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Review of local compartment parameter values for use with UK sites in the DORIS marine dispersion model

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Review of local compartment parameter values for use with UK sites in the DORIS marine dispersion model

J G Smith

Abstract

An internal review of the Environment Agency report ‘Parameter values used in coastal dispersion modelling for radiological assessments Report: SC060080/R3’ (Dewar et al, 2011) has highlighted some large differences between the parameter values used in the marine dispersion model, DORIS, included in PC-CREAM 08 (Smith and Simmonds, 2009) and those given in the EA report to define the local compartment. This report considers the reasons for the differences and makes recommendations on the most appropriate parameter values to use in DORIS.

The implications of the recommendations made for radiological impact assessments are addressed by comparing model predictions using proposed local compartment parameter values with those based on current DORIS parameter values and, where possible, with environmental measurements.

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1 Introduction

An internal review of the Environment Agency report 'Parameter values used in coastal dispersion modelling for radiological assessments Report: SC060080/R3' (Dewar et al, 2011) has highlighted some large differences between the parameter values used in the marine dispersion model, DORIS, included in PC-CREAM 08 (Smith and Simmonds, 2009) and those given in the EA report to define the local compartment. This report considers the reasons for the differences and makes recommendations on the most appropriate parameter values to use in DORIS.

Section 2 of this report reviews local compartment parameter values for all sites excluding Sellafield. Parameter values for the Sellafield site are considered in Section 3 because of the particular significance of this site. Sections 2 and 3 are divided into 3 subsections. In both cases, the first subsection considers the local compartment dimensions and flows and makes recommendations on the parameter values to use in DORIS. The second subsection deals with suspended sediment loads and sedimentation rates and again makes recommendations on the values to use. Finally, the third subsection considers the implications of the recommendations made for radiological impact assessments by comparing model predictions using proposed local compartment parameter values with those based on current DORIS parameter values. In addition, for Sellafield, environmental activity concentrations predicted by the DORIS model using historical discharges are compared with measurements using the extensive monitoring datasets available for this site. Individual doses calculated by PC-CREAM 08 have also been compared to doses based on environmental measurements. Section 4 is a summary of recommendations and conclusions.

1.1 Summary of EA report SC060080/R3

The dispersion of radionuclides discharged into UK coastal waters can be modelled using DORIS. In DORIS different sea regions are represented by compartments or boxes and the dispersion of radionuclides between the regions is modelled using transfer factors between the compartments. The region which receives the discharge is represented by a local compartment. The EA report SC060080/R3 (Dewar et al, 2011) presents detailed measurements of parameters that are relevant to the local compartments included in the DORIS model for a number of locations around the UK coast where discharges of radioactive material may occur. The data include compartment dimensions, volumetric exchange rates, sedimentation rates and suspended sediment loads.

The data from the EA report need to be considered carefully to ensure that they are appropriate for updating the current DORIS default values. The main issues include whether measurements were taken at an appropriate location, the size of the regions considered (the EA data sometimes cover small bays which may be too small to represent the local compartment) and robustness of the data (the EA report identifies some data as being extremely uncertain).

2. Parameter values for all sites other than Sellafield

2.1 Local compartment dimensions and flows

2.1.1 Review of data

The data currently used in DORIS to define the local marine compartments are based on the classification detailed in Appendix A of the report NRPB-R119 (Camplin et al, 1982). That report categorises typical coastal environments where discharges might occur into 3 types: estuarine, exposed coastal and sheltered coastal and provides generic values for the local compartments. In addition to these environment types some site specific local compartments were defined but the origin of the data used is unknown. For example, the local compartment for the nuclear facilities at Winfrith and Wylfa were categorised as exposed coastal in NRPB-R119 (Camplin et al, 1982) but with lower exchange rates between the local and regional compartments than the default values given in the report. For Heysham, Sizewell and Dounreay changes to the local compartments were introduced in the methodology described in (Smith and Simmonds, 2009) but again the source of the later data used is unclear. The environment types allocated to nuclear sites in the UK are listed in Table 1 along with the corresponding local compartment parameter values currently used in DORIS.

Table 2 lists values taken from the EA report (Dewar et al, 2011) for the same DORIS parameters as those considered in Table 1. For some nuclear sites the EA report presents data for a number of regions which could potentially represent the local compartment. For these sites the values in Table 2 have been selected on the basis that they are the most appropriate ones to use. For example, for sites discharging into the River Thames values for the ‘Thames outer estuary’ region listed in the EA report were used because this is considered to be the most likely region capable of supporting the dietary habits of the representative person.

Table 1 Current DORIS defaults for local marine compartments (Smith and Simmonds, 2009)

