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Estimation of Child Doses Using Habits Data and Profiling Total Dose Methodology

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Estimation of Child Doses Using Habits Data and Profiling Total Dose Methodology

The Centre for Environment, Fisheries and Aquaculture Science
Lowestoft Laboratory
Pakefield Road
Lowestoft
Suffolk
NR33 0HT

Marcus Grzechnik, Fiona Clyne and William Camplin

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1. Introduction

The Radioactivity in Food and the Environment (RIFE) report series (Environment Agency et al., 2006) presents United Kingdom government monitoring data and retrospective dose calculations relating to discharges from nuclear sites.

Total (or integrated) doses have been calculated in the RIFE report for the last three years using the 'Profiling Method', as described by Camplin *et al.* (2005). Because child consumption survey data is sparse, the method uses generic ratios for consumption and occupancy rates in order to calculate doses to children from the adult survey data. In particular, the 1-year and 10-year old age groups are focussed on.

Normally, during habits surveys, there are few children identified and interviewed. Therefore, child consumption and occupancy data are sparse. Because of this, actual data for children are not normally considered robust enough for use in dose assessments. Children's habits are therefore calculated from child/adult ratios and adult habits data. The child/adult ratios are derived from national surveys, which sample many more individuals of all age groups and produce more comprehensive child data. These are thus more reliable for generation of child/adult ratios.

It is the aim of this paper to investigate the effect that the use of habits survey data would have on assessed doses. The paper therefore compares and contrasts the total dose to children using actual child habits data and derived values. Doses were re-assessed for 10 nuclear sites in the UK (using data from the total dose assessment in RIFE-11, 2006). Those with the most comprehensive 1-year and 10-year old habits datasets were chosen, namely:

- Aldermaston & Burghfield,
- Amersham,
- Cardiff,
- Devonport,
- Hartlepool,
- Sellafield,
- Sizewell,
- Trawsfynydd,
- Winfrith,
- Wylfa.

Doses to age-groups of children specified by ICRP but not published in the RIFE report (*viz.* 3-month old, 5-year old and 15-year old) are included in this paper for completeness, as is a dose calculation for each individual in the Sellafield survey.

A short description of the profiling method for assessment of total dose is presented in Section 2. The methodology for using generic child ratios (as used in RIFE) is given in Section 3, and the use of child consumption and occupancy rates obtained directly from habits surveys is discussed in Section 4. The results of dose assessments are presented and discussed in Section 5, and Section 6 explores in more detail the dose calculations for individual children in the Sellafield survey. Finally, conclusions and recommendations are given in Section 7.

2. The Profiling Method of Total Dose Assessment

2.1 Introduction

This Section describes the methods, data and results used to assess total dose to the public near nuclear sites from all exposure pathways. The approach uses dietary and occupancy data collected from integrated habits surveys carried out around nuclear sites. The habits surveys are targeted at those most likely to be exposed around the site and gathers data on people's occupancy close to each site and local food intake rates.

2.2 Objectives

The Environment Agencies are required to ensure that doses to the public do not exceed 1mSv/y from all routine man made sources, except certain medical ones. Doses to the public are assessed and compared with the dose limit. For nuclear sites the dose assessment takes into account exposure to radionuclides in food and the environment and direct radiation. The assessment makes use of the monitoring results presented in the RIFE report.

2.3 Methods and data

The calculation method relies on the application of data from site-specific habits surveys (Camplin *et al*., 2005). This is possible because recent surveys have considered the habits of individuals in an integrated way, i.e. information for each individual has been recorded for all of the pathways of interest. Using the habits survey data, the people who are regarded as having the potential to receive the highest doses are identified for each major pathway at each site. Doses to the public from direct radiation are included in the assessment of total dose using information provided by the HSE (Stephen, 2006), who are responsible for assessing the dose to the public from direct radiation.

The methodology may be summarised in four steps:

1) Starting with the first pathway, individuals are selected from the habits data based on the 'cut-off' method whereby all those who have a consumption or occupancy rate within a factor of three of the maximum rate observed for the pathway are selected as members of the potential critical group for that pathway (Hunt *et al*., 1982; Preston *et al*., 1974).
2) Adult habits profiles for a particular pathway (for example fish consumers) are calculated by averaging the habits data selected by the cut-off method. The profile includes averages of all the other habits identified in the integrated habits survey. Habits profiles for children and infants are derived from the adult profiles using scaling factors.
3) Steps 1) and 2) are repeated for each pathway, thereby deriving a profile for each pathway and a series of potential critical groups.
4) Once all pathway profiles have been determined, doses are calculated for each profile using the environmental and food data. Doses from direct radiation (Stephen, 2006) are added to those profiled groups who spend time near to the nuclear site. The group with the highest dose near each site becomes the critical group.

3. Generic Child Ratios

Child consumption rates as used in RIFE total dose calculations have been estimated by applying a generic child/adult ratio to the adult consumption and occupancy rate for each group, mainly due to lack of site-specific data. The ratios used are shown in Table 1, and were derived from Smith & Jones (2003) and Byrom et al. (1995). A non-zero consumption rate for fish and shellfish for 1-year old children has been adopted from the maximum suggested by Smith & Jones (2003) because there has been some evidence from site-specific surveys that such consumption should be allowed for in order to ensure that doses are not underestimated.

Child dose rates calculated using PC CREAM differ from adults when dealing with plume-related pathways. The modelled child dose rates have been used as in RIFE for the relevant age groups to take into account breathing rates and indoor/outdoor occupancy differences. Because of this, the ratio applied in this case is set to 1.0.

Table 1. Child consumption ratios and pathways considered for total dose assessments.

Pathway	***Ratio: child/adult***	
	10-year old	***1-year old***
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	1.00	1.30
Mushrooms	0.45	0.15
Offal	0.50	0.28
Other Domestic Vegetables	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**	1.00	1.00
Direct Radiation	1.00	1.00

* Gamma External pathways are those associated with liquid discharges and exposure over substrates such as intertidal areas and riverbanks.

** Plume pathways are those related to gaseous discharges (e.g. inhalation from the plume, inhalation of resuspended sediments from ground deposits and external radiation from the plume and ground deposits).

