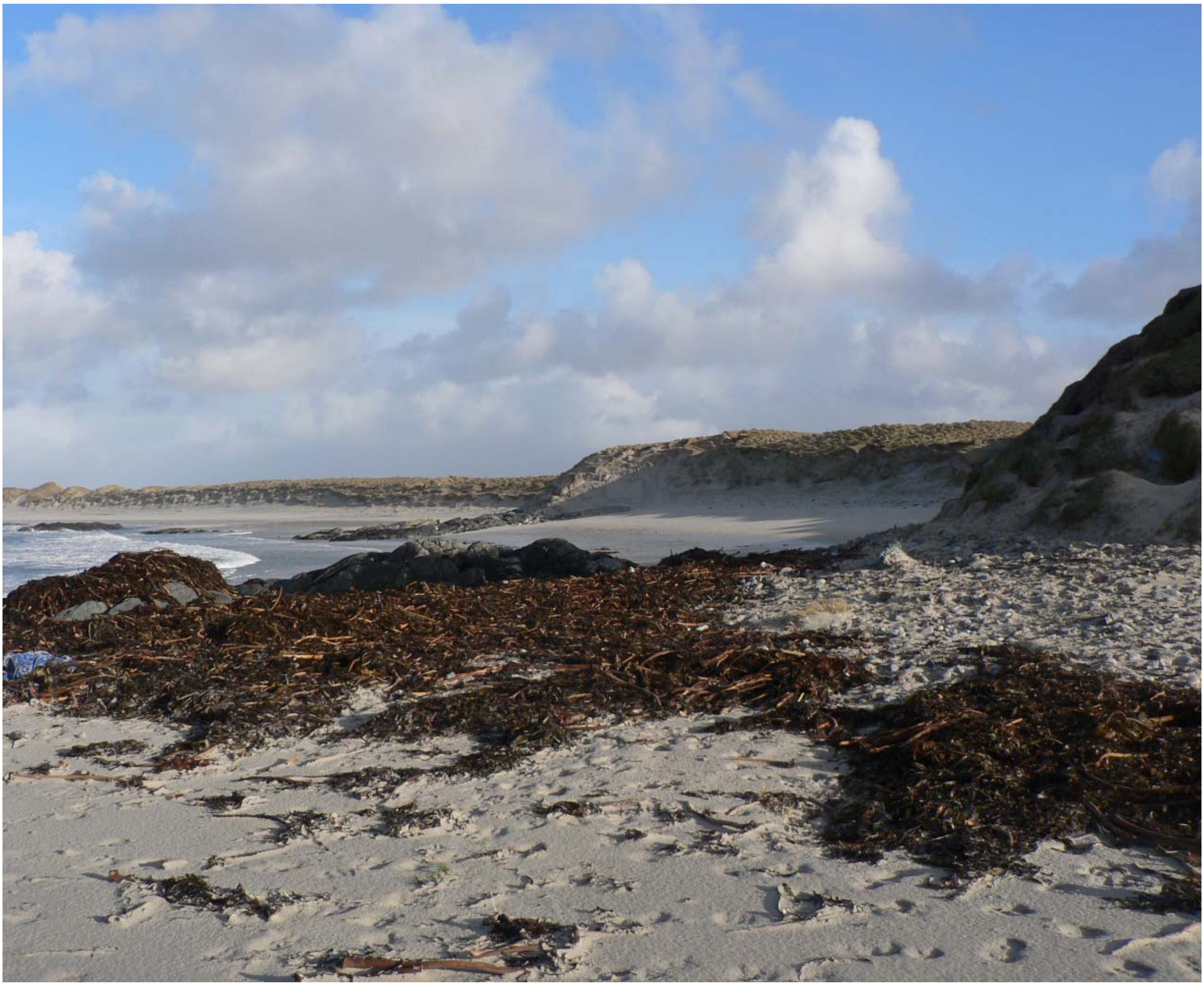
Transfer of Radioactivity from Seaweed to Terrestrial Foods and Potential Radiation Exposures to Members of the Public



Health Protection Agency

Food Standards Agency Scotland
Buidheann Inbhe-Bìdhe an Alba

Food Standards Agency

SEPA
Scottish Environment Protection Agency

Radiation Protection Division was formed on 1 April 2005 when the National Radiological Protection Board merged with the Health Protection Agency, under the provisions of the Health Protection Agency Act 2004.

As part of the Centre for Radiation, Chemical and Environmental Hazards, the Division carries out the Agency's work on ionising and non-ionising radiations. It undertakes research to advance knowledge about protection of people from the risks of these radiations; provides laboratory and technical services; runs training courses; provides expert information and has a significant advisory role in the UK.

Any questions relating to this document should be addressed to Press and Information, HPA Centre for Radiation, Chemical and Environmental Hazards, Chilton, Didcot, Oxfordshire OX11 0RQ, email: ChiltonInformationOffice@hpa.org.uk.

Website: www.hpa.org.uk

Transfer of Radioactivity from Seaweed to Terrestrial Foods and Potential Radiation Exposures to Members of the Public

J Brown, D Hammond, D Wilding, B T Wilkins, and C Gow

ABSTRACT

A number of radionuclides can be discharged into the Irish Sea from the Sellafield nuclear fuel reprocessing plant in Cumbria as authorised by the Environment Agency under the Radioactive Substances Act. Some of these radionuclides concentrate in seaweed which can then be used as a fertiliser and soil conditioner. This practice has been prevalent in Scotland in the past and is known to still be carried out at the present time. There are also some instances where animals graze seaweed directly from the foreshore. This combination of circumstances therefore provides a route for radionuclides discharged into the Irish Sea to transfer into terrestrial foodstuffs.

The aim of this study was to identify the extent of seaweed use in Scotland, understand the practices adopted, the extent to which food grown on seaweed treated land is consumed by individuals and to estimate potential radiation doses from ingestion of these foodstuffs. The radionuclide of primary interest is technetium-99 (^{99}Tc) due to relatively high historic discharges from the Sellafield nuclear site and measured concentrations in seaweed collected along the northwest coast of the British Isles. Samples of seaweed, soil, crops and animal products were collected from 20 locations from the northwest coast of Scotland and offshore islands, including Orkney and Shetland. These were analysed for ^{99}Tc and a range of other radionuclides. Radiation doses were estimated using measured concentrations of ^{99}Tc in foodstuffs and consumption data. The highest estimated doses from this pathway are small, being of the order of a few microsieverts (µSv) and the majority of the estimated doses are at least a factor of 100 lower. To place the doses in context, they are at least an order of magnitude lower than the dose from naturally occurring radionuclides in a typical UK diet and are small compared to the annual dose limit for members of the public of 1000 µSv per year. The doses estimated from this study would not justify a major programme of continuous monitoring. The data from current monitoring programmes could however be used to identify any trends which might suggest a requirement for changes to the programmes.

This study was part-funded by FSA and SEPA under contract R04003

Centre for Radiation, Chemical and Environmental Hazards
Radiation Protection Division
Chilton, Didcot, Oxfordshire OX11 0RQ

Approval: October 2009
Publication: November 2009
£15.00
ISBN 978-0-85951-652-5

This work was undertaken under the Environmental Assessment Department's Quality Management System, which has been approved by Lloyd's Register Quality Assurance to the Quality Management Standards ISO 9001:2000 and TickIT Guide Issue 5, certificate number 956546.

The analyses of ^{137}Cs, ^{90}Sr and isotopes of Pu were carried out under a formal system of quality assurance accredited under ISO17025:2000 (UKAS accredited testing laboratory 1269). The analyses of ^{99}Tc do not at present fall within the formal accreditation agreement, but were carried out under a comparable scheme of quality assurance.

Report version 1.0

NON-TECHNICAL EXECUTIVE SUMMARY

A number of radionuclides are discharged into the Irish Sea from the Sellafield nuclear fuel reprocessing plant in Cumbria under authorisation from the Environment Agency. Routine monitoring shows that some radionuclides concentrate in seaweed, although the effectiveness of this process depends on the radionuclide and the species of seaweed involved. Seaweed can be used as a fertiliser and soil conditioner, and there are also some instances where animals graze directly from the foreshore. This combination of circumstances provides a route for the transfer of radionuclides into terrestrial foodstuffs.

Close to the Sellafield site, there are some allotments where seaweed has been applied for several years. As part of its ongoing monitoring programme, the Food Standards Agency collects and analyses samples of vegetables from these sites. The results are published annually, and the estimated radiation doses are noted as being small compared to the annual dose limit for members of the public. Seaweed has also been traditionally used as a soil conditioner in parts of Scotland in the past and this practice continues to a limited extent today. A specific assessment of the current situation has therefore been carried out.

Concentrations of radionuclides in seaweed are monitored at a small number of locations, but these cannot be used directly with the predictive models regularly used for estimating likely radionuclide concentrations in foodstuffs and resultant radiation doses. The reasons for this are as follows.

- The type of seaweed applied to the land varies depending on availability and location which will affect the concentrations of radionuclides in soil at a particular location.
- The amount of seaweed applied will vary due to its availability and the personal choice of the gardeners.
- The amount of seaweed applied in earlier years will affect the concentrations of radionuclides in the soil at any given time.
- The amounts of radioactivity transferred from soil into the crops or from feed to grazing animals for this specific situation may be very different to those generally assumed in predictive mathematical models for soils not treated with seaweed.
- The consumption of food that is produced on seaweed treated land may differ from that typically assumed for people growing their own food.

Due to the specific nature of this assessment, it was, therefore, important to gather relevant information and analyse the radionuclide content of the foodstuffs produced. The project was part-funded by the Food Standards Agency (FSA) and the Scottish Environment Protection Agency (SEPA) and carried out by the Health Protection Agency (HPA). The radionuclide technetium-99 (^{99}Tc) is of primary interest because of relatively high historic discharges from the Sellafield nuclear site, long radioactive half-life, mobility in the marine environment, and incorporation into seaweed as indicated by routine surveillance monitoring. In addition, in some circumstances it is readily taken up by plants from soil.

Published monitoring data of radionuclide concentrations in seaweed indicated that the initial area of interest lay along the west and north coast of Scotland and offshore islands between Dumfries and Galloway, and Orkney and Shetland. A comprehensive sampling and measurement programme over this whole area would be impractical, and so enquiries were made to organisations including the National Farmers Union for Scotland (NFUS) and the Scottish Crofting Foundation (SCF) to obtain information on where seaweed is being used. This enabled the areas requiring more detailed study to be identified. Local representatives from the organisations were contacted and an article on the project was published in the SCF magazine “The Crofter”. From these initiatives a number of families and individuals from across the area of interest expressed an interest in taking part in the study.

Each of the families or individuals was visited and asked to provide information on the amounts of seaweed they applied, the frequency of application and any prior treatment such as composting. They were also asked about the crops that they grew on land treated with seaweed, including those to be used as animal fodder, and also whether they kept any animals that grazed directly on seaweed. Samples of the seaweed they used and soil from the treated land were collected and analysed.

The aim of this phase of the work was to decide which of the initial participants should be asked to provide further samples. The results showed that activity concentrations of radionuclides in seaweed and soils from the same geographical areas were reasonably comparable, and so all participants were asked if they would be willing to participate in the next phase of the work and all of them agreed.

