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Environment report RL05/06

Dose assessments in relation to disposal at sea under the London Convention 1972: judging *de minimis* radioactivity

For Defra
Project AA005

Environment Report RL 05/06

Dose assessments in relation to disposal at sea under the London Convention 1972: judging *de minimis* radioactivity

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Executive summary

The UK government is a signatory to the London Convention (1972) that prohibits the disposal of radioactive material at sea unless it fulfils exemption criteria developed by the International Atomic Energy Agency (IAEA). If both the following radiological criteria are satisfied:

(i) the effective dose expected to be incurred by any member of the public or ships crew is of the order of 10 μSv or less in a year;

(ii) the collective effective dose to the public or ships crew is not more than 1 man Sv per annum

then the material is deemed to contain *de minimis* levels of radioactivity and may be disposed at sea pursuant to it fulfilling all the other provisions under the Convention. The individual dose criteria are placed in perspective (i.e. very low), given that the average background dose to the UK population is ~2700 μSv/a.

In England and Wales, Defra continues to issue licences to operators for the disposal at sea of dredge material. However, many ports can be affected by the authorised discharge of low-level radioactive wastes from nuclear establishments around the coastline of the UK; both current and historical. The objective of this project was to assess whether disposal of dredging material from ports in England & Wales fulfil the radiological criteria. Dredging to obtain marine aggregates, was excluded from the remit of this project.

The coastline around England & Wales was divided into nine separate regions, based on the previous Sea Fisheries Inspectorate (SFI, now known as the Marine Fisheries Agency or MFA) districts. A review of existing data was carried out concerning the sources and specific activity of radionuclides in sediment for these individual regions. Additional information was also collated to enable the estimation of individual and collective doses, resulting from exposure to dredge material. Dose calculations were carried out by following the radiological assessment guidelines issued by the IAEA, in 2003, to provide conservative estimates.

The greatest radioactive contamination occurs at the small ports along the Cumbrian coastline (Region 1), to the north of the BNF Sellafield reprocessing plant. A case study of a recent operation at Whitehaven, the most affected port, indicated that the predicted dose to crew (~8 μSv) was close to 10 μSv. Results from subsequent field measurements indicated the actual dose might have been slightly greater than 10 μSv, although the error associated with the derived value was high. It is recommended that specific individual assessments continue for all Cumbrian ports.

Information concerning radionuclide activity in sediments from our major ports is sparse and the gaps have only been partially filled by the work reported here. Application of the available data indicated that, the *de minimis* criteria were met in the eight regions outside the northern Irish Sea. These generic radiological assessments will allow managers to reach an early decision in the future, as to whether the provisions of the London Convention are fulfilled, without the need for more detailed individual assessments. It is, nevertheless, recommended that the existing approach of appropriate measurements of radionuclide sediment activity continue for ports outside the Irish Sea, concomitant with measurements of other contaminants, to build up a more robust database.

1. INTRODUCTION

1.1 Background

In 1993 the UK accepted a global ban on the sea disposal of all radioactive wastes, under the London Convention 1972 (The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972), superseding the ban which applied only to high level radioactive waste. However, all materials, including natural and inert materials, contain natural radionuclides. In addition many are contaminated with artificial radionuclides from anthropogenic sources, such as global fallout due to past atmospheric testing of nuclear weapons. Therefore, the contracting parties to the London Convention recognised the need to develop definitions and guidelines whereby candidate materials (those wastes or other matter not otherwise prohibited from disposal at sea in accordance with annex I to the Convention) containing *de minimis* levels of radionuclides could be disposed of pursuant to the provisions of this Convention.

In England and Wales, Defra issues licences to ports, harbours and marinas for the disposal of material at sea (principally the disposal of dredged material) under Part II of the Food and Environment Protection Act, 1985 (United Kingdom – Parliament, 1985). The respective licensing authorities in Scotland and Northern Ireland are the Fisheries Research Services (on behalf of the Scottish Executive, Environment and Rural Affairs Department) and the Environment Heritage Service (on behalf of the Department of the Environment Northern Ireland). This activity is authorised because dredging and sea disposal of dredged material are essential to shipping and navigation in the UK. Without adequate depths within our ports, harbours and marinas, shipping, trade and recreational boating would be severely restricted. A small number of licences are also issued for disposal of other materials including fish waste (CEFAS, 2005*a*). Dredging to obtain marine aggregates, was excluded from the remit of this project. Given that almost all materials, including dredge deposits and fish waste, are naturally radioactive, it is permissible to dispose them at sea provided they fulfil the necessary exemption (*de minimis*) criteria.

1.2 Basis for the assessment of *de minimis* radioactivity

The current system of radiological protection is based entirely on the protection of human health. This has been developed over many decades and there are now internationally accepted guidelines and standards for national radiation protection authorities. There is currently no internationally-accepted basis for the protection of the environment, including flora and fauna, from the effects of radiation (Pentreath, 2004). Accordingly, the IAEA advice with regard to the *de minimis* issue is based on the protection of human health.

Materials are deemed to contain *de minimis* levels of radioactivity and may be disposed at sea, subject to their fulfilling all the other provisions of the Convention, provided both the following radiological criteria are satisfied:

(i) the effective dose expected to be incurred by any member of the public or ships crew is of the order of 10 μSv or less in a year;

(ii) the collective effective dose to the public or ships crew is not more than 1 man Sv per annum

1.3 Development of the *de minimis* concept under the London Convention 1972

The UK government ratified the London Convention 1972 on the 'Prevention of marine pollution by dumping of wastes and other matter' in November 1975. Annex I of the Convention banned the disposal of high-level radioactive waste at sea. However, all materials, including natural and inert materials, contain natural radionuclides and are frequently contaminated with artificial radionuclides from such anthropogenic sources as fallout due to past atmospheric nuclear testing. Recognising this, the first Consultative Meeting of the Convention in 1976 requested the IAEA to develop the concept of '*de minimis*' levels of radioactivity and a similar request was made in 1985. However, these requests did not lead to an agreed definition or approach to defining *de minimis*.

Paragraph 6 of Annex I of the Convention, as amended in 1993, prohibits the disposal at sea of 'Radioactive wastes and other radioactive matter' but it also states that:

> "Paragraph 6 does not apply to wastes or other materials (e.g. sewage sludge and dredged material) containing *de minimis* (exempt) levels of radioactivity as defined by the IAEA and adopted by the Contracting Parties. Unless otherwise prohibited by Annex I, such wastes shall be subject to the provisions of Annexes II and III as appropriate."

In adopting the resolution that prohibited the disposal at sea of radioactive waste via the amendment of Annex I, the Consultative Meeting noted its earlier request to the IAEA “to develop quantitative limits for ‘*de minimis*’ (exempt) levels of radioactivity” for the purposes of the London Convention.

In 1997 the Consultative Meeting was asked by the IAEA to review its request concerning the concept of *de minimis*, with a view to clarifying the task required of the IAEA. The revised task was defined as:

> “The meeting agreed that the IAEA should be requested to provide guidance for making judgements on whether materials planned to be dumped could be exempted from radiological control or whether a specific assessment was needed. The IAEA would then further be requested to provide guidance to national authorities responsible for conducting specific assessments.”

The IAEA responded to the first part of the request by providing the London Convention 20th Consultative Meeting in 1998 with a draft report titled ‘Application of radiological exclusion and exemption principles to sea disposal’. Following comments from that meeting, the IAEA published the revised document IAEA-TECDOC-1068 (IAEA, 1999) in March 1999 for consideration by the 21st Consultative Meeting in October 1999.

The London Convention 20th Consultative Meeting considered that the IAEA advice required some clarification for an audience that was likely to be unfamiliar with the terminology used in the field of radiological protection. They convened an inter-sessional Ad Hoc meeting of experts in May 1999 to provide that clarification and the resulting document was subsequently adopted by the 21st London Convention Consultative Meeting in October 1999 as the ‘Guidelines for the application of the *de minimis* concept under the London Convention 1972’ (London

Convention, 1999). This document contains a stepwise evaluation procedure to assess candidate materials to determine if they contain *de minimis* levels of radioactivity or if a specific assessment is required. This evaluation procedure is intended to be implemented through judgements based on available information regarding the provenance of candidate materials and sediments in the receiving marine environment, specifically at the dump-site. The questions posed at each of the first five steps are designed to be answered without the need for direct measurements of radionuclides in either the candidate material or the marine environment. In cases when there is insufficient existing information on which to base such judgements a specific assessment would be required. A summary of the stepwise evaluation procedure, to assess whether the exemption criteria are met, is given in Fig. 1.

Figure 1 - Stepwise evaluation procedure to assess whether materials may be disposed at sea in the context of the London Convention 1972 (taken from IAEA, 2003).

Step 1: Candidate material

1. Are the proposed materials eligible for dumping under the provisions of the London Convention 1972?
2. If NO, the material is not allowed to be dumped and no further consideration is warranted.
3. If YES, go to Step 2.

Step 2: Initial screen for sources of contamination

1. Is there reason to believe that the candidate material contains anything other than unmodified natural radionuclides at background comparable with that in the receiving environment and artificial radionuclides derived from global fallout?
2. If NO, the materials are *de minimis*.
3. If YES, go to Step 3.

Step 3: Assessment of additional causes/sources

1. What are the likely additional causes/sources contributing to the radioactivity in the materials?
2. If only unmodified natural causes/sources, go to Step 4.
3. If only anthropogenic causes/sources, go to Step 5.
4. If both anthropogenic and natural causes/sources, go to Step 5.

Step 4: Natural causes/sources

1. If the material were to be dumped, would it substantially increase radioactivity at the dumpsite?
2. If NO, the materials are *de minimis*.
3. If YES, go to Step 6.

Step 5: Anthropogenic causes/sources

1. Were the likely anthropogenic causes/sources part of exempted or cleared practices or excluded exposures?
2. If NO, go to Step 6
3. If YES, were the marine environmental exposure pathways considered by the national radiation protection authority and are these suitable to an assessment of the proposed dumping operation?

3.1. If YES, the materials are *de minimis*.
3.2. If NO, go to Step 6.

Step 6: Specific assessment

Materials not determined to be *de minimis* through the evaluation in Steps 1–5 above could also be determined to be *de minimis* by the application of a specific assessment if:

(i) the effective dose expected to be incurred by any member of the public or ships crew is 10 µSv or less in a year and;

(ii) the collective effective dose to the public or ships crew is not more than 1 man Sv per annum

Following the adoption of IAEA-TECDOC-1068 and the London Convention Guidelines referred to above, the 21st Consultative Meeting requested the IAEA to prepare additional guidance on conducting specific assessments to determine whether candidate materials for disposal at sea contained *de minimis* levels of radioactivity. After several years work, the IAEA provided a report to the London Convention Consultative Meeting in 2003 titled ‘Determining the suitability of materials for disposal at sea under the London Convention 1972: A radiological assessment procedure’ (IAEA, 2003) in fulfilment of the request from the London Convention. This report addressed Step 6 of the Stepwise Evaluation Procedure. The 25th London Convention Consultative Meeting in 2003 adopted the guidance from the IAEA.

The specific assessment process requires estimates of the quantity of the candidate material to be disposed of, its origin and the activity concentrations of the constituent radionuclides. The guidance provided by the IAEA is, however, pragmatic and allows for the nature and extent of a specific assessment to be determined in accordance with existing knowledge. Therefore, sediments containing only relatively minor amounts of artificial radionuclides need not be subjected to an unnecessarily detailed assessment process. Provided sufficient information is available to allow an estimate to be made of the radionuclide content of the candidate material, then it is possible to carry out screening dose calculations using the IAEA model. In its simplest form, their approach uses generic coefficients for dose per unit activity concentration calculated using reasonably conservative assumptions. However, the IAEA recommend that more specific dose coefficients be used whenever possible. This requires knowledge of the dispersive characteristics of the coastal environment, local human habits, details of the dredging operation etc.

If candidate materials assessed by the Stepwise Evaluation Procedure are deemed to contain *de minimis* levels of specific activity, then they can be regarded as ‘non-radioactive’ for the purposes of the London Convention 1972 and may be disposed of at sea subject to the other provisions of the convention.

1.4 General Application of the IAEA advice

In many locations of the UK the radioactivity of dredged sediment has the potential to be enhanced above background levels, arising from the authorised discharge of liquid and gaseous wastes from nuclear establishments (Environment Agency et al., 2004). In these cases, assessments have been required on an *ad hoc* basis and for assurance that there is no significant risk (e.g. to the food chain) from the disposal at sea of dredged sediment. More recently, this has been achieved using the generic radiological assessment procedure developed by the International Atomic Energy Agency (IAEA, 2003) and produced primarily as a tool for countries without an advanced radiological protection infrastructure. The simplistic methodology is not designed to provide a realistic assessment; instead it is a screening tool that provides conservative dose estimates due to the underlying assumptions.

The International Atomic Energy Agency emphasise that the responsible authority should attempt to come to a decision at the earlier stages of the evaluation process (Fig. 1), and that the generic radiological assessment should only be used when steps 1-5 have been fully considered.

1.5 England and Wales Approach to *de minimis* Assessments

With the publication of the full set of IAEA advice, Defra and CEFAS agreed that a more systematic assessment of the *de minimis* status of disposal operations around England and Wales was required. Application of the initial 5 steps in the Stepwise Evaluation Procedure to many of the candidate materials considered for disposal in the UK (e.g. sediments and fish waste) indicates that radiological assessments are likely be needed. This is because most are contaminated (albeit at very low levels) with radioactive discharges principally from Sellafield. The strategy adopted was to first carry out regional assessments for all relevant areas around England and Wales to identify where specific local assessments are required and ideally rule out some regions from requiring specific assessments. Specific assessments were expected to be required mainly, if not exclusively, in the Eastern Irish Sea.

It is intended to review the *de minimis* assessments periodically to confirm that the assumptions made in the original assessment remain valid. However, even where assessments have been carried out previously, re-assessment will be necessary if there are changes in the discharges of radioactive materials, if the volumes proposed for disposal change significantly or the disposal site location changes. In the latter case, changes in dumpsite characteristics would be the issue for consideration.

In the IAEA guidance, a set of conversion factors has been pessimistically derived which enable individual and collective doses to be calculated from concentrations of particular radionuclides in the candidate material. The calculations are performed for each radionuclide and then summed for comparison with the dose criteria. IAEA-TECDOC-1375 includes a description of the models used to derive the conversion factors and the default parameter values used in the calculations. For clarity, further details are provided in section 3.

In this project, sets of conversion factors will be derived that are more specific to proposed dumping operations in each of 9 regions around England and Wales (section 5). The operations represented will include dumping of maintenance dredged sediment from 9 regions around England and Wales (some close to nuclear establishments such as Sellafield, others more remote) and 1 to cover dumping of fish wastes. It is anticipated that these sets of conversion factors will then be applicable to most situations in these areas.

In the case of capital dredged material, 3 categories of material have to be considered in determining the requirement for specific assessments:

a) Where part of an arising consists of essentially maintenance dredged material i.e. recently deposited material at and immediately beneath the seabed, it should generally be treated as for maintenance dredged material in that port or region as appropriate.

b) Where an arising, or part of an arising, consists of geological material (i.e. material not previously exposed at the surface of the earth due to its depth below the seabed), it is very unlikely to be contaminated and may not require a specific assessment i.e. it may be capable of being determined to be *de minimis* in steps 1 - 5 of the Stepwise Evaluation Procedure.

c) Where there is a risk of an arising, or part of an arising, consisting of historically contaminated sediments (in radioactivity terms), a specific assessment is likely to be required in each case. This assessment would be able to utilise the information already gathered for the regional or other local assessments, but there would be a need to include historic monitoring data and may also be a need for sampling and analyses.

1.6 Current Project

The objective of this project was to develop the region specific assessments for England and Wales mentioned in section 1.5 above, to enable early decisions to be reached in the future concerning the necessity for specific assessments for maintenance dredging applications for ports in those areas. As such this research is directly relevant to the work of Defra, as part of its targets to i) fulfil the responsibilities of the UK government towards the London Convention 1972 and ii) develop appropriate assessment and monitoring techniques to reduce marine pollution.

The work carried out here included a review of existing data concerning the sources and specific activity of radionuclides in dredged sediment, for individual regions, based on the previous Sea Fisheries Inspectorate (SFI, now the Marine Fisheries Agency or MFA) districts, around the UK. Information was also collated to enable the calculation of appropriate dose coefficients. The available data were used to produce estimates of individual and collective dose to dredge operators and the public. In addition, an assessment was also carried for the disposal of fish waste in Cardigan Bay.

2. SOURCES OF RADIOACTIVITY, AND DREDGING ACTIVITY, IN COASTAL WATERS OF THE UK

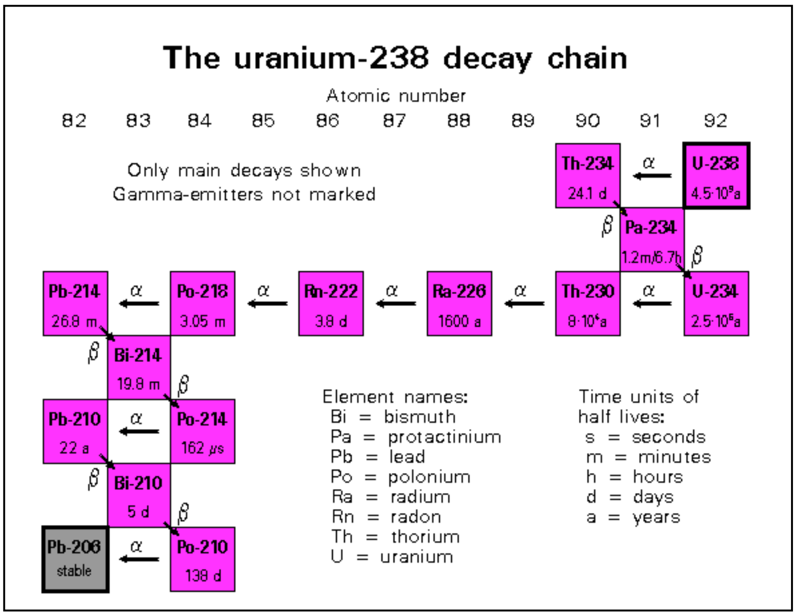
2.1 Radioactivity in the environment

Over sixty radionuclides can be found in the environment, and they can be placed in three general categories:

1. Primordial - present since the creation of the earth
2. Cosmogenic - formed as a result of cosmic ray interactions
3. Anthropogenic - enhanced or formed due to human actions

Primordial radionuclides have been present since the earth was created, and are therefore naturally occurring. They are typically long lived, with half-lives in the order of hundreds of millions of years. Uranium and thorium radionuclides are widely dispersed and common components of the earth's crust. Natural uranium, by mass, is 99.3 % ^{238}U and ~0.7 % ^{235}U. Thorium is, by mass, essentially 100 % ^{232}Th. The radioactive decay of ^{238}U, ^{235}U and ^{232}Th results in the formation of a large number of daughter products with variable half-lives and radioactive emissions (see Fig. 2 for a schematic illustration of the ^{238}U decay series). These three radionuclides, and their daughter products, are present in both the water column and seabed sediments of all UK coastal waters.

Figure 2 - Schematic diagram of the ^{238}U decay series



Cosmogenic radionuclides such as ^{3}H and ^{14}C are continuously produced in the upper atmosphere as a result of cosmic ray induced spallation and particle interactions. They are, therefore, also of natural origin. The majority have shorter half-lives than the primordial nuclides and are transported into coastal waters via the hydrologic cycle.

Some radionuclides arise from human activities such as industrial, medical or military uses of artificial radionuclides. In addition, sources of natural radionuclides (e.g. uranium) are concentrated by mining and other industrial activities. Humans have used radioactivity for one hundred years, and through its use, added to the natural inventories. This is true of UK coastal waters, most notably the Irish Sea, arising from nuclear fuel processing and power generation.

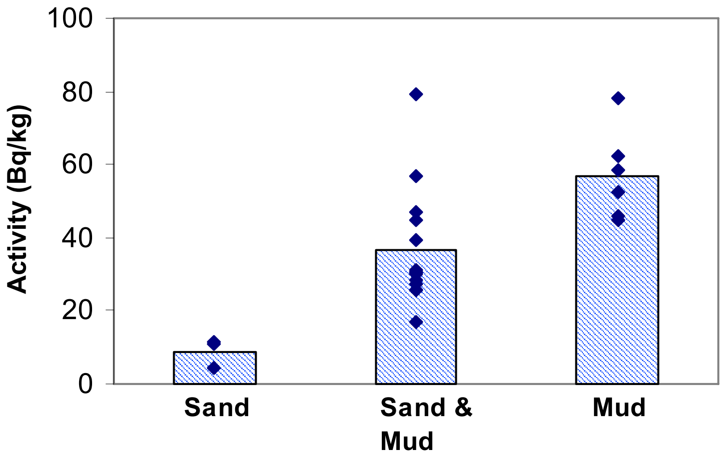
2.2 Background levels of natural series radionuclides

As mentioned previously, uranium and thorium are common components of the earth's crust. The distribution is, however, heterogeneous and concentrations of uranium and thorium in marine sands and clays are typically in the range 1 to 4 and 1 to 30 ppm, respectively (Ivanovich and Harmon, 1982). Uranium is found scattered in the faults of old igneous rocks. Thorium occurs in monazite and in uranothorite (a mixed Th,U silicate). Levels of uranium and thorium in coastal UK sediments are, therefore, variable, dependent upon the local geology. Another source of variation is grain-size as the activity tends to be greater in finer grained material (Emerson and Young, 1995; Noureddine et al., 1998).

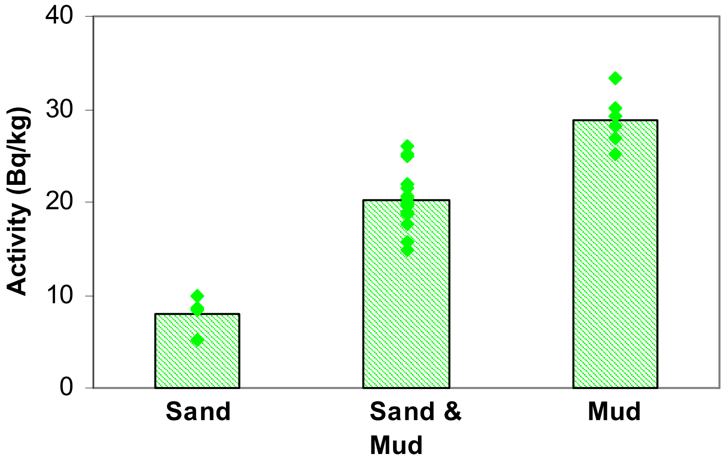
Published data concerning activities of natural series radionuclides in marine sediments, and applicable to the present project, appear sparse. The majority of data refer to measurements made in the course of geochemical and sedimentation studies in open waters. Background levels of ^{238}U and ^{232}Th in Irish Sea sediments have been reported to be in the range 1-20 and 5-30 Bq/kg, respectively (McCartney et al., 1990). Unfortunately data for these nuclides are not reported for most sediment samples analysed as part of routine monitoring programmes to assess radioactivity in the environment (Environment Agency et al., 2004). Nevertheless, information concerning their activity is required for the dose assessments carried out for the present study. Unpublished data, derived from the assay of gamma emitting radionuclides in a limited number of sediment samples by CEFAS for the Food Standards Agency (FSA) were, therefore, evaluated to estimate likely ranges in sand and mud. The sampling sites were distant from known anthropogenic inputs of natural radionuclides and were distributed around the coastline of England and Wales. The activities of ^{238}U, ^{226}Ra and ^{232}Th in these samples were inferred from values for their gamma emitting daughter products ^{234}Th, ^{214}Pb and ^{228}Ac, respectively. Although the errors associated with individual measurements are significantly greater than results derived from assay of the parent radionuclides by conventional α-spectrometry, the screening values are valuable and fit for purpose for the present project (Fig. 3).

Figure 3 - Indicative activities of selected natural series radionuclides in marine sediments around the coastline of England and Wales, at sites distant from known anthropogenic inputs. Dots indicate individual measurements and bars the average values.