4. Site-Specific Habits Survey Data

Ten total dose sites were chosen that contained child habits survey data. The sites and number of observations obtained are shown in Table 2. As a general rule, the smaller the number of observations made for an age group the more uncertain will be the consumption or occupancy ratio defined for that group.

The groups considered are consistent with those used in Habits Reports and recommended by ICRP:

3-month old: less than 1 year,
1-year old: greater than or equal to 1 year, less than 2 years,
5-year old: greater than or equal to 2 years, less than 7 years,
10-year old: greater than or equal to 7 years, less than 12 years,
15-year old: greater than or equal to 12 years, less than 17 years.

Adult doses (greater than 17 years) are not calculated explicitly using the profiling method in this paper; however, doses to adults presented in the RIFE report have been referenced at a later stage.

Table 2. Number of observations of child consumption obtained during habits surveys. It should be noted that some (but not all) pathway profiles for a particular site and age group will include the full number of observations.

Site	***Year***	***3mo***	***1yo***	***5yo***	***10yo***	***15yo***
Aldermaston & Burghfield	2002	8	27	106	50	35
Amersham	2004	1	3	24	25	33
Cardiff	2003	0	0	18	27	41
Devonport	2004	0	1	258**	357**	60**
Hartlepool	2001	0	0	20	26	28
Sellafield	2003*	1	1	27	26	33
Sizewell	2005	0	1	10	17	26
Trawsfynydd	2005	1	1	16	21	21
Winfrith	2003	4	10	38	22	25
Wylfa	2004	0	1	11	17	31

* Sellafield survey area is reviewed annually.
**Devonport includes a large number of children in schools that are surveyed for direct radiation only.

Site-specific habits data were merged into relevant pathways using the total dose profiling methodology as applied to adults in RIFE (see Environment Agency *et al.*, 2006). Environmental concentrations and species breakdown within total dose pathways were applied as for the RIFE-11 calculations. This is unlikely to have had a significant effect on the conclusion.

5. Dose Assessments

Dose assessments have been completed for the five age groups discussed in Section 4 using child data obtained from habits surveys. One-year old and 10-year old calculations are presented first, and compared with RIFE dose assessments. Three-month old, 5-year old and 15-year old doses at the ten sites have been presented and discussed for completeness even though no RIFE comparison can be made.

5.1 One-year olds

Total dose assessments were conducted for the ten sites using the two types of habits data described in Sections 3 and 4 (*viz*. generic ratios with adult habits data and child habits survey data). Doses and dominant profiles obtained for 1-year olds are presented in Table 3.

Table 2 shows that there are limited numbers of observations of 1-year old children at most of the sites. Aldermaston & Burghfield (27 children) and Winfrith (10) are the only sites with numbers surveyed in double figures. This lack of data can make interpretation difficult relative to dose standards.

To help compare the outputs from the two methods, the ratio

$$\frac{\text{Doses using generic ratios and adult habits (as in RIFE)}}{\text{Doses using child habits survey data}}$$

has been calculated for aquatic and terrestrial discharges and is presented for 1-year olds in Table 4. Of particular interest is where the ratio is less than 1 (highlighted numbers, indicating that RIFE doses are less than those obtained using child habits), as well as instances where the methods differ by an order of magnitude or more. The data on doses and ratios for 1 year-olds at each site is discussed below.

Aldermaston & Burghfield

This site has the greatest number of 1-year old children surveyed, however none of these have habits associated with aquatic discharges. The dominant pathways associated with aquatic discharges for generic RIFE ratios are external exposure on the riverbank and freshwater fish consumption – a dose of less than 5μSv was calculated.

Terrestrial discharges show the use of generic RIFE ratios giving a dose approximately 5 times larger than that obtained using child habits surveys. There is no consumption of milk observed for the 1-year old children in the habits survey, but the dominant profile found using the RIFE methodology is milk drinkers. The dominant profiles using the child habits data are plume pathways, potato, fruit, green vegetable and other vegetable consumption. In both cases doses of less than 5μSv were obtained.

Table 3. Comparison of doses to 1-year old children using generic ratios (as in RIFE) or child habits data (2s.f., μSv y^{-1}). Data have been split into aquatic and terrestrial discharge scenarios to increase detail – combined dose is either the aquatic or terrestrial dose in all cases.

		Dose from Aquatic Discharges		***Dose from Terrestrial Discharges***	
Site		***1 y/o Child Habits Data***	***Generic RIFE Ratios***	***1 y/o Child Habits Data***	***Generic RIFE Ratios***
Aldermaston/ Burghfield	*Dose*	0	6.1E-2	3.4E-1	1.6E+0
	Dominant profile	-	External exposure (riverbank)[1]	Plume pathways (0-250m)[2]	Milk consumers
Amersham	*Dose*	0	1.3E-2	2.5E+2	2.4E+2
	Dominant profile	-	External exposure (sand & stone)	Plume pathways (0-250m)[3]	Plume pathways (0-250m)
Cardiff	*Dose*	No Habits Observation	2.6E+0	No Habits Observation	4.6E+0
	Dominant profile		Sea fish consumers		Milk consumers[4]
Devonport	*Dose*	0	5.6E-2	3.3E-3	1.6E-1
	Dominant profile	-	Sea fish consumers	Plume pathways (0-250m)[3]	Domestic fruit consumers
Hartlepool	*Dose*	No Habits Observation	2.0E-1	No Habits Observation	2.0E+1
	Dominant profile		Sea fish consumers		Plume pathways (0-250m)
Sellafield	*Dose*	0	9.5E+1	4.0E+00	1.9E+1
	Dominant profile	-	Mollusc consumers	Milk consumers[4]	Milk consumers
Sizewell	*Dose*	3.0E-1	6.3E+0	3.0E-1	6.4E+1
	Dominant profile	Sea fish consumers[5]	External exposure (sediment)	Sea fish consumers[5]	Wild fruit and nut consumers
Trawsfynydd	*Dose*	0	2.0E+0	2.0E-2	2.1E+1
	Dominant profile	-	External exposure (sand & stone)	Sheep consumers[6]	Plume pathways (250-500m)
Winfrith	*Dose*	2.3E-1	2.0E-1	3.2E-3	1.1E+0
	Dominant profile	Sea fish consumers[7]	Sea fish consumers	Plume pathways (250-500m)[8]	Green vegetable consumers
Wylfa	*Dose*	0	3.1E-1	8.9E+0	9.1E+0
	Dominant profile	-	Crustacean consumers	Plume pathways (500-1000m)[9]	Plume pathways (0-250m)