As had been expected, the differences in the ways in which seaweed was used meant that, to make an appropriate estimate of the radiation doses received, the study would need to focus on measuring the radionuclide content in the foodstuffs produced on treated land. A second visit was therefore made to all of the participants at the end of the main growing season in 2007 and a range of vegetables and some samples of meat and offal were collected. Initial results from the analyses confirmed that the radionuclide of primary interest was technetium-99.

A radiological assessment requires information on the amounts of foodstuffs consumed as well as the amounts of radioactivity that they contain. All participants were therefore asked to estimate the quantities of foods they ate and how much was produced on seaweed treated land. For this purpose foodstuffs were divided into broad groups such as green vegetables, root crops and potatoes to help individuals estimate their consumption. The amounts estimated were in many cases much greater than those assumed in general assessments. This might reflect the availability of home-grown produce, the amount of outdoor physical work that the participants carried out, the difficulty that people have in estimating their consumption, or a combination of these factors.

The information on the amounts of food consumed was combined with the measured activity concentrations of technetium-99 in the various foodstuffs to estimate radiation exposures from consuming the foodstuffs produced on land treated with seaweed. A cautious approach was adopted so that levels of exposure were very unlikely to be underestimated. In all cases the levels of exposure were small, the highest values being 1000 times lower than the relevant limit for members of the public and at least an order of magnitude lower than the radiation exposure from consuming naturally occurring radionuclides in a typical UK diet. The highest estimated levels of exposure are also comparable with that from cosmic radiation during a flight to mainland Europe. The majority of the estimated exposures in this study were a factor of 100 – 1000 lower than the highest value discussed here.

The authors thank the participants in this study and the people and organisations that supplied HPA with information and contacts. The work would not have been possible without their sustained co-operation which is much appreciated.

CONTENTS

1 INTRODUCTION

A number of radionuclides are discharged into the Irish Sea from the Sellafield nuclear fuel reprocessing plant in Cumbria, as authorised by the Environment Agency under the Radioactive Substances Act. Some of the radionuclides discharged move northwards in the sea and some of these are readily taken up by seaweed. This can be seen from routine monitoring undertaken along the northwest coast of the British Isles, the results of which are published annually in a series of reports commonly referred to as RIFE (Radioactivity in Food and the Environment). The most recent in the series gives data for 2007 [Environment Agency *et al.*, 2008].

Seaweed can be used as a soil conditioner and fertiliser, and so because radionuclides can be taken up from seawater into seaweed, this can provide a means by which radionuclides discharged to sea can become incorporated into crops. This can be illustrated from monitoring data generated by the Food Standards Agency for a small number of allotments close to Sellafield where this practice takes place [Environment Agency *et al.,* 2008]. The radiation doses received by people eating food from these allotments are however very small. Seaweed can also be used as an animal feedstuff, with cattle and sheep grazing seaweed directly from the foreshore either on an opportunistic basis or as a major component of their diet.

In some parts of Scotland, seaweed is also being used as a fertiliser for land used to produce crops or animal feedstuffs, and in some areas sheep and cattle are known to graze directly on seaweed from the foreshore. Radionuclide concentrations in seaweed are regularly monitored at a small number of locations. However, these cannot be used directly with the predictive models regularly used for assessing radionuclide concentrations in foodstuffs and resultant radiation doses for the following reasons.

a The amount and type of seaweed applied to land or consumed by animals is likely to be very variable depending on availability, location and personal choice of the gardeners. This affects the radionuclide content in the soil.

b The amount of seaweed applied in earlier years will affect the concentrations of radionuclides in the soil at any given time.

c The transfer of radionuclides from the treated soil to crops and from feed to animal products in this situation may be very different from situations generally assumed in predictive terrestrial foodchain models for soils not treated with seaweed.

In addition, the consumption rates of food produced on land treated with seaweed could be significantly different from those assumed for general radiological assessments. For these reasons, a specific investigation has been carried out. The aims were to find out whether these practices are in common use along the coast of Scotland, explore whether radionuclides are transferred into the foodchain from seaweed and evaluate any resultant radiation doses. The work was part-funded by the Food standards Agency and the Scottish Environment Protection Agency (SEPA). The work was carried out by the Health Protection Agency, Radiation Protection Division (HPA-RPD), and the results are described in this report. The Food Standards Agency and SEPA will use the results to decide whether any routine surveillance monitoring is warranted in the future.

1.1 Approach adopted

The general study area was identified using readily available information on the extent of the use of seaweed together with published measurements of radionuclide concentrations in seaweed. Enquiries to relevant organisations such as the National Farmers Union and the Scottish Crofting Foundation enabled the area of interest to be refined. These organisations also provided assistance in identifying people that would be prepared to allow samples to be collected and to supply the ancillary information needed for the radiological assessment.

The people identified were contacted and visits to a number of sites were undertaken in the spring of 2007. The aims were to collect some initial samples of soil and seaweed, to undertake a more detailed survey of the use of seaweed as a soil conditioner and animal feed and to obtain information on the amounts of food produced on treated land that individuals actually consume.

The samples of soil and seaweed were analysed. The analytical data and the other information collected confirmed the initial view that it would be difficult to predict radionuclide concentrations in crops from those measured in seaweed. Sampling of the foodstuffs themselves across a wide variety of sites was therefore essential for any radiological assessment. Further visits were subsequently undertaken in September 2007 to collect samples of crops and animal products and these were analysed for a range of radionuclides. A radiological assessment was then undertaken using the analytical data and the information gathered on the use of seaweed and the amounts of foodstuffs that people consume.

The success of this project depended on securing and maintaining the co-operation of a number of individuals. Maintaining the anonymity of the participants was paramount as many of the participants give away spare produce or sell produce within the local community. An open approach was adopted with each of the individuals and families concerned, with updates being sent at appropriate times during the project. Thus, for example, after the first set of samples had been analysed, each participant received their results by letter giving relevant comparisons with published information such as that in RIFE, and care was taken to explain any technical terms. In addition, a senior member of the project team dealt with all of the correspondence and, along with support staff, carried out all of the field visits. This ensured continuity of contact.

Each of these aspects of the study is described in more detail in this report.

1.2 Selection of area for study

Monitoring data are available for selected radionuclides in seaweed from a limited number of locations along the coast of Scotland, published annually in RIFE (Radioactivity in Food and the Environment). The most recent in the series gives data for 2007 [Environment Agency *et al.*, 2008]. Data on radionuclide concentrations in seaweed, particularly ^{99}Tc, led to initial proposals of the area that needed to be considered. On this basis alone, the study needed to cover the coast and offshore islands between Dumfries and Galloway and Orkney and Shetland. A comprehensive programme of collecting data, taking samples and carrying out analyses over such a large area is not practical or cost effective. However, the locations that deserved detailed study were not selected just on the basis of where radionuclide concentrations in seaweed were highest. The extent to which seaweed was used as a soil conditioner or as an animal feed was also taken into account. It was for this reason that the first part of this project involved finding information on seaweed use.

For the Scottish coastline, some information on land use was readily available because it is required by SEPA in order to assess the effects of discharges from licensed nuclear sites. HPA-RPD had access to a survey of Dumfries and Galloway carried out in 2003 that indicated that seaweed was not being used to treat agricultural soil. In addition, a survey around the Dounreay site in Caithness in 2003 indicated that seaweed was not currently being applied to land used to grow crops although it had been used in the past. Current use is confined to one individual who applies seaweed to flower beds. Generally, however, the required information was not available for other areas along the coast and the offshore islands, and so specific investigations were needed.

Both current and previous practices are important in the context of this project. This is because the main radionuclides of interest have long radioactive half-lives, and the radionuclide concentrations in seaweed were higher in the 1970s and 1990s because of higher discharges from Sellafield at that time. Consequently, repeated applications of seaweed to the same piece of land over a period of years could result in an accumulation of radionuclides in the soil and radionuclides are likely to remain in the soil even if the practice has been discontinued. Radionuclide concentrations in crops grown on this land, or in animals that grazed on it, could therefore remain elevated for some time after treatment with seaweed has ceased. This could also be observed if the seaweed has been composted before application, although this would depend on how each radionuclide behaves during the composting process.

In contrast, concentrations of radionuclides in the tissues of animals that graze directly on seaweed will depend only on the activity concentrations in the seaweed being consumed and current feeding practices. This is because generally these animals are kept for a relatively short time before being sent for slaughter.

Contacts were made with trade organisations, local councils, the Crofting Commission and agricultural officers at SEPA Local Offices because such organisations generally have representatives who cover the areas of interest. Permission was sought to contact local representatives in the areas of interest, where appropriate. A summary of the type of information needed for the project was also provided at the time of initial contact.

Information gathered on the extent to which seaweed is or has been used was combined with the available monitoring data on radionuclide concentrations in seaweed to decide which areas were to be visited to find out further information on seaweed use and dietary habits and to collect samples for analysis. The areas where seaweed is predominantly used on the west coast of Scotland and offshore islands are shown in Figure 1 (crops) and Figure 2 (feed for animals).

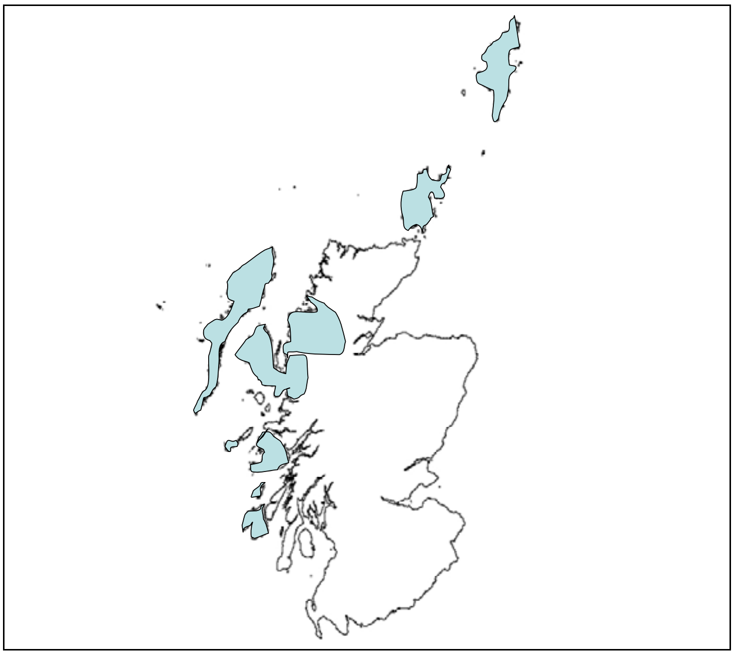


Figure 1 Areas where seaweed is used as a soil conditioner for crops (shaded in light blue) [© Crown Copyright. All rights reserved [Health Protection Agency][100016969], 2008]

