TA6 - Radiation Protection of the Public and the Environment

Understanding Pathways of Exposure Using Site-Specific Habits Surveys, Particularly New Pathways and Methodologies

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1. Introduction

There are three potential sources of radiation exposure from a nuclear site: liquid and gaseous radioactive discharges, and direct radiation. The public can come into contact with these sources of radiation in a number of different ways, known as pathways of exposure. Examples of these exposure pathways include consumption of fish caught near to the aquatic discharge outlet, consumption of food grown locally to the site, occupancy within the immediate vicinity of the site, or occupancy over intertidal sediments near the site. Assessment of radiation dose from these pathways requires an estimate of consumption and occupancy rates. In the United Kingdom (UK) these are obtained either from UK national surveys of diets, consumption rates and other habits or by local surveys in the vicinity of licensed nuclear facilities known as 'habits surveys'. The habits survey methodology essentially involves visiting the local area surrounding a nuclear site, identifying groups of individuals who have the greatest potential for exposure to radiation from site discharges or direct radiation, and collecting information about the type and extent of these people's habits. These habits data, together with concentrations of radioactivity in food and the environment, and dose coefficients, allow a combined dose from all pathways to be calculated (Grzechnik *et al*., 2006).

Over the years, the methodology for conducting habits surveys has evolved as emphases change. This paper highlights some of the more recent changes incorporated into the methodology and summarises the uniqueness of certain pathways of exposure at specific sites. Some site-specific information on critical rates of consumption and occupancy is also presented.

2. Background

2.1. Historic habits surveys

Habits surveys have been conducted by the Centre for Environment, Fisheries & Aquaculture Science (Cefas) and its predecessor organisations at nuclear sites in England, Scotland and Wales since 1954. In addition, habits surveys have also been conducted on the south-west coast of Scotland, the eastern coast of Northern Ireland and the Channel Islands. Figure 1 shows the locations of all nuclear sites currently considered as potential sites for habits surveys.

Figure 1. Locations of UK nuclear licensed sites where habits surveys are conducted.

In 1954, habits surveys began to be carried out for the Ministry of Agriculture, Fisheries and Food (MAFF) for pathways of exposure relating to liquid radioactive discharges (Hampson, 1957). For pathways of exposure relating to gaseous radioactive discharges generic statistics were used for assessments until 1996, when terrestrial site-specific surveys were introduced. Exposure to direct radiation was first considered in habits surveys for the Health and Safety Executive (HSE) in 1992.

In recent years combined surveys have been introduced. Combined surveys investigate pathways of exposure for all three sources of radiation (liquid and gaseous discharges and direct radiation) for each individual involved. Consumption and occupancy rates are recorded in a purpose-built database and in a single site-specific report. These surveys were introduced in 1999 in Scotland for the Scottish Environment Protection Agency (SEPA) and in 2001 in England and Wales for the Food Standards Agency (FSA). Since 2002, combined habits surveys in England and Wales have been carried out jointly for the Environment Agency (EA), FSA and HSE – that is those organisations responsible for ensuring that the public is protected in accord with national policy. The combined approach has enabled the calculation of doses for the combination of pathways. Table 1 shows the sites of all combined habits surveys conducted by Cefas, the site functions, the year the survey was conducted and who it was conducted for. Habits survey reports can be accessed via the Cefas website (www.cefas.co.uk).

2.2. Current radiological protection framework

UK policy on the control of radiation exposure via routine discharges from nuclear licensed sites has long been based on advice from the International Commission on Radiological Protection (ICRP). Of current relevance are the ICRP 60

Recommendations (ICRP, 1991), which embody the principles of justification of practices, optimisation of protection, and dose limitation.

Table 1. Combined habits surveys conducted by Cefas in the UK.