[1] External exposure (riverbank) and freshwater fish consumers have identical habits in this case.
[2] Plume pathways (0-250m), green vegetable, domestic fruit, potatoes, and other vegetable consumers have identical habits in this case.
[3] Plume pathways (0-250m) and direct radiation have identical habits in this case.
[4] Milk and beef consumers have identical habits in this case.
[5] Sea fish, root vegetable and potato consumers have identical habits in this case.
[6] Sheep, poultry and beef consumers have identical habits in this case.
[7] Sea fish and crustacean consumers have identical habits in this case.
[8] Plume pathways (250-500m) and direct radiation have identical habits in this case.
[9] Plume pathways (500-1000m) and direct radiation have identical habits in this case.

Amersham
Three 1-year olds have been observed at Amersham, each with no habits that may be related to aquatic discharges. A dose of less than 5μSv was obtained using the RIFE methodology, with the dominant profile external exposure to sand and stones.

For both methods the dominant profiles for terrestrial discharges were the inner plume pathways (0-250m), with virtually identical doses obtained. In this case, dose is mainly due to direct radiation from the site.

Cardiff
No habits for 1-year old children were obtained at this site, so comparison between the two methods was not possible. Doses of less than 5μSv were obtained for aquatic and terrestrial discharges using the RIFE methodology.

Devonport
A single 1-year old observation was obtained at Devonport, with no habits associated with aquatic discharges. A dose of less than 5μSv was obtained using the RIFE methodology.

For terrestrial discharge pathways the RIFE methodology produces a dose that is 50 times that obtained using child habits. The dominant pathways also differ in this case. This ratio differential may be of some concern, however in both cases the doses are less than 5μSv, and it is not preferable to rely on a single observation of child habits data as has been obtained in this case.

Hartlepool
No habits for 1-year old children were obtained at this site, so comparison between the two methods was not possible. A dose of less than 5μSv was obtained for aquatic discharges using the RIFE methodology. A dose of 20μSv was obtained for terrestrial discharges, with plume pathways (0-250m) the dominant profile.

Table 4. Ratios of generic RIFE doses to child habits survey doses (2s.f.). Ratios greater than 1 indicate that the (1-year old) generic ratios used in RIFE give rise to greater doses than the (1-year old) children surveyed.

Site	***Aquatic Discharges***	***Terrestrial Discharges***
Aldermaston & Burghfield	-	4.5
Amersham	-	1.0
Cardiff	-	-
Devonport	-	50
Hartlepool	-	-
Sellafield	-	4.8
Sizewell	21	210
Trawsfynydd	-	1000
Winfrith	0.86	360
Wylfa	-	1.0

N.B. Where RIFE prediction is less than the use of child habits data the ratio has been highlighted.

Sellafield
Habits for one 1-year old child were obtained at Sellafield. These habits gave no dose due to liquid discharges. The dose obtained using the RIFE methodology was 95μSv for mollusc consumers.

For terrestrial discharge pathways the RIFE methodology produces a dose that is 4.8 times that obtained using child habits. The dominant pathways are both milk consumption. The smaller dose (child habits) is less than 5μSv, however the larger dose (as reported in RIFE) is 19μSv.

Sizewell
A single 1-year old observation was obtained via habits surveys at Sizewell, with a dose of less than 5μSv obtained for aquatic and terrestrial pathways (sea fish, potato and root vegetable consumption). An aquatic dose from the external exposure (sediment) profile of 6.3μSv was obtained using the RIFE methodology. This dose was 21 times greater than that obtained using habits surveys of children.

The RIFE terrestrial pathway dose for 1-year olds was 64μSv (wild fruit and nut consumers), which is 210 times the value obtained from the child habits survey. These ratios may seem high, but it is not preferable to rely on a single observation of child habits data as has been obtained in this case.

Trawsfynydd
A single 1 year-old observation was obtained at Trawsfynydd, with no habits associated with aquatic discharges. A dose of less than 5μSv was obtained using the RIFE methodology.

For terrestrial discharge pathways the dose obtained using the RIFE methodology was 21μSv from plume pathways (250-500m). This is a factor of 1000 times greater than that obtained using the single 1-year old habits observation, which has no plume pathways associated with the dose. In this case the discrepancy can be explained by the assumption that plume occupancy times for children are identical to those for adults. In this case, the observed child has no occupancy within the plume area, and therefore has no contribution from this pathway. Again, it is not preferable to rely on a single observation of child habits data as has been obtained in this case as the habits observed may not be representative of the 'typical' population.

Winfrith
A total of 10 children in the 1-year old age group were observed during the habits survey at Winfrith. These child habits and the RIFE methodology both give doses under 5μSv with the dominant profile being sea fish consumers.

The RIFE terrestrial pathway dose for 1-year olds was 360 times the value obtained from the child habits survey (for differing profiles), however both doses were less than 5μSv.

Wylfa
A single 1-year old observation was obtained at Wylfa, with no habits associated with aquatic discharges undertaken. A dose less than 5μSv was obtained using the RIFE methodology.

The RIFE terrestrial pathway dose for 1-year olds (9.1μSv) was virtually equal to that obtained using the child habits survey (8.9μSv). Dominant profiles for both methods were plume pathways, but at differing distance bands.

5.2 Ten-year olds

Total dose assessments were conducted for the ten sites using the two types of habits data described in Sections 3 and 4. Doses and dominant profiles obtained for 10-year olds are presented in Table 5.

Table 2 shows that there are many more observations of 10-year old children compared to 1-year olds at most of the sites. Devonport (357 children) and Aldermaston & Burghfield (50) have the greatest number of surveyed individuals, and all ten sites have 10 or more observations. It is expected that more detailed conclusions based on the 10-year old assessments will be able to be made than for the 1-year olds.