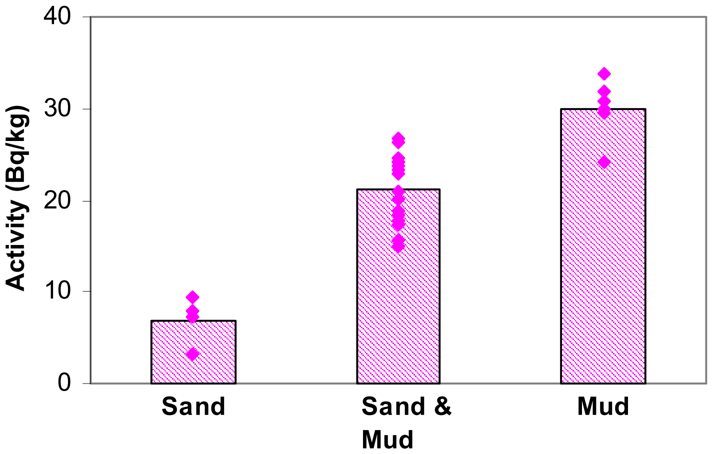
a) ^{238}U



b) ^{226}Ra



c) ^{232}Th

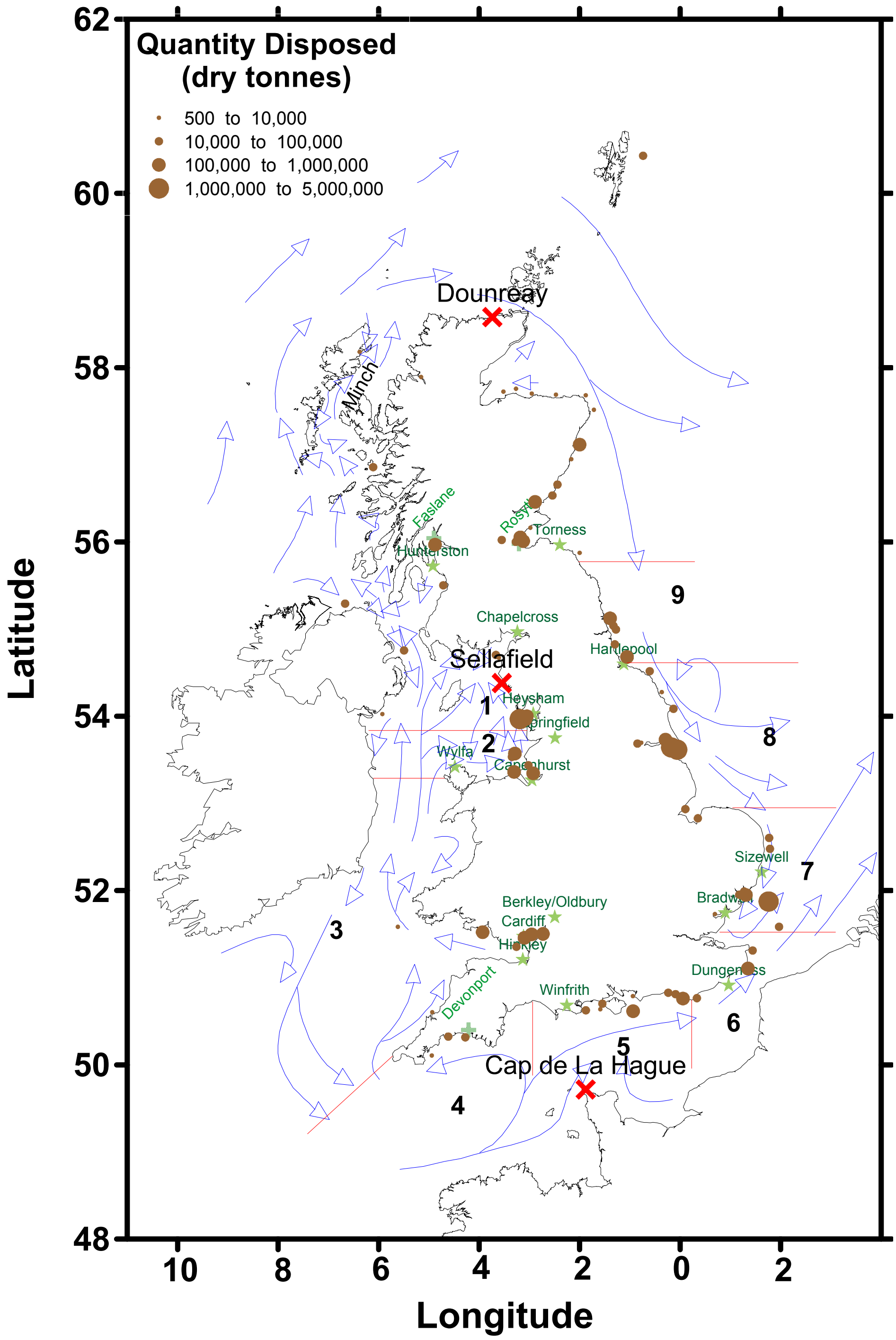


The scatter in the data in Figs. 3a-3c demonstrates that it is impossible to assign unique background activities for naturally occurring radionuclides due to the aforementioned sources of variation. In general terms, lower levels were observed in sandy material reflecting the lesser surface area available (per unit mass) for sorption. The average activity in fine-grained mud was greater than that in sand by ~4-6 fold. It seems reasonable to assume that, for local disposal, material removed in routine maintenance dredging operations will have similar levels of activity to seabed sediments at the disposal site. Therefore, unless anthropogenically enhanced levels were known to be present in a particular port (e.g. such as Whitehaven), the impact upon public exposure was assumed to be zero in the regional assessments (section 5). In the absence of information to the contrary, dredge operators were assumed to be exposed to levels typical of muddy material (i.e. ~60 Bq/kg ^{238}U, ~30 Bq/kg ^{226}Ra, and ~30 Bq/kg ^{232}Th) to indicate maximum dose. Predicted doses to crew (section 5), arising from 'background levels' of uranium and thorium radionuclides, were in the range ~3-5 μSv/a and therefore constituted a significant proportion of the *de minimis* criteria.

2.3 Radioactive discharges

Authorised discharges of radioactive wastes as liquid or gases are released from all the main nuclear sites in the UK. Their locations, along with the major UK dredge material disposal sites, the quantities of material disposed in 2003 and major surface currents in winter, are shown in Fig. 4.

Figure 4 - Location of major nuclear establishments and dredged material disposal sites in the UK.



(1) Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003. Arrows indicate major surface currents during winter. UK coastline divided into 9 regions for dose assessments, based on SFI districts.

The distribution of nuclear establishments around the UK coastline means that most ports in England & Wales could be affected to some extent by the releases of radioactive waste; both current and historical. Current discharges and disposals are authorised by the UK Environment Agencies under the Radioactive Substances Act 1993 (United Kingdom - Parliament, 1993). Summaries of the discharges from the nuclear sites are provided in the annual RIFE reports (Environment Agency et al., 2004). For completeness, it should be noted that discharges of radioactive waste from other sites such as hospitals, industrial sites and research establishments are also authorised under the Radioactive Substances Act, 1993 (United Kingdom -Parliament, 1993) but are not subject to the Nuclear Installations Act 1965 (United Kingdom - Parliament, 1965). Occasionally, the presence of radioactivity in the environment resulting from such discharges is detected within routine monitoring programmes. For example, iodine-131 originating from hospitals was detected in some marine samples in 2003 (Environment Agency et al., 2004). The largest discharge of anthropogenic radionuclides is from the British Nuclear Fuels (BNF) Sellafield reprocessing plant, situated on the Cumbrian coast, into the eastern Irish Sea.

The releases from Sellafield have been shown to significantly affect far field sites, albeit with significant lag time, due to transport concomitant with water movements (Prandle and Beechey, 1991). Migration of radionuclides occurs in a predominantly northerly direction in the Irish Sea, toward and out of the North Channel (Fig. 4). The plume emerging from the North Channel typically remains fairly well defined close to the western Scottish coastline and in the Minch, gradually mixing with uncontaminated Atlantic water (Jefferies et al., 1982). It flows into the North Sea via the Scottish coastal current and drifts slowly southwards, along the coastal margin, and eastwards. Once again, it gradually mixes with Atlantic water that provides the major water inflow into the North Sea. It exits the North Sea via the Norwegian Coastal Current.

One of the major factors influencing the transport and dispersion of radionuclides in the marine environment is their affinity for sedimentary material. This association is commonly expressed as a distribution coefficient (K_d) and is normally obtained from environmental observations (K_d = solid phase concentration divided by aqueous phase concentration). For example, ^{137}Cs has a relatively low affinity for sedimentary material in seawater ($K_d = 10^2$-10^3, Kershaw et al., 1992) and consequently greater than 90% of the total activity discharged from Sellafield has been removed from this area with the general water circulation. In contrast, Pu radionuclides and ^{241}Am have comparatively high affinities for particulate material ($K_d > 10^5$) and, therefore, most of the activity discharged from Sellafield has been retained within the sediments of the Irish Sea basin (Kershaw et al., 1999). Consequently, the relative amounts of Sellafield derived contamination in sedimentary material vary significantly between individual radionuclides with distance from the point of discharge.

Given that Sellafield has discharged waste to the Irish Sea for more than 50 years, the reservoir of contaminated sediment has been dispersed, to some extent, by general sediment transport processes. Some sediment has moved shoreward in association with the prevailing currents in the eastern Irish Sea (Burrows, 1986) and has resulted in deposition of Sellafield derived radionuclides in local ports and harbours, along with other intertidal and floodplain environments in this area (MacKenzie et al., 1994).

The quantities of radionuclides discharged from Sellafield have changed markedly with time (Kershaw et al., 1992). Following the introduction of stricter discharge authorisations and new effluent treatment systems in the 1980s, sharp reductions occurred in releases of most radionuclides from Sellafield. Although reprocessing of previously stored medium level wastes resulted in additional ^{99}Tc discharges to the Irish Sea in 1994 (Leonard et al., 1997), these were significantly reduced in 2004 (Mayall, 2005). The legacy of large historic discharges mean that remobilisation from contaminated seabed sediments now constitutes the predominant source of most long-lived artificial radionuclides in the Irish Sea (Leonard et al., 1999; McCubbin et al., 2002).

Enhanced concentrations of natural series radionuclides can occur in discharges from non-nuclear industries, particularly wastes released by phosphate fertiliser plants (Poole et al., 1995). In the UK, the large volumes of liquid and solid waste discharged into the eastern Irish Sea at Saltom Bay (near Whitehaven) from the Rhodia Consumer Specialities Ltd. (formerly Albright and Wilson) phosphoric acid production plant between 1954 and 1992 resulted in significantly enhanced levels of natural radionuclides in the local sediments and shellfish (Camplin et al., 1996). Operations at this plant changed in 1992 resulting in a large reduction in the volume of waste discharged (Poole et al., 1995). Subsequent monitoring indicated that concentrations of natural radionuclides in the local environment decreased accordingly (McCartney et al., 2000). Radionuclide activities in the sediment at Whitehaven Harbour remain enhanced, as a legacy of spillage during the unloading of ore from ships (FSA and SEPA, 2001). Discharges of radioactive substances by the non-nuclear industry into the sea have recently been reviewed (OSPAR, 2002; Betti et al., 2004). In the UK, discharges from non-nuclear sites are now considered insignificant in general and as such environmental monitoring of their effects is no longer undertaken routinely (Environment Agency et al., 2004).

2.4 Radiological protection standards

The generally accepted standards for human radiological protection, and which are adopted by international organisations, are based on the recommendations of the International Commission on Radiological Protection (ICRP). Radiation risks have been subject to intensive study and consequently the recommendations have developed significantly over the years. The most significant source of data has been the study of the Japanese atomic bomb survivors. Current estimates for stochastic effects indicate a nominal fatal cancer risk of 5×10^{-8} per μSv for a population of all ages. The ICRP-recommended dose limit of 1000 μSv/a for members of the public is consistent with a level of risk between 1 in 10^4 and 1 in 10^5 as the maximum tolerable involuntary risk for a member of the public.

The International Atomic Energy Agency (IAEA) have incorporated the ICRP recommendations into their Basic Safety Standards, adopting also as trivial (i) a dose of 10 μSv (equivalent to a fatal cancer risk of less than 1 in 10^6) and (ii) an annual collective dose of 1 man Sv for all practices. This is the basis for judging whether candidate materials, including dredged material, fulfil the exemption criteria for sea disposal.

To provide some perspective, for the rest of this report, the average natural background radiation dose rate to the world population due to cosmic rays, terrestrial gamma rays, inhalation of radon and from foodstuffs is ~2400 μSv/a (UNSCEAR, 2000). There can be significant variations between individuals due to location, habits, etc.; the natural background dose would generally be expected to be in the range 1000-10,000 μSv/a. In the UK, periodic reviews have been published since 1974 by the National Radiological Protection Board (now the Health Protection Agency - Radiation Protection Division) which have provided estimates of the exposure of the UK population from sources of ionising radiation, both natural and artificial. The latest review in this series (Watson et al., 2005) gives estimates of individual doses based predominantly on data collected for the years 2001 to 2003. The average annual dose (including a contribution from artificial radiation) was estimated to be ~2700 μSv.

2.5 Dredging activity in the UK

Dredging activities can be conveniently divided into capital and maintenance dredging (MEMG, 2003). These activities are most usually associated with port and harbour operations, but may also arise from construction activity. The focus of this study was on maintenance dredging. Dredging to obtain marine aggregates was excluded from the remit of this project. These materials are in any case likely to be of much less concern since they are predominantly coarse-grained and, therefore, likely to contain low levels of radionuclides.

Maintenance dredging is the periodic removal of material, deposited by natural processes, from areas that have been dredged previously. The extent of this activity is extremely variable between individual ports, being dependent upon local river flow, tidal currents and wave action. In some locations it is only undertaken once every five to ten years and in others on two to three occasions every year.

Capital dredging is the initial deepening of an area such as a channel or harbour but can also include excavation of underwater trenches for civil engineering works. A major port with a diversity of customers may need to carry out a capital project every few years.

Disposal at sea of dredged material has been commonplace since the end of the eighteenth century. Disposal sites were first selected for convenience in terms of proximity to the area of dredging activity, together with a location considered deep enough such that the accumulated deposit would not interfere with navigation. UK dredged material disposal sites are numerous – 177 being used at least once since 1990. The total quantity of material disposed to sea in the UK between 1999-2003 was in the range 16-33 million tonnes dry weight/annum (CEFAS, 2005a). The frequency of use of individual sites is extremely variable. The disposal site for a small fishing harbour or marina may receive maintenance dredging on an annual or bi-annual basis, consisting of a few thousand tonnes of marine sand moved into the harbour from the adjoining seabed by winter storms. In contrast, the disposal ground for a group of estuarine ports may receive this quantity of low-density silt on three or four occasions most days of the year. Much of this sediment will be of marine origin but some, particularly finer-grained material, will have been derived from land or intra-estuarine sources.

In 2003, 4 UK sea disposal sites received in excess of 1 million tonnes of dredged material. 22 received between 100,000 and 1 million tonnes and 48 between

10,000 and 100,000 tonnes (all as dry weight). Some 25, however, received less than 10,000 tonnes (dry weight) in that year. While a relatively small number of sites accounted for a large proportion of the UK's dredged material disposal in 2003, some material was deposited in at least 99 sites. Similar trends were apparent in data for 2002 (CEFAS, 2005a).

2.6 Other licensed activity

Under Part II of FEPA, licences are also issued for certain other activities that involve the deliberate deposit of articles or substances in the sea below the mean high water spring tide mark. The activities include the disposal of small quantities of fish waste, the use of tracers and biocides and burial at sea (CEFAS, 2005a). The anticipated radiological impact is minimal and, therefore, a radiological assessment was restricted to disposal of fish waste.

3 DOSE ASSESSMENT PROCEDURES

3.1 Sampling and analysis

The available data pertaining to radioactivity in sediments and biota around the UK, primarily from routine monitoring programmes (Environmental Agency et al., 2004), were collated and reviewed to identify gaps pertinent to the present project. This data was supplemented by assay of gamma emitting radionuclides in a limited number of composite sediment samples available to CEFAS from previous FEPA II dredge licensing applications.

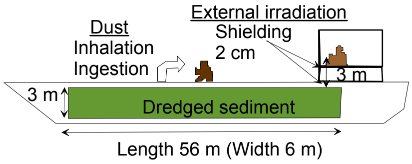
3.2 The generic IAEA dose assessment process

As mentioned previously, in its simplest form the assessment process uses information concerning radionuclide activity in dredge material together with generic dose coefficients to assess exposure of 1) dredge operators and 2) the public. The generic dose coefficients are derived from exposure models using default parameter values. Full details of the exposure models have been reported elsewhere (IAEA, 2003), but are briefly outlined here for clarity. Furthermore, upon request, a spreadsheet is available from the IAEA.

3.2.1 Dose to individual crew

During shipment of the dredged material, and during loading and disposal operations, the crew is considered to be exposed via three main pathways (Fig. 5).

Figure 5 - Schematic diagram of exposure pathways for ships crew and assumed geometry for external irradiation



The exposure pathways are:

i) Inadvertent ingestion of candidate material;

ii) Inhalation of particles resuspended from the surface of the candidate material;

iii) External exposure to radionuclides in the candidate material.

There are other exposure pathways that are not considered in the IAEA model, such as skin contamination if the members of the crew on board the ship are likely to handle the material. Information elsewhere (Hunt, 1984) indicates these are likely to be of lesser importance.

A list of the parameters used in the IAEA model for the calculation of individual doses to dredge operators (i.e. ships crew) is given in Table 1. Default values for these parameters, to be used when site-specific information is not available, are also listed here.

Table 1 - Parameters used in the calculation of individual doses to members of the crew

Parameter	**Symbol**	**Default Value**
Occupancy (External exposure) (h/a)	$t_{crew,\ ext}$	1.0×10^{3}
Working outside on board of ship (h/a)	$t_{crew,\ inh/ing}$	2.0×10^{3}
Breathing rate (m^3/a)	$R_{inh,\ crew}$	1.05×10^{4}
Inadvertent ingestion rate of material (kg/h)	H_{dust}	5.0×10^{-6}
Dust loading on board ship (kg/m^3)	DL_{ship}	2.5×10^{-9}
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	Variable(1)
Dose coefficient for ingestion	$DC_{ing}(j)$	Variable(2)
Dose coefficient for inhalation	$DC_{inh}(j)$	Variable(2)

(1) Variable between individual radionuclides (j). Default values are listed in Table II.III (IAEA, 2003)

(2) Values taken from standard sources but are variable between individual radionuclides (j).

3.2.2 Collective dose to crew

The collective dose is the sum of individual doses received in a given period of time by a specified population from exposure to a given source of radiation. Consequently, the collective dose to crew members is estimated in a straightforward way being the product of individual dose and the number of crew carrying out a dredging operation in a specified sea area. A list of the parameters involved, together with default values to be used when more specific information is not available, is provided in Table 2.

Table 2 - Parameters used in the calculation of collective doses to crew

Parameter	**Symbol**	**Default Value**
Number of crew members on single vessel	N_{crew}	10
Number of ships performing disposal operations at a single site	N_{ship}	1
Number of disposal sites in a specified sea area	N_{site}	10

The number of crew, working in a specified sea area, is the product of the three parameters listed in Table 2.

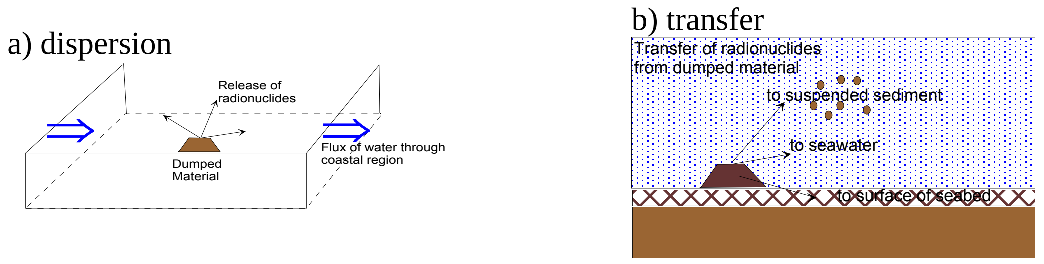
3.2.3 Dose to individual members of the public

Dose to individual members of the public is estimated by combining output from a simple box model, to simulate dispersion of dredge material in the marine environment, with habits data.

3.2.3.1 The sea dispersion model

Radionuclides released from the material dumped at sea disperse in the environment (Fig. 6a). The disposal is assumed to occur in relatively shallow well-mixed nearshore coastal waters, a few kilometres off the coast. It is also assumed that the release of radioactivity from the waste occurs at a constant rate and is completed within one year of the time of disposal. This process is simulated using a single-box model with instantaneous mixing throughout the volume of water in the box, and instantaneous equilibrium between radionuclides in the soluble phase, suspended particles and surficial seabed sediment (Fig. 6b). Although this model is highly simplistic and rather conservative, it is both convenient and adequate for radiological calculations. A similar, and only slightly more sophisticated interlinked box model, was used as part of the MARINA II study to investigate collective doses or effects of radioactive discharges on different countries in Europe (European Commission, 2002).

Figure 6 - Schematic diagram of model used to simulate dispersion and transfer of dredge material in the marine environment.



The radionuclide concentrations in seawater and sediments predicted by the model are average values over the entire volume of the box and the year of release. The radionuclides released into seawater may be taken up by marine organisms and thus enter the human food chain. Transfer to biota is calculated using element dependent concentration factors. Sea to land transfer is also included in the model. It is assumed that particles washed ashore remain in surface material and that the radionuclide concentration in beach sediment is a factor of 10 less than that in suspended particles.

As well as the radioactivity of the dredge material, the final activity in the seawater is dependent upon a number of parameters including the mass of dumped material, the volume, depth, suspended load and flux of seawater through the compartment. A list is given in Table 3, along with default values to be used in the absence of more specific information.

Table 3 - Parameters used in the dispersion model to predict radioactivity in seawater and seafood

Parameter	Symbol	Default value
Mass of candidate material dumped (kg/a)	M	1×10^{8}
Box Volume (m^3)	V	2×10^{9}
Flux of water through coastal region (m^3/a)	F	4×10^{10}
Depth of water column (m)	D	2×10^{1}
Thickness of boundary sediment layer in box (m)	L_B	1×10^{-2}
Effective sediment thickness (m)	d_S	1×10^{-1}
Bulk sediment and waste density (kg/m^3)	ρ_S, ρ_B	1.5×10^{3}
Suspended sediment concentration (kg/m^3)	S	3×10^{-3}
Dust loading on shore (kg/m^3)	DL_{shore}	2.5×10^{-10}
Seaspray concentration in air (kg/m^3)	C_{spray}	1×10^{-2}
Sediment distribution coefficient (m^3/kg)	$K_d(j)$	Variable(1)
Concentration Factor (m^3/kg)	CF (j,k)	Variable(1)

(1) Values taken from a 'standard' source, but are variable between individual elements (j) and biota (k)

3.2.3.2 Habits data

Members of the public in the vicinity of a disposal site are considered to be exposed via the following pathways:

i) Ingestion of seafood caught in the vicinity of the disposal site;

ii) External exposure to radionuclides deposited on the shore;

iii) Inadvertent ingestion of beach sediment;

iv) Inhalation of resuspended beach sediment;

v) Inhalation of seaspray.

Radiation doses to members of the public are estimated by combining data on their habits (fish/shellfish consumption, beach occupancy etc.) with predicted values of the activity levels in the relevant environmental materials. A list of the parameters used in the calculation of individual doses, along with default values to be used in the absence of more specific information, is given in Table 4.

Table 4 - Parameters (habits data) used in the calculation of individual doses to members of the public

Parameter	Symbol	Default Value (Adults)
Occupancy on sediments on shore (h/a)	t_{public}	1.6×10^3
Breathing rate (m^3/a)	$R_{inh,\ public}$	8.4×10^3
Ingestion rate of fish (kg/a)	H_B(fish)	5×10^1
Ingestion rate of crustacea (kg/a)	H_B(crustacea)	7.5
Ingestion rate of molluscs (kg/a)	H_B(molluscs)	7.5
Ingestion rate of sediment on beach (kg/h)	H_{shore}	5×10^{-6}
Dose coefficient for external irradiation on shore	$DF_{gr}(j)$	Variable(1)
Dose coefficient for ingestion	$DC_{ing}(j)$	Variable(1)
Dose coefficient for inhalation	$DC_{inh}(j)$	Variable(1)

(1) Values were taken from standard sources but are variable between individual radionuclides (j).

3.2.4 Collective dose to members of public

As mentioned previously, the collective dose is the sum of individual doses received in a given period of time by a specified population from exposure to a specified source of radiation.

Collective doses from consumption of seafood are calculated as the product of the predicted activity concentration in the seafood, net amounts available for human consumption and dose coefficient for each radionuclide, summed over all the relevant radionuclides. In turn, the amount available for human consumption is a function of the catch rate in the local compartment where sea disposal occurs, proportion imported/exported & diverted to non-food use and fraction that is edible.

Collective doses resulting from external exposure are estimated assuming that the beach acts as a surficial source with 2π geometry, combined with data for annual collective occupancy per unit length of coastline. A list of the parameters used in the IAEA assessment process, together with default values, is given in Table 5

Table 5 - Parameters used in the calculation of collective doses to members of the public

Parameter	Symbol	Default Value (Adults)
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	5.0×10^5
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	1.0×10^5
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	1.0×10^5
Fraction fish utilised for human consumption	f_B(fish)	0.5
Fraction shellfish utilised for human consumption	f_B(shellfish)	0.35
Annual collective shore occupancy per unit length (man h/a/m)	$O_{coll,shor}$	5×10^1
Coastline length for one site (m)	L_{shore}	1×10^4
Number of disposal sites	N_{sites}	10

3.3 Application of the IAEA model to UK sea disposal practices

In place of the default parameter values listed in section 3.2, a more detailed approach was adopted, using variable parameter values, to produce the regional assessments provided in this report. This approach was required to adequately account for variations in dispersion characteristics, local habits (seafood consumption, beach occupancy) and dredging practices. The rationale behind the adjustments to default parameters is described in this section.

3.3.1 Crew exposure

For reasons outlined below, the only parameters that were varied in subsequent regional assessments, to assess dose to dredge operators (Table 1), were $t_{crew, ext}$, $t_{crew, inh/ing}$ and $DF_{ship(j)}$. Default values were used for the dust loading factor on board ship (DL_{ship}), rate of sediment ingestion (H_{dust}) and rate of sediment inhalation ($R_{inh,crew}$). These three parameters relate to exposure via inadvertent ingestion or inhalation of contaminated material, when the crew come in close contact with sediment during loading or cleaning operations.

The default value of 2.5 x 10^{-9} kg/m^3 for DL_{ship} (Table 1) is pessimistically high, reflecting dusty conditions (IAEA, 2003). In practice this is likely to be significantly less if the hopper holding the sediment is covered or if the sediment remains wet. Maximising default values are also provided for H_{dust} and $R_{inh,crew}$. As these parameters are difficult to establish on a site-specific basis, no attempt was made to alter the default values.