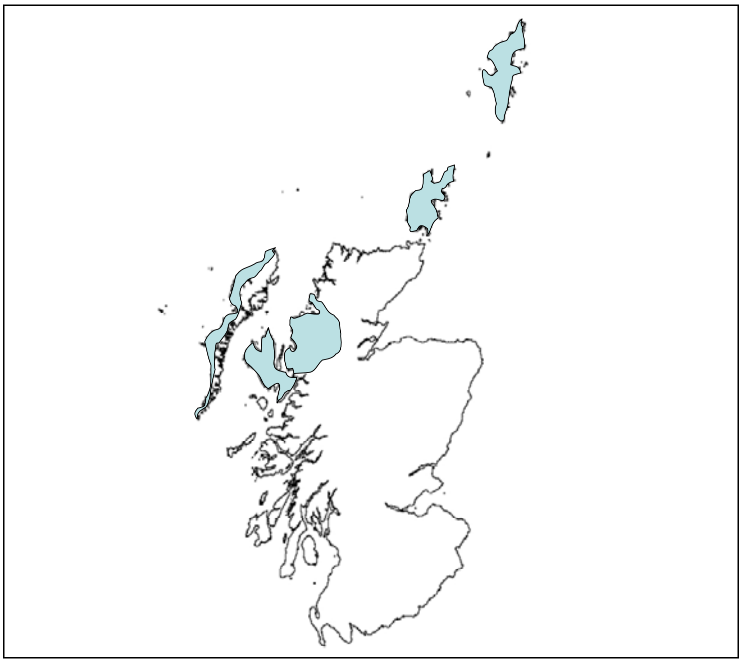


Figure 2 Areas where seaweed is used as an animal feed (shaded in light blue) [© Crown Copyright. All rights reserved [Health Protection Agency][100016969], 2008]

2 THE PRACTICE OF USING SEAWEED AS A SOIL CONDITIONER AND ANIMAL FEED

After the study area had been delineated, information was collected on the use of seaweed at 20 locations from within the area. Questions were asked to obtain information on the following:

- a what foods are produced on seaweed treated land or animal products obtained from animals directly grazing seaweed;
- b the scale of production at each location and whether food is produced for home consumption, is given away or sold commercially;
- c how seaweed is used and the timescales over which seaweed has been used at the location as a fertiliser or animal feed;
- d horticultural and animal husbandry practices;
- e how much of food consumed by individuals is produced from land treated with seaweed or from animals eating seaweed (produced either by the individuals themselves or by someone else);
- f period of the year over which foods are consumed;
- g typical consumption rates for categories of foodstuffs.

2.1 Scale of seaweed use

Seaweed is used on traditional crofts that have been family owned for several generations, farms and smaller garden plots where people are trying to grow a wider range of vegetables and fruit than traditionally possible on the machair* and open grassland. The predominant crop grown is potatoes with other vegetables being grown where conditions allow. A number of large gardens and more traditional crofts have been regenerated over the last 10 years by people moving into the area.

The sizes of the cultivated areas visited varied from a few small raised beds for growing vegetables on a croft being redeveloped, through mature large walled gardens to crofts with large areas of rough land used for arable crops, animal grazing and potatoes (e.g. on the machair on the west coast of the Outer Hebridean islands). A typical example of some raised beds is shown in Figure 3 and Figure 4 shows an area of the machair being readied for growing potatoes.

At the majority of locations visited, people are growing foods for their own consumption and that of their family. The quantities of many vegetables and fruit harvested are small due to the area of land being cultivated, the fertility of the land and the climate. Most people grow potatoes and these produce a good yield from seaweed treated land. In some cases, surplus potatoes are given to extended families and neighbours. A few

* The machair is a fertile, low-lying plain found adjacent to some coastal areas in north-west Scotland and western Ireland: the majority are found in the Outer Hebrides. The methods of ploughing, cropping, fertilising and grazing the land create a diverse patchwork of habitats, which in turn support a wide range of plants and animals. Traditionally, a mixed grazing regime with crops worked on a two to three year cycle is used on the machair.

people also sell some of their potato crop at local markets. For example one crofter who is trying to regenerate a croft sold about three 1.5 kg bags of potatoes each week between July and September in 2006.

A wide variety of green vegetables is grown in some locations, particularly those that are sheltered or where people have polytunnels, although only green vegetable species that are hardy, such as kale, can be grown in some locations exposed to high winds and frosts. Damage by rabbits and deer is also a problem in many areas. Table 1 shows the range of vegetable and fruit species being grown across the regions visited.

Within the area of study, there are locations where beef, lamb or mutton is produced from animals that graze directly on seaweed. At one location visited a small number of pigs are raised annually. These pigs do not have direct access to seaweed but are fed waste crops grown on seaweed treated land and are kept on soil that has previously received seaweed. In all cases meat is produced both for selling on the open market (on varying scales) and for people's own consumption.

Table 1 Foods produced at locations visited

Foods produced at locations visited[a]
Potatoes[b]
Tomatoes
Kale, cabbage, lettuce, salad leaves, brocolli, cauliflower, spinach, Brussel sprouts, chard, purple sprouting brocolli
Asparagus
Courgettes
Onions, leeks, garlic
Carrots, parsnips, artichokes, kohl rabi, swede, turnip
Runner beans, french beans, peas
Herbs
Beef and liver
Mutton, lamb and sheep liver
Pork
Chicken
Eggs
Apples, pears
Strawberries, raspberries, blackberries, gooseberries, loganberries, blueberries, blackcurrants
Rhubarb

Notes:

a) Many of these foods are only produced at a few locations.

b) Potatoes are grown at 19 of the 20 locations.

Figure 3 Example of raised beds for growing vegetables

Figure 4 Area of machair used for growing potatoes; seaweed applied

2.2 Agricultural and gardening practices

A number of different practices for using seaweed as a soil improver or fertiliser were observed. These can be summarised as:

a application of fresh seaweed directly to the land;
b collection of seaweed into piles and application of semi-rotten seaweed to the land;
c making compost with seaweed and often some other organic material such as bracken and adding this to soil 1 or 2 years later;
d making a liquid seaweed feed to use during the growing season.

In general, seaweed is collected over the winter months as it tends to be during this period that it is washed up onto the beaches by storms. The seaweed is either collected fresh from the beach or is left to partially rot on the beach prior to collection. The seaweed is then either applied directly to the land (fresh or rotted from the beach) or left to rot completely in piles prior to application. The seaweed is always left to rot prior to it being dug into vegetable plots or ploughed into arable land or larger croft plots used for potatoes. Figure 5 shows a close-up of a pile of rotting seaweed and Figure 6 shows seaweed applied to a vegetable plot that has largely rotted down over the winter and spring. Seaweed is also often used as mulch around fruit bushes, herbs and other non-annual plants.

The use of composted seaweed is less common and often depends on whether there is surplus seaweed available in a particular year. However, at one location the garden plots have been developed over the last 20 years and only composted seaweed has been used. At other locations, a mixture of seaweed compost and freshly applied seaweed is used. Figure 7 shows a compost heap comprising seaweed and other organic matter.

Liquid fertilisers were being made using seaweed at 3 of the locations visited. The methods vary from making a dilute solution, where seaweed is only soaked in water for 2-3 days before application, to making a very concentrated feed from seaweed that is left to rot fully to form a treacle-like substance which is then diluted as required prior to application.

The amount of seaweed applied varied across the locations visited and also between the types of crop being grown. In general, a larger quantity of seaweed per unit area is used for potatoes than for other vegetables and arable land. Typically seaweed is applied to soil used for potatoes to a depth of 120 – 150 mm (fresh) or 80 – 100 mm if rotted and about half this depth of seaweed is used for growing other vegetables and arable crops. Several people estimated the amount of seaweed they typically applied in a growing season. Typically 50 – 80 tonnes of seaweed per hectare are used for potatoes and the application rate for arable land used for growing oats and rye is about a factor of 2 lower.

On many of the traditional crofts potatoes are grown in so-called ‘lazy-beds’. Seaweed is spread onto land that has been left fallow for a number of years (up to 20 years), the turf is then turned over to form trenches and the potatoes are planted into the layer of seaweed. For vegetable plots, the seaweed is usually dug in when it has rotted down, although in one location, plants were being planted through the seaweed layer. Seaweed used as mulch is left to rot down naturally and is sometimes applied several times over the year as required.

Figure 5 Pile of rotting seaweed

Figure 6 Seaweed spread on a vegetable plot where it has largely rotted down

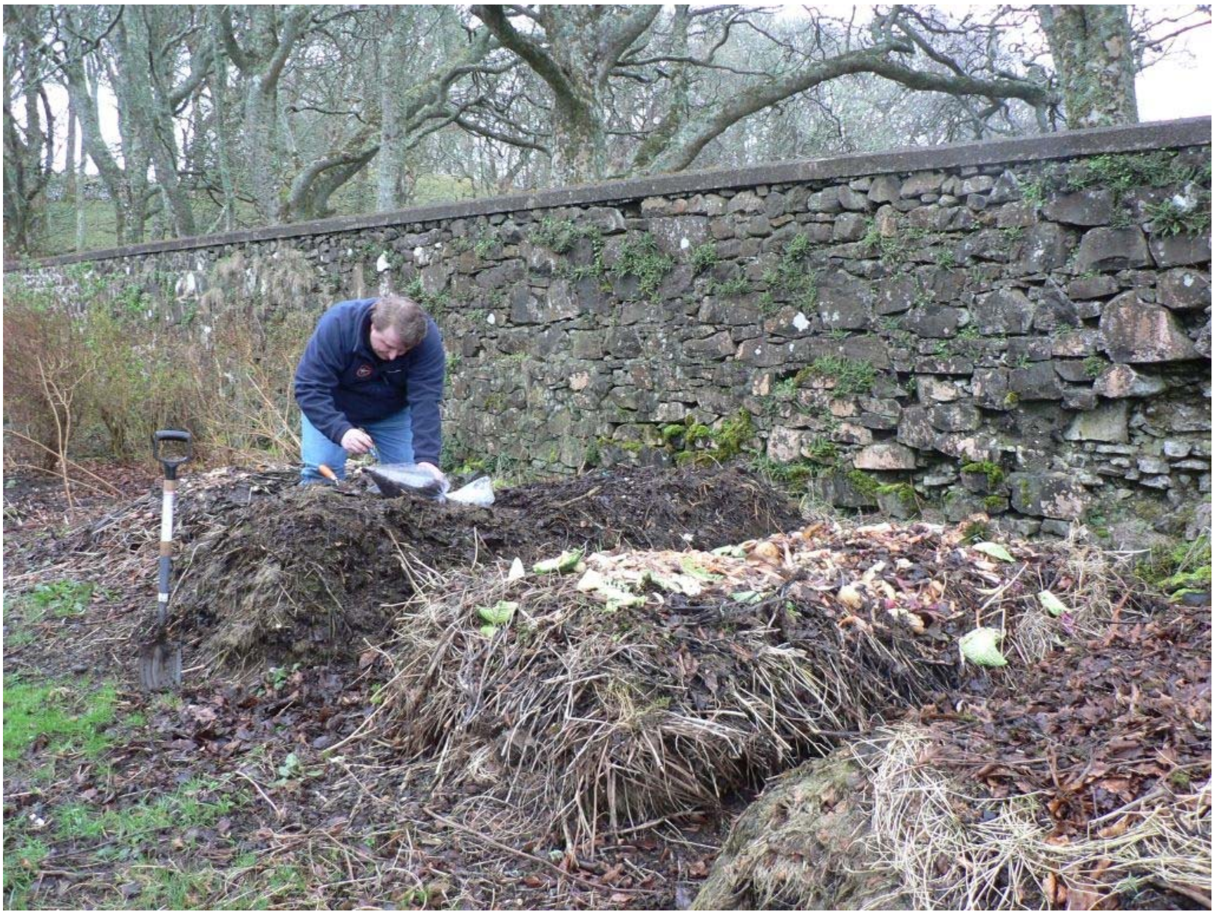


Figure 7 Example of compost made with seaweed

2.3 Frequency of use

The frequency with which seaweed is applied depends on the intensity of cropping, the area of land available for cultivation, the types of crop being grown, the rotation of crops and the availability of seaweed. For arable crops the land is typically sown with oats and rye for 2 years with seaweed applied each year. The land is then left fallow for 2 years and is used as rough grazing for sheep or cattle. At one location, the land was grazed for 5-6 years before being reused for arable crops.