Year	***Customer***	***Site name***	***Site activity at the time of survey***
1999	SEPA	Dounreay	Decommissioning & research
		Rosyth	Defence establishment
2000	SEPA	Chapelcross	Power generation
		Faslane	Defence establishment
2001	FSA	Berkeley/Berkeley Centre/Oldbury	Berkeley–decommissioning/Berkeley Centre-research/Oldbury-power generation
		Heysham 1 & 2	Power generation
		Sizewell A & B	Power generation
	SEPA	Hunterston A & B	A-decommissioning B-power generation
		Torness	Power generation
2002	EA, FSA & HSE	Aldermaston/Burghfield	Defence establishment
		Drigg	Low level nuclear waste repository
		Hartlepool	Power generation
2003	EA, FSA & HSE	Cardiff	Radiochemical production
		Sellafield	Fuel reprocessing (includes Calder Hall-decommissioning & Windscale)
		Winfrith	Decommissioning & research
	SEPA	Dounreay	Decommissioning & research
2004	EA, FSA & HSE	Amersham	Radiochemical production
		Devonport	Defence establishment
		Wylfa	Power generation
2005	EA, FSA & HSE	Dungeness A & B	Power generation
		Sizewell A & B	Power generation
		Trawsfynydd	Decommissioning
	SEPA	Chapelcross	Decommissioning
		Rosyth	Defence establishment

ICRP 60 was used in the formation of the European Union (EU) Basic Safety Standards (BSS) Directive 96/29/Euratom (CEC, 1996). Dose standards from this document and guidance from the International Atomic Energy Agency (IAEA) (1996) were incorporated into UK law in Ionising Radiation Regulations 1999 (IRR 99) (UK Parliament, 1999). In order to implement these dose standards Environment Agencies were issued with Ministerial Directions (The Scottish Executive, 2000; DETR, 2000a; The Welsh Assembly, 2002). The dose standard most relevant to habits surveys is that the sum of all radiation exposures does not exceed the dose limit of 1 mSv per year. Under IRR 99 the HSE is responsible for the regulation of direct radiation from operators' sites. For nuclear sites this function is carried out by its Nuclear Installations Inspectorate (NII).

Under the Radioactive Substances Act 1993 (RSA 93) (UK Parliament, 1993), Environment Agencies authorise discharges of radioactive waste. The FSA is a statutory consultee in this process in respect of nuclear licensed sites, and has the responsibility to ensure that any radioactivity present in food does not compromise food safety, and that authorised discharges of radioactivity do not result in unacceptable doses to consumers via the food chain. The FSA must also ensure that doses to the public via the food chain are within accepted EU limits.

In the UK, the method of protecting the public from radiation is based on the concept of a 'critical group' as recommended by ICRP (1966). A consultation paper on Statutory Guidance to the EA on the Regulation of Radioactive Waste Discharges (DETR, 2000b) affirms that for the UK, protection of the critical group is the appropriate radiological protection methodology to use. The critical group must be "…small enough to be reasonably homogenous with respect to age, diet and those aspects of behaviour that affect the doses received. Such a group should be representative of those individuals in the population expected to receive the highest dose…" (ICRP, 1966). It follows that if the dose to the critical group is acceptable in relation to relevant dose limits and constraints, doses to members of the public who are less exposed to radiation from the site will also be acceptable. Thus the principle of critical groups provides overall protection for the public. In the UK habits surveys have now become the preferred vehicle for identifying the critical group.

3. Habits survey methodology

3.1. Survey design and preparation

Preparatory work for habits surveys involves identifying relevant site-specific exposure pathways and establishing the individuals or groups of individuals involved. This is undertaken by liaising closely with people who have a wide knowledge of the local area, such as local authorities, Fisheries Inspectors, local clubs (including angling, beekeeping and horticultural associations), as well as nuclear site representatives and EA or SEPA site inspectors.

The areas potentially affected by the three sources of radiation (liquid and gaseous discharges and direct radiation) are used to determine the geographical extent of the survey areas. Pathways relating to liquid discharges are investigated in an aquatic survey area defined by considering site-specific local parameters; for example at coastal sites hydrographic information such as the tidal excursion is used. Pathways relating to gaseous discharges are investigated in a terrestrial survey area, which is defined as being the area contained within a circle of radius 5 km from the site centre. At Scottish sites there is the option of extending this radius up to a maximum of 20 km if conditions dictate that it is necessary. In the case of direct radiation exposure pathways, the survey area is defined as the area within 1 km of the licensed site. Table 2 shows the commonly identified pathways of exposure, that is those identified at 6 or more of the 20 sites where combined habits surveys have taken place.

Table 2. Commonly identified pathways of exposure.