Results from preliminary calculations indicated predicted doses were sensitive to changes in parameters related to exposure time ($t_{crew, ext}$ and $t_{crew, inh/ing}$). In the IAEA model, sediment is assumed to be loaded onto an independent barge that transports the material to an offshore site. Although this practice is followed at some ports in the UK (e.g. Southampton), it is not typical. Parameter values for the dose assessments carried out for this project were, therefore, adjusted to reflect regional practice. The effective external exposure time ($t_{crew, ext}$) for crew working on an independent barge is half that for the other two pathways ($t_{crew, inh/ing}$) as irradiation occurs only during transport to the disposal site, but not during the return journey. For other types of dredgers, estimation of external exposure time is more complicated dependent upon the relative amount time taken to fill a hopper and journey time to the disposal site. For the present project, $t_{crew, ext}$ was typically set equal to $t_{crew, inh/ing}$ to estimate maximum dose. This introduces another conservative assumption into the assessment process. Doses during loading will probably be lower given that i) some of the material is underwater; ii) the dredger only loads small quantity of material at a time and iii) the distance between operators and dredge material is most likely greater than during the transport to the dump site.

Derivation of appropriate values for $DF_{ship}(j)$ is a non-trivial task. They are variable dependent upon i) the physical properties of the dredged material (density, water content etc.), ii) the geometry of the ship (surface area and thickness of dredged material), iii) the average position of crew (in relation to the load) and iv) the design of the ship (composition and thickness of shielding material).

Dose coefficients for external irradiation for 2π geometry are provided in US EPA Federal Guidance Report No. 12 (Eckerman and Ryman, 1993) for both surficial and “infinitely thick” sources. In practice, the loads on UK dredgers act as an “infinitely thick” source. However, it is difficult to account for ship geometry. Since the surface area of the dredged material is not infinite, the solid angle subtended by the crew member relative to the mass of sediment in the hopper is significantly less than 2π. The solid angle is calculated by integrating over both the body surface facing the sediment and over all volume elements of the sediment (i.e. over all volume elements of the sediment mass). The dose coefficients provided in

IAEA-TECDOC-1375 are for one specific scenario only and were calculated using a specialist software package (Microshield). Shielding is assumed to be provided by steel with a density of 7.6 g/cm^3 and a thickness of 2 cm (one or two decks) between the upper side of the load and the crew member. The crew are assumed to be standing on a deck situated 2 m above a load of 1000 m^3 (~1.5 x 10^6 kg) wet sediment with surface area equal to 336 m^2. Values for $DF_{ship}(j)$ are calculated for a point 1 m above the deck on which the crew member is located (i.e. for a point 3 m above the upper surface close to the edge of the load).

In the UK, information derived via the licensing system under Part II of the Food and Environment Protection Act (1985) indicates a significant number of dredgers are used with considerably variable design and load. In many cases operations are not carried out using separate dredgers and barges. Instead, the dredgers themselves have hoppers to enable the same vessel to dredge and transport material to the disposal site. Selected details are provided in Table 6.

Table 6 - List and principal dimensions of selected dredgers mentioned in FEPA licensing applications in 2003/2004. Information concerning individual dredgers taken from website http://www.dredgers.nl/

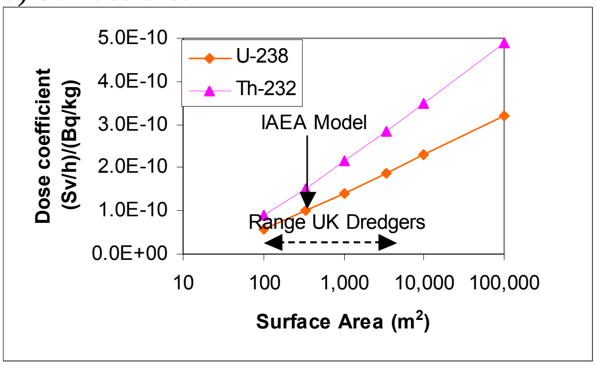
Vessel	Type[(1)]	Company	Hopper Capacity (m^3)	Length (m)
Amazone	THSD	Baggerbedrijf De Boer	2680	79
Lesse	THSD	Baggerbedrijf De Boer BV	1538	77
Hebble Sand	GHD	D. Cook, Hull (England)	550	48
Abigail H	GHD	Humber Workboats Ltd.	230	36
John M	CSD	Humber Workboats Ltd.		39
Modi R	THSD	Rohde Nielsen	1410	62
Sif R	THSD	Rohde Nielsen	2147	80
Thor R	THSD	Rohde Nielsen	2507	79
Barent Zanen	THSD	Royal Boskalis Westminster	8350	134
Cornelia	THSD	Royal Boskalis Westminster	6617	113
Cornelis Zanen	THSD	Royal Boskalis Westminster	8530	132
Flevo	THSD	Royal Boskalis Westminster	2130	79
Nautilus	THSD	Royal Boskalis Westminster	4400	90
Oranje	THSD	Royal Boskalis Westminster	15850	156
Queen of The Netherlands	THSD	Royal Boskalis Westminster	23400	174
Seaway	THSD	Royal Boskalis Westminster	13255	170
Sospan	THSD	Royal Boskalis Westminster	970	57
Sospan Dau	THSD	Royal Boskalis Westminster	1500	71
Waterway	THSD	Royal Boskalis Westminster	4900	98
WD Fairway	THSD	Royal Boskalis Westminster	35814	232
WD Gateway	THSD	Royal Boskalis Westminster	6085	134
WD Medway II	THSD	Royal Boskalis Westminster	3683	77
WD Severn	THSD	Royal Boskalis Westminster	1420	70
Hedwin	GHD	Port of Tyne Authority	500	
Cleveland County	TSHD	Tees & Hartlepool Port Authority Ltd.	1500	
Heortnesse	TSHD	Tees & Hartlepool Port Authority Ltd.	1500	78
Seal Sands	GHD	Tees & Hartlepool Port Authority Ltd.	500	48
Mersey Mariner	GHD	The Mersey Docks & Harbour Company	1900	78
Mersey Venture	THSD	The Mersey Docks & Harbour Company	2200	82
UKD Bluefin	TSHD	UK Dredging	3900	98
UKD Cherry Sand	GHD	UK Dredging	765	63
UKD Dolphin	TSHD	UK Dredging	2189	79
UKD Marlin	TSHD	UK Dredging	2692	85
Volvox Anglia	THSD	Van Oord	1202	67

(1) GHD and THSD denote Grab Hopper Dredger and Trailing Hopper Suction Dredger, respectively.

The data in Table 6 indicate that hopper capacities range from 230 m^3 (i.e. ~4 fold lower than that assumed in IAEA-TECDOC-1375) to 36,000 m^3 (i.e. ~36 x greater than that assumed in the generic IAEA model). Assuming the increase or decrease in hopper capacity (compared with the IAEA model) is similar for all three dimensions, comparable values for surface area are ~ 100 m^2 (i.e. 2.7 fold less) to 3360 m^2 (i.e. 11 x greater). The resources available to the present project did not justify purchase and training in the use of Microshield. Instead, calculations to assess the likely variation in external dose coefficients concomitant with ship geometry were carried out using a freely available applet (http://www.antenna.nl/wise/uranium/rdcx.html?src=v&shn=1). The range of radionuclides and geometry, for which calculations could be undertaken using this applet, was restricted (to cylindrical sources and natural series radionuclides). Dose calculations were carried out for a 3 m thick cylinder of soil with variable radius (hence surface area) at height 3 m above the upper surface with 2 cm steel shielding. The results indicate that the dose coefficients for ^{238}U and ^{232}Th (in secular equilibrium with all their daughter products) are variable, dependent upon the surface area and position of the crew with respect to the sediment load (Figs. 7a-7c). Similar trends were also observed for ^{234}Th and ^{40}K dose coefficients as representative of low (<0.1 MeV) and high (~1.5 MeV) energy gamma rays, respectively. Consequently, it seems reasonable to assume that the approach is appropriate for the effectively rectangular sources and range of gamma ray energies likely to be emitted from contaminated sediments contained in a hopper.

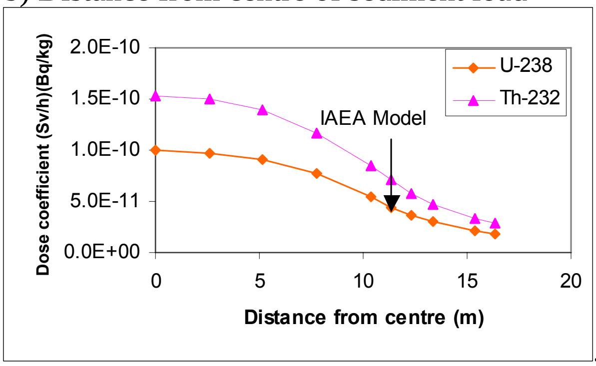
Figure 7 - Variation in ^{238}U and ^{232}Th external dose coefficients for material on ship concomitant with surface area and crew position. Calculations carried out for 3 m thick cylinder of sediment with variable radius (hence surface area) at height 3 m above the upper surface with 2 cm steel shielding. Calculations carried out using applet http://www.antenna.nl/wise/uranium/rdcx.html?src=v&shn=1

a) Surface area



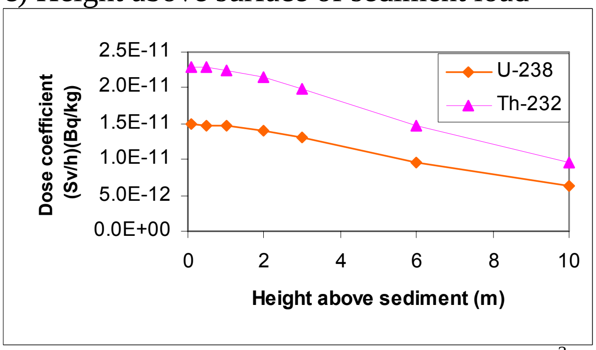
Dose coefficients are for crew above centre of sediment load

b) Distance from centre of sediment load



Dose coefficients are for surface area of 336 m^2 (i.e. radius of 10.3 m)

c) Height above surface of sediment load



Dose coefficients are for surface area of 100 m^2 (i.e. radius of 5.6 m) and 10 m away from centre of load

The data in Fig. 7a indicate that dose coefficients for both radionuclides increase concomitant with surface area (by ~ 3 fold between surface areas of 100 m^2 and 3360 m^2, which is the range estimated for dredgers used in the UK). The data in Fig. 7b demonstrate that dose coefficients decrease as a crew member moves away from the centre of the cylinder (by ~ 2 fold between the centre and the edge of the cylinder). Information obtained from UK Dredging (operators of the Bluefin, Cherry Sand, Dolphin and Marlin) indicates crew members might spend a significant portion of their time in the accommodation blocks that are situated some 5-6 m distant from the hopper (Drew, pers. comm.). This would result in a further ~ 2 fold decrease in the dose coefficients, compared with those appropriate to the edge of the sediment load. The data in Fig. 7c demonstrate the limited sensitivity of dose coefficients to differences in height above the sediment surface over the range 0.1-3 m (decrease of just 10 %, concomitant with increase in height).

Although not shown here, variations in source thickness above 0.5 m have little influence upon the dose coefficients (i.e. within range anticipated for UK dredgers). In effect, the sediment load on the ship acts as an infinitely thick finite plane source.

One variable that was not addressed here was whether the shielding provided by steel on the vessels used in UK differed significantly from that assumed in the IAEA model. This is not a trivial task and should perhaps be evaluated at a later stage. The shielding provided by a given thickness of steel varies significantly dependent upon gamma ray energy (i.e. the effect is variable between individual radionuclides). It is not, therefore, possible to make generic adjustments to all dose coefficients to allow for variable steel thickness as achieved for surface area and distance from sediment load.

3.3.2 Public exposure

3.3.2.1 Parameters related to sea dispersion

Information concerning mass (Table 3) is particularly important given the extreme variability in terms of extent and frequency of use of individual sites. In the UK, excellent data is available via the licensing system under Part II of the Food and Environment Protection Act (1985) (CEFAS, 2005a). Local compartment parameter values appropriate for UK (and other EC) nuclear establishments discharging to the marine environment are given in Simmonds et al. (1995) and European Commission (2002).

The equilibrium concentration factor approach is used in the sea dispersion model (CF and K_d for marine biota and sediment, respectively) to predict the accumulation of radionuclides from seawater by both marine biota and suspended sediment. CF values for biota, and K_d values for sediment, are normally obtained from environmental observations (CF = biota concentration divided by aqueous phase concentration). These have gained wide acceptance as a pragmatic measure despite the problems inherent in deriving and interpreting CF values (Lowman et al., 1971; IAEA, 2004). The K_d and CF values used in the IAEA-TECDOC-1375 model are taken from a 'standard' source (IAEA TRS 422; IAEA, 2004). However, results from preliminary calculations for the present project indicated predicted doses to the public were anomalously high. Closer examination indicated this was due to the CF values used for ^{210}Pb.

The ^{210}Pb CF values used for shellfish in the IAEA-TECDOC-1375 model are 9 x10^4 l/kg and 5 x 10^4 l/kg for crustacea and molluscs, respectively. In contrast, an average value for molluscs (mussels and winkles) of just ~1.2 x 10^3 may be derived from data arising from a survey of radioactivity in coastal regions of the UK (McDonald et al., 1991). This is significantly lower (by ~ 40 fold), compared with the recommended value. Moreover, results from a study of ^{210}Pb and ^{210}Po activity in fish and shellfish around the UK (Young et al., 2003) indicate levels tend to be lower in crustacea compared with molluscs (by 6 and 2 fold for ^{210}Pb and ^{210}Po, respectively). Extrapolation of these data indicates a more appropriate CF value for ^{210}Pb in UK crustacea is ~2 x 10^2. It is worth noting that information derived from a recent laboratory study of ^{210}Pb tracer uptake by the shrimp indicates that bioaccumulation occurs primarily from feeding on contaminated prey items rather than from the dissolved phase. A CF value as low as 50 was observed for accumulation from filtered seawater (i.e. ~ 3 orders of magnitude lower than the IAEA-TECDOC CF value). Therefore, the ^{210}Pb CF values used for shellfish in the IAEA-TECDOC-1375 model appear anomalously high for the UK environment. Values more appropriate for UK seafood (~2 x 10^2 and ~1.2 x 10^3) were, therefore, used in dose calculations (to the public) undertaken for the present project.

3.3.2.2 Parameters related to habits data

Information concerning seafood consumption and beach occupancy for critical groups (i.e. those individuals, or groups of individuals, receiving the highest radiation doses)
around individual nuclear establishments in the UK is available from routine monitoring programmes (Environment Agency et al., 2004). All these data have been used in the subsequent regional assessments, in place of the default values (Table 4), to derive estimates of exposure via the seafood consumption and external exposure pathways. As recommended by the IAEA (IAEA, 2003), no attempt was made to amend the other conservative parameter values ($R_{inh\ public}$, H_{shore}) relating to exposure via the sediment ingestion and inhalation pathways.

Information concerning seafood catches and landings by area of capture around the UK (ICES sea areas) is required to estimate collective dose (Table 5). Some data are available from routine monitoring programmes (http://statistics.defra.gov.uk/esg/publications/fishstat/). Catches in recent years have been volatile for a number of reasons including the effects of Total Allowable Catches (TACs) for particular species, variations in geographical distribution of fish and economic factors. The proportions exported and diverted to non-food use have also varied along with the emergence of new markets and sources of supply (e.g. the development of fish farming and marine aquaculture). As a consequence, in recent years, the international trade in fish and fish products has increased substantially.

In view of the difficulties in extricating relevant information, values previously identified for local marine compartments surrounding nuclear establishments in the EC (Simmonds et al., 1995) were used here. The application of these historic parameter values was considered fit for the purpose of the present project in providing maximum values for collective dose.

3.4 Comment on uncertainties

All assessment models are imperfect representations of reality as they contain approximations and simplifying assumptions. They also contain a number of transfer processes which are not fully understood and parameter values most of which are not accurately known (e.g. some of the dose coefficients for ingestion and inhalation, albeit that best estimates are taken from standard sources). There is, therefore, an inevitable uncertainty associated with all dose predictions, and these can be large (Cabianca et al., 1998; Grzechnik et al., 2002). For most of the assessments reported here (section 5), the uncertainty appears not be critical as i) the model output is designed to provide conservative dose estimates and ii) the derived dose values are well below the appropriate *de minimis* criteria.

Another source of uncertainty is that the activity of a significant number of gamma emitting radionuclides (e.g. ^{54}Mn, ^{95}Zr, ^{95}Nb, ^{54}Mn, ^{106}Ru, ^{125}Sb, ^{134}Cs, ^{144}Ce) in marine sediments are below detection in most of the samples analysed in routine monitoring programmes (Environment Agency et al., 2004). An assessment of the sensitivity of our predictions to gamma radionuclides below detection limits was made by calculating dose, assuming the activity was equal to reported detection limits. In all of the calculations considered here, the effect was not significant for the purposes of a *de minimis* assessment. Furthermore, data for radionuclides requiring radiochemical separation prior to assay (e.g. ^{90}Sr, ^{99}Tc, ^{210}Pb, ^{238}Pu, $^{239+240}Pu$, ^{241}Pu) are unsurprisingly sparse given the limited radiological significance of sediment ingestion/inhalation pathways and cost considerations. As appropriate, estimates of the activity of Pu radionuclides were made on the basis of data for ^{241}Am in sediment and knowledge of the cumulative quantities discharged to sea from Sellafield. Although not ideal this approach is reasonable at sites close to Sellafield (Regions 1 and 2) given that Pu and Am are highly particle reactive, and hence their fate following discharge is similar. Similarly, ^{90}Sr, ^{99}Tc and ^{137}Cs exhibit largely conservative behaviour in seawater and therefore estimates of the former radionuclides were made on the basis of sediment data for ^{137}Cs together with knowledge of the isotopic ratios of ^{137}Cs, with either ^{90}Sr or ^{99}Tc, in the cumulative Sellafield discharge.

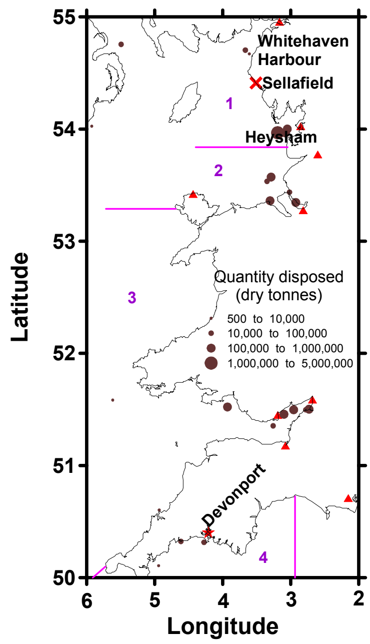
4. RECENT CASE STUDIES

Prior to undertaking calculations for individual regions (section 5), data from recent FEPA dredge licensing applications were revisited to inform subsequent assessments. The objective of re-evaluating previous case studies was to i) assess the most important radionuclides contributing to dose and ii) determine what were the most significant exposure pathways. The doses reported here are for specific operations, as opposed to annual assessments for individual regions (section 5).

4.1 Introduction

Recent radiological assessments, as part of FEPA dredge licensing applications, have been undertaken at Whitehaven in 2004, Heysham in 2002 and Devonport in 2000 (Fig. 8).

Figure 8 - Location of sites for which recent radiological assessments have been undertaken in conjunction with FEPA II dredge licensing applications. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003.



Data for radionuclide activity in sediment samples have been published in the relevant RIFE reports (Environment Agency et al., 2004). The assay is usually restricted to the determination of γ emitting radionuclides, which may be achieved relatively quickly and economically, by counting on a high purity Ge detector. As mentioned previously, this technique does not always provide data for some radiologically significant radionuclides (e.g. ^{210}Pb and Pu radionuclides). The radiometric determination of these nuclides is time consuming and labour intensive requiring chemical separation from all radiometric and gravimetric interferences followed by alpha or beta counting. Wherever possible, missing data has been extrapolated from existing information.

4.2 Whitehaven (2004)

In 2004, the Whitehaven Harbour Development Company lodged a FEPA licensing application to carry out a capital dredging programme in the South Harbour and in front of the Custom House Dock. The proposed removal of up to 30,000 tonnes (dry weight) sediment was to facilitate the provision of a new berthing system in the South Harbour, to replace the existing moorings. As part of the radiological assessment, six deep (up to ~ 2m) sediment cores were collected from Whitehaven Harbour in September 2004 by an external contractor (Caledonian Geotech). The sampling locations are shown in Figure 9a. Analyses were carried out on the top, middle and bottom sections. In addition to γ emitting radionuclides, separate analyses were also carried for ^{210}Po(^{210}Pb). The data have been reported elsewhere (Environment Agency et al., 2005) but are provided in Fig. 9b for clarity.

The dredging contractors (Humber Workboats) used a grab hopper dredger (the Abigail H) to carry out the operation. A schematic diagram of this vessel is provided in Fig. 9c. The length of the ship is ~36 m and the hopper capacity ~230 m^3. The hopper dimensions were ~11 m, ~6 m and ~3.5 m for length, breadth and depth, respectively. Consequently, the surface area of the hopper was ~66 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicates this change would result in a decrease in external dose by a factor of 0.54. It is appropriate to also take account of the fact that: i) crew members are likely to spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, decreasing external dose by a factor of ~2.7 (Fig.7b) and, ii) when sleeping the crew are likely to be ~ 1 m above the sediment surface, instead of ~ 3 m assumed in the IAEA model, increasing external dose by a factor of ~1.1 (Fig. 7c). The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~23 % of the default values. Following enquiries to the consultant associated with the dredging contractor, likely occupancy times of 1254 hours (~52 days) and 627 hours (~26 days) were estimated for the external exposure and ingestion pathways, respectively.

Information concerning dispersion and fish/shellfish consumption close to Sellafield is provided in Simmonds et al. (1995) and Environment Agency et al. (2004), respectively. The parameter values used in place of those in the generic IAEA model are listed in Table 7.

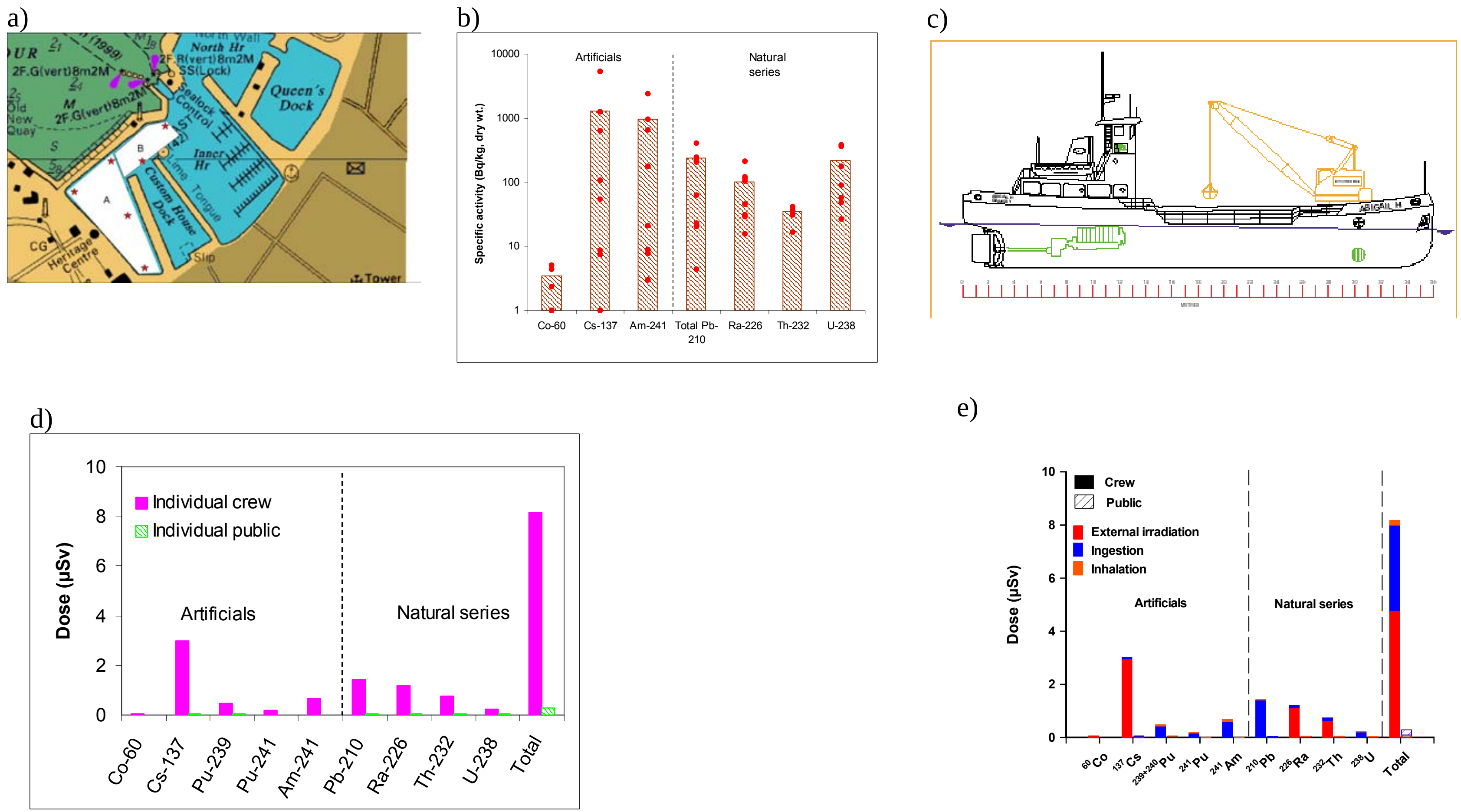
Table 7 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for dredging at Whitehaven in 2004. Values for F and S taken from Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data from RIFE-9 report (Environment Agency et al., 2004).