For potatoes, land is often not reused for a subsequent potato crop for between 5 and 20 years. Seaweed is applied only in the year in which the crop is going to be grown. This means that much of the land being used on the crofts for growing potatoes has seaweed applied only infrequently.

For smaller vegetable plots and raised beds seaweed is often applied every year or at least every 2-3 years, again depending on seaweed availability and the level of manpower available to collect it. In general, it is reasonable to say that most of the land used for vegetables receives seaweed at least once in a 2-3 year period.

This large variability in the frequency of use reaffirms the idea that any radiological impact needs to be assessed on the basis of measurements in crops rather than predictions based on activity concentrations in seaweed.

2.4 Use of seaweed as an animal feed

Animals are kept at a number of the locations visited. At several of these locations the animals did not have access to free grazing of seaweed from the beaches and were not fed fodder crops produced on land treated with seaweed. These animals were not considered further in this study. At other locations, animals, including chickens, have access to the beach and graze seaweed occasionally or are fed fodder crops produced on seaweed treated land. Information on the husbandry practices for such animals was gathered at 10 locations.

At the locations where animals have free access to seaweed on the beach and are known to consume it, the quantities that they eat are unknown. At other locations, potential intakes of radionuclides by the animals are via the consumption of pasture grass and fodder crops grown on land that has been treated with seaweed. At one location, 4 pigs are raised each year for slaughter. These pigs are not fed seaweed directly but they are given left-over vegetables that have been grown on seaweed treated land.

2.5 Consumption of foods grown on seaweed treated land

The primary objective of collecting information on consumption rates was to be able to estimate radiation doses from the ingestion of crops grown on land treated with seaweed or meat from home-reared animals that have consumed seaweed.

Due to the amount of produce available from gardens and crofts and the fact that people are often growing their own produce to have a healthier diet, a large fraction of the diet comprises home grown produce (see Table 2). For some locations, people are largely self-sufficient in a wide range of foodstuffs for the majority of the year, particularly vegetables and potatoes. At others, where the cultivated land area is small or the range of foods grown is small, people are only self-sufficient for one or two vegetables and only for part of the year. Those people that produce meat and eggs are largely self-sufficient in these products.

Estimates of consumption rates were obtained for the home-grown foodstuffs produced at each of the locations visited. Typically, people appear to have healthy diets with many people eating large portions of fresh vegetables and salad twice a day. Potatoes are also consumed most days as part of the main meal and often at other meals in soups. For those locations where meat is produced, it is often eaten 3 – 5 times a week and portion sizes are quite large. For example, at 2 of the locations visited the portion sizes for adult males were about 350 g and 1 kg (fresh mass).

These findings might reflect the availability of home-grown produce, the amount of outdoor physical work that the participants carry out, or the difficulty that people have in estimating their consumption of foodstuffs, or a combination of these factors. They do however illustrate the need to obtain specific data on the amount of home-produced food that is actually consumed.

Table 2 Level of self-sufficiency of home-produced foods for the locations visited

Location	Foodstuff	Information on level of self-sufficiency
1	Potatoes	100%
	Vegetables	Almost 100%
	Soft fruit	100% during season (some fruit preserved)
2	Potatoes	Not consumed by individual visited
3	Fruit and vegetables	75% averaged over the year
	Eggs	100%
	Potatoes	100%
4	Potatoes	100%
	Lamb/mutton	100% (eats very little other types of meat)
5	Potatoes	100%
6	Potatoes	100%
	Beef	100%
	Eggs	100%
7	Potatoes	100%
	Meat (beef/lamb)	100%
8	Potatoes, carrots	100%
9	Vegetables	100% June- November. 75% December - May
	Potatoes	100% during season for early varieties
	Soft fruit	100% during season (some fruit preserved)
10	Vegetables	10% maximum averaged over the year
11	Vegetables	90%
	Potatoes	100%
	Pork	100%
12	Potatoes	100% July - November
	Vegetables	Largely self-sufficient from June - August
13	Vegetables	50% averaged over year
	Potatoes	50% averaged over year
14	Soft fruit	100% (frozen out of season)
	Vegetables	50% averaged over year
	Potatoes	100% August - January
	Apples and orchard fruit	100% for 3 months of the year
15	Soft fruit	100% June - July
	Apples	100% September - March
	Potatoes	100% May – November
	Vegetables	100% May – November
16	Soft fruit	100% for 3 months
17	Potatoes	100%
	Vegetables	25% June – September
18	N/A	First year of seaweed use so no information
19	Eggs	100% for 9 months of the year
	Potatoes, onions, carrots	100%
	Vegetables	75% averaged over the year
20	Lamb/mutton	100%

3 RADIONUCLIDE CONCENTRATIONS IN SEAWEED, SOIL AND FOODSTUFFS

3.1 Sampling and analysis

Over the 20 locations considered, the samples collected included seaweed, soils, a wide range of crops and some animal products. The number of each type of sample is listed in Table 3.

Table 3 Samples collected

Sample type	Total number of samples collected	Number of samples analysed for: ^{99}Tc	^{137}Cs	^{239}Pu	^{90}Sr
Seaweed	18	9	18	0	0
Soil and compost	83	70	32	7	4
Control soils	29	28	11	0	1
Green vegetables and legumes	27	27	0	0	0
Potatoes	29	29	4	0	0
Root vegetables	5	5	2	0	0
Fruit (soft and orchard)	15	15	0	0	0
Meat and liver	9	9	8	5	5
Eggs	1	1	0	0	0
Cereals	10	10	1	0	0
Total	**226**	**203**	**76**	**12**	**10**

For comparison purposes, a limited number of samples, principally soil, were taken from areas that it was thought had not been treated with seaweed. There was a degree of uncertainty at some locations because knowledge of the site history only went back a few years and seaweed could have been applied at an earlier time. This potential problem is discussed further in Section 4.1. For the purposes of this report however all of these samples are referred to subsequently as “controls”.

Seaweed was mainly collected directly from the beaches at the locations that each of the participants used so that the sample was as representative as possible of that used on the land or consumed by animals. In all cases the seaweed was detached and collected from the strandline. In some cases, seaweed that had been relatively recently collected and was being stored prior to application on the land was sampled. Samples of the whole of the plant were collected, since this is what is applied to the land (see for example Figure 5). The samples of seaweed were kept cool during transport to the laboratory and then dried in an oven at 105°C. Many of the soil samples were collected from cultivated land. In such cases it is reasonable to assume that any radionuclides are uniformly distributed with depth within the rooting zone of the crops. Consequently, samples were collected to a depth of about 150 – 200 mm using a spade. On return to the laboratory the soils were oven dried at 105 °C and then well-mixed.

Crops were collected when they were mature and ready for consumption, and the edible parts were separated as soon as possible after collection to avoid soil contamination. Where necessary, vegetables were kept refrigerated until they arrived at the laboratory. Potatoes and root vegetables were scrubbed to remove any soil adhering to the skin but they were not peeled as the majority of participants ate them unpeeled. The edible parts of other vegetables were washed to remove any remaining soil. The fresh mass of each sample was then determined and the samples stabilised by freeze-drying. The fresh - dry mass ratio was determined. Samples of meat were collected by the individual farmers themselves and kept in a freezer until collection. On return to the laboratory they were thawed, any inedible material such as gristle was removed and the sample was then minced and loosely mixed prior to analysis.

The expectation was that the radionuclide of principal interest would be ^{99}Tc. Concentrations of this radionuclide were determined in the majority of samples (as shown in Table 3), using a method developed specifically for low level measurements. In particular, all foodstuff samples were analysed for ^{99}Tc. However, the presence of other radionuclides discharged to sea from the Sellafield site could not be ruled out and so selected samples were analysed using other methods. Using high-resolution gamma-ray spectrometry, the only radionuclide that could be detected was caesium-137 (^{137}Cs). Some other radionuclides of potential interest cannot be detected at environmental levels using this measurement technique. For example, strontium-90 (^{90}Sr) is readily taken up from soil by plants, while americium-241 (^{241}Am) and isotopes of plutonium (Pu), although not readily taken up from soil by plants could be of interest in the case of animals grazing directly on seaweed because these radionuclides are known to concentrate in the liver. The concentrations of these radionuclides were determined in a few selected samples using validated methods of radiochemical isolation*.

The overall analytical scheme is summarised in Table 3. The majority of the samples were analysed for ^{99}Tc, although only half of the seaweed samples collected were analysed for this radionuclide. Seaweed samples were collected early on in the study to scope the range of levels of ^{99}Tc in seaweed and soils across the region of interest prior to the selection of sites for further detailed study. Due to the length of time needed to undertake ^{99}Tc analyses, it was not possible to analyse the seaweed samples from all of the locations. The overriding constraint used was that at least one measurement of ^{99}Tc was made at each location; this was either a seaweed, soil or crop sample.

3.2 Results

The detailed analytical data for ^{137}Cs and ^{99}Tc at each location are shown in Tables 4 – 22. The activity concentrations are the result of a single analysis of each sample collected. Data for soil are given in terms of dry mass. Values for seaweed are given in

* The analyses of ^{137}Cs, ^{90}Sr, ^{241}Am and isotopes of Pu were carried out under a formal system of quality assurance accredited under ISO17025:2000. The analyses of ^{99}Tc do not at present fall within the formal accreditation agreement, but were carried out under a comparable scheme of quality assurance.

terms of fresh mass because seaweed application onto the land is estimated on this basis and fresh mass activity concentrations are published in the annual RIFE reports, allowing direct comparison of values. Data for foodstuffs are given in terms of fresh mass, since this is the form needed for radiological assessments because consumption rates are given in fresh mass. Data for control samples taken from the specific locations studied are given in Table 23. The control samples included soil taken from locations at Chilton in Oxfordshire and Perth in the eastern part of Scotland, well away from any influence of radioactive discharges from Sellafield. As expected, these samples did not show any detectable levels of ^{99}Tc.