Site	Type	Depth (m)	Volume (m^3)	Volumetric exchange rate ($m^3\ y^{-1}$)	Coastline length (m)	Dilution factor (Bq m^{-3} per Bq d^{-1})	Residual flow (m s^{-1})
Aldermaston	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Amersham	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Barrow	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Berkeley	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Bradwell	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Capenhurst	Exposed coastal	$2.0\ 10^{1}$	$2.0\ 10^{9}$	$8.0\ 10^{10}$	$1.0\ 10^{4}$	$4.6\ 10^{-9}$	$1.3\ 10^{-2}$
Cardiff	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Chapelcross	Sheltered coastal	$2.0\ 10^{1}$	$5.0\ 10^{9}$	$1.0\ 10^{11}$	$3.0\ 10^{4}$	$3.7\ 10^{-9}$	$1.9\ 10^{-2}$
Devonport	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Dounreay	Site specific	$4.0\ 10^{1}$	$3.2\ 10^{9}$	$1.6\ 10^{11}$	$3.2\ 10^{4}$	$2.3\ 10^{-9}$	$5.1\ 10^{-2}$
Dungeness	Exposed coastal	$2.0\ 10^{1}$	$2.0\ 10^{9}$	$8.0\ 10^{10}$	$1.0\ 10^{4}$	$4.6\ 10^{-9}$	$1.3\ 10^{-2}$
Hartlepool	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Harwell	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Heysham	Site specific	$1.0\ 10^{1}$	$1.0\ 10^{8}$	$8.0\ 10^{9}$	$1.0\ 10^{4}$	$4.6\ 10^{-8}$	$2.5\ 10^{-2}$
Hinkley Point	Sheltered coastal	$2.0\ 10^{1}$	$5.0\ 10^{9}$	$1.0\ 10^{11}$	$3.0\ 10^{4}$	$3.7\ 10^{-9}$	$1.9\ 10^{-2}$
Hunterston	Sheltered coastal	$2.0\ 10^{1}$	$5.0\ 10^{9}$	$1.0\ 10^{11}$	$3.0\ 10^{4}$	$3.7\ 10^{-9}$	$1.9\ 10^{-2}$
Oldbury	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Sizewell	Site specific	$1.0\ 10^{1}$	$3.0\ 10^{8}$	$1.1\ 10^{10}$	$1.0\ 10^{4}$	$3.3\ 10^{-8}$	$1.2\ 10^{-2}$
Springfields	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Torness	Exposed coastal	$2.0\ 10^{1}$	$2.0\ 10^{9}$	$8.0\ 10^{10}$	$1.0\ 10^{4}$	$4.6\ 10^{-9}$	$1.3\ 10^{-2}$
Trawsfynydd	Estuary	$1.0\ 10^{1}$	$2.0\ 10^{8}$	$4.0\ 10^{9}$	$1.0\ 10^{4}$	$9.1\ 10^{-8}$	$6.3\ 10^{-3}$
Winfrith	Site specific	$2.0\ 10^{1}$	$2.0\ 10^{9}$	$4.0\ 10^{10}$	$1.0\ 10^{4}$	$9.1\ 10^{-9}$	$6.3\ 10^{-3}$
Wylfa	Site specific	$2.0\ 10^{1}$	$2.0\ 10^{9}$	$4.0\ 10^{10}$	$1.0\ 10^{4}$	$9.1\ 10^{-9}$	$6.3\ 10^{-3}$

Table 2 EA data for local marine compartments (Dewar et al, 2011)

Site	EA candidate location	Depth (m)	Volume (m^3)	Volumetric exchange rate (m^3 y^{-1})	Coastline length (m)*	Dilution factor (Bq m^{-3} per Bq d^{-1})	Residual flow (m s^{-1})
Aldermaston	Thames estuary (outer)	8.7 10^0	6.6 10^8	2.6 10^{10}	2.5 10^4	1.4 10^{-8}	1.1 10^{-2}
Amersham	Thames estuary (outer)	8.7 10^0	6.6 10^8	2.6 10^{10}	2.5 10^4	1.4 10^{-8}	1.1 10^{-2}
Barrow	Walney channel/Barrow harbour	1.3 10^0	1.5 10^7	5.4 10^9	6.0 10^3	6.8 10^{-8}	3.9 10^{-2}
Berkeley	Severn estuary (inner)	4.0 10^0	1.3 10^8	1.8 10^{10}	2.4 10^4	2.0 10^{-8}	2.5 10^{-2}
Bradwell	Blackwater estuary	4.0 10^0	1.0 10^8	7.3 10^9	1.4 10^4	5.0 10^{-8}	1.2 10^{-2}
Capenhurst	Mersey estuary (outer)	8.0 10^0	3.3 10^8	2.0 10^{10}	1.8 10^4	1.8 10^{-8}	1.2 10^{-2}
Cardiff	Cardiff bay	7.0 10^0	1.9 10^8	1.7 10^{10}	1.5 10^4	2.2 10^{-8}	1.5 10^{-2}
Chapelcross	Solway Firth (inner)	3.6 10^0	7.0 10^8	7.4 10^{10}	3.4 10^4	5.0 10^{-9}	4.6 10^{-2}
Devonport	Tamar estuary	1.0 10^1	5.0 10^7	1.3 10^9	6.0 10^3	2.9 10^{-7}	1.8 10^{-3}
Dounreay#	-						
Dungeness	Dungeness coast	2.5 10^1	2.5 10^9	3.8 10^{10}	1.0 10^4	9.7 10^{-9}	4.8 10^{-3}
Hartlepool	Tees estuary	4.4 10^0	2.8 10^7	1.6 10^9	1.2 10^4	2.3 10^{-7}	4.6 10^{-3}
Harwell	Thames estuary (outer)	8.7 10^0	6.6 10^8	2.6 10^{10}	2.5 10^4	1.4 10^{-8}	1.1 10^{-2}
Heysham	Morecambe bay	4.6 10^0	8.2 10^8	8.2 10^{10}	4.0 10^4	4.5 10^{-9}	4.2 10^{-2}
Hinkley Point	Parrett estuary	2.4 10^0	5.8 10^6	1.5 10^9	1.0 10^4	2.5 10^{-7}	1.2 10^{-2}
Hunterston#	-						
Oldbury	Severn estuary (inner)	4.0 10^0	1.3 10^8	1.8 10^{10}	2.4 10^4	2.0 10^{-8}	2.5 10^{-2}
Sizewell	Aldeburgh coast	2.0 10^1	2.0 10^9	1.4 10^{10}	1.0 10^4	2.7 10^{-8}	2.2 10^{-3}
Springfields	Ribble estuary (outer)	-	1.1 10^8	1.4 10^{10}	1.3 10^4	2.6 10^{-8}	-
Torness#	-						
Trawsfynydd	Tremadog bay	8.6 10^0	1.5 10^9	3.8 10^{10}	4.0 10^4	9.7 10^{-9}	1.1 10^{-2}
Winfrith	Weymouth bay	6.0 10^0	5.1 10^7	8.2 10^8	8.0 10^3	4.5 10^{-7}	1.5 10^{-3}
Wylfa	Cemaes coast	2.7 10^1	2.7 10^9	3.2 10^{10}	1.0 10^4	1.2 10^{-8}	3.7 10^{-3}

* The coastline length in general relates to the linear distance from one end of the compartment to the other. However for bays and harbours it represents the total length of coastline in the compartment. For estuaries the total coastline length is double that presented here.