Parameter	Symbol	Whitehaven value	IAEA-TECDOC-1375 value
Dose to crew			
Occupancy (External exposure) (h/a)	$t_{crew,\ ext}$	1254	1000
Working outside on board of ship (h/a)	$t_{crew,\ inh/ing}$	627	2000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	23 % TECDOC values(1)	
Dose to public			
Flux of water through coastal region (m^3/a)	F	8.0×10^{10}	4.0×10^{10}
Mass of candidate material (kg/a)	M	3.0×10^{7}	1.0×10^{8}
Suspended sediment concentration (kg/m^3)	S	5.0×10^{-3}	3.0×10^{-3}
Ingestion rate of fish (kg/a)	H_B (fish)	39	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	21.5	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	24	7.5

(1) Variable between individual radionuclides (j)

The estimates of derived dose and the distribution between individual pathways, using values for dispersion parameters specific to Sellafield for public exposure, are shown in Figs. 9d and 9e, respectively.

Figure 9 - Predicted dose to individual members of crew and the public arising from dredging of Whitehaven Harbour in 2004. a) Location of sediment cores (stars), b) Specific activities of selected radionuclides on individual sediment samples. Bars indicate average values, c) Schematic diagram of the Abigail H dredger, d) Dose from individual radionuclides. Doses were derived using average activities shown in Fig. 7b. Values for plutonium radionuclides estimated from ^{241}Am data, assuming levels proportional to that in time integrated discharge, e) Dose distribution between individual pathways.



The data in Fig. 9b show that the specific activities of individual samples varied by more than an order of magnitude for the radionuclides considered here. The (perhaps inevitable) scatter in the data did not permit any consistent identification of variation between the six sampling sites, nor with depth. Therefore, the average values were used in the subsequent dose assessments. As mentioned previously, sediment in Whitehaven Harbour was known to contain significant activities of Pu radionuclides, ^{238}U and ^{232}Th. The average value for ^{241}Am was used to derive estimates for the activities of $^{239,240}Pu$ and ^{241}Pu assuming their activity was proportional to the isotopic ratio in the time integrated Sellafield discharges. This approach is reasonable given that both elements are highly particle reactive, hence the fate following discharge is similar. Both ratios vary with time due to ^{241}Pu decay and in-growth of ^{241}Am. In 2004, values for $^{241}Am/^{239,240}Pu$ and $^{241}Am/^{241}Pu$ were ~1.7 and ~0.2, respectively. The activities for ^{226}Ra, ^{232}Th and ^{238}U were derived by assuming they were in secular equilibrium with their daughter products ^{214}Pb, ^{228}Ac and ^{234}Th, all of which are γ emitters.

The values in Fig. 9b indicate that average radionuclide activities on the dredged sediment varied by almost three orders of magnitude from 3.5 Bq/kg (^{60}Co) up to 1306 Bq/kg (^{137}Cs). The average activity of ^{238}U (217 Bq/kg) was nearly four fold greater than the 'background' value estimated for mud (~60 Bq/kg) and consequently the assessment of dose to public included a contribution from natural series radionuclides.

Due to their differing emissions upon decay, all seven radionuclides together with $^{239,240}Pu$ and ^{241}Pu were radiologically significant (Fig. 9c). The derived total dose, for the radionuclides considered here, to individual members of the crew and public was ~8.2 μSv and ~0.3 μSv respectively. It is worth noting that the derived dose to crew using generic external dose coefficients and exposure times was significantly greater (by ca 3 fold) than the *de minimis* criterion (of the order of 10 μSv/a) due to the conservative assumptions. The nine most radiologically significant radionuclides identified here contributed more than 98 % of the total dose. The relative contribution from artificial radionuclides discharged from Sellafield and anthropogenically enhanced levels of ^{238}U natural series radionuclides, originating from operations at the former MARCHON plant, was similar for both crew and public. A critical pathway analysis (Fig. 9d) indicated that the dose to crew was due to both external exposure (~59 %) and accidental ingestion of contaminated sediment (~39 %). In contrast, the dose to individual members of the public was largely (~66 %) due to seafood consumption and external exposure (~29 %). The primary radionuclides contributing to the external exposure pathway to crew were ^{137}Cs (~62 %) and ^{226}Ra (~23 %). There were four main contributors towards the seafood consumption pathway for members of the public: ^{239,240}Pu (~27 %), ^{210}Pb (in secular equilibrium with ^{210}Po, ~20 %), ^{226}Ra (~18 %) and ^{232}Th (~17 %).

CEFAS has a laboratory at Whitehaven. This enabled local staff to i) liaise with the crew to assess how operational practices differed from model assumptions and ii) make measurements of gamma dose rates onboard the Abigail H (to compare with predicted values. In practice, the dredging operation took ~ 4 months (between January-May 2005). The crew worked the equivalent of 3 days on, 1 day off, leading to a slightly longer exposure time that initially assumed (~59 days compared with ~52 days). Results of gamma dose rates measurements, and associated dose estimates, are provided in Table 8.

Table 8 - Comparison of gamma dose rates (µGy/hr) in air on the Abigail H dredger at Whitehaven Harbour in 2004 with an empty and a full hopper. Measurements represent 300 s counts using a Mini Instruments 6-81 meter with an MC71 energy-compensated GM Tube, with typical error of ±0.004 µGy/hr.

Location	Empty Hopper (µGy/hr)	Full Hopper (µGy/hr)	Increase (µGy/hr)	External dose (µSv)
Wheelhouse	0.050±0.004	0.053±0.004	0.003±0.006	
Crane Cab	0.050±0.004	0.058±0.004	0.008±0.006	
Lower Bunk	0.055±0.004	0.063±0.004	0.008±0.006	
Adjacent to hopper	0.059±0.004	0.099±0.004	0.040±0.006	
Daily average (Skipper)			0.0072±0.033(1)	10±5(2)
Predicted dose				4.8(3)

(1) Average value derived assuming crew spend 12, 8 hours and 2 hours per day in the wheelhouse, lower bunk and next to hopper, respectively. Hopper assumed to be empty for 3 out of 24 hours. Error estimates propagated from typical scatter on individual values

(2) Estimated external dose, based on exposure time of 1416 hours

(3) See Fig. 9e

The results in Table 8 indicate that gamma dose rates were variable between individual locations onboard the Abigail H, with small but consistent increases when the hopper was filled with sediment. As expected, the greatest increase was observed next to the hopper containing contaminated sediment. The gamma dose rate adjacent to the loaded hopper is similar to values reported elsewhere (McDonald et al., 2005) for muddy Whitehaven sediment. Information provided to local CEFAS staff by the dredge operators indicated that two of the crew, normally the skipper and one other, typically spent ca two hours per day next to the hopper tidying and sorting dredged debris (anchor chains, tyres, shopping trolleys, etc.). Extrapolation of the measured gamma dose rates, to predict additional external exposure from the dredging operation, indicated a dose of ~10±5 μSv. This compares with the predicted value of ~4.8 μSv and represents fair agreement given the very large errors associated with both dose estimates. Taken at face value, if estimates of exposure via sediment ingestion and inhalation (see Fig. 9e) are added to measurements of external dose, the total dose to crew could conceivably have been as high as 14 μSv. To all intents and purposes this dose meets the *de minimis* criteria, despite that the model is formulated to provide maximum rather than realistic dose estimates, for all pathways (IAEA, 2003).

4.3 Heysham (2002)

In 2002, an assessment was carried out for the disposal of up to 300,000 tonnes dry weight (~ 499,000 tonnes wet weight or 378,000 m^3) of maintenance dredged material at IS200 (Morecambe Bay B) arising from the dredging down to ~1.5 m of material from the Heysham Approaches and the Inner Harbour. Six surficial sediment samples were collected and analysed for γ emitting radionuclides. Details of sampling locations and radionuclide activities have been reported elsewhere (Environment Agency et al., 2003). For clarity, the radionuclide data are shown in Fig. 10a.

The dredgers mentioned in the licence application are listed in Table 9.

Table 9 - List of dredgers mentioned in FEPA II licence application to dredge Heysham Approaches

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
Mersey Mariner	The Mersey Docks & Harbour Company	1900	78
Mersey Venture	The Mersey Docks & Harbour Company	2200	82
Ogmore	Heysham Boat Charters	440	44
Lesse	Baggerbedrijf De Boer BV	1538	77

In practice, the dredging was carried out using just three vessels that operated largely independently (MacLean, per. comm.). The Mersey Venture (a large suction dredger) and Mersey Mariner (a large grab dredger) were used to clear the entrance of the harbour and within the harbour, respectively. The Ogmore (a smaller vessel) was used to keep the area open near the power station. The TSD Lesse (owned by an outside contractor) was only called in when logistical support was required. The number of crew on each vessel was variable ranging from ~10 on the Mersey Mariner & Mersey Venture to 3-4 on the Ogmore. Dredging was normally carried out using only one vessel at any particular time and was subject to a number of interruptions such as tidal restrictions, vessel movements and weather. The total time take to complete the operation was as much as 80 days spread throughout the year carried out in separate periods lasting 3-4 days.

The combined hopper volume of the Mersey Venture & Mersey Mariner was ~4100 m^3 meaning that, on average, these vessels would have to make ~92 journeys to and from the dredge disposal site to dispose of 378,000 m^3 of dredged material. Reasonable estimates of the typical time taken to fill the hopper and to travel to and from the disposal site are ~ 3 and 2 hours, respectively (i.e. the total time taken to dispose of any one load of dredged material was ~5 hours). Therefore, although the entire operation took much longer, the average exposure time of the crew on these vessels was ~461 hours or 19 days. As mentioned previously, the vessels operated largely independently and the Ogmore was working in the area significantly longer (MacLean, per. comm.). Assuming this vessel was engaged in dredging operations ~10 hours a day for 80 days of the year, a reasonable estimate of the exposure time for their crew is 800 hours. Calculations were, therefore, carried out for dredging using the Ogmore to assess maximum dose.

Assuming the hopper dimensions of the Ogmore are ~37 m, ~4.4 m and ~2.7m for length, breadth and depth, respectively, the surface area is ~163 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in a small decrease in external dose coefficients (by a factor of ~0.75). In the absence of any information concerning likely positioning of crew on the Ogmore, it was pessimistically assumed that occupancy was adjacent to the hopper. The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~75 % of the default values.

Information concerning dispersion and fish/shellfish consumption close to Heysham is provided in Simmonds et al. (1995) and Environment Agency et al. (2004), respectively. The parameter values used in place of those in the generic IAEA model are listed in Table 10.

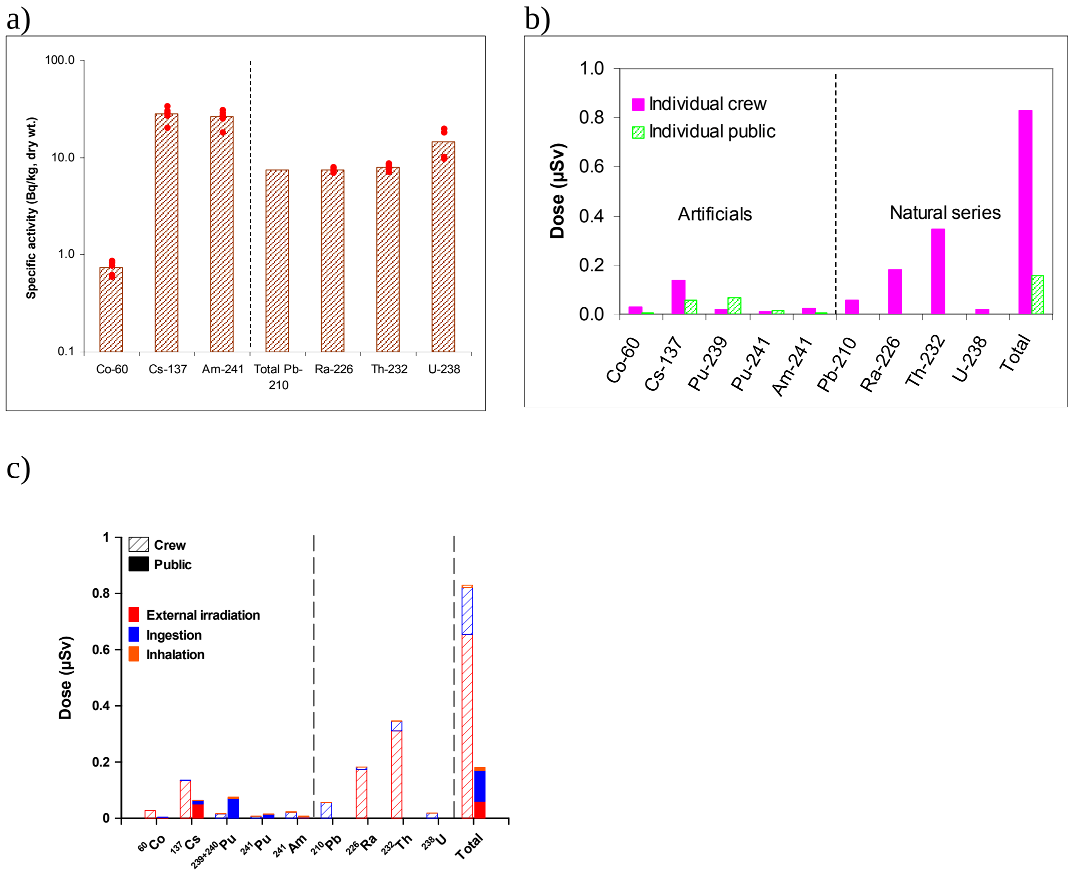
Table 10 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for dredging at Heysham in 2002. Values for F, S and D taken from Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data from RIFE-9 report (Environment Agency et al., 2004).

Parameter	Symbol	Heysham value	IAEA-TECDOC-1375 value
Dose to crew			
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	800	1000
Working outside on board of ship (h/a)	$t_{crew, inh/ing}$	800	2000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	75 % TECDOC values(1)	
Dose to public			
Flux of water through coastal region (m^3/a)	F	8.0×10^9	4.0×10^{10}
Box Volume (m^3)	V	1.0×10^8	2.0×10^9
Mass of candidate material (kg/a)	M	3.0×10^8	1.0×10^8
Suspended sediment concentration (kg/m^3)	S	1.0×10^{-2}	3.0×10^{-3}
Depth	D	10	20
Ingestion rate of fish (kg/a)	H_B (fish)	36	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	18	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	19	7.5
Occupancy on sediments on shore (h/a)	t_{public}	1.2×10^3	1.6×10^3

(1) Variable between individual radionuclides (j)

The estimates of dose and the distribution between individual pathways, using values for dispersion parameters specific to Heysham, are shown in Figs. 10b and 10c, respectively.

Figure 10 - Predicted dose to individual members of crew and the public arising from dredging of Heysham Approaches in 2002. a) Specific activities of selected radionuclides on individual sediment samples. Bars indicate average values, b) Dose for individual radionuclides. Values were derived using average activities shown in Fig. 10a. Values for plutonium radionuclides estimated from ^{241}Am data, assuming levels proportional to that in time integrated discharge. Value for ^{210}Pb derived by assuming secular equilibrium with ^{226}Ra, c) Dose distribution between individual pathways.



Inspection of the data in Fig. 10a indicates that the activities of both artificial and ^{238}U natural series radionuclides on sediment from Heysham were significantly less (up to two orders of magnitude) than those at Whitehaven (Fig. 7b). The average activities of ^{232}Th and ^{238}U (8 and 14 Bq/kg, respectively) were similar to the average 'background' activities of 7 and 9 Bq/kg estimated for sandy material (Figs 3a-3c). It seems reasonable to conclude that the observed levels for natural series radionuclide represent the local background and are not anthropogenically enhanced (i.e. these nuclides do not contribute to dose to members of the public).

The derived total dose to individual members of the crew and public was ~0.8 and 0.2 μSv, respectively (Fig. 10b). Both values are significantly lower than the *de minimis* criterion (of the order of 10 μSv). The most significant radionuclides contributing to crew exposure were natural series ^{238}U and ^{232}Th, whilst those for members of the public were $^{239,240}Pu$ and ^{137}Cs. A critical pathway analysis (Fig. 10c) indicated that the dose to crew was due to both external exposure (~79 %) and accidental ingestion of contaminated sediment (~20 %). In contrast, the predominant pathway contributing to public exposure was seafood consumption (~61 %). The primary radionuclides contributing to the external exposure pathway to crew were ^{232}Th progeny (~48 %), ^{226}Ra (~27 %) and ^{137}Cs (~21 %). The primary radionuclide contributing to the seafood consumption pathway for members of the public is $^{239,240}Pu$.

4.4 Devonport (2000)

In 2000, an assessment was carried out for the disposal of up to 66,000 tonnes (dry weight) of capital dredged material arising from the dredging of material from the Tamar estuary, close to the Remote Ammunitioning Facility (RAFT) about 1 nautical mile upstream from the Devonport Royal Dockyard near Plymouth. The vessels used to carry out the work are listed in Table 11.

Table 11 - Dredgers used to dredge Tamar estuary close to RAFT facility at Devonport Dockyard in 2000

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
UKD Bluefin	UK Dredging	3900	98
UKD Cherry Sand	UK Dredging	765	62

The largest dredger used in operations at Devonport in 2000 (UKD Bluefin) had a hopper capacity of 3900 m^3. Its length, breadth and draught were ~98 m, 18 m and ~6.7 m, respectively. Assuming the hopper dimensions are ~88 m, ~9 m and ~4.5 m for length, breadth and depth, respectively, the surface area is ~792 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicates this change would result in an increase in external dose coefficients by a factor of 1.3. This is counteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the external dose (Fig. 7b). The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~45 % of the default values.

Information on the contractors website (http://www.ukdredging.com/proj_keliston.htm) indicates that a reasonable estimate of the time taken to complete this phase of the operation is in the order of one month. In fact, this application was part of a wider phased operation involving the disposal of some 485,000 m^3 maintenance dredged material and 50,000 m^3 capital material at PL031 (Rame Head) between December 2000 and February 2002. In practice UK Dredging Crews work 2 weeks on duty and 2 weeks off duty, when on duty they live on board for the 14 days. Therefore, the maximum exposure time for the purposes of this assessment, for operations carried out in December 2000, is 336 hours.

Activities carried out at the Devonport Dockyard include maintaining, refitting and refuelling nuclear powered submarines in dry docks. Data from surveillance programmes indicates that sediment in the area of the Tamar estuary contains trace levels of ^{137}Cs and ^{241}Am (Environment Agency et al., 2005). Activation products such as ^{60}Co are below detection and the influence of discharges from the submarine related operations therefore appears minimal. The ^{137}Cs and ^{241}Am found here are likely to have originated from other widespread sources such as global weapons test fallout or releases from distant nuclear fuel reprocessing plants. In 2000, surficial sediment samples were collected from twelve locations, together with a further six at depths ranging from ~1-2 m. All the samples were analysed for γ emitting radionuclides (FSA and SEPA, 2001). For clarity, the data are also provided in Fig. 11a.

The disposal site for the dredged material was Rame Head South (PL031) within Whitsand Bay (the centre of the site lies approximately 3 km to the west of the Rame Head peninsula). Although there has been a significant amount of work carried out to assess the potential environmental impact of the disposal of dredged material at the Rame Head site (CEFAS, 2005b), the derived doses to public did not justify the efforts in working up these detailed data. For the purposes of this assessment, values for the dispersion parameters F, S and D, provided in Simmonds et al. (1995) for the Cap de la Hague nuclear fuel reprocessing plant (France), were considered as being readily applicable to estimate annual average radionuclide activities in seawater (i.e. the uncertainty was not critical). Data concerning consumption of fish and shellfish in the vicinity of Devonport is provided in the RIFE-9 report (Environment Agency et al., 2004), albeit that not based on recent information (the last habit survey around this establishment was carried out in 1992).

The parameter values used in place of those in the generic IAEA model are listed in Table 12.

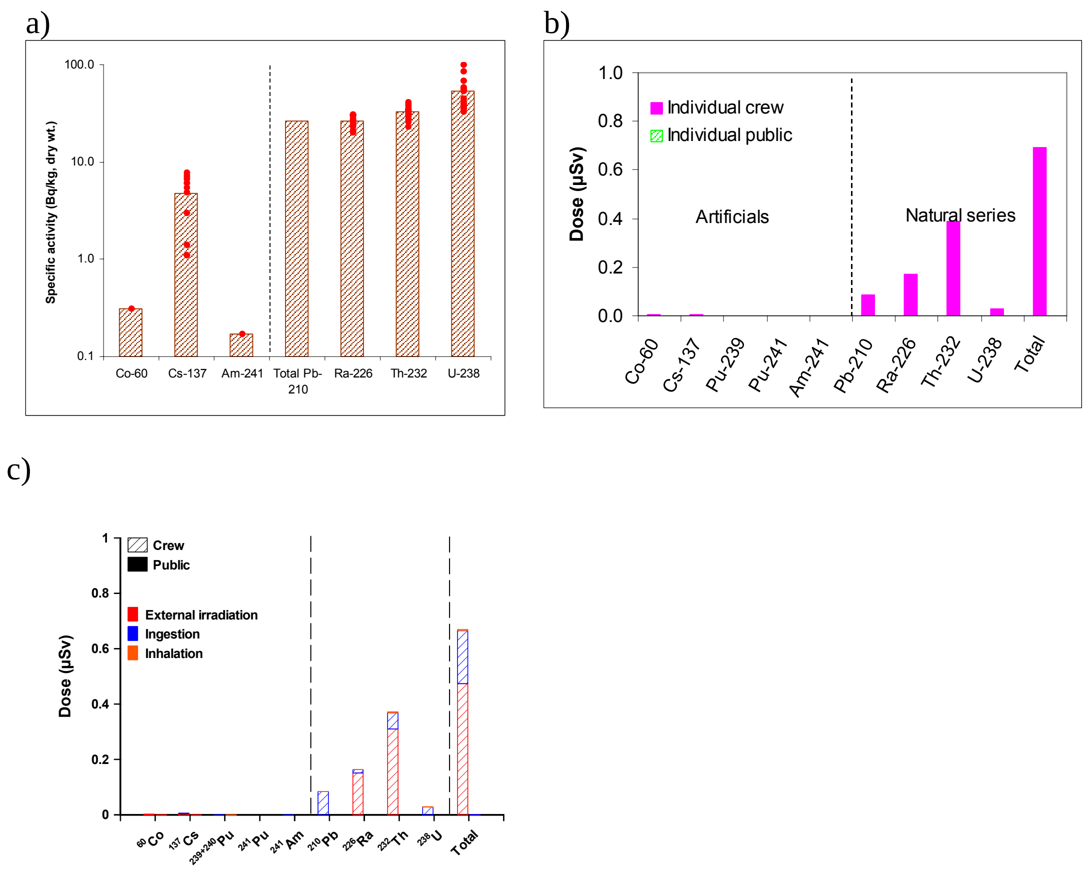
Table 12 - Changes to default parameters given in IAEA-TECDOC-1375, for purpose of assessing dredging at Devonport in 2000. Values for F, S and D taken from Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data from RIFE-9 report (Environment Agency et al., 2004). Mass of candidate material (M) derived from FEPA II licensing application.

Parameter	Symbol	Devonport value	IAEA-TECDOC-1375 value
Dose to individual crew			
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	336	1000
Working outside on board of ship (h/a)	$t_{crew, inh/ing}$	336	2000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	45 % TECDOC values$^{(1)}$	
Dose to individual public			
Flux of water through coastal region (m^3/a)	F	8.0×10^{10}	4.0×10^{10}
Mass of candidate material (kg/a)	M	6.6×10^{7}	1.0×10^{8}
Suspended sediment concentration (kg/m^3)	S	1.0×10^{-2}	3.0×10^{-3}
Depth	D	20	20
Ingestion rate of fish (kg/a)	H_B (fish)	13	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	5	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	7.5	7.5

(1) Variable between individual radionuclides (j)

The estimates of dose and the distribution between individual pathways, using values for dispersion parameters specific to Devonport, are shown in Figs. 11b and 11c, respectively.

Figure 11 - Predicted dose to individual members of crew and the public arising from dredging near Devonport Dockyard in 2000. a) Specific activities of selected radionuclides on individual sediment samples. Data for ^{60}Co and ^{241}Am indicate reported detection limits. Bars indicate average values, b) Dose for individual radionuclides. Values were derived using average activities shown in Fig. 11a. Value for ^{210}Pb estimated by assuming secular equilibrium with ^{226}Ra, c) Dose distribution between individual pathways.



.

The only artificial radionuclide detected in these samples was ^{137}Cs and its presence was restricted to surficial sediment. The activities of ^{60}Co and ^{241}Am were below detection in these samples but were included in the present conservative assessment. ^{60}Co is an 'indicator' of submarine discharges and the activity was assumed to be 0.3 Bq/kg (the reported detection limit for these samples). Extremely low activities of ^{241}Am (~0.2 Bq/kg) have been found in samples of Kinterbury mud in the 1990s. Although not detected in the current samples, this activity was pessimistically assumed to be present. The average activities of ^{234}Th, ^{214}Pb and ^{228}Ac (the gamma emitting daughter products of ^{238}U, ^{226}Ra and ^{232}Th, respectively) were 54, 27 and 33 Bq/kg, respectively. These values were similar to the average 'background' values estimated for mud (Fig. 3a).

The derived total dose to individual members of the crew and public was ~0.7 μSv and ~0.001 μSv respectively (Fig. 11b). Both values are markedly lower than the *de minimis* criterion (of the order of 10 μSv). The most significant radionuclides contributing to crew exposure were natural series ^{238}U and ^{232}Th, whilst those for members of the public were ^{60}Co and ^{137}Cs. A critical pathway analysis (Fig. 11c) indicated that the dose to crew was due to both external exposure (~72 %) and accidental ingestion of sediment (~28 %). The predominant pathway contributing to public exposure was external exposure (~92 %). The primary radionuclides contributing to the external exposure pathway to crew were ^{232}Th progeny (~66 %) and ^{226}Ra progeny (~32 %).