To help compare the outputs from the two methods, the ratio;

$$\frac{\text{Doses using generic ratios and adult habits (as in RIFE)}}{\text{Doses using child habits survey data}}$$

has been calculated for aquatic and terrestrial discharges and is presented for 10-year olds in Table 6. Of particular interest is where the ratio is less than 1 (highlighted numbers, indicating that RIFE doses are less than those obtained using child habits), as well as instances where the methods differ by an order of magnitude or more. The data on doses and ratios for 10–year olds at each site is discussed below.

Table 5. Comparison of doses to 10-year old children using generic ratios (as in RIFE) or child habits data (2s.f., μSv y^{-1}). Data have been split into aquatic and terrestrial discharge scenarios to increase detail – combined dose is either the aquatic or terrestrial dose in all cases.

		Dose from Aquatic Discharges		***Dose from Terrestrial Discharges***	
Site		***10 y/o Child Habits Data***	***Generic RIFE Ratios***	***10 y/o Child Habits Data***	***Generic RIFE Ratios***
Aldermaston/ Burghfield	*Dose*	3.2E-2	1.0E+0	1.3E+0	9.5E-1
	Dominant profile	Freshwater crustacean consumers	External exposure (riverbank)[1]	Potato consumers	Milk consumers
Amersham	*Dose*	0	1.9E-1	2.4E+2	2.4E+2
	Dominant profile	-	External exposure (sand & stones)	Plume pathways (0-250m)	Plume pathways (0-250m)
Cardiff	*Dose*	5.5E+0	4.3E+0	1.2E+0	1.7E+0
	Dominant profile	Sea fish consumers	Sea fish consumers	Domestic fruit consumers	Milk consumers[2]
Devonport	*Dose*	1.2E-1	2.2E-1	1.4E-1	2.0E-1
	Dominant profile	Sea Fish consumers	External exposure (sediment)	Green vegetable consumers	Green vegetable consumers
Hartlepool	*Dose*	7.7E-1	4.1E-1	2.8E-1	2.0E+1
	Dominant profile	Sea fish consumers	Sea fish consumers	Root vegetable consumers[3]	Plume pathways (0-250m)
Sellafield	*Dose*	3.6E+2	1.8E+2	1.5E+1	1.2E+1
	Dominant profile	Mollusc consumers	Mollusc consumers	Domestic fruit consumers	Plume pathways (250-500m)
Sizewell	*Dose*	3.5E+1	9.1E+0	7.3E+1	7.5E+1
	Dominant profile	Sea fish consumers	External exposure (sediment)	Plume pathways (0-250m)	Wild fruit and nut consumers
Trawsfynydd	*Dose*	2.0E+1	4.8E+0	2.0E+1	2.0E+1
	Dominant profile	External exposure (sand & stones)[4]	External exposure (sand & stones)	Plume pathways (500-1000m)[4]	Plume pathways (250-500m)
Winfrith	*Dose*	1.4E+0	9.7E-1	5.2E-1	8.5E-1
	Dominant profile	External exposure (sediment)	External exposure (sediment)	Milk consumers	Green vegetable consumers
Wylfa	*Dose*	2.1E+0	2.7E+0	8.9E+0	9.3E+0
	Dominant profile	Crustacean consumers	External exposure (sediment)	Plume pathways (500-1000m)[5]	Plume pathways (0-250m)

[1] External exposure (riverbank) and freshwater fish consumers have identical habits in this case.
[2] Milk and beef consumers have identical habits in this case.
[3] Root vegetable, potato, domestic fruit, green vegetable and other vegetable consumers have identical habits in this case.
[4] Plume pathways (500-1000m), external exposure (sand & stones) and direct radiation have identical habits in this case.
[5] Plume pathways (500-1000m) and direct radiation have identical habits in this case.

Table 6. Ratios of generic RIFE doses to child habits survey doses (2s.f.). Ratios greater than 1.0 indicate that the generic (10-year old) ratios used in RIFE give rise to greater doses than the (10-year old) children surveyed.

Site	***Aquatic Discharges***	***Terrestrial Discharges***
Aldermaston/Burghfield	31	0.75
Amersham	-	1.0
Cardiff	0.78	1.5
Devonport	1.9	1.4
Hartlepool	0.53	71
Sellafield	0.49	0.78
Sizewell	0.26	1.0
Trawsfynydd	0.24	1.0
Winfrith	0.67	1.6
Wylfa	1.3	1.0

N.B. Where RIFE prediction is less than the use of child habits data the ratio has been highlighted.

Aldermaston & Burghfield

A total of 50 10-year olds were observed during the habits survey at Aldermaston & Burghfield. Aquatic dose using this surveyed data was 31 times lower than that obtained using the RIFE methodology, however both doses were below 5μSv. The dominant profiles differed for each methodology.

The dose to terrestrial discharge pathways was also less than 5μSv for both methods of calculation, but in this case the RIFE methodology dose was less than that obtained using the child habits survey by a factor of 0.75. Dominant profiles were milk and potato consumers respectively.

Amersham

During the Amersham habits survey 25 10-year old observations were recorded, with no habits associated with aquatic discharges undertaken. The dose calculated using the RIFE methodology was less than 5μSv.

Terrestrial doses for both methodologies are dominated by the plume pathways (0-250m) profile, giving a dose of 240μSv.

Cardiff

Twenty-seven observations of 10-year olds' habits were made during the Cardiff habits survey. The aquatic dose calculated due to the dominant profile (sea fish consumers) for this survey was 5.5μSv, which is slightly greater than that obtained in RIFE (by a factor of 1.3).

Terrestrial discharge doses were both less than 5μSv. RIFE doses were 1.5 times larger than those obtained using child habits surveys and the dominant pathways differed.

Devonport
A total of 357 individual 10-year olds were surveyed at Devonport. The aquatic doses obtained using the RIFE methodology (sea fish consumers profile) were 1.9 times those obtained from the child habits survey data (external exposure over sediment), however both doses were under 5μSv.

Terrestrial discharge doses for the two methodologies (both to the green vegetable consumers profile) were less than 5μSv. RIFE doses were 1.4 times larger than those obtained using child habits surveys.

Hartlepool
During the habits survey at Hartlepool, data was obtained for 26 10-year olds. Doses due to aquatic discharges were less than 5μSv, with RIFE doses around half the amount of those using the child habits survey.