Some of the measured radionuclide concentrations have the symbol “<” in front of them. This means that radioactivity was not detected in that particular sample. We cannot say that the radionuclide is not present in the sample because, although the measurement equipment that we use is very sensitive, it still gives a small number of counts even when no sample is present. A limit of detection is therefore calculated which depends on factors such as the time that was actually spent making the measurement and the size of the sample that was used in the analysis. In addition, complicated chemistry is undertaken to extract radionuclides, such as technetium, from the original sample material. Not all of the radionuclide is recovered during this extraction, but the proportion that is actually counted compared with what was in the original sample can be calculated using another radioisotope of the same element that is not in the original material. The proportion that is recovered also affects the limit of detection. Overall, this means that, whenever a radionuclide cannot be detected, each sample will have its own limit of detection, and it is these figures that are given in the tables. Levels of a radionuclide in such samples are *less than* the limit of detection, and this is indicated by a “<” symbol.’

There are locations where several soil samples from the same cultivated plot or from nearby plots were collected. In these cases, all the samples were analysed and variability between the samples can be observed even when they were taken from a small plot of land. Variability between soil samples across a small plot is expected as it is likely that the radioactivity will not be distributed uniformly throughout the soil that was collected. Taking small quantities of soil for analysis from the large sample collected may also lead to further differences between the individual results. For this reason, where possible, crop samples were taken from more than one point over the plot where they were grown and then combined for analysis. This ensures that the measured activity concentrations are as representative as possible of the crop eaten.

Table 4 Measured radionuclide concentrations in seaweed, soil and foods; location 1

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.2	-
Soil used for potatoes in 2006, Bq per kg dry	30	40
Soil to be used for potatoes in 2007, Bq per kg dry	35	3
Tilled garden soil, Bq per kg dry	75	210
Potatoes from 2006. Bq per kg fresh	1	0.6
Blackcurrants from 2007, Bq per kg fresh	-	<0.5
Redcurrants from 2007, Bq per kg fresh	-	<0.5
Blackberries from 2007, Bq per kg fresh	-	<0.5
Croft potatoes from 2007, Bq per kg fresh	-	0.3
Garden potatoes from 2007, Bq per kg fresh	-	0.2
Potatoes (earlies) from 2007, Bq per kg fresh	-	1
Kale from 2007, Bq per kg fresh	-	40
Cabbage from 2007, Bq per kg fresh	-	7
Carrots from 2007, Bq per kg fresh	-	5
Broad beans from 2007, Bq per kg fresh	-	0.3
Garden soil, used for broad beans in 2007, Bq per kg dry	-	25
Garden soil, used for cabbage and carrots in 2007, Bq per kg dry	-	170
Soil from land above potato lazy beds, no seaweed, Bq per kg dry	-	<3
Soil between house and garden plot, no seaweed, Bq per kg dry	-	3

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 5 Measured radionuclide concentrations in seaweed, soil and foods; location 2

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.2	-
Soil used for potatoes in 2006, Bq per kg dry	15	-
Soil to be used for potatoes in 2007, Bq per kg dry	20	3
Soil to be used for arable crops in 2007, Bq per kg dry	15	-
Potatoes(I) from 2007, Bq per kg fresh	-	< 0.2
Soil used for potatoes(I) in 2007, Bq per kg dry	-	3
Potatoes(II) from 2007, Bq per kg fresh	-	< 0.3
Soil used for potatoes(II) in 2007, Bq per kg dry	-	<2
Cereals(I) from 2007 (cut from field), Bq per kg fresh	-	0.1
Soil used for cereals(I) in 2007, Bq per kg dry	-	-
Cereals(II) from 2007 (collected from ground/few ears), Bq per kg fresh	-	6
Cereals(III) from 2007 (cut from field), Bq per kg fresh	-	0.5
Soil used for cereals(III) in 2007, Bq per kg dry	-	<0.8
Soil, no seaweed, Bq per kg dry	-	< 3

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 6 Measured radionuclide concentrations in seaweed, soil and foods; location 3

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.2	125
Soil used for artichokes in 2006, Bq per kg dry	20	100
Soil from control plot, not used since 1890, Bq per kg dry	30	< 2
Artichokes, Bq per kg fresh	0.4	0.4
Kale (1) from 2007, Bq per kg fresh	-	20
Soil used for Kale (1) in 2007, Bq per kg dry	-	170
Kale (2) from 2007, Bq per kg fresh	-	15
Soil used for Kale (2) in 2007, Bq per kg dry	-	150
Eggs, Bq per kg fresh	-	< 1
Blackberries never been grown using seaweed, Bq per kg fresh	-	< 0.1

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 7 Measured radionuclide concentrations in seaweed, soil and foods; location 4

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.1	50
Soil used for potatoes in 2006, Bq per kg dry	15	2
Soil to be used for oats in 2007, Bq per kg dry	15	3
Soil to be used for potatoes in 2007, Bq per kg dry	10	-
Land to be used for grazing in 2007	20	<2
Potatoes from 2006, Bq per kg fresh	<0.09	0.09
Potatoes (Desiree) from 2007, Bq per kg fresh	-	0.1
Potatoes (Sharps Express) from 2007, Bq per kg fresh	-	0.1
Mutton, Bq per kg fresh	7	< 0.5
Cereals (collected from the ground post harvest/ mainly stalks), Bq per kg fresh	-	0.5
Soil used for potatoes in 2007, Bq per kg dry	-	3
Liver, Bq per kg fresh	-	< 0.9

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 8 Measured radionuclide concentrations in seaweed, soil and foods; location 5

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.2	-
Soil to be used for potatoes in 2007, Bq per kg dry	20	<2
Soil to be used for oats/rye in 2007, Bq per kg dry	10	7
Potatoes from 2007, Bq per kg fresh	-	0.1
Silage (as fed) from 2007, Bq per kg dry	-	1
Soil near the house where no seaweed has been applied, Bq per kg dry	-	< 3

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 9 Measured radionuclide concentrations in seaweed, soil and foods; location 6

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Kelp, Bq per kg fresh	0.2	30
Bladderwrack, Bq per kg fresh	0.2	140
Soil to be used for potatoes in 2007, Bq per kg dry	10	5
Soil to be used for cereals in 2007, Bq per kg dry	15	<2
Potatoes from 2006, Bq per kg fresh	<0.2	0.06
Silage from 2006, Bq per kg fresh	2	0.1
Beef joint (animal access to seaweed on shore) , Bq per kg fresh	8	< 0.9
Beef mince (animal access to seaweed on shore) , Bq per kg fresh	8	< 1
Mutton joint (animal access to seaweed on shore), Bq per kg fresh	30	< 0.9
Soil from rough land near to house, no seaweed, Bq per kg dry	-	5

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 10 Measured radionuclide concentrations in seaweed, soil and foods; location 7

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.4	-
Soil intended for potato crop in 2007, Bq per kg dry[b]	<0.6	4
Soil to be used for cereals in 2007, Bq per kg dry	20	-
Soil, no seaweed, Bq per kg dry	20	< 2
Potatoes (Record) from 2007, Bq per kg fresh	-	< 0.4
Potatoes (Pentland) from 2007, Bq per kg fresh	-	< 0.4
Soil used for potatoes in 2007, Bq per kg dry[c]	-	< 1
Silage to be used for winter feed for cattle in 2007, Bq per kg dry	-	0.2
Beef joint, (animal access to seaweed on shore), Bq per kg fresh	30	< 0.5
Mutton joint, (animal access to seaweed on shore), Bq per kg fresh	3	< 0.5
Cereals (high levels of seaweed applied), Bq per kg fresh	-	< 0.1
Cereals (low levels of seaweed applied), Bq per kg fresh	-	< 0.2
Soil taken from end of field with high levels of seaweed application, Bq per kg dry	-	<0.8
Soil taken from end of field with low levels of seaweed application, Bq per kg dry	-	<1
Meadow hay silage, no seaweed applied, Bq per kg dry	-	< 0.3
Soil used for potatoes, never had seaweed applied, Bq per kg dry	-	< 3
Potatoes (Maris Piper and other varieties), never had seaweed applied, Bq per kg fresh	-	< 0.3

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

b) Sample taken in March 2007

c) Sample taken following harvest of potato crop in 2007

Table 11 Measured radionuclide concentrations in seaweed, soil and foods; location 8

Material, units	^{137}Cs[a]	^{99}Tc[a]
Seaweed, Bq per kg fresh	0.4[b]	-
Soil from existing garden vegetable plot, Bq per kg dry	15	7
Soil from new garden vegetable plot, Bq per kg dry	25	<2
Soil on the croft for potatoes in 2007, Bq per kg dry	15	2
Potatoes from 2007, Bq per kg fresh	-	< 0.1
Carrots from 2007, Bq per kg fresh	-	< 0.1
Beetroot from 2007, Bq per kg fresh	-	< 0.1
Soil from raised beds used for carrots and beetroot in 2007, Bq per kg dry	-	<1
Soil taken from behind house, no seaweed, Bq per kg dry	-	< 2

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

b) Seaweed used from the same location as visit 7

Table 12 Measured radionuclide concentrations in seaweed, soil and foods; location 9

Material, units	^{137}Cs[a]	^{99}Tc[a]
Seaweed, Bq per kg fresh	0.3	-
Soil from polytunnel 1, Bq per kg dry	25	-
Soil from outdoor vegetable plot for 2007, Bq per kg dry	30	-
Soil from raised bed used for carrots in 2006, Bq per kg dry	30	15
Soil from polytunnel 2, Bq per kg dry	15	10
Control soil, no seaweed applied for at least 18 years	20	<6
Carrots from 2006, Bq per kg fresh	0.2	0.5
Strawberries from 2006, Bq per kg fresh	-	<0.1
Strawberries from 2007 grown in polytunnel 2, Bq per kg fresh	-	<0.1
Tomatoes from 2007 grown in polytunnel 1, Bq per kg fresh	-	<0.2
Early potatoes from 2007 grown in polytunnels 1 and 2, Bq per kg fresh	-	<0.1
Cabbage from 2007, Bq per kg fresh	-	0.7
Mixed legumes (broad beans, peas, French beans) from 2007 grown in polytunnel 1, Bq per kg fresh	-	0.5
Cucumber from 2007 grown in polytunnel 3, no seaweed applied in 2007, Bq per kg fresh	-	<0.06
Soil used for strawberries in 2007, Bq per kg dry	-	5
Soil used for tomatoes in 2007, Bq per kg dry	-	10
Soil used for cucumber in 2007, Bq per kg dry	-	<2
Soil used for cabbage in 2007, Bq per kg dry	-	15
Soil used for French beans in 2007, Bq per kg dry	-	30
Lettuce from 2007 grown outside in garden plot, Bq per kg fresh	-	0.7
Soil used for lettuces in 2007, Bq per kg dry	-	60

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 13 Measured radionuclide concentrations in seaweed, soil and foods; location 10

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.2	-
Soil used for potatoes in 2007, Bq per kg dry	20	<2
Soil used for soft fruit for in 2007, Bq per kg dry	15	4
Soil used for vegetables in 2007, Bq per kg dry[b]	15	35
Soil used for vegetables in 2007, Bq per kg dry[b]	20	-
Kale from 2007, Bq per kg fresh	-	2
Red cabbage from 2007, Bq per kg fresh	-	0.2
Potatoes from 2007, Bq per kg fresh	-	< 0.9
Broad beans from 2007 (shelled), Bq per kg fresh	-	< 0.2
Blackcurrants from 2007, Bq per kg fresh	-	< 0.2
Soil used for broad beans in 2007, Bq per kg dry	-	2
Soil used for cabbage and kale in 2007, Bq per kg dry	-	15
Soil taken from area of garden that has had no seaweed, Bq per kg dry[c]	-	10

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

b) Soil taken from two separate vegetable beds in garden.

c) Seaweed use prior to 10 years ago uncertain.