4.5 Case studies summary

The information from these case studies indicates that:

1) The predicted dose to crew at Whitehaven (~8.2 μSv) was close to the *de minimis* criterion (of the order of 10 μSv). Field measurements indicate the

actual dose could conceivably have been up to ~14 μSv. In practice, this was probably not the case given the conservative approach to dose estimates in the IAEA model;

2) The predicted dose to crew at Heysham and Devonport was well below the *de minimis* criterion;

3) Dose to crew is largely due to external exposure (>60 %) with a secondary contribution from accidental ingestion of sediment;

4) The most important radionuclides contributing to the external exposure pathway are ^{137}Cs, and the gamma emitting progeny of ^{226}Ra and ^{232}Th;

5) The predicted dose to individual members of the public at all three ports was well below 10 μSv;

6) Dose to the public, in areas affected by Sellafield discharges, is largely (>85 %) due to the seafood consumption pathway;

7) The primary artificial radionuclide contributing to the seafood consumption pathway is $^{239, 240}Pu$;

8) The specific activity of ^{238}U natural series radionuclides was significantly variable between the three locations. Information concerning their activity in harbour sediments is sparse but is important to provide a credible assessment of dose to crew;

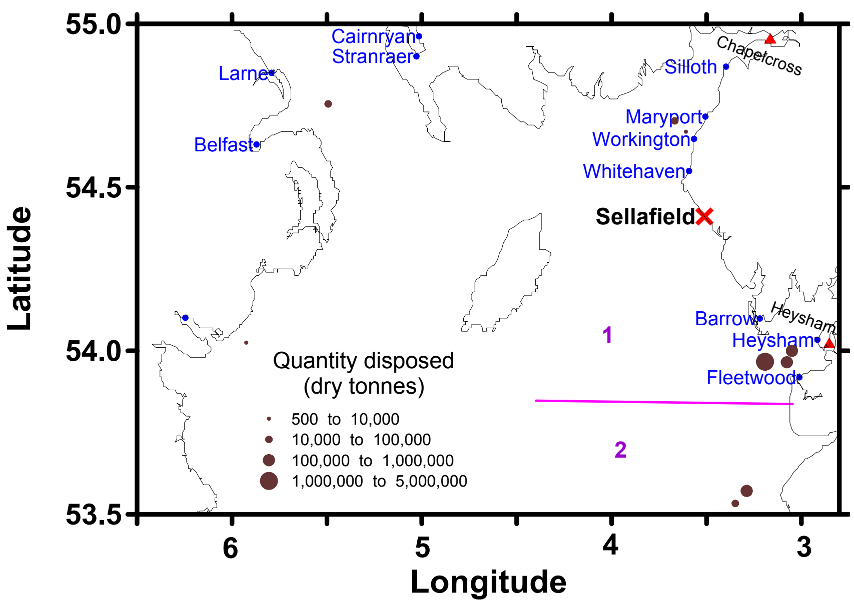
9) There was large variation in dose commitment to both crew and members of the public between Heysham and Whitehaven despite that both ports are in Region 1 (North-Eastern Irish Sea).

5. DOSE CALCULATIONS FOR INDIVIDUAL REGIONS

5.1 Region 1 (North-Eastern Irish Sea)

Region 1 comprises the coastline of Lancashire, Cumbria and the southern Solway coast. A map of selected English ports, dredge disposal sites and nuclear establishments is provided in Fig. 12. For reasons explained later in this section, the generic dose assessments provided here exclude the small ports to the north of Sellafield along the Cumbrian coastline, including Whitehaven, Workington, Maryport and Silloth.

Figure 12 - Location map for Region 1. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003



There are three nuclear establishments in this region (Chapelcross, Heysham and Sellafield). British Nuclear Fuels (BNF) operates four Magnox-type reactors at Chapelcross. Since 1980, the Chapelcross Processing Plant, which produces tritium, has also operated on this site. Liquid waste is discharged to the Solway Firth under authorisation from SEPA. The establishment at Heysham comprises two separate nuclear power stations both powered by Advanced Gas Cooled Reactors(AGRs). Disposals of radioactive waste from both stations are made under authorisation via adjacent outfalls in Morecambe Bay. Operations and facilities at Sellafield include fuel element storage, the Magnox and oxide fuel reprocessing plants, mixed oxide fuel manufacture, decommissioning and clean-up of some nuclear facilities, and the Calder Hall Magnox nuclear power station. Calder Hall ceased electricity production in March 2003 and is now preparing for defuelling prior to decommissioning. Radioactive waste discharges include a very minor contribution from the UKAEA Windscale site, which includes facilities operated by AEA Technology. The most significant discharges are made from the BNF fuel element storage ponds and the reprocessing plants, which handle irradiated Magnox and oxide fuel from the UK nuclear power programme, and some fuel from abroad.

Wastes discharged to sea from these establishments are dispersed via tides that enter the Irish Sea from the Atlantic Ocean through both the St. George's and North Channels, with the two paths meeting in the vicinity of the Isle of Man. Tidal currents in the northern Irish Sea are generally weak and do not exceed 2 m/sec (roughly 4 knots) (Jones et al., 2004). The low tidal currents allow mud-sand belts to accumulate close to the Cumbrian coast. These areas of deposition tend to be associated with large tidal ranges. Those occurring along the Lancashire and Cumbrian coasts, where the mean spring range is 8 m, are second only in the UK to those in the Bristol Channel. As mentioned previously, migration of the wastes discharged from Sellafield occurs predominantly in a northerly direction and therefore the small ports to the north of Sellafield along the Cumbrian coastline, including Whitehaven, Workington, Maryport and Silloth, are most affected by the releases.

Further enquiries were made to managers at these ports, to supplement the information derived from the Whitehaven case study. At the port of Workington, contractors are called in when an area silts up (typically in the winter months) such that dredging operations occur between September-February. The quantities removed are relatively small (e.g. ~17,500 m^3 or ~0.03 Million Tonnes dry weight in December 2003 and ~40,000 m^3 or ~0.06 Million Tonnes dry weight in February 2004). These operations take 1-2 weeks. Between September 1998 to September 2002, the harbour had a contract with Dutch Dredging and removal was carried out by the TSD Lesse (a trailing hopper suction dredger). Dredged material is disposed at two sites. In 2003 the disposal, (~0.03 Million Tonnes dry weight) was at IS240 (Solway Firth) whereas in 2002 ~0.04 Million Tonnes dry weight was dumped at IS241 (Workington Anchorage). The last licence application from Silloth was in 2000 for the removal of up to ~0.05 Million Tonnes of material from the New Dock for disposal at site IS250. Enquiries to the port manager indicated that the vessel used was the UKD Cherry Sand (a grab hopper dredger) and that the operation took 7-10 days. In summary, dredging at these ports is intermittent and the quantity removed tends to be relatively low. The exposure time for the crew appears significantly less that at Whitehaven in 2004.

It is perhaps fortuitous that the greatest disposal in this region occurs in Morecambe Bay at IS200 and IS205 (Morecambe Bay B and Barrow D), to the south of Sellafield. In 2003, ~0.2 Million Tonnes and ~1.3 Million Tonnes dredged material (dry weight) were dumped at IS200 and IS205, respectively. A similar quantity was disposed at IS200 in 2002, although there was no disposal at IS205.

The dredgers mentioned in licence applications for use at ports in Region 1 are listed in Table 13.

Table 13 - List of dredgers mentioned in FEPA II licence applications in 2003 for ports in Region 1.

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
Abigail H	Humber Workboats	230	36
Hebble Sand	D. Cook, Hull (England)	550	48
Mersey Mariner	The Mersey Docks & Harbour Company	1900	78
Modi R	Rohde Nielsen	1410	62
Sir R	Rohde Nielsen	2147	80
Sospan	Royal Boskalis Westminster	970	57
Sospan Dau	Royal Boskalis Westminster	1500	71
UKD Cherry Sand	UK Dredging	765	63
UKD Dolphin	UK Dredging	2189	79
WD Medway	Royal Boskalis Westminster	3683	77
WD Severn	Royal Boskalis Westminster	1420	70

The dredgers listed for use in operations at ports in Region 1 have hopper capacities in the range 230-3683 m^3. The largest vessel was the WD Medway with a hopper capacity of 3700 m^3. Assuming the hopper dimensions are ~45 m, ~17 m and ~4.6 m for length, breadth and depth, respectively, the surface area is ~774 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in an increase in external dose coefficients by a factor of ~1.3. This is, counteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the external dose (Fig. 7b). The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~45 % of the default values.

Information concerning dispersion, shoreline occupancy and fish/shellfish catches and consumption close to Heysham, Sellafield and Chapelcross is provided in Simmonds et al. (1995) and Environment Agency et al. (2004). The parameter values used in place of those in the generic IAEA model are listed in Table 14. Inspection of the data for parameters F, V and D indicate that the dispersive characteristics vary significantly between Heysham (in Morecambe Bay) and Sellafield (along the more open Cumbrian coastline).

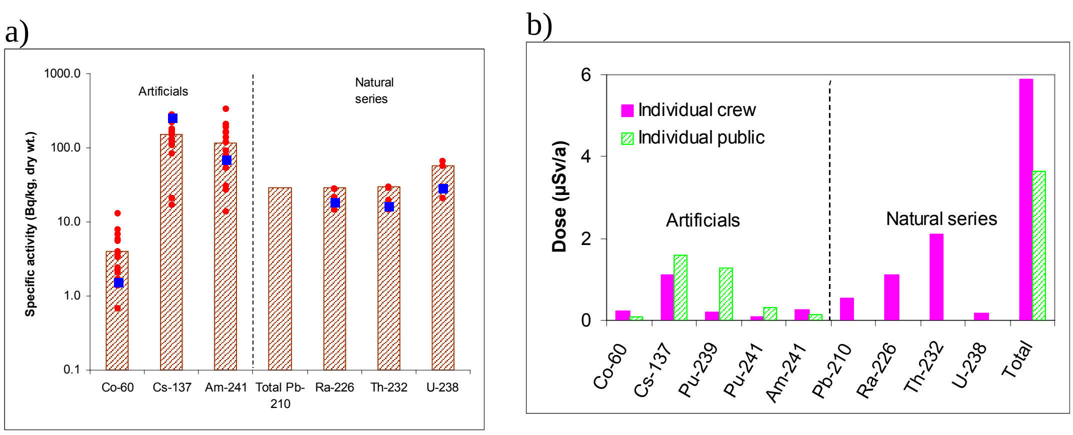
Table 14 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for Region 1. Values for F, S, D, N_B(fish), N_B(crustacea) and N_B(molluscs) taken from Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data are from RIFE-9 report (Environment Agency et al., 2004). Mass of candidate material (M) derived from FEPA II licensing applications for the Barrow D disposal site (IS205) in 2003.

Parameter	Symbol	Values for Heysham	Values for Sellafield	IAEA-TECDOC-1375 value
Dose to individual crew				
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	2000	2000	1000
Dose coefficient for external irradiation onboard ship	$DF_{ship(j)}$	45 % TECDOC values(1)		
Collective dose to crew				
Number of ships for one disposal site	N_{ship}	3		1
Dose to individual public				
Flux of water through coastal region (m^3/a)	F	8.0×10^9	8.0×10^{10}	4.0×10^{10}
Volume of seawater in box (m^3)	V	1.0×10^8	2.0×10^9	2.0×10^9
Mass of candidate material (kg/a)	M	1.3×10^9		1.0×10^8
Suspended sediment concentration (kg/m^3)	S	1.0×10^{-2}	5.0×10^{-3}	3.0×10^{-3}
Depth water column (m)	D	10	20	20
Ingestion rate of fish (kg/a)	H_B (fish)	36	39	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	18	21.5	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	19	24	7.5
Collective dose to public				
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	2.3×10^2	1.2×10^6	5.0×10^5
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	5.8×10^4	1.7×10^5	1.0×10^5
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	9.5×10^4	4.4×10^4	1.0×10^5

(1) Variable between individual radionuclides (j)

Dose assessments were based on monitoring data in the vicinity of the nuclear establishments, together with quantities dumped at IS205, in an attempt to represent a worse case scenario for ports to the south of Sellafield. The sediment data for Whitehaven Harbour shown previously were excluded from this assessment as this location is considered to present a special case, requiring individual consideration. Given the aforementioned variation in dispersive characteristics, separate calculations were carried out using parameter values appropriate for Heysham and Sellafield. The dose estimates are shown in Fig. 13b, for Heysham as these provided the greater values for members of the public.

Figure 13 - Generic assessment of dose to individual members of crew and the public arising from dredging in Region 1 at ports to the south of Sellafield. a) Specific activities of selected radionuclides on individual sediment samples. Squares are measurements from a composite dredge sample at Barrow. Bars indicate average values for artificial radionuclides and average 'background' activity for natural series nuclides (Fig. 3a), b) Dose estimates for individual radionuclides, derived using parameter values for Heysham. Doses were derived using activities denoted by bars in Fig. 13a.



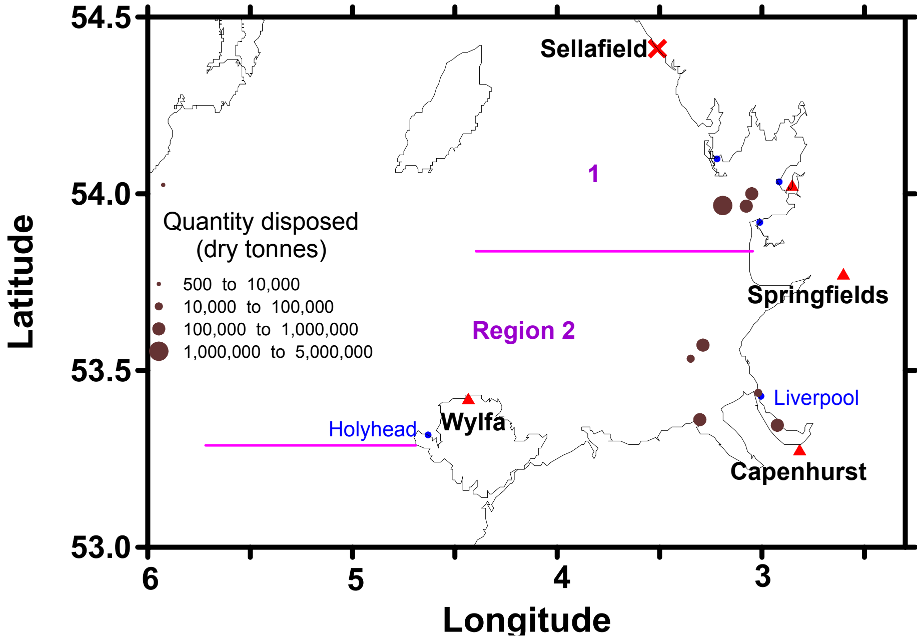
Inspection of the data in Fig. 13a indicates that the activities of artificial gamma emitting radionuclides were variable (<300 Bq/kg dry weight ^{137}Cs & ^{241}Am and <13 Bq/kg dry weight ^{60}Co). It is however clear that the average values are significantly lower than those observed in mud samples from Whitehaven Harbour (Fig. 9b). As noted previously, the highest activities of most radionuclides are associated with fine-grained material. It is conceivable that the disparity is due to the different contractors involved in the various monitoring programmes collecting different samples. The limited available data for natural series radionuclides were consistent with 'background' levels estimated for muddy material. There are no available data for unsupported ^{210}Pb. Consequently, ^{210}Pb was assumed to be in secular equilibrium with ^{226}Ra. It is unclear whether the recent monitoring data (Environment Agency, 2004) involves the analysis of sand or mud at Whitehaven, Workington, Harrington and the Outer Harbour at Maryport. This is one of the reasons why the generic assessment for Region 1 excludes these small ports to the north of Sellafield. Another reason is that the monitoring data is for surface sediments only and it is conceivable that subsurface material may be significantly more contaminated (as observed at some of the Whitehaven sampling sites, Fig. 9b).

The derived total dose to individual members of the crew and public was ~6 μSv/a and ~4 μSv/a respectively (Fig. 13b). The dose to crew was split between artificial and natural series radionuclides. Collective doses to crew and public were ~2 x 10^{-3} and 6 x 10^{-2} man Sv/a, respectively. All the derived dose values were less than the *de minimis* criteria (of the order of 10 μSv/a and 1 manSv/a for individual and collective dose, respectively). The dose assessment for members of the public using parameter values for Sellafield was significantly lower (~1 μSv/a). It is worth re-emphasising that this generic assessment excludes the small ports along the Cumbrian coastline to the north of Sellafield where further data are required to confirm activities on muddy material.

5.2 Region 2 (South-Eastern Irish Sea)

Region 2 comprises the coastline of north Wales and Lancashire extending from Holyhead (Anglesey) in the south up to Morecambe Bay in the north. A map of selected ports, dredge disposal sites and nuclear establishments is provided in Fig. 14.

Figure 14 - Location map for Region 2. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003



This region contains a large disposal site (IS140, Site Z) located off the mouth of the Mersey servicing Liverpool. In 2003, ~0.95 Million Tonnes dredged material (dry weight) was dumped at IS140. A slightly greater quantity was disposed here in 2002 (~1.5 Million Tonnes). The strength of water movements in this region is variable. Currents are strong (over 1.5 m/s) between Anglesey and the Isle of Man but much weaker (of the order of 0.5 m/s) in the Liverpool Bay region.

There are three nuclear establishments in this region (Capenhurst, Springfields and Wylfa). The main functions undertaken at Capenhurst (Cheshire) and Springfields (Lancashire) are uranium enrichment and manufacture of fuel elements, respectively. Liquid radioactive wastes from Capenhurst consist primarily of tritium, uranium plus its daughter products and technetium-99 arising from operations involving recycled fuel. The effluent is discharged into Riveracre Brook and eventually enters the Mersey. Liquid wastes from Springfields consist primarily of thorium and uranium and their decay products; the effluent is discharged by pipeline to the Ribble estuary. Relatively high concentrations of ^{234}Th, and its daughter ^{234m}Pa, can occur in sediments from the Ribble estuary as a result of these discharges (Assinder et al., 1997). It is not clear whether this influence extends significantly beyond the estuary, but is likely to be limited due to the short half-life of ^{234}Th (24 days). The nuclear power station at Wylfa on the Isle of Anglesey generates electricity from two Magnox reactors. The impact of the discharges is very low (Environment Agency et al., 2004). Although not in Region 2, the main influence upon levels of artificial radionuclides in the sediments appears to be releases from Sellafield. There is evidence that Liverpool Bay may form a backwater where the Sellafield wastes may significantly accumulate, under certain conditions. (Leonard et al., 2004). More specifically, accumulation appears to occur during tidal surges, produced by rapidly moving atmospheric depressions that significantly increase the flow of water into the northern Irish Sea from the Atlantic.

The dredgers mentioned in licence applications for use at ports in Region 2 are listed in Table 15.

Table 15 - List of dredgers mentioned in FEPA II licence applications in 2003 for ports in Region 2.

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
Flevo	Royal Boskalis Westminster	2130	79
Hebble Sand	D. Cook, Hull (England)	550	48
Mersey Mariner	The Mersey Docks & Harbour Company	1900	78
Mersey Venture	Midland Montague Leasing Ltd. / Forward Leasing GB Ltd.	2200	82
Ogmore	Heysham Boat Charters	440	44
Sospan Dau	Royal Boskalis Westminster	1500	71
UKD Dolphin	UK Dredging	2189	79
WD Medway II	Royal Boskalis Westminster	3683	77
WD Severn	Royal Boskalis Westminster	1420	70

The dredgers listed for use in operations at ports in Region 2 have hopper capacities in the range 440-3683 m^3. The largest vessel was the WD Medway II with a hopper capacity of 3700 m^3. Assuming the hopper dimensions are ~45 m, ~17 m and ~5 m for length, breadth and depth, respectively, the surface area is ~774 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in an increase in external dose by a factor of ~1.3. This small increase is counteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the external dose. The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~45 % of the default values.

Information concerning dispersion, shoreline occupancy and fish/shellfish catches and consumption close to Capenhurst, Springfields and Wylfa is provided in Simmonds et al. (1995) and Environment Agency et al. (2004). Average values for these parameters were used in place of those in the generic IAEA model and are listed in Table 16.

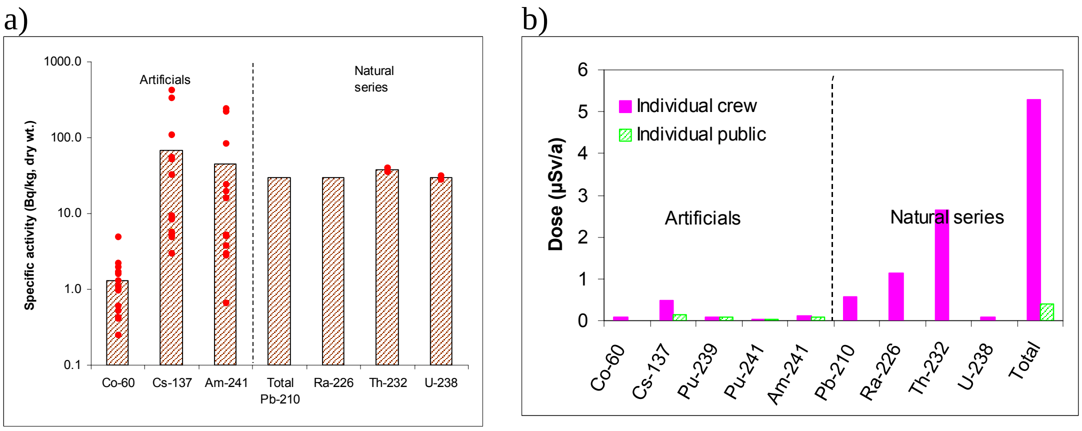
Table 16 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for Region 2. Values for F, S, D, N_B(fish), N_B(crustacea) and N_B(molluscs) taken from Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data from RIFE-9 report (Environment Agency et al., 2004). Mass of candidate material (M) derived from FEPA II licensing applications for the Site Z disposal site (IS140) in 2003.

Parameter	Symbol	Region 2 value	IAEA-TECDOC-1375 value
Dose to individual crew			
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	2000	1000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	45 % TECDOC values(1)	
Collective dose to crew			
Number of ships for one disposal site	N_{ship}	4	1
Dose to individual members of the public			
Flux of water through coastal region (m^3/a)	F	4.1×10^{10}	4.0×10^{10}
Box Volume (m^3)	V	1.4×10^9	2.0×10^9
Mass of candidate material (kg/a)	M	9.5×10^8	1.0×10^8
Suspended sediment concentration (kg/m^3)	S	1.0×10^{-1}	3.0×10^{-3}
Depth water column (m)	D	17	20
Ingestion rate of fish (kg/a)	H_B (fish)	68	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	19	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	5.9	7.5
Collective dose to the public			
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	3.2×10^3	5.0×10^5
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	3.6×10^4	1.0×10^5
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	5.9×10^4	1.0×10^5

(1) Variable between individual radionuclides (j)

Dose assessments based on radionuclide data along the Lancashire and North Wales coastline, together with quantities dumped at IS140, are likely to represent a worse case scenario for Region 2. The dose estimates are shown in Fig. 15b.

Figure 15 - Generic assessment of dose to individual members of crew and the public arising from dredging in Region 2. a) Specific activities of selected radionuclides on individual sediment samples. Bars indicate average values, b) Dose estimates for individual radionuclides. Doses were derived using average activities shown in Fig. 15a.



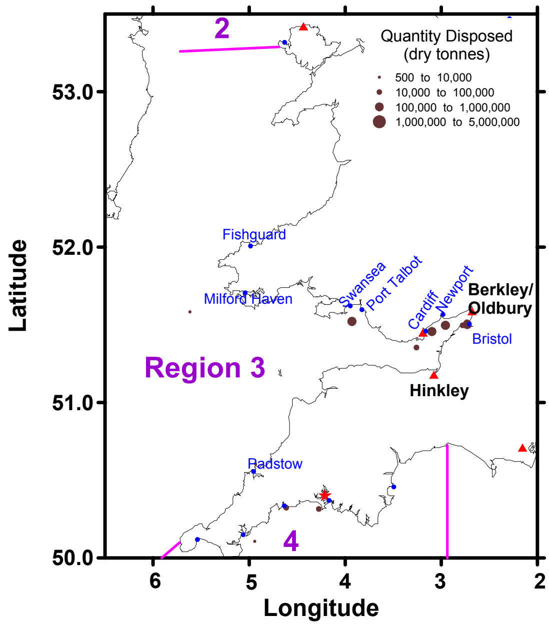
Inspection of the data in Fig. 15a indicates that the activities of artificial radionuclides (^{137}Cs and ^{241}Am) were significantly variable ranging from <1- ~400 Bq/kg dry weight. The main cause of the variability is likely to be variation in grain-size, levels being greatest on fine grained muddy material (McCartney et al., 1994). It seems reasonable to assume that distance from Sellafield provides another, more minor, source of variation. There are very limited data available for ^{238}U and ^{232}Th, with analyses being confined to sediments collected from the Ribble estuary. The activities in these samples (~30 and 38 Bq/kg for ^{238}U and ^{232}Th, respectively) were within the range of estimated ‘background’ levels (Figs.

3a-3c). To estimate dose to crew, ^{226}Ra and ^{210}Pb were assumed to be in secular equilibrium with ^{238}U. The derived total dose to individual members of the crew and public was ~5 μSv/a and ~0.4 μSv/a respectively (Fig. 15b). The proportion of the dose to crew resulting from contamination by artificial radionuclides was minor (~15 %). Collective doses to crew and public were both ~2 x 10^{-3} man Sv/a. All the derived dose values were less than the *de minimis* criteria (of the order of 10 μSv/a and 1 manSv/a for individual and collective dose, respectively).