Terrestrial dose calculated using the RIFE methodology was 20μSv, which is significantly higher (by a factor of 71) than the dose obtained using child habits. This difference can be attributed entirely to the inclusion of an adult rate of occupancy near the site in the RIFE methodology, whereby the dominant dose calculated is from direct radiation. No occupancy within 1km of the site was observed for children.

Sellafield
Data were obtained for 26 children aged 10 during the Sellafield habits survey. The aquatic dose obtained using this child habits data (360μSv) was approximately twice that calculated using the RIFE methodology. The dominant profile for both methods was mollusc consumers. The large difference between these two doses (~180μSv) can be explained by examining the dominant mollusc consumption pathway, which accounts for 85-90% of the dose at Sellafield. The RIFE methodology assumes 25% of the adult consumption (34kg) of molluscs, which gives an overall consumption rate for 10-year olds of 8.5kg per year. The child habits survey gives a consumption rate of molluscs for 10-year olds of 18.6kg, which is over twice the amount used for RIFE calculations and is equivalent to the application of a factor of 0.55 to the adult consumption.

Terrestrial doses obtained using the RIFE methodology (12μSv) is less than that obtained using the child habits data (15μSv) by a factor of 0.78. Dominant pathways also differ, however any differences between the two methodologies are dominated by the aquatic dose at this site.

Sizewell
A total of 17 10-year olds were surveyed at Sizewell. Aquatic doses calculated using the RIFE methodology (9.1μSv; external exposure over sediment) were lower than those obtained using 10-year old habits (35μSv; sea fish consumers); these differ by a factor of 0.26. The main reason for this discrepancy is the choice of profile. The change in habits from adjusted adult data (in RIFE) to 10-year old data has included a significant difference in the occupancy time within the inner plume region. This has accounted for almost

the entire dose difference. It should also be noted that the terrestrial doses are dominant at this site, so this discrepancy is not particularly significant.

Terrestrial doses using the RIFE methodology were 75μSv, dominant profile wild fruit and nut consumers. Using habits survey data, a similar dose (73 μSv) was obtained, but this is attributed to an alternative dominant pathway (plume pathways, 0-250m).

Trawsfynydd

A total of 21 individual 10-year olds were surveyed at Trawsfynydd. The aquatic doses obtained using the RIFE methodology (4.8μSv) were 0.24 times those obtained from the child habits survey data (20μSv). Both doses were due to the same dominant profile (external exposure to sand and stones).

Terrestrial discharge doses for the two methodologies were both to plume pathways of differing distance bands. RIFE doses (20μSv) were equivalent to those obtained using child habits surveys.

Winfrith

A total of 22 children in the 10-year old age group were observed during the habits survey at Winfrith. These child habits and the RIFE methodology both give doses under 5μSv with the dominant profile of external exposure to sediment. The ratio of RIFE dose to child habits is 0.67 in this case.

The RIFE terrestrial pathway dose for 10-year olds was 1.6 times the value obtained from the child habits survey (for differing profiles), however both doses were less than 5μSv.

Wylfa

A total of 17 children in the 10-year old age group were observed during the habits survey at Wylfa. These child habits and the RIFE methodology both give doses under 5μSv, with RIFE dose 1.3 times larger than that obtained using child habits data. Dominant profiles differed in this case.

The RIFE terrestrial pathway dose for 10-year olds (9.3μSv) was equal to that obtained using the child habits survey. Dominant profiles for both methods were plume pathways, but at differing distance bands.

5.3 Three-month olds

Total dose assessments were conducted for the ten sites using the child data obtained in habits surveys. Doses and dominant profiles obtained for 3-month olds are presented in Table 7.

Overall no significant doses to consumption pathways have been found for 3-month olds surveyed – all doses due to consumption are below 5μSv. At Amersham, direct radiation doses dominate for local inhabitants, which is similar to the adult dose.

Table 7. Statement of doses to 3-month old children using child habits data (2s.f., μSv y^{-1}). Data have been split into aquatic and terrestrial discharge scenarios to increase detail – combined dose is either the aquatic or terrestrial dose in all cases.

Site		***Dose from Aquatic Discharges***	***Dose from Terrestrial Discharges***
Aldermaston/ Burghfield	*Dose*	0	6.3E-3
	Dominant profile	-	Plume pathways (500-1000m)[1]
Amersham	*Dose*	0	2.40E+2
	Dominant profile	-	Plume pathways (0-250m)[2]
Cardiff	*Dose*	No Habits Observation	
	Dominant profile		
Devonport	*Dose*	No Habits Observation	
	Dominant profile		
Hartlepool	*Dose*	No Habits Observation	
	Dominant profile		
Sellafield	*Dose*	2.5E+0	0
	Dominant profile	External exposure (Sand & Mud)	-
Sizewell	*Dose*	No Habits Observation	
	Dominant profile		
Trawsfynydd	*Dose*	0	6.2E-2
	Dominant profile	-	Sheep consumers[3]
Winfrith	*Dose*	0	3.2E-3
	Dominant profile	-	Plume pathways (250-500m)[4]
Wylfa	*Dose*	No Habits Observation	
	Dominant profile		

[1] Plume pathways (500-1000m) and direct radiation have identical habits in this case.
[2] Plume pathways (500-1000m) and direct radiation have identical habits in this case.
[3] Sheep and beef consumers have identical habits in this case.
[4] Plume pathways (250-500m) and direct radiation have identical habits in this case.

5.4 Five year-olds

Total dose assessments were conducted for the ten sites using the child data obtained in habits surveys. Doses and dominant profiles obtained for 5-year olds are presented in Table 8.

The most interesting feature to note for the 5-year old age group is that the dose to Sellafield mollusc consumers is 440μSv per year. This exceeds the doses to 1-year olds (95μSv), 10-year olds (180μSv) and adults (410μSv) reported in RIFE.

Table 8. Statement of doses to 5-year old children using child habits data (2s.f., μSv y^{-1}). Data have been split into aquatic and terrestrial discharge scenarios to increase detail – combined dose is either the aquatic or terrestrial dose in all cases.

