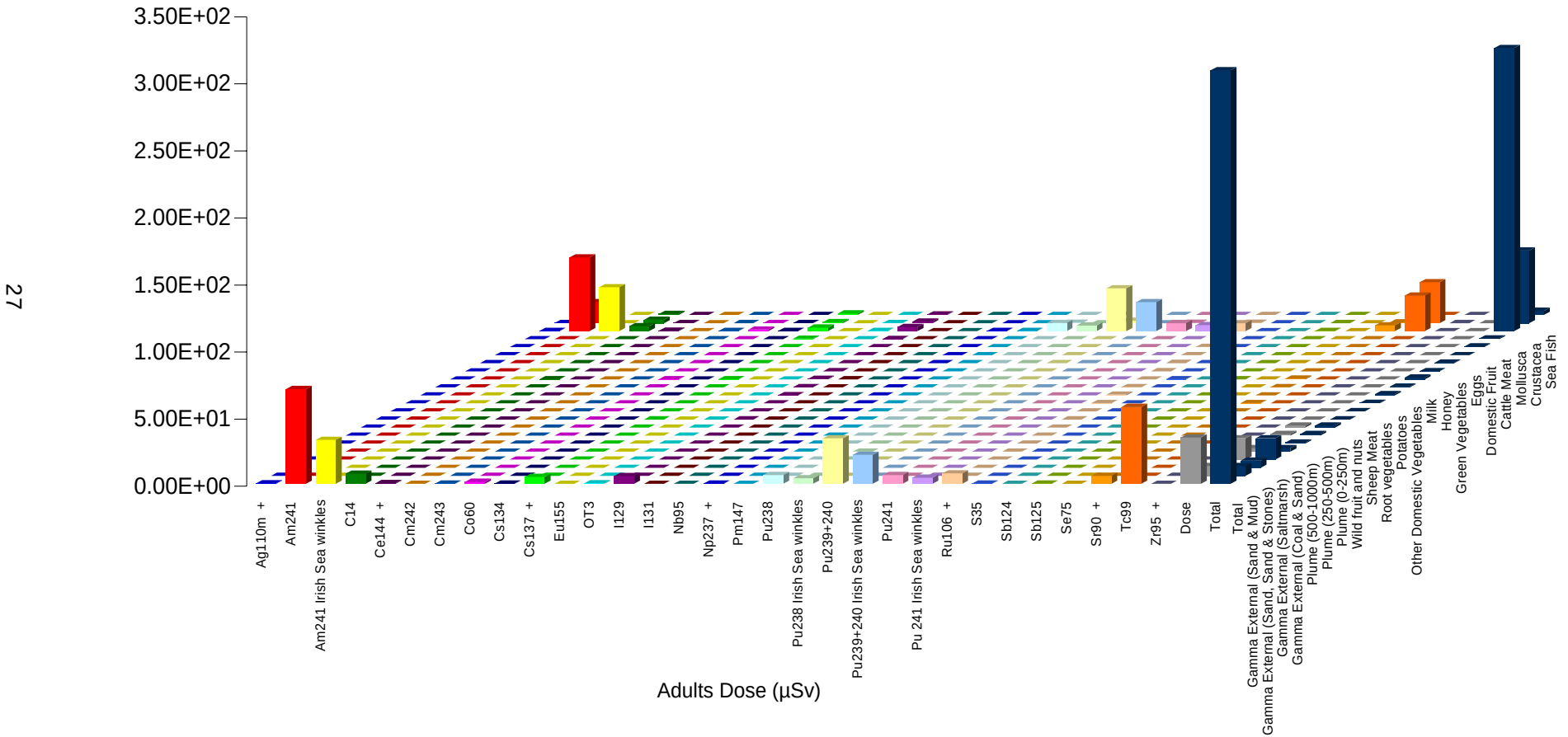
This appendix presents adult dose by radionuclide and pathway for Sellafield for each option. The nuclides and pathways were selected to reflect the most important contributions. Where dose for a nuclide was zero for all pathways, and where dose for a pathway was zero for all nuclides, data were excluded.



Sellafield - Method C



Sellafield - Method D



Sellafield - Method E