5.3 Region 3 (West England and Wales)

Region 3 comprises the coastline of south-west England and Wales. A map of selected ports, dredge disposal sites and nuclear establishments is provided in Fig. 16.

Figure 16 - Location map for Region 3. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003.



The largest disposal sites in this region are located in the Bristol Channel. In 2003, the greatest amount of dredging was carried out at Port Talbot and Swansea resulting in the disposal of ~0.63 Million Tonnes dredged material (dry weight) at the Swansea Bay (Outer) site LU130. Almost double this quantity was disposed here in 2002 (~1.3 Million Tonnes). The mean tidal range at spring tides along the coast shows a steady and large increase north-eastwards, from 5 m at Land's End to 12.3 m at Avonmouth. This increase is due to the amplification of the tidal movement as it is funnelled up the Bristol Channel. The tidal range of the Severn Estuary, at around 12 metres, is the largest in the UK and the second largest in the world. Within the Bristol Channel, the ebb flow is dominant, with complex circulatory flows around the major sandbanks. On the northern side of the peninsula and into the Bristol Channel, current speeds steadily increase. Admiralty Charts give a maximum surface ebb current of 4.6 m/s off Foreland Point near Lynton, North Devon, and a maximum flood current of 4.2 m/s off Weston-super-Mare, Somerset. Offshore, current speeds are slightly lower, ranging from 0.7 m/s off Lundy to over 3.0 m/s in the Bristol Deep off Avonmouth. Tidal current speeds in the Severn estuary generally exceed 1.5 m/s at springs and 0.75 m/s at neaps, meaning water parcels can move up to 25 km during a flood or ebb tide (Uncles, 1984). The currents are locally parallel to coastlines with little cross channel flow.

There are three nuclear establishments in this region (Berkley, Hinkley and Oldbury). Berkeley Power Station (Gloucestershire) ceased electricity generation in March 1989, but small amounts of radioactive wastes still need to be disposed of as part of decommissioning operations. In addition there is a component of the discharge from the adjoining Berkeley Technology Centre. The Oldbury Power Station (Gloucestershire) still continues operations and because the effects of both sites are on the same area, Berkeley and Oldbury are considered together for the purposes of environmental monitoring. Liquid radioactive wastes are discharged to the Severn estuary. There are two separate 'A' and 'B' stations at Hinkley Point (Somerset). The 'A' station is comprised of Magnox reactors whilst the 'B' station has AGRs. Magnox Electric announced the closure of Hinkley Point 'A' May 2000, although it only began to be decommissioned in 2004. Discharges of liquid effluent are made into the Bristol Channel. In addition, GE Healthcare (formerly Amersham plc) produces a wide range of isotopically-labelled compounds, predominantly tritium (^{3}H) and carbon-14 (^{14}C), for use in life science research at their radiopharmaceutical plant in Cardiff (Wales). The liquid effluents are discharged to the Ystradyfodwg and Pontypridd (Y&P) trunk sewer and conveyed into the Severn estuary. Monitoring around all these establishments indicates the specific activities of artificial radionuclides in sediment are low (Environment Agency et al., 2004).

The dredgers mentioned in licence applications for use at ports in the Bristol Channel are listed in Table 17.

Table 17 - List of dredgers mentioned in FEPA II licence applications in 2003 for ports in Region 3.

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
Sospan	Royal Boskalis Westminster	970	57
Sospan Dau	Royal Boskalis Westminster	1500	71
Thor R	Rohde Nielsen	2507	79
UKD Bluefin	UK Dredging	3900	98
UKD Cherry Sand	UK Dredging	765	63
UKD Dolphin	UK Dredging	2189	79
UKD Marlin	UK Dredging	2692	85
WD Medway II	Royal Boskalis Westminster	3683	77

The dredgers listed for use in operations at ports in Region 3 have hopper capacities in the range 765-3900 m^3. The largest vessel was the UKD Bluefin with a hopper capacity of 3900 m^3. Assuming the hopper dimensions are ~88 m, ~9 m and ~4.5 m for length, breadth and depth, respectively, the surface area is ~792 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in an increase in external dose by a factor of 1.3. This change is counteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the external dose. The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~45 % of the default values.

Information concerning dispersion, shoreline occupancy and fish/shellfish catches and consumption close to Berkley/Oldbury and Hinkley Point are provided in Simmonds et al. (1995) and Environment Agency et al. (2004). The parameter values used in place of those in the generic IAEA model are listed in Table 18. Inspection of the data for parameters F, V and D indicates that the dispersive characteristics vary significantly between Hinkley Point (in the Bristol Channel) and Berkley/Oldbury (close to the head of the Severn estuary).

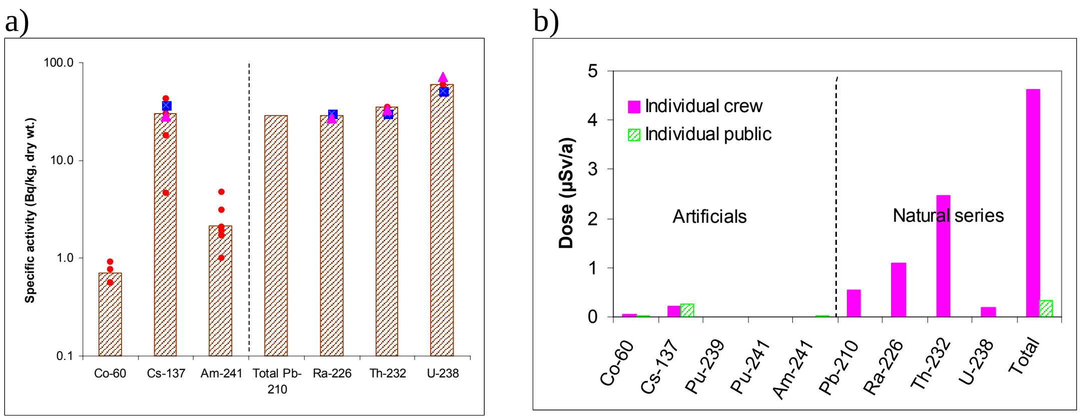
Table 18 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for Region 3. Values for F, S, D, N_B(fish), N_B(crustacea) and N_B(molluscs) taken from Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data are from RIFE-9 report (Environment Agency et al., 2004). Mass of candidate material (M) derived from FEPA II licensing applications for the Outer Swansea Bay disposal site (LU130) in 2003.

Parameter	Symbol	Values for Hinkley	Values for Oldbury	IAEA-TECDOC-1375 value
		Dose to individual crew		
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	2000	2000	1000
Dose coefficient for external irradiation onboard ship	$DF_{ship(j)}$	45 % TECDOC values[(1)]	45 % TECDOC values[(1)]	
		Collective dose to crew		
Number of disposal sites	N_{site}	12	12	10
Number of ships for one disposal site	N_{ship}	2	2	1
		Dose to individual public		
Flux of water through coastal region (m^3/a)	F	1.0×10^{11}	4.0×10^{9}	4.0×10^{10}
Box Volume (m^3)	V	5.0×10^{9}	2.0×10^{8}	2.0×10^{9}
Mass of candidate material (kg/a)	M	6.3×10^{8}	6.3×10^{8}	1.0×10^{8}
Suspended sediment concentration (kg/m^3)	S	2.0×10^{-1}	2.0×10^{-1}	3.0×10^{-3}
Depth water column (m)	D	20	10	20
Ingestion rate of fish (kg/a)	H_B (fish)	43	18	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	9.8	2.3	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	1.8	7.5[(2)]	7.5
		Collective dose to public		
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	7.5×10^{4}	3.0×10^{3}	5.0×10^{5}
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	1.3×10^{4}	4.2×10^{3}	1.0×10^{5}
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	1.3×10^{5}	4.2×10^{4}	1.0×10^{5}

(1) Variable between individual radionuclides (j)
(2) No data provided for mollusc consumption at Oldbury, hence default value used.

Dose assessments based on radionuclide data in the vicinity of the nuclear establishments, together with quantities dumped at LU130, are likely to represent a worse case scenario for Region 3. Given the aforementioned variation in dispersive characteristics, separate calculations were carried out using parameter values appropriate in Berkley/Oldbury and Hinkley Point. The dose estimates are shown in Fig. 17b, for Berkley/Oldbury as these provided the greater values for members of the public.

Figure 17 - Generic assessment of dose to individual members of crew and the public arising from dredging in Region 3. a) Specific activities of selected radionuclides on individual sediment samples. Dots represent results from RIFE monitoring programme. Squares and triangles are measurements from composite dredge samples at Cardiff and Bristol, respectively. Bars indicate average values, b) Dose estimates for individual radionuclides, derived using parameter values for Berkley/Oldbury. Doses were derived using average activities shown in Fig. 17a.



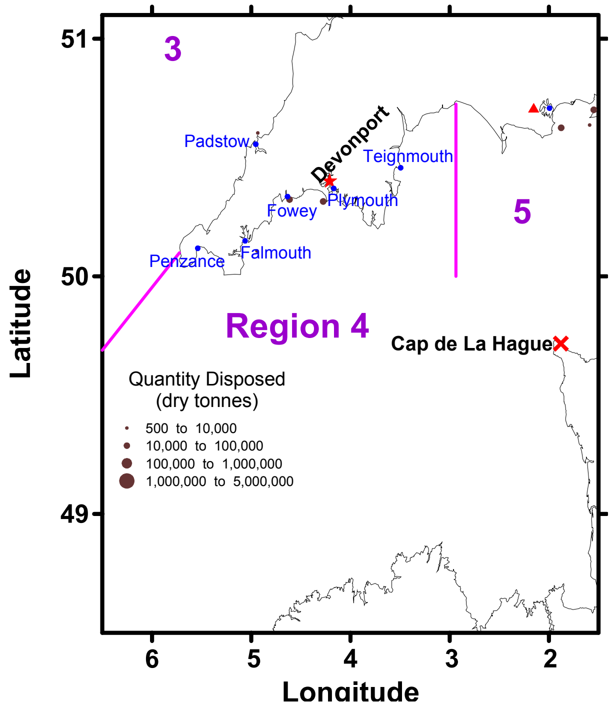
Inspection of the data in Fig. 17a indicates that the activities of artificial radionuclides were low (<50 Bq/kg dry weight ^{137}Cs and < 5 Bq/kg dry weight ^{60}Co & ^{241}Am). The activity of natural series radionuclides on composite dredge samples from Bristol and Cardiff were consistent with 'background' levels estimated for muddy material. There are no available data for unsupported ^{210}Pb. Consequently, ^{210}Pb was assumed to be in secular equilibrium with ^{226}Ra.

The derived total dose to individual members of the crew and public was ~4.6 μSv/a and ~0.3 μSv/a respectively (Fig. 17b). The dose assessment for members of the public using values for Hinkley was significantly lower (0.02 μSv/a). The proportion of the dose to crew resulting from contamination by artificial radionuclides was minor (~6 %). Collective doses to crew and public were both ~1 x 10^{-3} man Sv/a. All the derived dose values were less than the *de minimis* criteria (of the order of 10 μSv/a and 1 manSv/a for individual and collective dose, respectively).

5.4 Region 4 (South-West England)

Region 4 comprises the coastline of south-west England extending from Lyme Regis in the east to Lands End in the west. A map of selected ports, dredge disposal sites and nuclear establishments is provided in Fig. 18.

Figure 18 - Location map for Region 4. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003



With the exception of the Rame Head site (PL031), close to Plymouth, disposal of dredged material occurs at a relatively low level in this region with <0.1 Million Tonnes dredged material (dry weight) being dumped at any single site since 2000. Although the typical quantity disposed at Rame Head in the last 20 years has been in the range 0.1-0.25 Million Tonnes (dry weight), up to 1 Million Tonnes has been dumped on two occasions over the last 20 years (1986 and 2001) (CEFAS, 2005b). In general terms, tidal currents in this region flood eastwards and ebb westwards. The tidal range at Lyme Bay is ~4 m, increasing to over 4.5 m towards the west. The tidal range increases progressively offshore into the English Channel and is particularly high near the Channel Islands. Currents are at their strongest (in the region of 2 m/s at mean spring tides) around headlands, such as Start Point, and in the Channel between the Isles of Scilly and the mainland. Within embayments, such as Lyme Bay, currents are relatively weak especially in shallow water. For much of the central part of the English Channel the maximum speed of tidal currents is between 0.75 m/s and 1.25 m/s.

The only nuclear establishment in this region, on the English coast, is the Devonport Dockyard (DML), situated on the Tamar estuary in Devon, where nuclear submarines are serviced. The closest nuclear fuel reprocessing plant at Cap de la Hague (northern France) is not considered to be a significant source of activity to ports in this area as transport of its discharges is predominantly eastward along the European coastline (Salamon et al., 1991). Data from surveillance programmes indicates that sediment in the area of the Tamar estuary contains trace levels of ^{137}Cs and ^{241}Am (Environment Agency et al., 2005). Activation products such as ^{60}Co are below detection and the influence of discharges from the submarine related operations therefore appears minimal. The ^{137}Cs and ^{241}Am found here are likely to have originated from other widespread sources such as global weapons test fallout or releases from distant nuclear fuel reprocessing plants.

The dredgers mentioned in licence applications for use at ports in Region 4 are listed in Table 19.

Table 19 - List of dredgers mentioned in FEPA II licence applications in 2003 for ports in south-west England.

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
UKD Cherry Sand	UK Dredging	765	63
Volvox Anglia	Van Oord	1202	67
Sospan	Royal Boskalis Westminster	970	57
Sospan Dau	Royal Boskalis Westminster	1500	71

The dredgers listed for use in operations at the ports of south-west England have hopper capacities in the range 765- 1500 m^3. The largest vessel was the Sospan Dau with a hopper capacity of 1500 m^3. Assuming the hopper dimensions are ~64 m, ~7 m and ~3.4 m for length, breadth and depth, respectively, the surface area is ~448 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in only a small increase in external dose (by a factor of just ~1.1). This change is counteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the external dose. The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~38 % of the default values.

Values for the dispersion parameters F, V, S and D, provided in Simmonds et al. (1995) for the Cap de la Hague nuclear fuel reprocessing plant (France), were considered as being readily applicable to estimate annual average radionuclide activities in seawater in this region. Although there has been a significant amount of work carried out to assess the potential environmental impact of the disposal of dredged material at Rame Head site (CEFAS, 2005b), the derived doses to members of the public did not justify the effort in working up these more detailed results to provide a refined estimate (i.e. the uncertainty was not critical). Data concerning consumption of fish and shellfish in the vicinity of Devonport is provided in the RIFE-9 report (Environment Agency et al., 2004), albeit that not based on recent information (the last habit survey around this establishment was carried out in 1992). Values for these parameters, used in place of those in the generic IAEA model, are listed in Table 20.

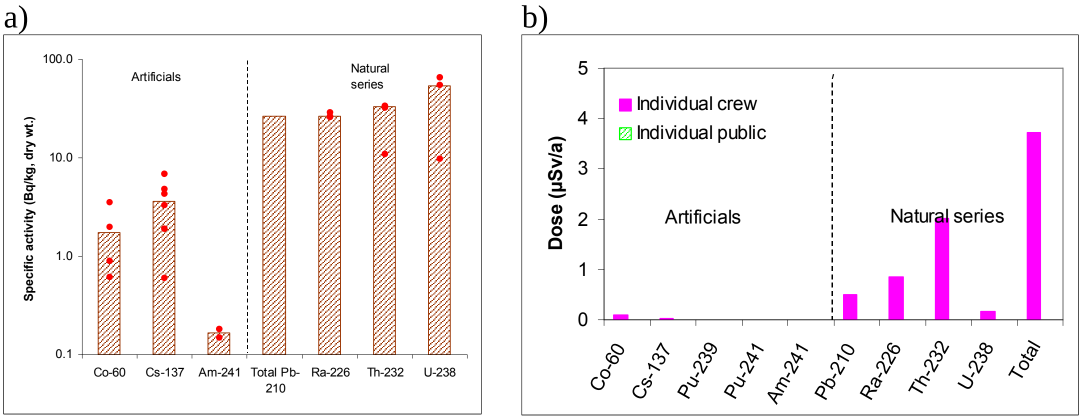
Table 20 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for Region 4. Values for F, S, D are those for Cap de la Hague in Table 4.5 (Simmonds et al., 1995). N_B(fish), N_B(crustacea) and N_B(molluscs) are values for Winfrith. Fish/shellfish consumption data from RIFE-9 report (Environment Agency et al., 2004). Mass of candidate material (M) derived from disposal at Rame Head disposal site (PL031) in 2001.

Parameter	Symbol	Region 4 value	IAEA-TECDOC-1375 value
Dose to individual crew			
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	2000	1000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	38 % TECDOC values(1)	
Dose to individual members of the public			
Flux of water through coastal region (m^3/a)	F	8.0×10^{10}	4.0×10^{10}
Mass of candidate material (kg/a)	M	5.2×10^{8}	1.0×10^{8}
Suspended sediment concentration (kg/m^3)	S	1.0×10^{-2}	3.0×10^{-3}
Depth water column (m)	D	20	20
Ingestion rate of fish (kg/a)	H_B (fish)	13	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	5	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	7.5	7.5
Collective dose to the public			
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	4.2×10^{4}	5.0×10^{5}
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	1.2×10^{5}	1.0×10^{5}
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	3.5×10^{4}	1.0×10^{5}

(1) Variable between individual radionuclides (j)

Dose assessments based on radionuclide data in the vicinity of Devonport, together with quantities dumped at PL031 in 2001, are likely to represent a worse case scenario for Region 4. The dose estimates are shown in Fig. 19b.

Figure 19 - Assessment of dose to individual members of crew and the public arising from dredging in Region 4. a) Specific activities of selected radionuclides on individual sediment samples. Bars indicate average values for artificial radionuclides and average activity for natural series nuclides in Tamar estuary (Fig. 11a), b) Dose estimates for individual radionuclides. Doses were derived using activities denoted by bars in Fig. 19a.



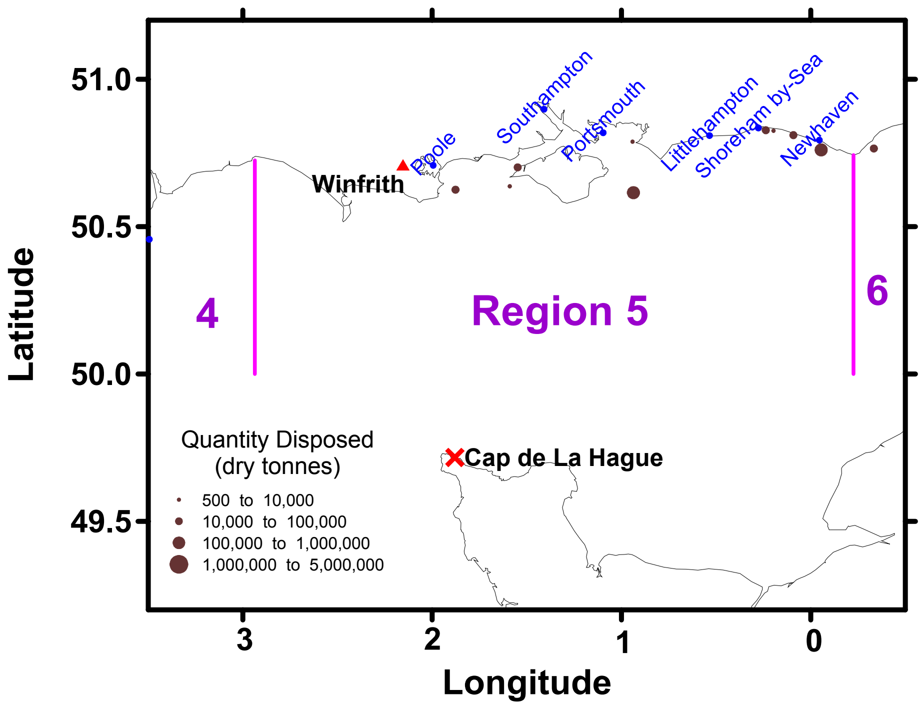
Inspection of the data in Fig.19a indicates that the activities of artificial radionuclides (^{60}Co, ^{137}Cs and ^{241}Am) were low (<10 Bq/kg dry weight). The activity of natural series radionuclides on sediment from the Tamar estuary is consistent with 'background' levels estimated for muddy material. There are no available data for unsupported ^{210}Pb. Consequently, ^{210}Pb was assumed to be in secular equilibrium with ^{226}Ra.

The derived total dose to individual members of the crew and public was ~3.7 µSv/a and <0.1 µSv/a respectively (Fig. 19b). The proportion of the dose to crew resulting from contamination by artificial radionuclides was minor (<5 %). Collective doses to crew and public were ~4 x 10^{-4} and 4 x 10^{-5} man Sv/a, respectively. All the derived dose values were less than the *de minimis* criteria (of the order of 10 µSv/a and 1 manSv/a for individual and collective dose, respectively).

5.5 Region 5 (Southern England)

Region 5 comprises the coastline of southern England extending from Lyme Regis in the west to Newhaven in the east. A map of selected ports, dredge disposal sites and nuclear establishments is provided in Fig. 20.

Figure 20 - Location map for Region 5. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003



This region contains a large disposal site (WI060, Nab Tower) located off the Isle of Wight servicing marinas and ports in the Solent, Southampton Water and Portsmouth areas. In 2003, the greatest contribution was from Southampton and ~0.41 Million Tonnes dredged material (dry weight) was dumped at WI060. An almost identical quantity was disposed here in 2002 (~0.43 Million Tonnes).

The tidal currents in this region flood eastwards and ebb westwards. The smallest tidal ranges in the whole of the UK, less than 2.0 m at spring tides, are found in the Poole/Christchurch Bay areas. West of Swanage the range increases, but even at Portland it is only 2.5 metres. The tidal range increases progressively offshore into the English Channel. One peculiar feature of the tides in this region is the distortion of tidal curves due to the effect of shallow water. A consequence of this is that tides have a marked 'double low water' between Portland Harbour and Kimmeridge Bay. From Swanage to Southampton 'double high waters' occur. In Poole and Christchurch Bays, this distortion results in a long stand of the tide at, or very close to, the high water level. The strength of the currents is extremely variable. The strongest tidal currents are present off Portland Bill where they may reach over 3.5 m/s. Strong tidal currents, often with associated overfalls, occur off pronounced headlands such as Selsey Bill, St Catherine's Point and St Alban's Head. Overfalls occur where the seabed falls away sharply, and where surface water

travels faster than that close to the seabed, leading to down-flows of water (similar to eddies). Within the main embayments, such as Christchurch Bay, Poole Bay and Weymouth Bay, currents are relatively weak, especially in shallow water. For much of the central part of the English Channel the maximum speed of tidal currents is between 0.75 m/s and 1.25 m/s. Within the Solent, strong currents flow through the Hurst Narrows (1.8 m/s on spring tides) at the western entrance to the Solent. However, at the entrances to Portsmouth, Langstone and Chichester Harbours, surface currents may reach in excess of 3 m/s on full spring ebb.

The only UK nuclear establishment in this region is at Winfrith in Dorset, although discharges are now extremely low. Discharges into Weymouth Bay commenced in

1970 arising from the operation of a prototype steam-generating heavy-water reactor. The effluent consisted primarily of activation products of Co, Cr, Fe, Mn, Ni and Zn. Discharges peaked in the late 1970s. The reactor was shut down in 1990. Although discharges have continued since that date, the activity levels are only a small fraction of those during the reactor life. The nuclear reprocessing plant at Cap de la Hague (northern France) is not considered to be a significant source of activity to ports in this area as transport of its discharges is predominantly eastward along the European coastline (Salamon et al., 1991). Monitoring of radionuclides in sediment around this establishment ceased in 1999. The last available data (MAFF & SEPA, 1999) indicates the specific activities of artificial radionuclides in sediment are low.

The dredgers mentioned in licence applications for use at the Solent ports are listed in Table 21.

Table 21 - List of vessels mentioned in FEPA II licence applications in 2003 for ports in Region 5.

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
U.K.D. Bluefin	UK Dredging	3900	98
U.K.D. Dolphin	UK Dredging	2189	79
U.K.D. Marlin	UK Dredging	2692	85
W.D. Medway	Royal Boskalis Westminster	3683	77

The dredgers listed for use in operations at the Solent ports have hopper capacities in the range 2189-3900 m^3. The largest vessel was the UKD Bluefin with a hopper capacity of 3900 m^3. Assuming the hopper dimensions are ~88 m,

~9.5 m and ~4.7 m for length, breadth and depth, respectively, the surface area is ~792 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in an increase in external dose by a factor of ~1.3. This change is counteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the external dose. The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~45 % of the default values.

Information concerning dispersion, shoreline occupancy and fish/shellfish catches and consumption close to Winfrith is provided in Simmonds et al. (1995) and Environment Agency et al. (2004). Values for these parameters were used in place of those in the generic IAEA model and are listed in Table 22.