Site		***Dose from Aquatic Discharges***	***Dose from Terrestrial Discharges***
Aldermaston/ Burghfield	*Dose*	0	2.5E-1
	Dominant profile	-	Milk consumers
Amersham	*Dose*	0	2.4E+2
	Dominant profile	-	Plume pathways (0-250m)[1]
Cardiff	*Dose*	1.5E+1	1.6E+0
	Dominant profile	Sea fish consumers	Milk consumers
Devonport	*Dose*	6.8E-2	1.2E-1
	Dominant profile	Sea Fish consumers	Green vegetable consumers
Hartlepool	*Dose*	1.1E+0	4.0E-2
	Dominant profile	Mollusc consumers	Root vegetable consumers[2]
Sellafield	*Dose*	4.4E+2	8.0E+0
	Dominant profile	Mollusc consumers	Plume pathways (250-1000m)
Sizewell	*Dose*	7.0E-1	2.9E+1
	Dominant profile	Sea fish consumers	Plume pathways (0-250m)[3]
Trawsfynydd	*Dose*	2.3E-1	1.9E+1
	Dominant profile	Fish consumers	Plume pathways (500-1000m)[4]
Winfrith	*Dose*	2.9E-1	8.4E-2
	Dominant profile	Mollusc consumers	Domestic fruit consumers[5]
Wylfa	*Dose*	1.0E+1	1.0E+1
	Dominant profile	Plume pathways (250-500m)[6]	Plume pathways (250-500m)

1 Plume pathways (0-250m) and direct radiation have identical habits in this case.

2 Root vegetable, potato, domestic fruit, green vegetable and other vegetable consumers have identical habits in this case.

3 Plume pathways (0-250m), external exposure (sediment) and direct radiation have identical habits in this case

4 Plume pathways (500-1000m) and direct radiation have identical habits in this case.

5 Domestic fruit and wild fruit and nut consumers have identical habits in this case.

6 This profile also has a large dose due to external exposure, explaining why it dominates both aquatic and terrestrial doses for Wylfa.

This can be explained by the dose per unit intake value for ^{210}Po – this value is approximately four times larger for 5-year olds than for adults. The critical consumption rate of molluscs for adults in the habits survey was 34kg y^{-1}. The critical rate for 5-year old consumption of molluscs obtained in the habits surveys of the children near Sellafield is 13.9kg y^{-1}, which is equivalent to applying a factor of 0.41 to the adult consumption rate. For comparison (as shown in Table 1), factors of 0.05 and 0.25 are applied for shellfish consumption from 1 and 10 year-olds respectively. It can be concluded that the combination of the relatively high rate of consumption of molluscs by 5-year old children (i.e. greater than or equal to 2 years, less than 7 years) observed in the habits survey and the increased dose per unit intake for 5-year olds has caused the high dose observed here.

Finally, it is worthy of note that the high consumption rate of 13.9kg per year for molluscs reported here can be attributed to a single child aged 2 years.

5.5 Fifteen-year olds

Total dose assessments were conducted for the ten sites using the child data obtained in habits surveys. Doses and dominant profiles obtained for 15-year olds are presented in Table 9.

As with other age groups, the dose to the 15-year old Sellafield mollusc consumers dominates at 450μSv per year. The dose to this age group is the highest for the mollusc consumers, and would thus be the critical group if it were reported in RIFE. Dose to adults (410μSv) is, however, not significantly less than the dose to 15-year olds at this site, both dose calculations being within a 10% tolerance.

Table 9. Statement of doses to 15-year old children using child habits data (2s.f., μSv y^{-1}). Data have been split into aquatic and terrestrial discharge scenarios to increase detail – combined dose is either the aquatic or terrestrial dose in all cases.

Site		***Dose from Aquatic Discharges***	***Dose from Terrestrial Discharges***
Aldermaston/ Burghfield	*Dose*	3.0E-2	1.0E+0
	Dominant profile	Freshwater crustacean consumers	Milk consumers
Amersham	*Dose*	1.1E-1	2.4E+2
	Dominant profile	External exposure (sand & stones)	Occupancy in water
Cardiff	*Dose*	1.9E+1	1.3E+0
	Dominant profile	Sea fish consumers	Potato consumers
Devonport	*Dose*	2.3E-1	1.5E-1
	Dominant profile	Sea Fish consumers	Wild fruit and nut consumers
Hartlepool	*Dose*	1.2E+0	3.3E-1
	Dominant profile	Sea fish consumers	Domestic fruit consumers
Sellafield	*Dose*	4.5E+2	1.3E+1
	Dominant profile	Mollusc consumers	Cow meat consumers
Sizewell	*Dose*	6.1E-1	7.8E+1
	Dominant profile	Occupancy in water	Plume pathways (0-250m)
Trawsfynydd	*Dose*	2.1E+1	1.9E+1
	Dominant profile	External exposure (sand & stones)[4]	Plume pathways (500-1000m)
Winfrith	*Dose*	7.3E-1	1.5E+0
	Dominant profile	Plume pathways (500-1000m)	Milk consumers[1]
Wylfa	*Dose*	1.8E+0	1.0E+1
	Dominant profile	Sea fish consumers	Plume pathways (250-500m)

[1] Milk, pig, poultry and sheep meat consumers have identical habits in this case.

5.6 Discussion

Each of the ten sites has been investigated in the preceding sections for five age groups. Doses obtained from aquatic and terrestrial radiological sources have been identified individually using the methodology for child doses applied in RIFE (using adult habits) and relevant child habits surveys.

Differences in dose outputs (and sometimes profiles) have been found at a number of the sites; however some sites have proven to be more important than others. These differences are deemed to be less important (and hence do not require further discussion in the context of RIFE dose assessment) when;

A) No child habits data are obtained,
B) Doses are less than 5μSv, the reporting minimum in RIFE,
C) Doses from one discharge type are dominated by doses from other sources, i.e. doses due to terrestrial discharges are less important due to large doses due to aquatic discharges at a site, or vice versa.

These three situations, and cases where the doses predicted by the two methods are considered to be either equal (within 10%) or require further discussion, are summarised in Table 10.

Overall, Table 10 shows that further discussion is required for Cardiff, Hartlepool, Sellafield, Sizewell and Trawsfynydd. The doses obtained using the two methodologies at the other five sites fall into the categories stated above or give approximately equal dose calculations.