Pathways of exposure relating to liquid radioactive waste discharges
Consumption of: fish, crustaceans, molluscs, wildfowl
Intertidal occupancy over: mud, rock, salt marsh, sand, sand and mud, sand and stones
Handling of: fishing gear, sediment
Occupancy: in water, on water
Pathways of exposure relating to gaseous radioactive waste discharges
Consumption of: green vegetables, other vegetables, root vegetables, potato, domestic fruit, milk, cattle meat, pig meat, sheep meat, poultry, eggs, wild/free foods, rabbits/hares, honey, wild fungi, venison, fish
Pathways of exposure relating to direct radiation
Occupancy: indoors, outdoors

3.2. Data collection

During the survey individuals who have been identified as having a higher potential to be exposed to radiation from a nuclear site are contacted and asked whether they would be willing to be interviewed about their relevant activities. Questions are used to establish consumption, occupancy and handling rates for all exposure pathways. At this stage familiar terms such as the number of chicken eggs consumed per week are used in order to quantify the results. In combined surveys interviewees are asked, where possible, about exposure pathways relating to all three sources of radiation. For example, although a fisherman might initially be approached because of his potential exposure due to liquid discharges, he would also be asked to provide information relating to gaseous discharges and direct radiation. Data are only recorded for consumption, occupancy and handling rates that take place in the survey area of interest in relation to each source of radiation. For example, when being asked about the consumption of green vegetables, the interviewee would only need to provide data for green vegetables grown in the terrestrial survey area.

3.3. Data recording and analysis

All data collected during fieldwork are input into a custom-made database, which has been designed to facilitate reliable data processing and archiving of habits data. The raw data are entered into the database where each individual is assigned a unique identifier (observation number) to assist in maintaining data quality, and to enable data protection issues to be adhered to.

The database converts the survey data into the relevant units (kg/y or l/y for consumption and h/y for occupancy and handling) using a variety of conversion factors. These include produce weights (Hessayon, 1990 & 1997; Good Housekeeping, 1994), information supplied by the Meat and Livestock Commission and edible fraction data researched by Cefas. It is important to distinguish between the edible fraction of food items and the total weights, since this can make a significant difference to the overall consumption rates. For example, an interviewee who claims to consume 1 kg/y of winkles would only be consuming approximately 0.2 kg/y of flesh weight if 1 kg/y were the total weight, including the shells.

Since one of the criteria for selecting a critical group is homogeneity based on age, and because different dose coefficients apply to children, ingestion data are structured into age groups consistent with those used in ICRP 72 (1996). The six groups are: 3 months old (0 to 1 year old), 1 year old (1 to 2 years old), 5 year old (>2 to 7 years old), 10 year old (>7 to 12 years old), 15 year old (>12 to 17 years old), adults (>17 years old).

In order to identify the critical group the ‘cut-off’ method described by Hunt *et al*. (1982) is used. With this method, critical rates for each exposure pathway are calculated by taking the arithmetic mean of the maximum observed rate and all rates observed within a factor of 3 of the maximum value (termed the lower threshold value). For example, for intertidal occupancy over sand, if the highest occupancy rate were 900 h/y, all occupancy rates equal to or greater than 300 h/y would be averaged to derive the critical rate. The factor of 3 is based on considerations of homogeneity (ICRP, 1966).

Each group of people whose data has contributed to a critical rate for an exposure pathway is called a ‘potential critical group’. Assessments are carried out to calculate the

average dose to each potential critical group, and the group with the highest dose can then be denoted the critical group.

4. Results

Consumption rate data can be used to highlight the variation in critical rates at the different sites. Figure 2 summarises data from the 20 most recent combined habits surveys at UK sites. Critical rates from habits surveys were collated for each food group and each site, the highest and lowest of which are shown on the graph as the maximum and minimum habits survey critical consumption rates. The average habits survey rates for each food group in Figure 2 were calculated by averaging the critical rates for that food group from all sites.

Where possible, habits survey data in Figure 2 are compared with mean and 97.5th percentile rates derived from national statistics based on a dietary and nutritional survey of British adults (Byrom *et al*., 1995). In contrast with habits surveys, the national statistics survey did not target people living near nuclear sites and included foods regardless of whether they were locally produced.