Table 14 Measured radionuclide concentrations in seaweed, soil and foods; location 11

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.20	90
Soil used for pigs in 2007, Bq per kg dry	10	-
Soil used for vegetables in 2007, Bq per kg dry	10	15
Limed soil used for vegetables in 2007, Bq per kg dry	15	-
Lettuce (mixed varieties) from 2007, Bq per kg fresh	-	2
Broccoli from 2007, Bq per kg fresh	-	4
Cabbages from 2007, Bq per kg fresh	-	15
Swiss chard (red) from 2007, Bq per kg fresh	-	15
Soil used for Swiss chard in 2007, Bq per kg dry	-	15
Soil used for lettuce in 2007, Bq per kg dry	-	45
Soil from top end of croft plot that has never been cultivated, Bq per kg dry	-	< 3

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 15 Measured radionuclide concentrations in seaweed, soil and foods; location 12

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.3	-
Soil used for vegetables in 2007, Bq per kg dry	15	2
Soil in raised beds used for vegetables in 2007 (no seaweed), Bq per kg dry	3	<2
Soil from croft land to be used for potatoes in 2007, no seaweed ever applied, Bq per kg dry	30	<2
Potatoes from 2007 from croft, Bq per kg fresh	-	0.1
Soil used for potatoes on croft in 2007, Bq per kg dry	-	8
Lettuce from 2007 grown in raised beds, Bq per kg fresh	-	1
Potatoes from 2007, grown in new plot of land with no seaweed applied, Bq per kg fresh	-	< 0.1
Soil used for potatoes in 2007, no seaweed ever applied, Bq per kg dry	-	< 5

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 16 Measured radionuclide concentrations in seaweed, soil and foods; location 13

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Soil used for vegetables in 2007, Bq per kg dry	20	70
Soil from flower garden, no seaweed, Bq per kg dry	30	< 2
Cabbage and cauliflower from 2007, Bq per kg fresh	-	0.6
Peas and sugar snap peas from 2007, Bq per kg fresh	-	< 0.2
Potatoes (early variety) from 2007, Bq per kg fresh	-	0.2
Soil used for peas in 2007, Bq per kg dry	-	110
Soil used for potatoes in 2007, Bq per kg dry	-	10
Soil used for cabbage in 2007, Bq per kg dry	-	20

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained below

Table 17 Measured radionuclide concentrations in seaweed, soil and foods; location 14

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	1	240
Soil used for vegetables in raised beds for 2007, Bq per kg dry	30	-
Soil used for soft fruit in 2007, Bq per kg dry	30	30
Composted seaweed (from 2006) to be used in 2007 on garden, Bq per kg fresh	3	75
Soil from control site (edge of lawn), Bq per kg dry	10	< 2
Celery from 2007, Bq per kg fresh	-	< 0.5
Lettuce from 2007, Bq per kg fresh	-	0.2
Mixed legumes from 2007, Bq per kg fresh	-	0.3
Potatoes from 2007, Bq per kg fresh	-	< 0.1
Courgettes from 2007, Bq per kg fresh	-	<0.1
Soil used for celery in 2007, Bq per kg dry	-	60
Soil used for lettuce in 2007, Bq per kg dry	-	< 2
Currants and raspberries from 2007, Bq per kg fresh	-	< 0.1

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 18 Measured radionuclide concentrations in seaweed, soil and foods; location 15

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.3	55
Compost (approx. 20% seaweed) for use in 2007, Bq per kg fresh	6	40
Soil from asparagus bed, Bq per kg dry	15	-
Soil to be used for vegetables in 2007, Bq per kg dry	15	35
Soil used for soft fruit in 2007, Bq per kg dry	15	50
Soil from around apple tree, Bq per kg dry	20	55
Soil from garden, no seaweed, Bq per kg dry	25	3
Mixed berries (gooseberries, strawberries and raspberries) from 2007, Bq per kg fresh	-	< 0.3
Kale from 2007, Bq per kg fresh	-	0.5
Broad beans from 2007, Bq per kg fresh	-	< 0.4
Apples (windfalls and damaged) from 2007, Bq per kg fresh	-	< 0.1
Potatoes from 2007, Bq per kg fresh	-	< 0.1
Soil used for broad beans in 2007, Bq per kg dry	-	35
Soil used for kale in 2007, Bq per kg dry	-	65

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 19 Measured radionuclide concentrations in seaweed, soil and foods; location 16

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Soil used for blueberries, Bq per kg dry	25	10
Soil used for blackcurrants, Bq per kg dry	20	30
Soil from site, no seaweed, Bq per kg dry	45	< 2
Raspberries from 2007, Bq per kg fresh	-	< 0.2
Blueberries from 2007, Bq per kg fresh	-	< 0.3
White currants from 2007, Bq per kg fresh	-	< 0.3

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 20 Measured radionuclide concentrations in seaweed, soil and foods; location 17

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	0.4	-
Soil in raised beds used for vegetables in 2007, Bq per kg dry	70	-
Soil in raised bed used for potatoes in 2007, Bq per kg dry	40	30
Soil site, no seaweed, Bq per kg dry	50	< 3
Potatoes from 2007 grown in raised beds, Bq per kg fresh	-	< 0.1
Calabrese/Kale from 2007, Bq per kg fresh	-	2
Soil used for potatoes in 2007 grown in raised beds, Bq per kg dry	-	15
Soil used for kale in 2007, Bq per kg dry	-	2
Potatoes grown on croft land, never had seaweed, Bq per kg fresh	-	< 0.1

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 21 Measured radionuclide concentrations in seaweed, soil and foods; location 18

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh (2 samples taken)	1	-
	1	-
Soil used for vegetable plot in 2007, Bq per kg dry	10	<7
Soil from control site (no seaweed), Bq per kg dry	*10*	3
Potatoes (Duke of York and Wilja) from 2007, Bq per kg fresh	-	0.1

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 22 Measured radionuclide concentrations in seaweed, soil and foods; location 19

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Seaweed, Bq per kg fresh	1	650
Seaweed / bracken compost to be used in 2007, Bq per kg dry	8	2200
Soil used for vegetable plot in 2007, Bq per kg dry	15	300
Soil, no seaweed, Bq per kg dry	15	3
Garden compost from compost heap, Bq per kg dry	-	10200
Greenhouse spent compost taken from several tubs used for tomatoes 2007, Bq per kg dry	-	2200
Garden soil from lower end of plot nearer the sea used for crops in 2007, Bq per kg dry	-	210
Garden soil from top end of plot used for crops in 2007, Bq per kg dry	-	440
Tomatoes from 2007, Bq per kg fresh	-	1
Potatoes from 2007, Bq per kg fresh	-	3
Chard from 2007, Bq per kg fresh	-	25

A dash (-) means that we have not analysed the sample for that radionuclide.

a) Values marked as ‘<’ are explained above.

Table 23 Measured radionuclide concentrations in seaweed, soil and foods; location 20

Material, units	$^{137}Cs^{a}$	$^{99}Tc^{a}$
Meat from leg of mutton from 2007, Bq per kg fresh	0.3	< 0.5
Sheep kidney from 2007, Bq per kg fresh	0.4	< 0.5

a) Values marked as ‘<’ are explained above.

Table 24 Radionuclide concentrations in control samples

Location	Sample type	Radionuclide concentrations[a], Bq kg^{-1}, dry mass for soil Bq kg^{-1}, fresh mass for crops ^{99}Tc	^{137}Cs
1	Soil (croft)	<3	
	Soil (nearer coast)	3	
2	Soil	<3	
3	Blackberries	<0.1	
	Soil	<2	
4	None		
5	Soil	<3	
6	Cereals (barley)	0.1	
	Soil	5	
7	Soil	<3	20
	Potatoes	<0.3	
8	Soil	<2	
9	Soil	<6	20
10	Soil[b]	10	
11	Soil	<3	
12	Potatoes	<0.1	
	Soil	<5.0	
13	Soil	<2	30
14	Soil	<2	10
15	Soil	3	25
16	Soil	<2	45
17	Soil	<3	50
18	Soil	3	10
19	Soil	2	15
Inland on Skye (taken from land along the B6885)	Soil	<3	
	Soil	<3	
	Soil	<3	
	Soil	2	
	Soil	<3	
	Soil	<3	
Perth	Soil	<3	
Oxfordshire	Soil	<3	

a) Values marked as '<' are explained above.

b) History of seaweed use not known earlier than 10 years ago

3.3 Discussion

3.3.1 Concentrations of ^{99}Tc in environmental samples

The data for soils at individual locations show the influence of variations in the frequency with which land is treated with seaweed and the amount applied. For example, at

Location 9, soils were collected from around a variety of crops grown in polytunnels which have been in use for different lengths of time. The measured concentrations of ^{99}Tc are in the range < 2 – 60 Bq kg^{-1} (see Table 12). At Location 1 (see Table 4), a 'lazy bed' system is used for growing potatoes and an individual bed typically only receives seaweed infrequently. In contrast, a garden plot at the same location receives seaweed most years. The measured concentrations of ^{99}Tc in soil were 3 – 40 - Bq kg^{-1} in two of the 'lazy beds' sampled and 210 Bq kg^{-1} in the garden plot, reflecting the differing application of seaweed over the years. At Location 19, the soil used to grow crops comprises compost made with seaweed. In effect, seaweed has been added to the soil every year for the last 30 years as the garden plot has been developed. As expected, this soil showed the largest accumulation of ^{99}Tc from seaweed application. The ^{99}Tc concentrations in soils at this location were significantly higher than those observed from other sites where application was less frequent or where seaweed had been applied over a shorter period. The concentrations in soils and compost at Location 19 ranged from 210 - 2200 Bq kg^{-1}. The species of seaweed used will also have an effect on the resultant concentrations in treated land. In most cases, the seaweed used was a mixture of species and this was what was analysed. However, at one location, animals had access to two species on different beaches, kelp and bladderwrack. The results from this location (Location 6) can be used to illustrate the potential variation in radionuclide concentrations between species, the observed concentration in bladderwrack being more than 4 times greater than the value in kelp (see Table 9).

At many of the locations, the highest concentrations of ^{99}Tc have been observed in green vegetables, particularly leafy green vegetables such as chard and kale. Radionuclide concentrations in legumes and other green vegetables such as lettuce and cabbage tend to be lower at most locations. Examples of this are at Location 10 (Table 13) and Location 1 (Table 4), where radionuclide concentrations in kale are 5 – 10 times higher than in other above-ground vegetables. All of the locations visited were within 1 km of the sea, with many of them, including Location 1, being exposed and very close to the sea.