Table 10. Summary of dose comparison between the two methods broken down by site, age-group and discharge type. Doses are denoted to be: Equal – if doses are predicted within 10%; A – No child habits are obtained; B – Doses are less than 5μSv; *C – Doses from aquatic/terrestrial sources are less significant than those from the alternative source; * – Further discussion is required as doses differ significantly.*

Site	***Aquatic Discharges***		***Terrestrial Discharges***	
	1y	*10y*	*1y*	*10y*
Aldermaston/Burghfield	A	B	B	B
Amersham	A	A	Equal	Equal
Cardiff	A	*	A	B
Devonport	A	B	B	B
Hartlepool	A	B	A	*
Sellafield	A	*	*	C
Sizewell	*	C	*	Equal
Trawsfynydd	A	C	*	Equal
Winfrith	B	B	B	B
Wylfa	A	B	Equal	Equal

1-year olds

The differences in dose calculations at Sizewell, Trawsfynydd and Sellafield for 1-year olds may be considered to be less important because the child habits survey is represented by one individual only. This effectively increases the uncertainty in the calculation due to the limited sample size. In all four 1-year old cases highlighted for further investigation the dose obtained using the RIFE methodology is larger than that obtained from using the child habits for the specified discharge pathways. This shows that the RIFE methodology is not underestimating doses in this case, but also indicates that certain key pathways of exposure that contribute to higher doses in adults have not been observed for the 1-year old individual surveyed.

10-year olds

The RIFE methodology shows a significantly higher terrestrial dose to Hartlepool 10-year olds than that obtained using child habits survey data. This can be attributed to direct radiation, whereby no occupancy within 1km of the site was observed for children. The RIFE methodology uses adult data for conservatism.

Doses calculated for RIFE at Cardiff (4.3μSv) have increased by approximately 30% when child habits are used (5.5μSv). The same dominant profile (sea fish consumers) has been found to be responsible for the dose, with a 6.6kg critical consumption rate obtained for fish consumption in the child habits survey. Adult consumption was 24.3kg per year, and when a factor of 0.2 is applied (as in Table 1) the overall 10-year old consumption rate is 4.9kg. In order for the equivalent consumption rate to be obtained for both sets of habits a factor of 0.27 would need to be applied to the adult data. It is interesting to note that a factor of 0.25 is currently applied to adult fresh fish consumption rates for 10-year olds, however 0.2 is applied for sea fish. Overall, however, the dose to 10-year olds observed in the habits survey is extremely close to the 5μSv threshold for reporting in RIFE, and can still be considered to be very low and thus not particularly significant.

Doses to 10-year olds from aquatic discharges at Sellafield have shown the largest overall difference between the two methodologies (180μSv). The difference in dose can be attributed to mollusc consumption rates. From the discussion in Section 5.2, it is apparent that the ratio used in the RIFE methodology for mollusc consumption (0.25 for 10-year olds) is much lower than that observed in the Sellafield child habits survey (0.55). It should be noted, however, that the mollusc consumers profile using 10-year old child habits data is actually made up of 2 individuals, and thus may refer to extreme local habits. The generic habits ratios used in the RIFE methodology are based on much larger population sizes.

6. Individual Dose Assessment

To give a further basis for comparison a dose calculation for specific individuals has been conducted at the Sellafield site. This site has been focussed on due to the higher child doses obtained in Section 5. The methodology known as 'Method A' or the 'Individual Method', as applied by Camplin *et al.* (2005), has been applied in this case. This involves a full dose calculation being performed for each individual in the habits survey.

For doses to children there are two ways to incorporate ICRP dose coefficients:

- To groupings of child age groups, as given in Section 4, or
- As linearly interpolated values according to the age (in years) of the individual.

In this case a linear interpolation has been used, thus defining an age-specific dose coefficient for each child within the survey. Standard adult dose coefficients have been applied to individuals aged 16 and over. Example interpolations for various radionuclides are presented in Table 11.

Table 11. Dose coefficients (Sv Bq^{-1}) for each age group obtained using linear interpolation of ICRP values. Interpolated values are denoted by 'interp', and those provided in ICRP publications are highlighted.

	Po-210	Pu-238	Pu-239+240	Pu-241	Am-241
Adult	1.20E-06	2.30E-07	2.50E-07	4.80E-09	2.00E-07
15 year old	1.60E-06	2.20E-07	2.40E-07	4.80E-09	2.00E-07
14yo (interp)	1.80E-06	2.24E-07	2.46E-07	4.86E-09	2.04E-07
13yo (interp)	2.00E-06	2.28E-07	2.52E-07	4.92E-09	2.08E-07
12yo (interp)	2.20E-06	2.32E-07	2.58E-07	4.98E-09	2.12E-07
11yo (interp)	2.40E-06	2.36E-07	2.64E-07	5.04E-09	2.16E-07
10 year old	2.60E-06	2.40E-07	2.70E-07	5.10E-09	2.20E-07
9yo (interp)	2.96E-06	2.54E-07	2.82E-07	5.18E-09	2.30E-07
8yo (interp)	3.32E-06	2.68E-07	2.94E-07	5.26E-09	2.40E-07
7yo (interp)	3.68E-06	2.82E-07	3.06E-07	5.34E-09	2.50E-07
6yo (interp)	4.04E-06	2.96E-07	3.18E-07	5.42E-09	2.60E-07
5 year old	4.40E-06	3.10E-07	3.30E-07	5.50E-09	2.70E-07
4yo (interp)	5.50E-06	3.33E-07	3.53E-07	5.55E-09	2.95E-07
3yo (interp)	6.60E-06	3.55E-07	3.75E-07	5.60E-09	3.20E-07
2yo (interp)	7.70E-06	3.78E-07	3.98E-07	5.65E-09	3.45E-07
1 year old	8.80E-06	4.00E-07	4.20E-07	5.70E-09	3.70E-07
3 month old	2.60E-05	4.00E-06	4.20E-06	5.60E-09	3.70E-06

As with the Profile Method described in Section 2, a combination of habits survey data and environmental concentrations (as applied in RIFE-11) were used for the individual dose assessment. Doses were calculated for each individual in the survey, and individuals were then ranked according to dose. Individuals with doses above one third of the maximum were then selected and their doses averaged. The result is the dose to the target group.