Not included in EA Report (Dewar et al, 2011)

The data in Tables 1 and 2 were reviewed to determine whether DORIS parameter values should be updated for future versions of PC-CREAM 08. The criteria used in this review were:

- **a** ensure that data from the EA report represent a suitable location for each discharging site;
- **b** check that EA data were appropriate for DORIS parameters;
- **c** review sources of EA data and their robustness;
- **d** estimate dilution factors and residual velocities and compare them with measurements;
- **e** compare EA data with current DORIS default values and measurements.

These considerations were applied to each discharging site in PC-CREAM 08. The decisions made and their justifications are described in Sections 2.1 and 3.1, and the recommended parameter values are presented in Tables 3 and 37. Where data from the EA report were not suitable and existing DORIS data were difficult to justify, for example due to the absence of a suitable reference, new generic data have been developed. These locations include sites discharging into sheltered or exposed coastal regions. For these sites a standard surface area of 1 10^8 m^2 was assumed and information from Appendix A of (Camplin et al, 1982) was used (Table 3) to derive, for sheltered and exposed sites respectively, the volumes of the local compartment (1 10^9 m^3 and 2 10^9 m^3) and number of exchanges per year (20 y^{-1} and 40 y^{-1}).

One of the key parameters that determine the environmental activity concentrations is the volumetric exchange rate (m^3 y^{-1}). This is referred to as VER in this report and is defined as the net volume of water transferred between the local and regional compartments in unit time. To ensure that the mass of water is conserved in each compartment the net volume of water transferred from the local to the regional compartment must be balanced by an equal volume of water being transferred from the regional to the local compartment. If the volume of water exchanged over the period of interest is significantly greater than the volume of the local compartment, which is the case for all locations considered here, then a dilution factor can be calculated based solely on the VER. Doses calculated in PC-CREAM 08 are based on annual exposures and consequently environmental activity concentrations averaged over the period of one year are used in the dose calculations. The dilution factor for the local compartment is the steady state concentration in unfiltered sea water per unit release rate of a given pollutant. If loss processes such as radioactive decay and adsorption are ignored then a dilution factor can be estimated as the reciprocal of the VER. Multiplying the dilution factor by the release rate will give an estimate of the activity concentration in seawater. Dilution factors have been calculated for VERs currently used in DORIS, those suggested by EA and those proposed for future use in DORIS (Tables 1 to 3). Dilution factors are presented in units of Bq m^{-3} per Bq d^{-1} for comparison with the literature.

The VERs taken from the EA report are net volumetric exchange rates and were derived by considering the volume of water exchanged between the local and regional compartments during a full tidal cycle (such as, from one high tide to another). However, assumptions were also made about the proportion of exchanged water that is recycled from tide to tide, for instance the volume of water expelled from a compartment on an ebb tide that is returned to the same compartment on the flood tide. For all the sites considered in Table 2 it was assumed that 90% of the exchange volume is returned to the local compartment during a tide cycle. In this way a net exchange rate is calculated and this is presented here for comparison with the DORIS volumetric exchange rates.

In addition, some useful data are available from the MAFF Fisheries Research Data Report No 34 (Baxter and Camplin, 1993), which presents dilution factors (Bq l^{-1} per TBq d^{-1}) for discharges of ^{137}Cs from a number of UK nuclear sites. These dilution factors are site specific and based on measurements made at various sampling points, although some of these are at a considerable distance from the discharge point. Nevertheless, they give an indication of the value of dilution factors for each site and have been taken into consideration when deriving new data for DORIS (Sections 2.1.2.1 to 2.1.2.18).

Another parameter that has been calculated as input to this review is the residual flow. This is an estimate of the net current speed (m s^{-1}) through the local compartment. The values of the residual flows presented in Tables 1 to 3 should only be considered as indicative because they are based on simplifying assumptions that do not take account of the multiple directions of flow of residual currents that occur in real conditions. As a general guide such flows lie between 0.01 and 0.05 m s^{-1} around the UK coast (Aldridge, 2006; Round, 1998). Default residual flows for the current version of DORIS are generally at the lower end of this range with notable exceptions being Dounreay at 5.1 10^{-2} m s^{-1} and Sellafield at 1.6 10^{-1} m s^{-1}. Residual velocities based on the EA data are more variable but generally consistent with this range although some low values were also included (for example, for Tamar estuary and Aldeburgh coast).

2.1.2 Recommendations

2.1.2.1 Aldermaston, Amersham and Harwell

In PC-CREAM 08 it is assumed that radioactive material from these 3 sites is discharged into the River Thames. A local compartment for DORIS needs to be defined to calculate individual doses from subsequent discharges into the marine environment. The EA report (Dewar et al, 2011) includes data for 3 distinct parts of the Thames Estuary but the outer region is considered to be the most appropriate in terms of its ability to support the habits of the representative person for the marine environment. The volume of the compartment and the volumetric exchange rate given in the EA report are larger than the default values used in DORIS. Consequently, the dilution factor in the EA report is 6-times smaller (such as 1.4 10^{-8} Bq m^{-3} per Bq d^{-1} compared to 9.1 10^{-8} Bq m^{-3} per Bq d^{-1}). The EA data are based on measurements and are recommended for all sites included in DORIS discharging to the Thames Estuary.