A few samples of crops grown on land that had not been treated by seaweed were also collected. The results are shown in Table 24. In all cases, measured radionuclide concentrations are close to or below the limit of detection. In no cases were these samples taken from locations where activity was detectable in the soil.

Taken together, these results suggest that there is the possibility that at some locations the observed radionuclide concentrations in above-ground leafy crops such as kale or chard could be partly due to the direct deposition of activity onto the foliage. This could occur via the transport of spray or suspended fine sediment landwards from the sea. Any contribution from direct deposition is most likely to be observed in leafy green vegetables that have a large exposed surface area which forms the edible part of the crop

The monitoring data for allotments close to Sellafield that have been treated with seaweed are consistent with this idea, since the radionuclide concentrations in leafy green vegetables such as spinach tend to be higher than in other green vegetables by an order of magnitude as shown in the RIFE reports for 2003 and 2005 [Environment Agency *et al.*, 2004, 2006]. However, the limited collection of samples in this study and the uncertainty of the historic use of seaweed at many of the locations mean that no firm conclusions can be drawn.

Many of the soil control samples were shown to have concentrations of ^{99}Tc that are below detection limits. In many cases the land usage was known for at least 1 – 2 generations and so it was clear that seaweed had not been applied over the operating time of the Sellafield site (and hence not subject to radionuclides from discharges from the site). In other cases, however, the land usage was only known back to when the current occupants took over the land. This may have been for periods of only a few years, and for one cultivated site at least it is conceivable that seaweed could have been applied in earlier years. For example, at Location 10 (Table 13), the sample of control soil gave a measurable value of 10 Bq kg^{-1}. Some control samples of soil, where small radionuclide concentrations were measurable in the soil, were very close to the sea, for example at Location 1.

Radionuclide concentrations in potatoes and other root vegetables were typically less than a few Bq kg^{-1} and at many sites were below the limit of detection. All radionuclide concentrations measured in fruit, meat and eggs were below the limit of detection. The very small activity concentrations in meat and eggs are an important finding for those cases where animals graze directly on seaweed on the foreshore. There are few data on the transfer of Tc from feed to animal tissue [Green and Woodman, 2003] and those which are available indicate that transfer is expected to be low. It is very difficult to estimate the amount of seaweed being consumed by animals in these circumstances and so predictions based on monitoring data for seaweed and sparse data on uptake to animals would have large associated uncertainties. Again, this illustrates the importance of making measurements on the foods consumed.

Cereals and silage were studied because these crops are used as animal feedstuffs for cattle and sheep. Radionuclide concentrations were less than 1 Bq kg^{-1} in all samples except one; although it should be noted that the sample with the higher radionuclide concentration was not representative of the whole harvested crop: the crop had been harvested and only remnants of the crop were available. Overall, however, these values did not indicate that radionuclide concentrations in animal products would give any cause for concern if the crops are consumed by cattle or sheep.

3.3.2 Concentrations of other radionuclides in environmental samples

All meat and offal samples were analysed for gamma-emitting radionuclides: only ^{137}Cs was detected and the results are shown in Table 4 - Table 23. The ^{137}Cs concentrations in meat observed at some locations were higher than expected compared with values available for meat at several locations in Scotland as reported in RIFE [Environment Agency *et al.,* 2005]. The highest most recent concentration of ^{137}Cs in meat in Scotland reported in RIFE is 0.14 Bq kg^{-1} compared with values in the range of 3 – 30 Bq kg^{-1} measured in samples collected in this study. The consumption of seaweed and crops is not believed to be sufficient to account for the measured values. The concentrations of ^{137}Cs in meat and kidney from sheep that are known to graze only seaweed support this view as the measured concentrations are one to two orders of magnitude lower than those from the other locations studied (see Table 23). The concentrations of ^{137}Cs measured in meat from cattle grazing pasture with only opportunistic grazing of seaweed are broadly consistent with those that might be expected from the consumption of rough pasture land contaminated with ^{137}Cs from the Chernobyl accident in 1986.

Concentrations of ^{239,240}Pu and ^{90}Sr were determined in several of the samples of meat and offal that were collected. The data for offal were particularly important because actinide elements concentrate in liver and kidney. Consequently, these samples provided the most sensitive test of whether, in the area of interest, these radionuclides were being concentrated in seaweed and then being transferred to grazing animals. All of the results were less than the limit of detection, and so these radionuclides were not considered further.

Concentrations of ^{137}Cs in the soils that have received seaweed were broadly similar to those in the control soils analysed. The range of concentrations of ^{137}Cs in soils where seaweed has been applied was <0.6 – 75 Bq kg^{-1} dry mass compared with 10 – 50 Bq kg^{-1} dry mass in the control soils. This indicates that the ^{137}Cs in seaweed is not contributing significantly to the levels of ^{137}Cs in the soils. The observed concentrations of ^{137}Cs in seaweed are also consistent with this view, since they are low compared with the values observed in the soil. The ^{137}Cs in soils will be dominated by contributions from the fallout from weapons testing in the atmosphere together with any deposition from the Chernobyl accident. There could be a contribution from liquid discharges from Sellafield via deposition in seaspray, but any deposition resulting from atmospheric discharges from the Sellafield site should be minimal. A few measurements of ^{90}Sr and $^{239+240}$Pu were also made in soils and ^{90}Sr was also measured in one control soil. Similarly to ^{137}Cs, no significant difference was observed between concentrations of ^{90}Sr in seaweed treated soils and the control soil and values were low, ranging between 2 and 6 Bq kg^{-1} dry mass. Concentrations of $^{239+240}$Pu in soils were also low, with values ranging between 0.5 and 0.9 Bq kg^{-1} dry mass. For both ^{90}Sr and ^{239,240}Pu, measured concentrations in soil are consistent with measured values arising from the fallout from weapons testing in the atmosphere [Haywood *et al*, 1980].

3.3.3 Comparison of results with published routine surveillance data

In the RIFE programme, seaweed is used as an indicator material, ie. it provides a convenient measure of environmental conditions for particular radionuclides that have a high uptake from sea water. Sampling for the RIFE programme specifically involves the collection of the newly grown tips of seaweed fronds which provides an indicator of the effects of recent discharges from the Sellafield site. However, in this study the whole plant has been collected as this is what is used on the land (see Section 3). Radionuclide concentrations measured in the whole plant could be different from those in the growing tips as seaweed can live in the sea for many years. Any comparison of RIFE data with the results from the present study is complicated further because the species of seaweed collected may differ, and the differences in radionuclide concentrations between species at the same location have been illustrated in this study (data from Location 6, shown in Table 9) and in RIFE. In addition, the concentrations observed in an indicator material such as seaweed will be dependent upon the season of the year, since if the plants are growing rapidly there may be a growth dilution effect.

Overall, therefore, any direct comparison between the measured values in the present study and those in the RIFE programme must be made cautiously. However, as samples are routinely collected from the general area covered by the present study as part of the RIFE programme, it is useful to look at whether the measured radionuclide concentrations in this study are broadly similar with those reported in RIFE. Table 25 gives a summary of the data collected for ^{99}Tc in recent years, together with data from the present study. It should be noted that the actual locations used in this study differ from those in the RIFE programme. Given all of the possible complicating factors, the concentrations of ^{99}Tc in the two sets of samples are broadly comparable. For the reasons given earlier, radionuclide concentrations in seaweed cannot be used to predict the resultant concentrations in foodstuffs produced on seaweed treated land. However, the need for monitoring of such foodstuffs should be considered if the results of the RIFE programme indicate any sudden or sustained increases in the radionuclide concentrations in a single species of seaweed at a specific location.

Table 25 Comparison of concentrations of ^{99}Tc in seaweed with values in RIFE across the region of interest

Concentrations of ^{99}Tc in seaweed in region of interest, Bq kg^{-1}, fresh mass					
Study		RIFE [Environment Agency *et al.*, 2005; 2006; 2007; 2008]			
Location	Year, 2007	2004	2005	2006	2007
3	125	<12 - 350	4.4 - 110	4.5 - 660	90 - 360
4	50				
6	30 (kelp)				
6	140 (bladderwrack)				
11	90				
14	240				
15	55				
19	650 (rotted seaweed)				

a) Range of RIFE values for growing tips of seaweed given *for Fucus vesiculosus* collected at Stornoway, Isle of Lewis; *Porphyra* collected at Knock Bay, Isle of Mull, seaweed (no species given) collected at Islay and Campbeltown, *Fucus serratus* at Lerwick and *Ascophyllum nodosum* collected at Cape Wrath. Measurements for all locations are not available every year.

As part of the RIFE programme, the Food Standards Agency (FSA) monitors allotments around Sellafield that have been regularly treated with seaweed. A comparison has been made between the concentrations of ^{99}Tc measured in soil and selected crops from these allotments with measured values from this study (Table 26). This shows that, both for soils and selected crops, the measured concentrations in the regional area under consideration in this study were significantly lower than those found at the allotments near Sellafield. The Food Standards Agency has reported that the radiation doses received by people who eat crops from these allotments are typically 1% of the dose limit for members of the public [Environment Agency *et al.*, 2008]. These results indicate, therefore, that it is unlikely that radiation doses received by people who eat crops from seaweed treated land in the area of interest in this study will be of concern. An assessment of radiation doses is discussed in Section 4.

Table 26: Comparison of concentrations of ^{99}Tc in crops with values in RIFE from Sellafield allotments

	Tc-99 concentrations in crops, Bq kg^{-1}, fresh mass	
Crop	Range of values from study (number of measurements)	Range of values from RIFE for 2004 – 2007[a] (number of measurements)
Potatoes	<0.05 – 3 (29)	<0.6 – 26 (12)
Root vegetables	<0.06 – 5 (5)	30 – 100 (4)
Legumes	<0.2 – 0.5 (6)	<0.3 – 58 (4)
Kale, chard and spinach beet	0.5 – 40 (9)	270 – 1200 (2)
Cabbage & cauliflower	0.2 – 15 (7)	<0.2 – 97 (4)

a) Environment Agency *et al.*, 2005; 2006; 2007; 2008.

4 ASSESSMENT OF INDIVIDUAL RADIATION DOSES

For the reasons given earlier, the dose assessment has been based only on the measured radionuclide concentrations in foodstuffs. No attempt has been made to use the observed radionuclide concentrations in seaweed or soil to predict doses. The dose assessment was confined to ^{99}Tc, since there was no evidence of transfer of other radionuclides via seaweed to terrestrial foodstuffs. The basic approach adopted was as follows. The measured concentrations of ^{99}Tc in foods given in Table 4 - Table 23 were considered to be representative of the levels in the foods consumed over a year by the individuals at each of the locations considered. These data were combined with the information obtained on consumption rates of the different foods to assess the amount of ^{99}Tc ingested over a year.