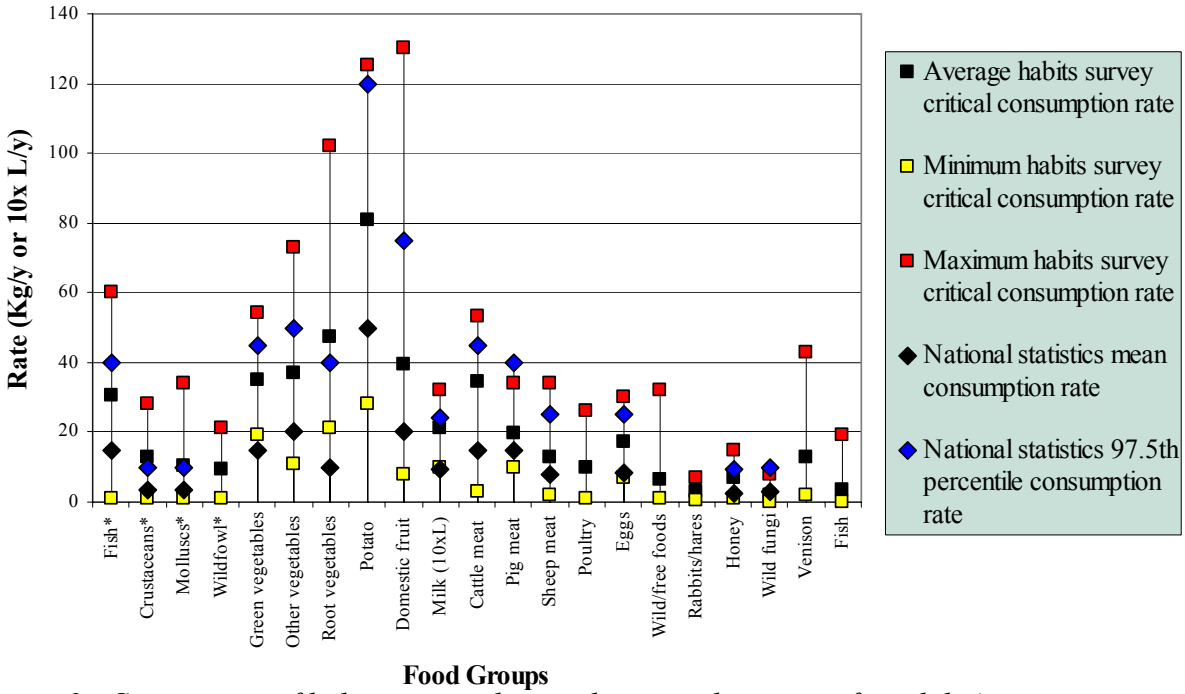

Figure 2. Comparison of habits survey data with national statistics for adults' consumption rates. Asterisked food groups (*) are affected by liquid discharges; all other food groups are affected by gaseous discharges.

The graph emphasises the variability in maximum and minimum habits survey critical consumption rates at different sites. In general, when this variability is compared with national statistics it shows that using national statistics rates in site-specific dose assessments could either provide an over or underestimate of dose to the public. This highlights the need for habits surveys that provide consumption rates which represent the specific sites.

5. Evolution of habits survey methodology and results

Habits survey methodology must be flexible enough to incorporate new pathways and site-specific issues as they arise. It must also accommodate evolving assessments needs. The evolution in methodology has recently brought to light a range of unusual exposure pathways and foods.

5.1. Uncommon foods

In addition to the 33 common exposure pathways (shown in Table 1), Table 3 summarises uncommon foods identified in combined habits surveys (Sellafield data also includes updates from reviews which are conducted annually).

Table 3. Uncommon consumption pathways discovered in combined habits surveys.

Exposure pathway	***Food***	***Site***	***No. of people***	***Maximum consumption rates (kg/y or l/y)***
Uncommon pathways of exposure relating to liquid radioactive waste discharges				
Molluscs	Razor fish	Sellafield, Winfrith	4	0.80
Crustaceans	Crayfish	Aldermaston/Burghfield	4	1.2
Hydrophytes	Samphire	Heysham, Sellafield, Rosyth	7	3.0
	Porphyra	Sellafield	2	0.10
	Sea Kale	Dungeness	2	0.50
	Unidentified seaweed species	Hartlepool, Winfrith	2	0.20
Uncommon pathways of exposure relating to gaseous radioactive waste discharges				
Milk	Sheep milk	Winfrith	4	12
	Goat milk	Winfrith, Amersham, Dounreay	24	230
	Cream (cow's milk)	Sizewell	5	3.0
Goat meat	Goat meat	Winfrith	5	1.4
Eggs	Guinea fowl eggs	Aldermaston/Burghfield	3	5.2
	Peacock eggs	Aldermaston/Burghfield	3	1.1
Rabbits/hares	Hares	Hunterston, Sellafield, Sizewell, Dounreay, Trawsfynydd	17	5.0
Wild/free foods	Nettles	Hunterston	8	0.50
Crustaceans	Crayfish	Amersham	2	1.3
Molluscs	Garden snails	Hunterston	1	0.30
Hydrophytes	Watercress	Winfrith, Amersham	12	50

To illustrate how uncommon these pathways are, the number of people in Table 3 can be compared with the total number of individuals recorded in combined habits surveys to date; approximately 17,000.