2.1.2.2 Barrow

A nuclear licence site operates at Barrow-in-Furness primarily for the building, testing and commissioning of nuclear submarines. The EA report (Dewar et al, 2011) makes the assumption that discharges from Barrow occur into Walney Channel and Barrow Harbour. This is a relatively small region (1.5 10^{7} m^{3}) and the assumption that it can support the habits of the representative person is considered cautious, meaning it would lead to an over estimate of the dose. The volumetric exchange rate between local and regional compartments is correspondingly low (5.4 10^{9} m^{3} y^{-1}) and gives rise to a dilution factor of 6.8 10^{-8} Bq m^{-3} per Bq d^{-1}. This value is similar to that calculated using the current DORIS default data ($9.1\ 10^{-8}$ Bq m^{-3} per Bq d^{-1}), which is representative of general estuarine conditions. The recommendation is to use the EA data for discharges in this region but because of the small size of the local compartment it may be necessary to assume that a larger proportion of locally caught seafood is derived from the regional compartment. When assessing doses, local habits surveys should be reviewed to inform this decision.

2.1.2.3 Berkeley and Oldbury

These 2 nuclear power stations are in the process of being decommissioned. They are both located on the Severn Estuary within the region defined as the inner Severn Estuary in the EA report (Dewar et al, 2011). The volume of this region in the EA report is given as $1.3\ 10^{8}$ m^{3} and the VER is $1.8\ 10^{10}$ m^{3} y^{-1}. The dilution factor is estimated to be $2.0\ 10^{-8}$ Bq m^{-3} per Bq d^{-1} which is less than the value of $9.1\ 10^{8}$ Bq m^{-3} per Bq d^{-1} calculated from the current DORIS default data but which compares well with the measured value of about $2\ 10^{-8}$ Bq m^{-3} per Bq d^{-1} given in the MAFF Report No 34 (Baxter and Camplin, 1993). The DORIS data are based on generic estuarine conditions which were derived for Bradwell and the Blackwater Estuary (Camplin et al, 1982). Because the Severn Estuary has a much higher tidal range the data from the EA report are considered more appropriate and recommended for these sites.

2.1.2.4 Bradwell

The partially decommissioned nuclear power station at Bradwell discharges into the Blackwater Estuary. The current default data in DORIS that describe the local compartment for this region are based on the generic estuarine conditions defined in (Camplin et al, 1982), meaning a volume of $2\ 10^{8}$ m^{3} and a VER of $4\ 10^{9}$ m^{3} y^{-1}. The estimated dilution factor is therefore $9.1\ 10^{-8}$ Bq m^{-3} per Bq d^{-1}. The EA report (Dewar et al, 2011)(Dewar et al, 2011)(Dewar et al, 2011) looked at this region in some detail and suggested the use of a volume of $1\ 10^{8}$ m^{3} and a VER of $7.25\ 10^{9}$ m^{3} y^{-1}. The latter corresponds to a dilution factor of about $5.0\ 10^{-8}$ Bq m^{-3} per Bq d^{-1}. This is consistent with the current DORIS default value and also with the value in the MAFF Report No 34 (Baxter and Camplin, 1993) of about $7\ 10^{-8}$ Bq m^{-3} per Bq d^{-1}. It is recommended that the EA data be used for this site.

2.1.2.5 Capenhurst

The current default data used in DORIS for this site are based on the generic exposed coastal region as defined in (Camplin et al, 1982). However, since discharges from this site are into the Mersey River via Rivacre Brook, it is recommended that the data for the outer Mersey estuary from the EA report (Dewar et al, 2011) be used. The volume of the local compartment given in that report is $3.3\ 10^{8}$ m^{3} and the VER is $2.0\ 10^{10}$ m^{3} y^{-1}. The estimated dilution factor would therefore be $1.8\ 10^{-8}$ Bq m^{-3} per Bq d^{-1}, which is greater than the value of $4.7\ 10^{-9}$ Bq m^{-3} per Bq d^{-1} derived using current DORIS data.

2.1.2.6 Cardiff

For discharges into the Cardiff Bay area the current default data used in DORIS represent generic estuarine conditions: a volume of 2 10^{8} m^{3} and a VER of 4 10^{9} m^{3} y^{-1}. In the EA report (Dewar et al, 2011) the volume of this region is estimated to be 1.9 10^{8} m^{3} but the VER is 1.7 10^{10} m^{3} y^{-1}. The high VER presented in the EA report (Dewar et al, 2011) is consistent with the high tidal range of the Severn Estuary. For this reason, it is recommended that the local compartment for discharges into this region, which does not include Cardiff Basin because this is segregated by the Cardiff Bay Barrage, is defined by the data taken from the EA report for Cardiff Bay. The estimated dilution factor using data from the EA report is 2.2 10^{-8} Bq m^{-3} per Bq d^{-1} which compares with a value of 9.2 10^{-8} Bq m^{-3} per Bq d^{-1} using current DORIS default data. Measurements of dilution factor are not available for this site although a dilution factor of about 2 10^{-8} Bq m^{-3} per Bq d^{-1} is given in the MAFF Report No 34 (Baxter and Camplin, 1993) for Berkeley and Oldbury which discharge into the Severn Estuary.

2.1.2.7 Chapelcross

Discharges from decommissioning activities at Chapelcross enter the Solway Firth and the current DORIS default data for this region are based on the transit time of soluble material from Chapelcross to the mouth of the Solway Firth (Camplin et al, 1982). Using the DORIS data, a dilution factor of 3.7 10^{-9} Bq m^{-3} per Bq d^{-1} can be derived. It is reassuring that a similar dilution factor of 5.0 10^{-9} Bq m^{-3} per Bq d^{-1} can be derived from data in the EA report (Dewar et al, 2011) for the inner reaches of this estuary. Although the volume of the body of water comprising the inner reaches is significantly smaller than the DORIS default it is considered to be large enough to support the habits of the representative person and very much part of the marine environment. It is therefore recommended to use data from the EA report to define the local compartment for this site.