Estimates of the amount of radionuclides ingested are not sufficient on their own to evaluate the resulting radiation doses. This is because radionuclides differ in their mode of decay (for example, alpha, beta or gamma-radiation), their radioactive half-life and their behaviour after they have entered the body (ie whether they concentrate in particular organs and how long they remain there). In addition, different organs vary in their sensitivity to radiation. To bring all of these factors on to a common basis, the International Commission on Radiological Protection (ICRP) uses the concept of effective dose. Effective dose is expressed in units known as sieverts [ICRP, 1991]. In practice, environmental assessments are usually given in terms of millisieverts (mSv) (which is one thousandth of one sievert) or microsieverts (µSv) (which is one millionth of one sievert). In the remainder of this report, effective dose has been referred to simply as “dose”[*]. Internationally-agreed data have been published relating the amount of a radionuclide ingested to the resultant dose [ICRP, 1996). These are usually referred to as dose coefficients. Dose coefficients, ie the dose per unit intake of radioactivity, for ^{99}Tc via ingestion, were taken from the compendia published by the International Commission on Radiological Protection (ICRP). In the present study the appropriate dose coefficients were combined with the estimated annual intakes of activity to provide

[*] The dose calculated in this study is the committed effective dose from one years intake of foodstuffs.

the resultant doses. Several assumptions had to be made in the use of the available data and these are described below. A cautious approach has been adopted for public protection purposes. Actual doses from ingestion should be lower than the values estimated using this methodology and assumptions.

In those cases where the radionuclide concentration is reported as below the limit of detection, the value of the detection limit has been treated as an actual measured value for the dose assessment. This will provide an estimate of the upper bound of the ingestion doses that could be received. This was a reasonable approach in this case because the detection limit values were not so large that they made a major contribution to the overall dose estiamtes. The measurement uncertainties associated with the analytical data were not taken explicitly into account.

In some cases, samples of some of the crops grown were not available. In these cases, radionuclide concentrations were estimated based on the values observed in other foodstuffs at that location for which data were available, combined with a comparison of values from other locations where samples of all of the foodstuffs of interest were obtained.

At some locations, consumption rate data were only available for a given food group, for example green vegetables, rather than for individual foods. In such cases, for the purposes of the dose assessment the highest activity concentration measured in a given sample from that food group at that location was assumed to be representative of activity concentrations in all foods from that group. Again, this is a cautious approach that provides an estimate of the potential upper bound of the ingestion doses.

The highest predicted doses are small, being of the order of a few microsieverts (μSv) in a year. The majority of the estimated doses were factors of 100 - 1000 lower than the highest values. These doses have been derived using cautious estimates of consumption rates and the highest concentration of ^{99}Tc in each food group, as described above. Consequently, actual doses could be significantly lower, particularly those relating to vegetables. This is because the highest concentrations of ^{99}Tc in vegetables are those in kale and chard, these being typically 10 times higher than for other vegetables, whereas in practice a range of vegetables is consumed across the year.

The result from this study that the doses are small[*], is consistent with the conclusions that have made for people consuming food from allotments close to the Sellafield site where seaweed is used as a fertiliser. The Food Standards Agency report that the doses from ^{99}Tc received by people growing food in the allotments close to the Sellafield site are about 10–15 μSv in a year [Environment Agency *et al,.* 2005, 2006, 2007, 2008, 2009]. Concentrations of ^{99}Tc measured in foods in this study are significantly lower than those measured at the Sellafield allotments (see Section 3.3.3) and so radiation doses will also be significantly lower.

[*] Individual radiation dose, regardless of its origin, is likely to be regarded as trivial if it is of the order of some tens of microsieverts per year [IAEA, 1998].

To place the doses estimated in this study in context, they are at least 1000 times smaller than the annual dose limit for members of the public [ICRP, 1991], with many of the estimated doses being an additional factor of 100 – 1000 lower. As part of the Government's responsibility for food safety, radioactivity in the whole diet is determined based on diet samples from regions throughout the UK. Doses arising from consuming a typical diet at average rates are assessed for adults and reported in RIFE, the latest report being for 2007 [Environment Agency *et al.,* 2008]. The mean annual dose from naturally occurring radionuclides (excluding potassium-40) present in a typical diet in the UK was 56 µSv in 2007*. This is noticeably higher than the doses reported in this study. Another comparison that can be made is that the doses estimated in the present study are comparable with a dose that would be received from cosmic radiation during a return flight to Western Europe.

4.1 Discussion

The estimated doses from ingestion of foods are considered very small at all of the locations studied. There are differences between the individual locations as a result of variations in the foodstuffs produced, the way that the land has been treated and the amounts of food that are being consumed over the year. It was difficult, in particular, to obtain accurate estimates of consumption rates from the participants, but as noted in Section 4, the overall approach has been cautious and actual doses should not be higher than the estimated values. Nevertheless, the differences between locations emphasise that, in cases such as this, it is difficult to justify a generalised approach until the scale of the radiological situation has been assessed.

At Location 19, the soil used to grow crops comprises compost made with seaweed. In effect, seaweed has been added to the soil every year for the last 30 years as the garden plot has been developed. As expected, this soil showed the largest accumulation of ^{99}Tc from seaweed application. The ^{99}Tc concentrations in soils at this location were significantly higher than those observed from other sites where application was less frequent or where seaweed had been applied over a shorter period. The concentrations in soils and compost at Location 19 ranged from 210 - 2200 Bq kg^{-1}. However, the corresponding values in the crop were typically a few Bq kg^{-1} (expressed in terms of the fresh mass of the crop), the highest concentration of ^{99}Tc being in chard (25 Bq kg^{-1}). These values are similar to those observed at other locations and, as at all of the other locations, the resultant doses give no cause for concern.

In predictive models, the transfer of radionuclides from soil to crops is often expressed in terms of a soil – plant transfer factor (TF). The TF is the quotient of the radionuclide concentration in the crop (which can be expressed in terms of either fresh or dry mass) and the radionuclide concentration in the dry soil. The present study did provide some opportunities to derive soil – crop TFs for ^{99}Tc and these will be reported elsewhere. As an example, data from a number of locations gave TF values in the range of about 10^{-3}-

* It should be noted that ^{99}Tc is not a naturally occurring radionuclide and any contribution from this radionuclide is not included in this value.

10^{-2}. This is much lower than the TF value currently used for crops in the HPA-RPD foodchain model, FARMLAND [Brown and Simmonds, 1995] and the value recommended by the International Atomic Energy Agency [IAEA, 1994]. Consequently, an assessment based on a combination of measured values in seaweed or soil from treated land and generalised TF values would overestimate the transfer to crops and therefore the resultant doses. The TF values found in the present study are not unique, and, for example, similar values have been observed in land that has been reclaimed from the sea [Green *et al.,* 1995]. This observation does however reinforce once again the importance of using measurements of the foodstuffs themselves in this type of site-specific radiological dose assessment. The small soil-plant transfer factors that have been consistently found across all the locations also provides reassurance that ^{99}Tc incorporated in seaweed is not readily taken up into crops grown on land treated with seaweed.

The levels of dose estimated in this study indicate that there is no need for a major programme of sampling and measurements in foodstuffs from seaweed treated land. The problems associated with making predictions based on measured concentrations of radionuclides in seaweed have been emphasised earlier in this report. However, the results from the monitoring programme reported in RIFE could, with care, be used to discern whether radionuclide concentrations in seaweed are increasing and, therefore, whether more specific surveillance of foodstuffs produced on treated land is warranted.

5 CONCLUSIONS

The key conclusions and recommendations can be summarised as follows.

- Seaweed is still being used as a soil conditioner and animal feedstuff along the west and north coasts of Scotland, the offshore islands and on Orkney and Shetland.
- Technetium-99 is the radionuclide of primary interest and it was readily detected in the samples of seaweed collected from within the area of interest studied here and also in many samples of soil that had been treated with seaweed.
- Concentrations of ^{99}Tc in foodstuffs produced on land treated with seaweed are very low and, in many cases, are below the detection limits of the sensitive analytical techniques used. In all cases where animals graze seaweed on the beach, the concentrations of ^{99}Tc in meat and offal were below detection limits.
- Cautious estimates of doses from ingestion of foods produced on seaweed treated land are small and give no cause for concern.
- Measurements of radionuclide concentrations in seaweed that are routinely undertaken as part of the RIFE programme cannot be used to predict what the resultant radionuclide concentrations in foodstuffs are because of variations in land management practices, the amounts of foodstuffs consumed and the amounts of ^{99}Tc transferred to foodstuffs from seaweed via the soil.

- Estimates of doses from ingestion of foodstuffs produced from land treated with seaweed need to be based on measurements in the foodstuffs themselves.

The magnitude of the doses from ingestion estimated in this study does not justify a major programme of continuous monitoring of this exposure pathway. However, the data from current monitoring programmes could be used to indicate when further sampling and measurements might be needed.

6 ACKNOWLEDGEMENTS

This study would not have been possible without the full co-operation of members of the public who use seaweed as a soil improver or animal feed. The authors would especially like to thank all of the people who kindly offered their time to talk about their use of seaweed, the practices adopted and their food consumption. We are also very grateful for the food samples that they provided for analysis.

A number of people were very helpful in identifying local contacts and putting HPA in contact with people who were prepared to take part in the study. We would particularly like to thank Patrick Krause from the Crofting Association, Jamie Hepburn from SEPA and Alasdair MacEachen from the Western Isles Council.

We would also like to thank staff from the Radiation and Environmental Monitoring Department of HPA-RPD in Scotland and our laboratories at Chilton for their assistance in undertaking the field trips in Scotland and preparation of the samples prior to analysis and, in particular, Lorna Mitchell, Robert Pritchard and Helen McFarlane.

7 REFERENCES

Brown J and Simmonds JR (1995). FARMLAND. *A dynamic model for the transfer of radionuclides through terrestrial foodchains*. NRPB-R273, Chilton, UK

Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency (2004). Radioactivity in Food and the Environment, 2003.

Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency (2005). Radioactivity in Food and the Environment, 2004.

Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency (2006). Radioactivity in Food and the Environment, 2005.

Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency (2007). Radioactivity in Food and the Environment, 2006.

Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency (2008). Radioactivity in Food and the Environment, 2007.

Green NG, Wilkins BT, Hammond DJ and Davidson MF (1995). *Transfer of radionuclides to vegetables and other crops in an area of land reclaimed from the sea: A compilation of data*. NRPB-M538, Chilton, UK.

Green N and Woodman RFM (2003). *Recommended transfer factors from feed to animal products.* NRPB-W40, Chilton, UK.

Haywood SM, Simmonds JR and Linsley GS (1980). *The development of models for the transfer of ^{137}Cs and ^{90}Sr in the pasture-cow-milk pathway using fallout data*. NRPB-R110, Chilton, UK

IAEA (1988). *Principles for the exemption of radioation sources and practices from regulatory control*, Safety Series No. 89, IAEA, Vienna.

IAEA (1994). *Handbook of parameter values for the prediction of radionuclide transfer in temperate environments*. Technical report series No. 364, IAEA, Vienna.

ICRP (1991). 1990 *Recommendation of the International Commission on Radiological Protection.* ICRP Publication 60. *Annals of ICRP* **21**. Nos 1-3.

ICRP (1996). *Age-dependent doses to members of the public from intakes of radionuclides: Part 5. Compilation of ingestion and inhalation dose coefficients*. ICRP Publication 72. *Annals of ICRP* **26**(1).

Watson J, Jones AL, Oatway WB and Hughes JS (2005). *Ionising radiation exposure of the UK population: 2005 review*. HPA-RPD-001, hpa.org.uk.