Doses calculated using the Individual Method are presented in Table 12. These have been given as an overall dose including all surveyed individuals (regardless of age), and have also been broken down into ICRP age groupings. Information regarding the number of individuals surveyed in each age grouping as well as those with high doses (determined by the cut-off method) has been included for information.

Table 12. The doses (μSv) obtained using the Individual Method for calculating total dose at Sellafield. The 'Number of High Dose Individuals' column refers to the number of people chosen by the cut-off method (i.e. doses within a factor of three of the maximum).

Group	***Number of Individuals Surveyed***	***Maximum Dose***	***Number of High Dose Individuals***	***Group Dose***
3-month old	1	2.5	1	2.5
1-year old	1	4.0	1	4.0
5-year old	27	720	4	530
10-year old	30	510	3	470
15-year old	33	690	2*	450
Adults	580	530	10	360
All	670	720	15	480

* Second highest dose (211μSv) included to increase group size even though its value is lower than the cut-off (231μSv).

The breakdown of dose for the various age groups using the Individual Method shows that the highest dose is obtained for the 5-year old group (530μSv). This group includes 4 high dose individuals, as defined by the cut-off method. The 15-year olds are dominated by the highest dose consumer (690μSv) – there are no other individuals amongst the 15-year olds with doses within a factor of three of this maximum value, however the second highest consumer has been included in the group to increase the sample size. The doses to 10-year olds (470μSv) are also higher than the dose calculated to adults (360μSv).

When all age groups are combined the dose is increased to 480μSv. This is 70μSv higher than the highest total dose presented in RIFE.

Additionally, all high dose individuals have a dominant pathway of mollusc consumption.

A tabular comparison summarising doses using RIFE methodology (generic ratios with Profiling Method) and child habits (for both Profiling Method and

Individual Method) is shown in Table 13. Overall, the profiling method used in RIFE can be considered to give a reasonable representation (or over-estimate) for Adult and 1-year old doses in this case. However, the doses to 10-year old children at Sellafield appear to be underestimated in RIFE.

Table 13. Doses (μSv) obtained using RIFE methodology and Child Habits Data (with Profile Method), and the Individual Method for calculating total (aquatic) dose at Sellafield.

Group	***RIFE Method***	***Profiling & Child Habits***	***Individual Method***
3-month old	-	2.5	2.5
1-year old	95	0	4.0
5-year old	-	440	530
10-year old	180	360	470
15-year old	-	450	450
Adults	410		360
All ages	-		480

7. Discussion and Recommendations

Retrospective dose assessments have been conducted for ten nuclear sites around the United Kingdom to compare and contrast two methods of calculating doses to children. The first of these methods is equivalent to that used in RIFE-11, with generic child dose ratios for 10- and 1-year olds applied to adult consumption rates. The second methodology used data for these age groups from site-specific (and age-specific) habits surveys.

It has been found that at five out of the ten sites (*viz*. Aldermaston & Burghfield, Amersham, Devonport, Winfrith and Wylfa) either:

1) Doses from both methods are equal,
2) No child habits data were obtained,
3) Doses are less than 5μSv, the reporting minimum in RIFE, or
4) Doses from one discharge type (aquatic or terrestrial) are dominated by doses from the other source. For this dominant source, any of the three points mentioned above may apply.

These sites do not require further discussion, as the adoption of alternate child consumption ratios will not significantly change the doses compared with those already presented in RIFE.

At three more sites (Hartlepool, Sizewell and Trawsfynydd) the doses calculated using the RIFE methodology are significantly higher than those calculated using child habits data. This can be attributed to certain habits (such as occupancy close to the site) that are applied to children at the same rates as adults. At certain sites the RIFE methodology may be refined where these child habits are known via specific survey information.

Doses at Cardiff were relatively small (just above the 5μSv threshold), but the dose using child habits survey data was 30% higher than that obtained using the RIFE methodology. This difference could be overcome by changing the child consumption ratio of sea fish (currently 0.2) to match that of freshwater fish (0.25).

Calculations for 10-year old aquatic doses at Sellafield show the most significant differences in dose between the two methodologies. In this case, the high consumption rates of molluscs observed during the surveying of childrens' habits has meant that the dose due to child habits is significantly greater than that calculated using the RIFE method. It has been shown that the dose to 10-year olds calculated using the child dose methodology (360μSv) is twice that obtained for 10-year olds in RIFE-11 (180μSv).

Furthermore, it is worthy of note that the Sellafield (aquatic) doses calculated for other age groups have given rise to doses that exceed those reported in RIFE for adults (reported as 410μSv). The dose to Sellafield mollusc consumers obtained for 5-year olds (440μSv) and 15-year olds (450μSv) exceeds the adult dose, but remains within 10% of the RIFE value.

Additional individual dose calculations performed at Sellafield have shown doses as high as 720μSv (for a 2-year old); however, the dose to a critical group including all ages has been calculated at 480μSv. The dominant pathway for dose is mollusc consumption.

In conclusion, we consider that this analysis shows that **the existing methods and data for calculating child dose in RIFE are fit-for-purpose**. In particular, the use of generic factors to determine child habits is appropriate. It should also be noted that the differential between doses using each of the methods investigated here becomes less significant when compared to the uncertainties in dose prediction, such as variations in natural background or dose coefficients.

However, it is recommended that further work is undertaken to improve estimates of generic child habits, making use of the results obtained from site-specific habits surveys. Such an analysis is likely to result in a doubling of the shellfish consumption ratio for the 10-year old age group. If such a change is adopted there will be a more realistic estimate of dose made for that age group.

There remains an issue for shellfish consumption ratios at ages between 2 and 7. No age group currently represents their consumption in RIFE, but it is evident that it can be important. It may be prudent to accept that the 1-year old age group must take account of consumption beyond its defined range of 1-2 years. We recommend the analysis is extended to consider options for dealing with this.

8. Acknowledgements

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Suffolk NR33 0HT UK

Tel +44 (0) 1502 56 2244
Fax +44 (0) 1502 51 3865
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