2.1.2.8 Devonport

Discharges from Devonport dockyard occur into the Tamar estuary. The region identified in the EA report (Dewar et al, 2011) for the local compartment is relatively small, with a volume of 5 10^{7} m^{3} and a VER of 1.3 10^{9} m^{3} y^{-1}. Consequently, the dilution factor is relatively high 2.9 10^{-7} Bq m^{-3} per Bq d^{-1} which compares with a value of 9.1 10^{-8} Bq m^{-3} per Bq d^{-1} adopted in DORIS for a generic estuary. Although the region defined in the EA report is small it is recommended that these data be used because they better represent the local conditions. However, because of the small size of the local compartment it may be necessary to assume that a larger proportion of locally caught seafood comes from the regional compartment. Existing local habit surveys should be reviewed by those carrying out dose assessments to inform this decision and if new surveys are conducted then the source of the marine food and occupancies in this region should be investigated carefully.

2.1.2.9 Dounreay

The Dounreay site is located on an exposed stretch of the north coast of Caithness. The EA report (Dewar et al, 2011) does not include data for coastal locations in Scotland and therefore the characteristics of this site are assumed to be consistent with those of a generic exposed coastal site. Measurement data (Baxter and Camplin, 1993) suggest a lower dilution factor for this site compared to others, meaning about 4 10^{-9} Bq m^{-3} per Bq d^{-1}, and this is consistent with the higher residual flow rates typical of this region. The volume of the local compartment used in the current version of DORIS is 3.2 10^{9} m^{3}, while the VER is 1.6 10^{11} m^{3} y^{-1}. The corresponding dilution factor is 2.3 10^{-9} Bq m^{-3} per Bq d^{-1}. However, for consistency with other sites it is recommended that the revised DORIS data for a generic exposed coastal site are used, meaning a volume of 2 10^{9} m^{3} and a VER of 8 10^{10} m^{3} y^{-1}, corresponding to a dilution factor of 4.6 10^{-9} Bq m^{-3} per Bq d^{-1}.

2.1.2.10 Dungeness, Sizewell and Wylfa

For exposed coastal regions like those around the nuclear power plants at Dungeness, Sizewell and Wylfa that are not constrained by land masses the EA report (Dewar et al, 2011) considers a local compartment of standard area 1 10^{4} m by 1 10^{4} m. However, the average sea depths vary as do the exchange rates. For Dungeness, Sizewell and Wylfa the average local compartment depths and volumes are 25 m and 2.5 10^{9} m^{3}, 20 m and 2.0 10^{9} m^{3}, and 27 m and 2.7 10^{9} m^{3}, respectively. The VERs given in the EA report and the corresponding dilution factors for the local compartments at these sites are 3.8 10^{10} m^{3} y^{-1} and 9.7 10^{-9} Bq m^{-3} per Bq d^{-1}, 1.4 10^{10} m^{3} y^{-1} and 2.7 10^{-8} Bq m^{-3} per Bq d-1, and 3.2 10^{10} m^{3} y^{-1} and 1.2 10^{-8} Bq m^{-3} per Bq d^{-1}, respectively. The current dilution factors used in DORIS for these coastal sites are 4.6 10^{-9}, 3.3 10^{-8} and 9.1 10^{-9} Bq m^{-3} per Bq d^{-1}, respectively. The dilution factors for Dungeness and Sizewell in MAFF Report No 34 (Baxter and Camplin, 1993) are about 9 10^{-9} and 3 10^{-8} Bq m^{-3} per Bq d^{-1}, respectively, and are consistent with those derived using the EA data for these 2 sites. It is recommended that the data from the EA report are used for all 3 sites.

2.1.2.11 Hartlepool

The majority of the discharges of radioactive liquid effluent are made to Hartlepool Bay, which is located outside of the Tees Estuary, with a minor component being discharged directly to the River Tees. Therefore, it is not considered appropriate to use the local compartment data provided for the Tees Estuary from the EA report. It is recommended that the DORIS default parameters for a generic sheltered coastal location are used, corresponding to a dilution factor of 1.8 10^{-8} Bq m^{-3} per Bq d^{-1}.

2.1.2.12 Heysham

The nuclear power plant at Heysham discharges into the Irish Sea. Although this site is located near to Morecambe Bay discharges occur outside of the bay and therefore the local compartment should be considered as sheltered coastal. The current DORIS VER for the local compartment is 8 10^{9} m^{3} y^{-1} corresponding to a dilution factor of 4.6 10^{-8} Bq m^{-3} per Bq d^{-1}. This is a site specific value but it is not clear how it was derived. It is also an order of magnitude greater than the dilution factor calculated using the EA data (4.5 10^{-9} Bq m^{-3} per Bq d^{-1}) (Dewar et al, 2011). Given the location of the discharge it is recommended that the revised local compartment parameter values for a sheltered coastal site are used for Heysham, meaning, a volume of 1 10^{9} m^{-3} and a VER of 2 10^{10} m^{3} y^{-1}, which corresponds to a dilution factor of 1.8 10^{-8} Bq m^{-3} per Bq d^{-1}.