5.2. New pathways

Since combined habits surveys were introduced, increasing emphasis has been placed on using a holistic approach. Information is collected regarding pathways, however minor, in order to perform accurate integrated dose assessments. This development has been driven by the Environment Agencies' responsibilities, under the relevant Directions, to assess the total dose from all pathways.

Four pathways of exposure recently introduced into habits surveys are occupancy rates 'in' and 'on' water affected by either liquid or gaseous discharges. These data are used in two ways; firstly, to assess potential dose from contaminated water, suspended sediment

in the water column or substrate under the water, and secondly, to assess the potential dose from water inhalation (sea spray) or ingestion.

Additional pathways include exposure to liquid or dried sewage sludge. The first habits survey to include these pathways was Cardiff in 2003. Subsequent sites were Devonport and Amersham, both in 2004. In all three cases, these pathways were investigated because the nuclear sites' liquid discharges flowed through nearby sewage works. Employees from the sewage works could potentially be exposed to the liquid discharges when dealing with sewage sludge.

Data from existing pathways have recently been utilised in new ways for dose assessment purposes. Two examples relate to the use of surveyed occupancy rates. Occupancy rates for exposure over intertidal sediments were previously used only to assess external exposure, but are now also used to assess internal exposure from inhalation and ingestion of sediments. Occupancy rates within 1 km of the site were previously only used to assess direct radiation, but are now also used to assess the dose that people receive from various pathways directly related to the gaseous discharge plume.

5.3. Site-specific methodologies

Habits survey methodology is adapted on a site-by-site basis to incorporate variation in local parameters. Variation between sites may arise either as a result of site operations or differences in local topography. Case studies of differences due to site operations and topography are shown in Tables 4 and 5 respectively.

Table 4. Case studies of variations due to site operations.

Site	Situation	Exposure pathways affected
Sellafield	Dismantling of 3 redundant discharge pipelines offshore lead to debris being washed-up on local and distant beaches	Occupancy over intertidal areas
Sellafield	Seepage of groundwater through dunes at a beach in the Sellafield aquatic survey area	Consumption of freshwater
Dounreay	Radioactive particles washed up on a beach in the Dounreay aquatic survey area	Occupancy over and handling of intertidal sediments
Chapelcross	Overland pipeline carrying liquid discharges to the sea	Occupancy in the vicinity of the pipeline

Table 5. Case studies due to local topography.

Site	Situation	Exposure pathways affected
Wylfa, Torness	Warm water from site outfall created good conditions for bass. Unlike some sites, there were no restrictions on bass angling.	Consumption of bass and occupancy over intertidal areas
Chapelcross, Dungeness, Berkeley/Oldbury	Low lying tide washed areas in the aquatic areas used for grazing livestock	Occupancy over intertidal areas, livestock consumption
Sellafield, Hunterston, Hartlepool, Heysham, Torness, Devonport, Faslane	Seaweed from the aquatic survey areas used as a fertiliser for growing vegetables	Sea to land transfer of radionuclides
Sellafield, Hunterston, Wylfa, Trawsfynydd, Dounreay, Faslane, Sizewell, Cardiff, Winfrith, Amersham, Devonport	Water from the terrestrial survey area extracted via springs, boreholes, wells and streams	Consumption of surface or groundwater

6. Conclusions

Habits surveys around nuclear sites in the UK have evolved significantly over the past 50 years. The discovery of new and unusual pathways at specific sites has been a notable feature, as have the changes in methodology over the years.

The most important recent development has been the introduction of combined surveys. These have enabled profiles of consumption and occupancy to be created, which in turn have enabled the calculation of doses that are integrated across all pathways. Additionally, combined habits surveys have highlighted the variation in critical rates across sites. Comparisons of national statistics and habits data show that habits surveys help to take into account this variability, and thus dose assessments will be more likely to calculate doses to the most exposed individuals. This ensures that the public is adequately protected.

In the future it is envisaged that further sites will be surveyed using the combined technique. Other pathways of potential radioactivity exposure are always being investigated, and the methodology refined to help ensure optimal data quality.

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