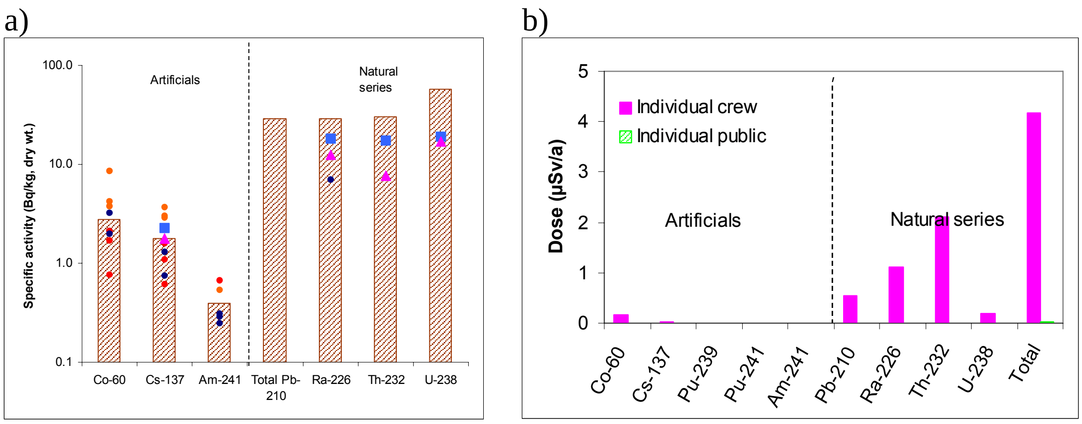
Table 22 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for Region 5. Values for F, S, D, N_B(fish), N_B(crustacea) and N_B(molluscs) are those for Winfrith in Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data from RIFE-9 report (Environment Agency et al., 2004). Mass of candidate material (M) derived from FEPA II licensing applications for the Nab Tower disposal site (W1060) in 2003.

Parameter	Symbol	Region 5 value	IAEA-TECDOC-1375 value
Dose to individual crew			
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	2000	1000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	45 % TECDOC values[(1)]	
Collective dose to crew			
Number of ships for one disposal site	N_{ship}	3	1
Dose to individual members of the public			
Flux of water through coastal region (m^3/a)	F	4.0×10^{10}	4.0×10^{10}
Mass of candidate material (kg/a)	M	4.1×10^{8}	1.0×10^{8}
Suspended sediment concentration (kg/m^3)	S	1.0×10^{-2}	3.0×10^{-3}
Depth water column (m)	D	20	20
Ingestion rate of fish (kg/a)	H_B (fish)	40	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	15	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	14	7.5
Collective dose to the public			
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	4.2×10^{4}	5.0×10^{5}
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	1.2×10^{5}	1.0×10^{5}
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	3.5×10^{4}	1.0×10^{5}

(1) Variable between individual radionuclides (j)

Dose assessments based on radionuclide data in the vicinity of Winfrith, together with quantities dumped at Nab Tower (WI060), are likely to represent a worse case scenario for Region 5. The dose estimates are shown in Fig. 21b.

Figure 21 - Generic assessment of dose to individual members of crew and the public arising from dredging in Region 5. a) Specific activities of selected radionuclides on individual sediment samples. Dots represent results from RIFE monitoring programme, or literature data. Squares and triangles are measurements of composite dredge samples from Portsmouth and Shoreham, respectively. Bars indicate average values for artificial radionuclides and average 'background' activity for natural series nuclides (Fig. 3a), b) Dose estimates for individual radionuclides. Doses were derived using activities denoted by bars in Fig. 21a.



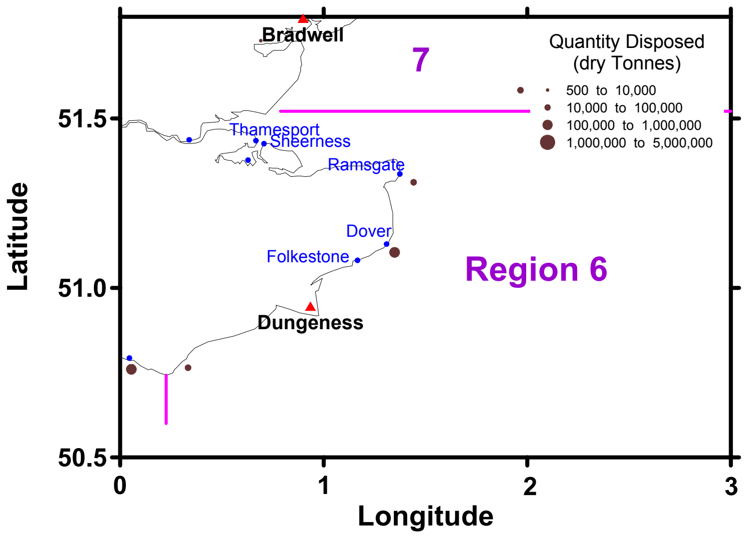
Inspection of the data in Fig. 21a indicates that the activities of artificial radionuclides (^{60}Co, ^{137}Cs and ^{241}Am) were low (<10 Bq/kg dry weight). Large counting errors were associated with our measurements of natural radionuclides in composite dredge samples from Portsmouth and Shoreham. Therefore, the values used for the dose assessment to crew were the average 'background' activity on mud (Figs. 3a-3c), to estimate maximum exposure. It is worth noting that the activity assumed for ^{226}Ra is greater than that for supported ^{210}Pb activity in tertiary sediments from the Solent (Cundy et al., 1996) and Pagham Harbour (Sussex) (Cundy et al., 2002). Although unsupported ^{210}Pb data were reported for a number of core samples (Cundy et al., 1996, 2002), it is not possible to apply these data to that in dredged material with any certainty. Consequently, ^{210}Pb was assumed to be in secular equilibrium with ^{226}Ra.

The derived total dose to individual members of the crew and public was ~4 μSv/a and <0.1 μSv/a respectively (Fig. 21b). The proportion of the dose to crew resulting from contamination by artificial radionuclides was minor (<5 %). Collective doses to crew and public were ~1 x 10^{-3} and 6 x 10^{-5} man Sv/a, respectively. All the derived dose values were less than the *de minimis* criteria (of the order of 10 μSv/a and 1 manSv/a for individual and collective dose, respectively).

5.6 Region 6 (South-East England)

Region 6 comprises the coastline of eastern England. A map of selected ports, dredge disposal sites and nuclear establishments is provided in Fig. 22.

Figure 22 - Location map for Region 6. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003



This region does not contain any large disposal sites, compared with those present off the Thames, Humber and Tees estuaries. In 2003, the greatest amount of dredging was carried out at ports along the Kent coast, resulting in the disposal of ~0.25 Million Tonnes dredged material (dry weight) at DV010. A slightly greater quantity was disposed here in 2002 (~0.37 Million Tonnes). The tidal regime in the Dover Strait is characterised by moderate to large spring tidal ranges (3–12 m) and strong currents. The tidal current speeds in the eastern English Channel increase towards the Straits of Dover, owing to the restriction of the channel and the presence of tidal sand ridges aligned with the direction of flow. The currents are also strengthened by winds that are dominantly south-westerly to westerly. The maximum speed of tidal streams at Dover is about 1.75 m/s. Consequently, the eastern Channel is a storm-wave environment characterised by short period waves that are important in mobilising bedload within the shallow (<20 m) nearshore zone.

The only nuclear establishment in this region is at Dungeness. There are two separate power stations on this site. The ‘A’ station is powered by Magnox reactors whilst the ‘B’ station has Advanced Gas Cooled Reactors (AGRs). Discharges of liquid effluent are made via adjacent outfalls into the English Channel. Monitoring around this establishment indicates the specific activities of artificial radionuclides in sediment are low and the impact of the discharges appears to be minor (Environment Agency et al., 2004).

The dredgers mentioned in licence applications for use at ports in Region 6 are listed in Table 23.

Table 23 - List of dredgers mentioned in FEPA II licence applications in 2003 for ports in Region 6.

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
David Church	Dover Harbour Board	800	50
UKD Bluefin	UK Dredging	3900	98
UKD Cherry Sand	UK Dredging	765	63
UKD Dolphin	UK Dredging	2189	79
UKD Marlin	UK Dredging	2692	85
Volvox Anglia	Van Oord	1202	67

The dredgers listed for use in operations at ports in Region 6 have hopper capacities in the range 765-3900 m^3. The largest vessel was the UKD Bluefin with a hopper capacity of 3900 m^3. Assuming the hopper dimensions are ~88 m, ~9.5 m and ~4.7 m for length, breadth and depth, respectively, the surface area is ~792 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in an increase in external dose by a factor of ~1.3. This change iscounteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the external dose. The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~45 % of the default values.

Information concerning dispersion, shoreline occupancy and fish/shellfish catches and consumption close to Dungeness is provided in Simmonds et al. (1995) and Environment Agency et al. (2004). Values for these parameters were used in place of those in the generic IAEA model and are listed in Table 24.

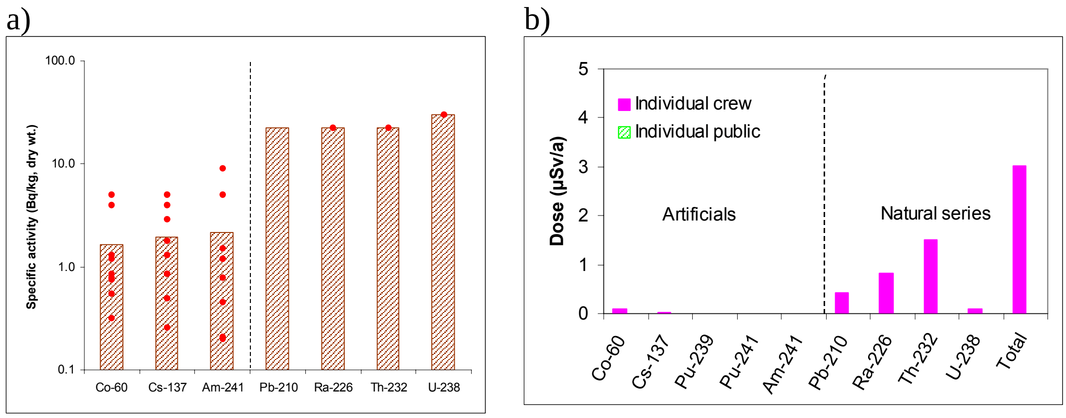
Table 24 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for Region 6. Values for F, S, D, N_B(fish), N_B(crustacea) and N_B(molluscs) are those for Dungeness in Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data from RIFE-9 report (Environment Agency et al., 2004). Mass of candidate material (M) derived from FEPA II licensing applications for the Dover disposal site (DV010) in 2003.

Parameter	Symbol	Region 6 value	IAEA-TECDOC-1375 value
Dose to individual crew			
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	2000	1000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	45 % TECDOC values[(1)]	
Collective dose to crew			
Number of ships for one disposal site	N_{ship}	3	1
Dose to individual members of the public			
Flux of water through coastal region (m^3/a)	F	8.0×10^{10}	4.0×10^{10}
Mass of candidate material (kg/a)	M	2.6×10^{8}	1.0×10^{8}
Suspended sediment concentration (kg/m^3)	S	1.0×10^{-2}	3.0×10^{-3}
Depth water column (m)	D	20	20
Ingestion rate of fish (kg/a)	H_B (fish)	59	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	17	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	15	7.5
Collective dose to the public			
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	2.7×10^{3}	5.0×10^{5}
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	1.3×10^{4}	1.0×10^{5}
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	5.9×10^{4}	1.0×10^{5}

(1) Variable between individual radionuclides (j)

A dose assessment based on radionuclide data in the vicinity of Dungeness, together with quantities dumped at the Dover site (DV010), is likely to represent a worse case scenario for Region 6. The dose estimates are shown in Fig. 23b.

Figure 23 - Generic assessment of dose to individual members of crew and the public arising from dredging in Region 6. a) Specific activities of selected radionuclides on individual sediment samples. Bars indicate average values, b) Dose estimates for individual radionuclides. Doses were derived using average activities shown in Fig. 23a.



Inspection of the data in Fig. 23a indicates that the activities of artificial radionuclides were low (<5 Bq/kg dry weight ^{137}Cs and < 9 Bq/kg dry weight ^{241}Am). Published data for natural series radionuclides is extremely sparse, being limited to single measurements of ^{238}U and ^{232}Th in a sample of sand from Eastbourne. The activity of both nuclides in this sand sample was low (<5 Bq/kg, dry weight; McDonald et al., 1991). An average value of ~10 Bq/kg has been reported for supported ^{210}Pb activity in saltmarsh sediments of the Medway estuary (Spencer et al., 2003). Unpublished CEFAS data for the activity of gamma emitting daughter products in material from Rye Harbour indicated activities of ~22, 30 and

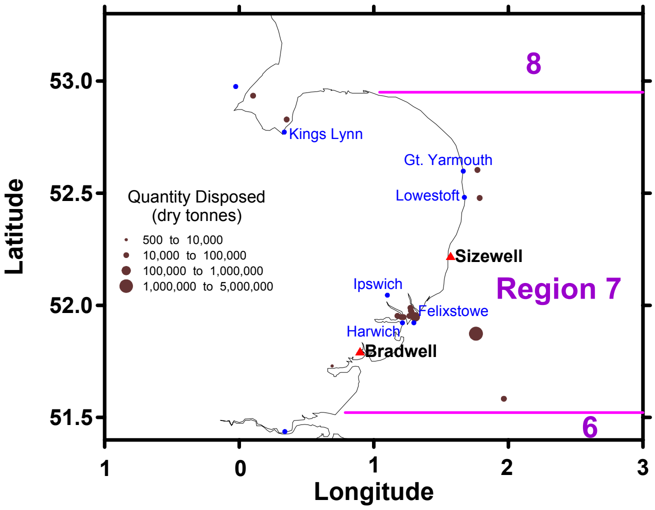
~22 Bq/kg, dry weight for ^{226}Ra, ^{238}U and ^{232}Th, respectively. The maximum values were used to assess dose (Fig. 23b). To the best of this author's knowledge, there are no appropriate data for ^{210}Pb and it was, therefore, were assumed to be in secular equilibrium with ^{226}Ra.

The derived total dose to individual members of the crew and public was ~3 μSv/a and <0.1 μSv/a respectively (Fig. 23b). The proportion of the dose to crew resulting from contamination by artificial radionuclides was minor (<5 %). Collective doses to crew and public were ~9 x 10^{-4} and 1 x 10^{-5} man Sv/a, respectively. All the derived dose values were less than the *de minimis* criteria (of the order of 10 μSv/a and 1 manSv/a for individual and collective dose, respectively).

5.7 Region 7 (Eastern England)

Region 7 comprises the coastline of eastern England in based on the Eastern SFI district. A map of selected ports, dredge disposal sites and nuclear establishments is provided in Fig. 24.

Figure 24 - Location map for Region 7. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003



This region contains large disposal sites located off the Orwell and Stour estuaries. In 2003, the greatest amount of dredging was carried out at Felixstowe and Harwich resulting in the disposal of ~2.0 Million Tonnes dredged material (dry weight) at the Inner Gabbard site TH052. A slightly lower quantity was disposed here in 2002 (~1.6 Million Tonnes).

The tidal currents in the Southern North Sea flood southwards and ebb northwards. To the north, the maximum tidal current increases southwards, from approximately 0.5 m/s knot in the north to 1.5 m/s knots in the south. The tidal range follows a similar pattern, increasing from ~2 m in the north to ~5 m in the south. Tidal ranges tend to greater in this region compared with those further to the north.

There are two nuclear power stations in this region. The Magnox power station at Bradwell (Essex) stopped electricity production in 2002 after 40 years of operation and is now being decommissioned. It is still authorised to discharge liquid wastes to Blackwater estuary. There are two stations at Sizewell (Suffolk). The ‘A’ station has two Magnox reactors whilst the ‘B’ station has a Pressurised Water Reactor (PWR). Discharges of liquid effluent are made via adjacent outfalls to the North Sea. Monitoring around these establishments indicates the specific activities of artificial radionuclides in sediment are low. Their presence has been attributed to long range transport of historic disposals from Sellafield and weapon test fallout (Environment Agency et al., 2004). Therefore, the impact of discharges from both power stations appears to be minor.

The dredgers mentioned in licence applications for use at Felixstowe and Harwich are listed in Table 25.

Table 25 - List of dredgers mentioned in FEPA II licence applications in 2003 for Felixstowe and Harwich.

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
Barent Zanen	Royal Boskalis Westminster	8350	134
Cornelia	Royal Boskalis Westminster	6617	113
Cornelis Zanen	Royal Boskalis Westminster	8530	132
Nautilus	Royal Boskalis Westminster	4400	90
Oranje	Royal Boskalis Westminster	15,850	156
Queen of The Netherlands	Royal Boskalis Westminster	23,400	174
Seaway	Royal Boskalis Westminster	13,255	170
Sospan	Royal Boskalis Westminster	970	57
Sospan Dau	Royal Boskalis Westminster	1500	71
Waterway	Royal Boskalis Westminster	4900	98
WD Fairway	Royal Boskalis Westminster	35,814	232
WD Gateway	Royal Boskalis Westminster	6085	134
WD Medway II	Royal Boskalis Westminster	3683	77

The dredgers listed for use in operations at Felixstowe and Harwich have hopper capacities in the range 970-35,814 m^3. The largest vessel was the WD Fairway with a hopper capacity of ~36,000 m^3. Assuming the hopper dimensions are ~190 m, ~21 m and ~9 m for length, breadth and depth, respectively, the surface area is ~3700 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in an increase in external dose by a factor of ~1.9. This change is counteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the dose. The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~66 % of the default values.

Information concerning dispersion, shoreline occupancy and fish/shellfish catches and consumption close to Bradwell and Sizewell is provided in Simmonds et al. (1995) and

Environment Agency et al. (2004). Average values for these parameters were used in place of those in the generic IAEA model and are listed in Table 26.

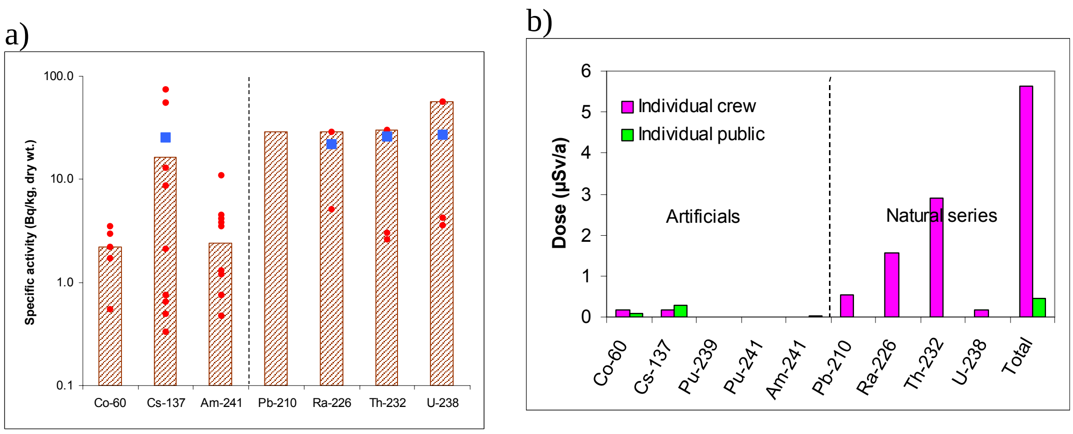
Table 26 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for Region 7. Values for F, V, S, D, N_B(fish), N_B(crustacea) and N_B(molluscs) were derived from data for Bradwell and Sizewell in Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data from RIFE-9 report (Environment Agency et al., 2004). Mass of candidate material (M) derived from FEPA II licensing applications for the Inner Gabbard disposal site (TH052) in 2003.

Parameter	Symbol	Region 7 value	IAEA-TECDOC-1375 value
Dose to individual crew			
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	2000	1000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	66 % TECDOC values(1)	
Collective dose to crew			
Number of ships for one disposal site	N_{ship}	3	1
Dose to individual members of the public			
Flux of water through coastal region (m^3/a)	F	7.0×10^9	4.0×10^{10}
Box Volume (m^3)	V	2.5×10^8	2.0×10^9
Mass of candidate material (kg/a)	M	2.0×10^9	1.0×10^8
Suspended sediment concentration (kg/m^3)	S	1.4×10^{-1}	3.0×10^{-3}
Depth water column (m)	D	10	20
Ingestion rate of fish (kg/a)	H_B (fish)	42	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	5.8	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	6.5	7.5
Collective dose to the public			
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	2.5×10^3	5.0×10^5
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	3.6×10^4	1.0×10^5
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	6.7×10^5	1.0×10^5
Annual collective shore occupancy per unit length coastline (man h/a/m)	$O_{coll,shor}$	100	50

(1) Variable between individual radionuclides (j)

Dose assessments based on radionuclide data in the vicinity of Bradwell & Sizewell, together with quantities dumped at the Inner Gabbard site (TH052), are likely to represent a worse case scenario for Region 7. The dose estimates are shown in Fig. 25b.

Figure 25 - Assessment of dose to individual members of crew and the public arising from dredging in Region 7. a) Specific activities of selected radionuclides on individual sediment samples. Dots represent results from RIFE monitoring programme. Squares are measurements of a composite dredge sample from Ipswich. Bars indicate average values for artificial radionuclides and average 'background' activity for natural series nuclides (Fig. 3a), b) Dose estimates for individual radionuclides. Doses were derived using activities denoted by bars in Fig. 25a.



Inspection of the data in Fig. 25a indicates that the activities of artificial radionuclides were low (<75 Bq/kg dry weight ^{137}Cs and < 11 Bq/kg dry weight ^{241}Am). Published data for natural series radionuclides is extremely sparse, being limited to single measurements of ^{238}U and ^{232}Th in a sample of sand from Gt. Yarmouth. The activity of both nuclides in this sand sample was low (~ 3 Bq/kg, dry weight; McDonald et al.,

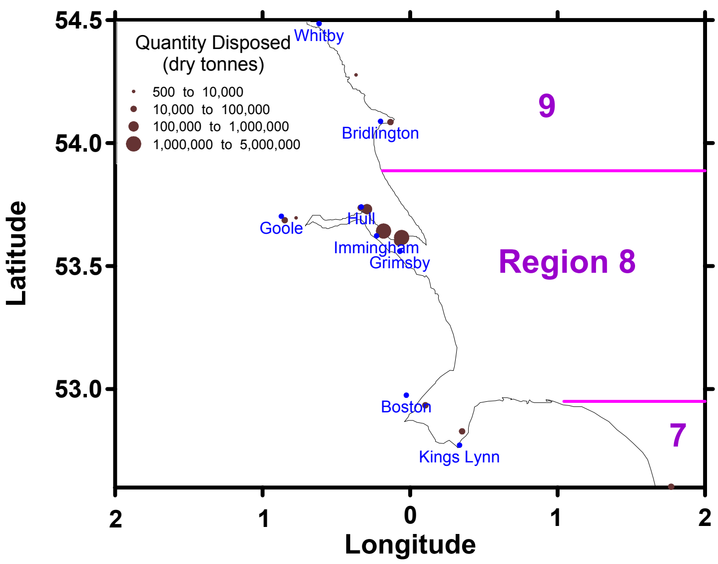
1991) and significantly less than that found in the composite dredge sample from Ipswich. Therefore, the values used for the dose assessment to crew were the average 'background' activity on mud (Figs. 3a-3c) that are roughly an order of magnitude greater. To the best of this author's knowledge, there are no appropriate data for ^{210}Pb, and this nuclide was therefore assumed to be in secular equilibrium with ^{226}Ra.

The derived total dose to individual members of the crew and public was ~6 μSv/a and ~0.5 μSv/a respectively (Fig. 25b). The proportion of the dose to crew resulting from contamination by artificial radionuclides was minor (~6 %). Collective doses to crew and public were ~2 x 10^{-3} and 4 x 10^{-3} man Sv/a, respectively. All the derived dose values were less than the *de minimis* criteria (of the order of 10 μSv/a and 1 manSv/a for individual and collective dose, respectively).

5.8 Region 8 (Humber)

Region 8 comprises the coastline of eastern England, around the Humber and Wash estuaries. A map of selected ports and dredge disposal sites is provided in Fig. 26.

Figure 26 - Location map for Region 8. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003



This region contains large disposal sites located off the Humber estuary. The Humber is a turbid, macrotidal estuary and is the largest in Britain, draining a catchment of approximately 24 000 km^2. In 2003, the greatest amount of dredging was carried out at Grimsby and Immingham resulting in the disposal of ~3.6 Million Tonnes dredged material (dry weight) at the Humber 1A site HU080. A slightly lower quantity was disposed here in 2002 (~2.1 Million Tonnes) and compares with an average value for 1985 – 1993 of about 1.4 Million tonnes. It is worth noting that the Humber 1A disposal site is situated at the mouth of the estuary such that anthropogenically derived sediment from the estuary mixes with natural particles eroded from the coastline. The impact of resuspension of dumped material is probably fairly minor given that riverine sources of suspended particulate material to the Humber estuary are an order magnitude smaller than the estimated inputs from the erosion of the local (Holderness) coastline (McCave, 1987).

There is no nuclear establishment in this region. It seems reasonable to assume that, as found in the Tees estuary (to the north in region 9), the specific activities of artificial radionuclides in sediment are low. A limited amount of data for the Humber estuary is available from a study involving the use of ^{137}Cs and ^{210}Pb as geochronological tracers to assess sediment mixing processes (Lee and Cundy, 2001) and from measurements carried out for the present project.

The dredgers mentioned in licence applications for use at ports in Region 8 in 2003 are listed in Table 27.

Table 27 - List of dredgers mentioned in FEPA II licence applications in 2003 for ports in Region 8.

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
UKD Bluefin	UK Dredging	3900	98
UKD Cherry Sand	UK Dredging	765	63
UKD Dolphin	UK Dredging	2189	79
UKD Marlin	UK Dredging	2692	85
Sospan	Royal Boskalis Westminster	970	57

The dredgers used in operations at ports in Region 8 have hopper capacities in the range 765-3900 m^3. The largest vessel was the UKD Bluefin with a hopper capacity of 3900 m^3. Assuming the hopper dimensions are ~88 m, ~9 m and ~4.5 m for length, breadth and depth, respectively, the surface area is ~792 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in an increase in external dose by a factor of 1.3. This change is counteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the external dose. The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~45 % of the default values.