2.1.2.13 Hinkley Point

The nuclear power plant at Hinkley Point discharges into the Bristol Channel. Although this site is located near to the Parrett Estuary discharges occur outside of the estuary and therefore the local compartment for this site should be considered as sheltered coastal. The current DORIS VER for the local compartment is 1 10^{11} m^3 y^{-1} corresponding to a dilution factor of 3.7 10^{-9} Bq m^{-3} per Bq d^{-1}. This value is much lower than that calculated if the EA data (Dewar et al, 2011) are used (2.5 10^{-7} Bq m^{-3} per Bq d^{-1}) and also lower than that derived from measurement data (about 3 10^{-8} Bq m^{-3} per Bq d^{-1} (Baxter and Camplin, 1993)). It is not clear how the current DORIS values were derived but the EA data are for the Parrett Estuary. Therefore, for consistency, it is recommended that the revised generic sheltered coastal parameters are used for this site, meaning a volume of 1.0 10^9 m^3 and VER of 2.0 10^{10} m^3 y^{-1}. The corresponding dilution factor is 1.8 10^{-8} Bq m^{-3} per Bq d^{-1}.

2.1.2.14 Hunterston

The nuclear power plant at Hunterston discharges into the Firth of Clyde. The EA report (Dewar et al, 2011) does not include data for coastal locations in Scotland and therefore the characteristics of this site are assumed to be similar to those of other sheltered coastal sites. Measurement data (Baxter and Camplin, 1993) suggest a dilution factor of about 4 10^{-8} Bq m^{-3} per Bq d^{-1}. The volume of the local compartment adopted in the current version of DORIS is 5.0 10^9 m^3 and VER is 1.0 10^{11} m^3 y^{-1}. The corresponding dilution factor is 3.7 10^{-9} Bq m^{-3} per Bq d^{-1} which appears to be too low. It is recommended that the revised DORIS data for a generic sheltered coastal site is used, meaning a volume of 1 10^9 m^3 and a VER of 2 10^{10} m^3 y^{-1}, corresponding to a dilution factor of 1.8 10^{-8} Bq m^{-3} per Bq d^{-1}.

2.1.2.15 Springfields

The nuclear fuel production facility at Springfields discharges into the Ribble estuary. The volume of the local compartment given in the EA report (Dewar et al, 2011) for this site is 1.1 10^8 m^3 and the VER is 1.4 10^{10} m^3 y^{-1}. The dilution factor is 2.6 10^{-8} Bq m^{-3} per Bq d^{-1} which compares with a value of 9.1 10^{-8} Bq m^{-3} per Bq d^{-1} in DORIS for a generic estuary. Although the value in DORIS is more conservative, meaning it would result in a greater activity concentration in the seawater of the local compartment by a factor of about 3, it is recommended that the EA data should be used because they better represent the local conditions. The mean depth of the outer Ribble Estuary is assumed to be 3 m which is based on the volume and surface area given in the EA report (Dewar et al., 2011).

2.1.2.16 Trawsfynydd

The nuclear power plant at Trawsfynydd is currently being decommissioned but discharges still occur into Tremadog Bay. The volume of the local compartment given in the EA report (Dewar et al, 2011) for this site is 1.5 10^9 m^3 and the VER is 3.8 10^{10} m^3 y^{-1}. The dilution factor is calculated to be 9.7 10^{-9} Bq m^{-3} per Bq d^{-1} which is about 2.5 times greater than the factor of 3.7 10^{-9} Bq m^{-3} per Bq d^{-1} adopted in DORIS for a sheltered coastal location. It is recommended that the EA data should be used because they better represent the local conditions.

2.1.2.17 Torness

The Torness site is located outside of the Firth of Forth near Dunbar on the East Lothian coastline. The EA report (Dewar et al, 2011) does not include data for coastal locations in Scotland and therefore the characteristics of this site are assumed to be consistent with those of a generic exposed coastal site. The volume of the local compartment is assumed to be $2.0\ 10^{9}$ m^3 and the VER is $8.0\ 10^{10}$ $m^3\ y^{-1}$. The corresponding dilution factor is $4.6\ 10^{-9}$ Bq m^{-3} per Bq d^{-1}.

2.1.2.18 Winfrith

Discharges from the decommissioning activities at Winfrith do not occur into the region of Weymouth Bay as defined in the EA report (Dewar et al, 2011). Liquid discharges are to the pumping house at Arish Mell which is west of Lulworth Cove. Therefore, it is not considered appropriate to use the local compartment data provided for Weymouth Bay from the EA report. Currently DORIS assumes this is an exposed coastal location with a dilution factor of $9.1\ 10^{-9}$ Bq m^{-3} per Bq d^{-1}. However, because of the location of Arish Mell, parameters for a sheltered coastal location are considered more appropriate. The revised default values for the VER and dilution factor for such a location are $2\ 10^{10}$ $m^3\ y^{-1}$ and $1.8\ 10^{-8}$ Bq m^{-3} per Bq d^{-1}, respectively.

Table 3 Proposed new data for local marine compartments for DORIS

Site	Location	Depth (m)	Volume (m^3)	Volumetric exchange rate ($m^3\ y^{-1}$)	Coastline length (m)*	Dilution factor (Bq m^{-3} per Bq d^{-1})	Residual flow (m s^{-1})
Aldermaston	Thames estuary (outer)	$8.7\ 10^{0}$	$6.6\ 10^{8}$	$2.6\ 10^{10}$	$2.5\ 10^{4}$	$1.4\ 10^{-8}$	$1.1\ 10^{-2}$
Amersham	Thames estuary (outer)	$8.7\ 10^{0}$	$6.6\ 10^{8}$	$2.6\ 10^{10}$	$2.5\ 10^{4}$	$1.4\ 10^{-8}$	$1.1\ 10^{-2}$
Barrow	Walney Channel/Barrow harbour	$1.3\ 10^{0}$	$1.5\ 10^{7}$	$5.4\ 10^{9}$	$6.0\ 10^{3}$	$6.8\ 10^{-8}$	$3.9\ 10^{-2}$
Berkeley	Severn estuary (inner)	$4.0\ 10^{0}$	$1.3\ 10^{8}$	$1.8\ 10^{10}$	$2.4\ 10^{4}$	$2.0\ 10^{-8}$	$2.5\ 10^{-2}$
Bradwell	Blackwater estuary	$4.0\ 10^{0}$	$1.0\ 10^{8}$	$7.3\ 10^{9}$	$1.4\ 10^{4}$	$5.0\ 10^{-8}$	$1.2\ 10^{-2}$
Capenhurst	Mersey estuary (outer)	$8.0\ 10^{0}$	$3.3\ 10^{8}$	$2.0\ 10^{10}$	$1.8\ 10^{4}$	$1.8\ 10^{-8}$	$1.2\ 10^{-2}$
Cardiff	Cardiff bay	$7.0\ 10^{0}$	$1.9\ 10^{8}$	$1.7\ 10^{10}$	$1.5\ 10^{4}$	$2.2\ 10^{-8}$	$1.5\ 10^{-2}$
Chapelcross	Solway Firth (inner)	$3.6\ 10^{0}$	$7.0\ 10^{8}$	$7.4\ 10^{10}$	$3.4\ 10^{4}$	$5.0\ 10^{-9}$	$4.6\ 10^{-2}$
Devonport	Tamar estuary	$1.0\ 10^{1}$	$5.0\ 10^{7}$	$1.3\ 10^{9}$	$6.0\ 10^{3}$	$2.9\ 10^{-7}$	$1.8\ 10^{-3}$
Dounreay#	Exposed coast	$2.0\ 10^{1}$	$2.0\ 10^{9}$	$8.0\ 10^{10}$	$1.0\ 10^{4}$	$4.6\ 10^{-9}$	$1.3\ 10^{-2}$
Dungeness	Dungeness coast	$2.5\ 10^{1}$	$2.5\ 10^{9}$	$3.8\ 10^{10}$	$1.0\ 10^{4}$	$9.7\ 10^{-9}$	$4.8\ 10^{-3}$
Hartlepool	Sheltered coast	$1.0\ 10^{1}$	$1.0\ 10^{9}$	$2.0\ 10^{10}$	$1.0\ 10^{4}$	$1.8\ 10^{-8}$	$6.3\ 10^{-3}$
Harwell	Thames estuary (outer)	$8.7\ 10^{0}$	$6.6\ 10^{8}$	$2.6\ 10^{10}$	$2.5\ 10^{4}$	$1.4\ 10^{-8}$	$1.1\ 10^{-2}$
Heysham#	Sheltered coast	$1.0\ 10^{1}$	$1.0\ 10^{9}$	$2.0\ 10^{10}$	$1.0\ 10^{4}$	$1.8\ 10^{-8}$	$6.3\ 10^{-3}$
Hinkley Point#	Sheltered coast	$1.0\ 10^{1}$	$1.0\ 10^{9}$	$2.0\ 10^{10}$	$1.0\ 10^{4}$	$1.8\ 10^{-8}$	$6.3\ 10^{-3}$
Hunterston#	Sheltered coast	$1.0\ 10^{1}$	$1.0\ 10^{9}$	$2.0\ 10^{10}$	$1.0\ 10^{4}$	$1.8\ 10^{-8}$	$6.3\ 10^{-3}$
Oldbury	Severn estuary (inner)	$4.0\ 10^{0}$	$1.3\ 10^{8}$	$1.8\ 10^{10}$	$2.4\ 10^{4}$	$2.0\ 10^{-8}$	$2.5\ 10^{-2}$
Sizewell	Aldeburgh coast	$2.0\ 10^{1}$	$2.0\ 10^{9}$	$1.4\ 10^{10}$	$1.0\ 10^{4}$	$2.7\ 10^{-8}$	$2.2\ 10^{-3}$
Springfields~	Ribble estuary (outer)	$3.0\ 10^{0}$	$1.1\ 10^{8}$	$1.4\ 10^{10}$	$1.3\ 10^{4}$	$2.6\ 10^{-8}$	$2.5\ 10^{-2}$
Torness#	Exposed coast	$2.0\ 10^{1}$	$2.0\ 10^{9}$	$8.0\ 10^{10}$	$1.0\ 10^{4}$	$4.6\ 10^{-9}$	$1.3\ 10^{-2}$
Trawsfynydd	Tremadog bay	$8.6\ 10^{0}$	$1.5\ 10^{9}$	$3.8\ 10^{10}$	$4.0\ 10^{4}$	$9.7\ 10^{-9}$	$1.1\ 10^{-2}$
Winfrith#	Sheltered coast	$1.0\ 10^{1}$	$1.0\ 10^{9}$	$2.0\ 10^{10}$	$1.0\ 10^{4}$	$1.8\ 10^{-8}$	$6.3\ 10^{-3}$
Wylfa	Cemaes coast	$2.7\ 10^{1}$	$2.7\ 10^{9}$	$3.2\ 10^{10}$	$1.0\ 10^{4}$	$1.2\ 10^{-8}$	$3.7\ 10^{-3}$

* The coastline length in general relates to the linear distance from one end of the compartment to the other. However for bays and harbours it represents the total length of coastline in the compartment. For estuaries the total coastline length is double that presented here.

The coastline breadth of all these compartments is assumed to be $1\ 10^{4}$ m.

~ Average depth of outer Ribble estuary based on volume and surface area given in (Dewar et al, 2011).