There is no immediately applicable information concerning dispersion, shoreline occupancy and fish/shellfish catches and consumption for members of the public living in the vicinity of the Humber estuary. Although the tidal range and freshwater flow is well known (e.g. the tidal range varies between 6.4 (mean spring tidal range) and 3.2 m (mean neap tidal range) at Immingham near the mouth of the Humber), it is difficult to apply this information to provide average values for F and V in the simple box model used here. It seems reasonable, therefore, to use the information for the Tees estuary (Region 9). The parameters used in place of those in the generic IAEA model are listed in Table 28.

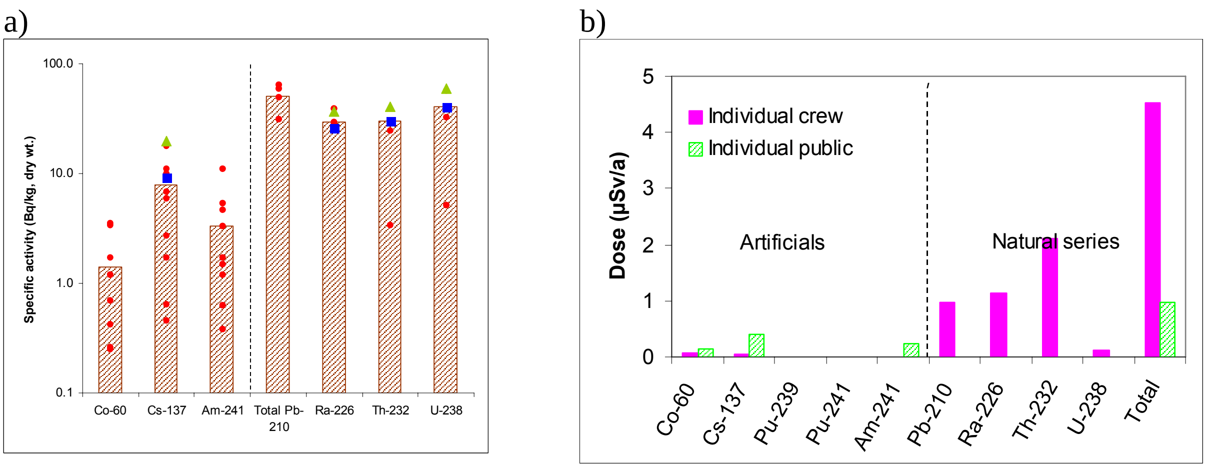
Table 28 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for Region 8. Mass of candidate material (M) derived from FEPA II licensing applications for the Humber 1A disposal site (HU080) in 2003.

Parameter	Symbol	Region 8 value	IAEA-TECDOC-1375 value
Dose to individual crew			
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	2000	1000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	45 % TECDOC values[(1)]	
Collective dose to crew			
Number of ships for one disposal site	N_{ship}	3	1
Dose to individual members of the public			
Flux of water through coastal region (m^3/a)	F	4.0×10^9	4.0×10^{10}
Box Volume (m^3)	V	2.0×10^8	2.0×10^9
Mass of candidate material (kg/a)	M	3.6×10^9	1.0×10^8
Suspended sediment concentration (kg/m^3)	S	2.0×10^{-1}	3.0×10^{-3}
Depth water column (m)	D	10	20
Ingestion rate of fish (kg/a)	H_B (fish)	32	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	15	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	12	7.5
Collective dose to the public			
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	2.3×10^3	5.0×10^5
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	6.6×10^4	1.0×10^5
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	1.6×10^4	1.0×10^5

(1) Variable between individual radionuclides (j)

Dose assessments based on a combination of radionuclide data for the Tees estuary/our own measurements, together with quantities dumped at the Humber 1A disposal site (HU080), are likely to represent a worse case scenario for Region 8. The dose estimates are shown in Fig. 27b.

Figure 27 - Generic assessment of dose to individual members of crew and the public arising from dredging in Region 8. a) Specific activities of selected radionuclides on individual sediment samples. Dots represent results from RIFE monitoring programme around Hartlepool nuclear power station. Squares and triangles are measurements of composite dredge samples from the Humber estuary. Bars indicate average values, b) Dose estimates for individual radionuclides. Doses were derived using average activities shown in Fig. 27a.



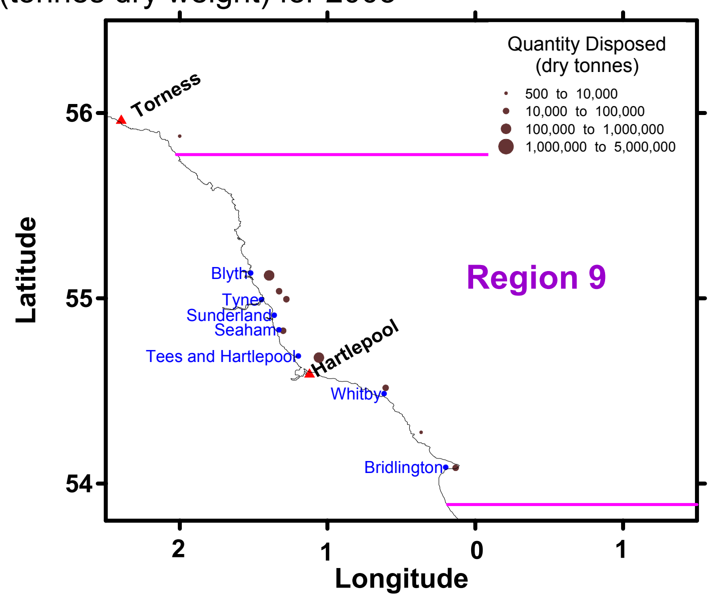
The activities of artificial radionuclides were low (<18 Bq/kg dry weight ^{137}Cs and < 11 Bq/kg dry weight ^{241}Am). The activities of natural series radionuclides were similar to the average 'background' activity on mud (Figs. 3a-3c).

The derived total dose to individual members of the crew and public was ~5 μSv/a and ~1 μSv/a respectively (Fig. 27b). The proportion of the dose to crew resulting from contamination by artificial radionuclides was minor (<5 %). Collective doses to crew and public were ~1 x 10^{-3} and 3 x 10^{-3} man Sv/a, respectively. All the derived dose values were less than the *de minimis* criteria (of the order of 10 μSv/a and 1 manSv/a for individual and collective dose, respectively).

5.9 Region 9 (North-East England)

Region 9 comprises the coastline of North-East England. A map of selected ports, dredge disposal sites and nuclear establishments is provided in Fig. 28.

Figure 28 - Location map for Region 9. Legend indicates amounts of dredged material deposited (tonnes dry weight) for 2003



This region contains large disposal sites located off the Tyne and Tees estuary. In 2003, the greatest amount of dredging was carried out at Middlesborough and Hartlepool resulting in the disposal of ~0.64 Million Tonnes dredged material (dry weight) at sites Tees Bay A and C (TY150 and TY160). A slightly greater quantity was disposed here in 2002 (~0.86 Million Tonnes). The River Tees is one of the largest rivers of north-east England and flows through the heavily industrialized conurbation of Teesside, comprising the towns of Stockton-on-Tees, Billingham and Middlesbrough. From Middlesbrough's Newport Bridge to the river mouth, a distance of approximately 15 km, the estuary is almost entirely flanked by port facilities and industrial sites, including one of the largest chemical and petrochemical complexes outside the USA.

The tidal currents in this region flood southwards and ebb northwards. North of the Farne Islands, the nearshore maximum tidal current speed during mean spring tides is 0.5 m/s (approximately equivalent to 1 knot), increasing to about 0.7 m/s in Tees Bay. The tidal current flow offshore runs more or less north to south, but closer to the shore the flow is affected by the form of the coast. For example, tidal currents are stronger around headlands such as Flamborough Head (up to 1.5 m/s), and eddies or gyres may form within embayments such as Druridge Bay and Hartlepool Bay.

The only nuclear establishment in this region is the power station at Hartlepool with two Advanced Gas Cooled Reactors (AGRs). Monitoring around this establishment indicates the specific activities of artificial radionuclides in sediment are low. The presence of the most significant artificial radionuclide (radiocaesium) has been attributed to long range transport of historic disposals from Sellafield and weapon test fallout (Environment Agency et al., 2004). Therefore, the impact of discharges from the Hartlepool power station appears to be minor. There are, however, indications that levels of natural series radionuclides in some locations of the Tees estuary are enhanced, possibly due to historic discharges of slag from local steel works. Detailed data typical of fine grained dredged material in this area via routine radiological monitoring programmes is largely lacking. However, a limited amount of information for the Tees estuary is available from a single survey in the late 1980s (McDonald et al., 1991) and from a study involving the use of ^{210}Pb as a geochronological tracer to assess historical contaminant fluxes (Plater et al., 1999).

The dredgers mentioned in licence applications for use at Middlesborough/Hartlepool in 2003 are listed in Table 29.

Table 29 - List of dredgers mentioned in FEPA II licence applications in 2003 for Region 9.

Vessel	Owner	Hopper Capacity (m^3)	Length (m)
Cleveland County	Tees & Hartlepool Port Authority Ltd.	1500	
Heortnesse	Tees & Hartlepool Port Authority Ltd.	1500	78
Seal Sands	Tees & Hartlepool Port Authority Ltd.	500	48
Amazone	Baggerbedrijf De Boer	2680	79
Lesse	Baggerbedrijf De Boer	1538	77
Hedwin	Port of Tyne Authority	500	
UKD Bluefin	UK Dredging	3900	98
UKD Marlin	UK Dredging	2692	85

The dredgers used in operations at Hartlepool have hopper capacities in the range 500-1500 m^3 and are therefore of similar magnitude to that assumed in the IAEA model (1000 m^3). Dredgers with slightly greater capacities have been listed for in

FEPA licence applications at Blyth and Newcastle. The largest vessel was the UKD Bluefin with a hopper capacity of 3900 m^3. Assuming the hopper dimensions are ~88 m, ~9 m and ~4.5 m for length, breadth and depth, respectively, the surface area is ~792 m^2, compared with 336 m^2 assumed in the IAEA model. The data in Fig. 7a indicate this change would result in an increase in external dose by a factor of 1.3. This change is counteracted by the fact crew members spend a significant portion of their time in the accommodation blocks situated some 5-6 m distant from the hopper instead of ~ 1 m as assumed in the IAEA model, resulting in an ~ 3 fold decrease in the external dose. The overall effect is that the external dose coefficients ($DF_{ship}(j)$) are reduced to ~45 % of the default values.

Information concerning dispersion, shoreline occupancy and fish/shellfish catches and consumption close to Hartlepool is provided in Simmonds et al. (1995) and Environment Agency et al. (2004). Parameter values used in place of those in the generic IAEA model are listed in Table 30.

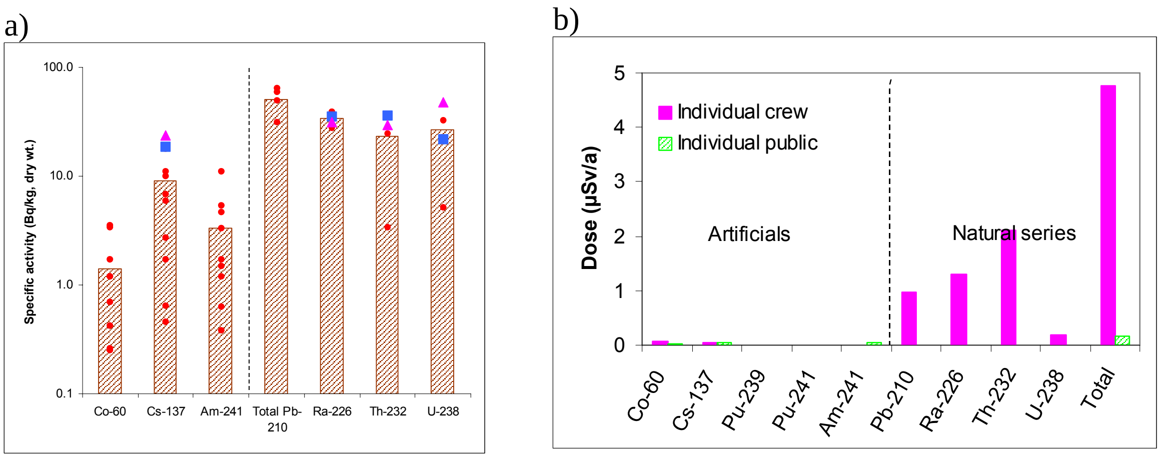
Table 30 - Changes to default parameters given in IAEA-TECDOC-1375, to derive assessment for Region 9. Values for F, S, D, N_B(fish), N_B(crustacea) and N_B(molluscs) are those for Hartlepool in Table 4.5 (Simmonds et al., 1995). Fish/shellfish consumption data from RIFE-9 report (Environment Agency et al., 2004). Mass of candidate material (M) derived from the combined FEPA II licensing applications for the Tees Bay A and C disposal sites (TY150 and TY160) in 2003.

Parameter	Symbol	Region 9 value	IAEA-TECDOC-1375 value
Dose to individual crew			
Occupancy (External exposure) (h/a)	$t_{crew, ext}$	2000	1000
Dose coefficient for external irradiation onboard ship	$DF_{ship}(j)$	45 % TECDOC values(1)	
Collective dose to crew			
Number of ships for one disposal site	N_{ship}	3	1
Dose to individual members of the public			
Flux of water through coastal region (m^3/a)	F	4.0×10^9	4.0×10^{10}
Box Volume (m^3)	V	2.0×10^8	2.0×10^9
Mass of candidate material (kg/a)	M	6.4×10^8	1.0×10^8
Suspended sediment concentration (kg/m^3)	S	2.0×10^{-1}	3.0×10^{-3}
Depth water column (m)	D	10	20
Ingestion rate of fish (kg/a)	H_B (fish)	32	50
Ingestion rate of crustacea (kg/a)	H_B (crustacea)	15	7.5
Ingestion rate of molluscs (kg/a)	H_B (molluscs)	12	7.5
Collective dose to the public			
Annual fish catch in the area of a single site (kg/a)	N_B(fish)	2.3×10^3	5.0×10^5
Annual crustacea catch in the area of a single site (kg/a)	N_B(crustacea)	6.6×10^4	1.0×10^5
Annual mollusc catch in the area of a single site (kg/a)	N_B(molluscs)	1.6×10^4	1.0×10^5

(1) Variable between individual radionuclides (j)

Dose assessments based on radionuclide data in the vicinity of Hartlepool, together with the combined quantities dumped at the Tees Bay A and C sites (TY150 and TY160), are likely to represent a worse case scenario for Region 9. The dose estimates are shown in Fig. 29b.

Figure 29 - Generic assessment of dose to individual members of crew and the public arising from dredging in Region 9. a) Specific activities of selected radionuclides on individual sediment samples. Dots represent results from RIFE monitoring programme, or literature data. Squares and triangles are measurements of composite dredge samples from the Tyne and Tees, respectively. Bars indicate average values for artificial radionuclides and average ‘background’ activity for natural series nuclides (Fig. 3a), b) Dose estimates for individual radionuclides. Doses were derived using activities denoted by bars in Fig. 29a.



Inspection of the data in Fig. 29a indicates that the activities of artificial radionuclides were low (< 24 Bq/kg dry weight ^{137}Cs and < 11 Bq/kg dry weight ^{241}Am). Data in Plater et al. (1999), for cores collected in the Tees estuary, were used to estimate ^{210}Pb activities. These data show the presence of ‘excess’ ^{210}Pb activity in surface sediments

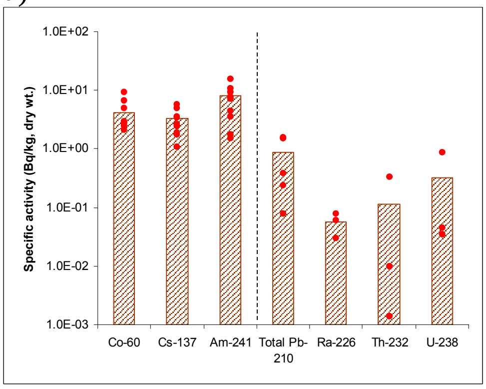
The derived total dose to individual members of the crew and public was ~5 µSv/a and ~0.2 µSv/a respectively (Fig. 29b). The proportion of the dose to crew resulting from contamination by artificial radionuclides was minor (<5 %). Collective doses to crew and public were ~1 x 10^{-3} and 5 x 10^{-4} man Sv/a, respectively. All the derived dose values were less than the *de minimis* criteria (of the order of 10 µSv/a and 1 manSv/a for individual and collective dose, respectively).

5.10 Disposal of fish wastes

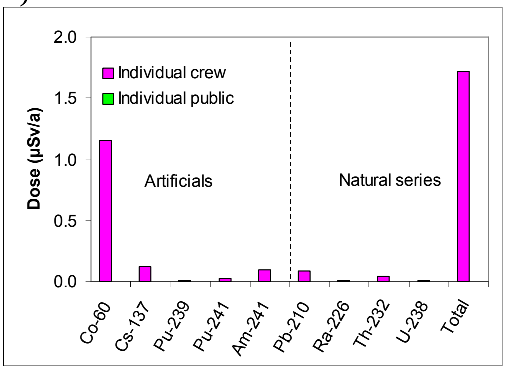
The UK has licensed small quantities of fish waste for disposal at sea since 1996. This activity is largely restricted to the disposal of shell waste to IS015 (New Quay Bay) from the Quay Fresh & Frozen Foods Ltd. shellfish processing plant at New Quay, Dyfed, Wales. The quantities disposed of are small (<0.002 Million Tonnes per annum, CEFAS, 2005a) and do not involve the use of a ship. As a worst case scenario, it was assumed that all the shellfish was obtained from the Sellafield coastal area and that the activity in the shell waste was similar to that in the edible fraction. It is considered likely that, for most radionuclides, the latter assumption would provide a conservative estimate of the concentrations in the shell material, albeit that shellfish could conceivably adapt to metal contaminated sediments by deposition in the shell. Dose estimates were derived using the same dose coefficients appropriate to Region 3 (that encompasses the New Quay Site) and are shown in Fig. 30b. Estimates for crew are provided, in the event that a vessel should be required for future waste disposal throughout the year.

Figure 30 - Assessment of dose to individual members of a (hypothetical) crew and the public arising from the disposal of fish waste. a) Specific activities of selected radionuclides in shellfish. Bars indicate average values, b) Dose estimates for individual radionuclides. Doses were derived using average

a)



b)



Inspection of the data in Fig. 30a indicates that the activities of artificial radionuclides were low (< 4 Bq/kg wet weight ^{60}Co/^{137}Cs and < 8 Bq/kg wet weight ^{241}Am). The activities of natural series radionuclides, used for the dose assessment to crew, were the average 'background' values in shellfish (Environment Agency et al., 2004).

The derived total dose to individual members of the crew and public was ~1.7 µSv/a and <0.1 µSv/a respectively (Fig. 30b). Collective doses to crew and public were ~2 x 10^{-5} and 2 x 10^{-5} man Sv/a, respectively. All the derived dose values were less than the *de minimis* criteria (of the order of 10 µSv/a and 1 manSv/a for individual and collective dose, respectively) even allowing for the conservative assumptions made in the assessment.

6. RECOMMENDATIONS IF PREDICTED DOSES EXCEED SCREENING CRITERIA

None of the doses predicted here, either from the case studies or generic regional assessments, exceeded the *de minimis* criteria. Our experience here indicates that predicted doses to individual crew were closer to the *de minimis* criteria than doses to individual members of the public, or collective dose. In the event that the predicted dose to individual crew for a future operation did exceed the *de minimis* criteria, we recommend a staged approach. In the first instance it may be helpful to attempt to characterise the sources, exposure pathways, and receptors in a more realistic way, as undertaken in the 2004 Whitehaven case study, as the conservative nature of the screening methodology proved unduly pessimistic. If predicted doses remain above the *de minimis* criteria the possibility of restricting the crew exposure time should be considered, assuming that all other considerations enable the operation to be licensed. Once the operation has commenced, it may also be useful to make measurements of external dose rates/dust loading on board ship, to compare with assumed values used in the original dose assessments and further revise exposure times accordingly.

7. SUMMARY

The London Convention 1972 prohibits the disposal of radioactive material at sea unless the candidate material can be shown to contain *de minimis* levels of radioactivity (i.e. the effective dose expected to be incurred by any member of the public or ships crew is of the order of 10 μSv or less in a year and the collective effective dose to the public or ships crew is not more than 1 man Sv per annum).

Many of the ports in England and Wales, that Defra licenses to dispose of dredged material, can be affected by the authorised discharge of low level radioactive wastes from nuclear establishments around the coastline of the UK. Consequently, radiological assessments are sometimes required before licences are issued.

In the present study, generic regional radiological assessments of maintenance dredging operations were carried out to allow managers to reach an early decision of whether the provisions of the London Convention 1972 are likely to be fulfilled, without the need of specific individual assessments. The coastline around England & Wales was divided into nine separate regions, based on the previous Sea Fisheries Inspectorate (SFI, now the Marine Fisheries Agency or MFA) districts. Dose calculations were carried out by following the radiological assessment guidelines issued by the IAEA, in 2003, to provide conservative estimates.

The greatest radioactive contamination occurs at the small ports along the Cumbrian coastline (Region 1), to the north of the BNF Sellafield reprocessing plant. A case study of a recent operation at Whitehaven, the most affected port, indicated that the predicted dose to crew (~8 μSv) was close to 10 μSv. Results from subsequent field measurements indicated the actual dose could conceivably have slightly been slightly greater, albeit that this was probably not the case given the conservative approach to dose estimates in the IAEA model. It is recommended that specific individual assessments continue for all Cumbrian ports.

Information concerning radionuclide activity in sediments from our major ports is sparse and the gaps have only been partially filled by the work reported here.

Application of the available data indicated that, the *de minimis* criteria were met in the eight regions outside the northern Irish Sea (Table 31/Fig. 31).

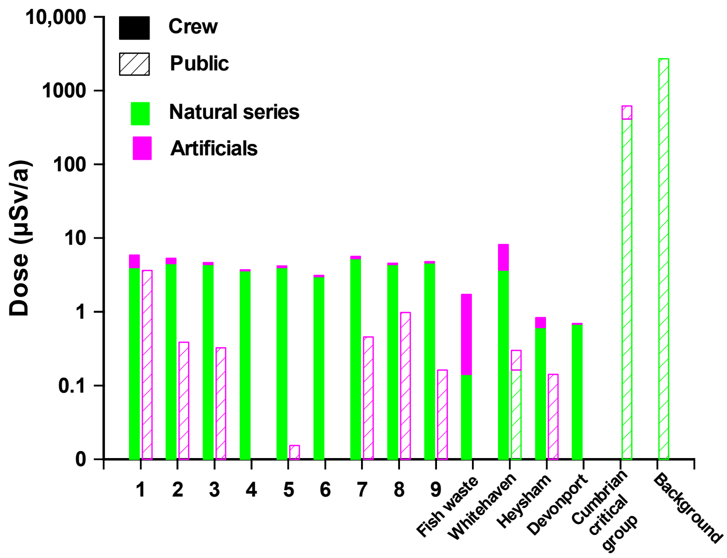
Table 31 – Summary of case studies and generic dose assessments to members of crew and public arising from dredging around the coastline of England and Wales. Dose to crew includes contribution from natural series uranium and thorium radionuclides present in all marine sediment.

Region	**Individual dose (µSv/a)**		**Collective dose (manSv/a)**	
	Crew	**Public**	**Crew**	**Public**
1 (North-Eastern Irish Sea)[(1)]	5.9	3.6	2×10^{-3}	6×10^{-2}
2 (South-Eastern Irish Sea)	5.3	0.4	2×10^{-3}	2×10^{-3}
3 (West England and Wales)	4.6	0.3	1×10^{-3}	1×10^{-3}
4 (South-West England)	3.7	<0.1	4×10^{-4}	4×10^{-5}
5 (Southern England)	4.2	<0.1	1×10^{-3}	6×10^{-5}
6 (South-East England)	3.1	<0.1	9×10^{-4}	1×10^{-5}
7 (Eastern England)	5.6	0.5	2×10^{-3}	4×10^{-3}
8 (Humber)	4.5	1.0	1×10^{-3}	3×10^{-3}
9 (North-East England)	4.8	0.2	1×10^{-3}	5×10^{-4}
Fish Waste	1.7	<0.1	2×10^{-5}	2×10^{-5}
Whitehaven (2004) [(2)]	8.2	0.3		
Heysham (2002) [(2)]	0.8	0.2		
Devonport (2000) [(2)]	0.7	<0.1		

(1) Assessments for Region 1 excludes small ports to the north of Whitehaven for which further data are required to provide robust dose estimates.

(2) Dose values are for individual operations, as opposed to annual doses for regional assessments.

Figure 31 – Summary of individual dose predictions to members of crew and public arising from dredging around the coastline of England and Wales. Data for dose to high rate consumers of fish and shellfish in Cumbria (Environment Agency et al., 2004) and average background dose rate to the UK population (Watson et al, 2005) are included for comparison.



The data in Fig. 31 indicate that although the estimated dose to individual crew in all regions was a significant fraction of the *de minimis* criteria (~30-60 %), the large majority (excepting Region 1) was due to the presence of naturally occurring uranium and thorium series nuclides that are present in all marine sediment. The dose estimates reported here are placed in perspective (i.e. very low), given that i) the average background dose to the UK population is ~2700 µSv/a and ii) the dose to the critical group of high rate consumers of fish and shellfish in Cumbria in 2003 was ~620 µSv/a. It is, nevertheless, recommended that the existing approach of appropriate measurements of radionuclide sediment activity continue for ports outside the Irish Sea, concomitant with measurements of other contaminants. This will help build a more robust database for any revised assessments that may be required to meet future demand.

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