2.1.3 Model results using proposed values

The impact of using the proposed local compartment parameter values of Table 3 has been investigated for 3 radionuclides. These radionuclides are used as examples only, they are representative of radionuclides that behave differently in the environment and may not actually be discharged from every site. Tables 4 and 5 show the activity concentrations of ^{3}H, ^{137}Cs and ^{241}Am in unfiltered seawater and seabed sediments in the 50th year of a continuous discharge of 1 Bq y^{-1} from each site, which were calculated using the current DORIS default parameter values and proposed new values. Table 6 shows the ratio between the activity concentrations calculated using the 2 sets of data; in general the ratios are essentially the same for both media for a given radionuclide and site. The ratios are also similar for different radionuclides in the same media and in general reflect the difference in the proposed and current values of the VER. The notable exceptions are the ratios for ^{241}Am in unfiltered seawater and seabed sediments at the Capenhurst, Dounreay, Heysham, Hunterston and Winfrith sites. For these sites the ratios for ^{241}Am in unfiltered seawater and seabed sediments are less than those for ^{3}H and ^{137}Cs with the exception of Capenhurst for which the ^{241}Am ratios are greater. It is difficult to identify a pattern in the results that would explain the behaviour of ^{241}Am at each site but it is clear that the high sediment distribution coefficient (k_d) for this radionuclide means that the sedimentation process has a greater influence over the dispersion. In these circumstances the suspended sediment load, sedimentation rate and volume of the local compartment play an important role.

An investigation using the Heysham site data showed that a decrease in the VER by a factor of about 2 resulted in a small increase in the ^{241}Am activity concentrations in all media but a more significant increase for ^{137}Cs and ^{3}H. In addition, an increase in the volume of the compartment by a factor of 10 reduced activity concentrations of ^{241}Am in seawater and sediments by a factor of 3 but had little effect on ^{137}Cs and ^{3}H concentrations. This can be explained by the fact that the sediment partition coefficient (k_d) for americium is much greater than that for caesium or tritium and as a result of the adsorption/desorption process the ^{241}Am is held up in the sediments before it can be removed from the local compartment by the advection of water. The change in volume of the local compartment has little effect on activity concentrations of ^{137}Cs and ^{3}H because for these radionuclides the VER is the dominant parameter. However, the lateral movement of seabed sediments is not modelled in DORIS so any ^{241}Am adsorbed onto these sediments is not subject to such losses. In this case changes in the local compartment volume that inevitably affect the mass of seabed sediments impact on sediment and ultimately seawater activity concentrations.

In general, the results show that while a change in the value of the VER is the most important factor affecting activity concentrations in seawater and sediments other parameters have a notable influence on model results.

The results in Table 6 show that ratios of modelled activity concentrations are generally within a factor of 5 with the exception being Trawsfynydd for which activity concentrations using proposed data are a factor of 10 less than those using current data. Similar changes in estimates of individual dose can be expected where exposures are related to interactions with the local compartment.

A comparison of activity concentrations in some regional compartments has been carried out for discharges from Hinkley Point and Trawsfynydd (Tables 7 and 8). This shows that for the radionuclides and compartments considered the proposed changes have very little effect on the model predictions.

Table 4 Activity concentration per unit continuous release (Bq y^{-1}) in local compartment (DORIS current data) in the 50th year

	Unfiltered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Site	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
Aldermaston, Amersham and Harwell	2.5 10^{-13}	2.5 10^{-13}	2.5 10^{-13}	1.1 10^{-09}	3.1 10^{-10}	4.3 10^{-13}
Barrow	2.2 10^{-13}	2.6 10^{-13}	2.6 10^{-13}	1.1 10^{-09}	4.5 10^{-11}	4.4 10^{-13}
Oldbury/Berkeley	2.5 10^{-13}	2.5 10^{-13}	2.5 10^{-13}	1.1 10^{-09}	3.1 10^{-10}	4.3 10^{-13}
Bradwell	2.5 10^{-13}	2.5 10^{-13}	2.5 10^{-13}	1.1 10^{-09}	3.1 10^{-10}	4.3 10^{-13}
Capenhurst	1.3 10^{-14}	2.0 10^{-14}	2.0 10^{-14}	1.1 10^{-10}	3.6 10^{-12}	3.5 10^{-14}
Cardiff	2.5 10^{-13}	2.5 10^{-13}	2.5 10^{-13}	1.1 10^{-09}	3.1 10^{-10}	4.3 10^{-13}
Chapelcross	6.9 10^{-15}	1.4 10^{-14}	1.4 10^{-14}	3.4 10^{-10}	2.6 10^{-12}	2.4 10^{-14}
Devonport	2.4 10^{-13}	2.5 10^{-13}	2.5 10^{-13}	2.2 10^{-9}	3.9 10^{-10}	4.3 10^{-13}
Dounreay	5.1 10^{-15}	6.3 10^{-15}	6.3 10^{-15}	2.8 10^{-9}	1.3 10^{-11}	1.1 10^{-14}
Dungeness	1.2 10^{-14}	1.3 10^{-14}	1.3 10^{-14}	9.8 10^{-10}	2.5 10^{-11}	2.2 10^{-14}
Hartlepool	2.5 10^{-13}	2.5 10^{-13}	2.5 10^{-13}	1.1 10^{-9}	3.1 10^{-10}	4.3 10^{-13}
Heysham	9.6 10^{-14}	1.3 10^{-13}	1.3 10^{-13}	4.7 10^{-9}	2.5 10^{-11}	2.3 10^{-13}
Hinkley Point	1.0 10^{-14}	1.0 10^{-14}	1.1 10^{-14}	4.5 10^{-11}	1.3 10^{-11}	1.8 10^{-14}
Hunterston	8.7 10^{-15}	1.0 10^{-14}	1.0 10^{-14}	7.0 10^{-10}	2.0 10^{-11}	1.7 10^{-14}
Sizewell	9.0 10^{-14}	9.1 10^{-14}	9.2 10^{-14}	9.9 10^{-10}	1.5 10^{-10}	1.6 10^{-13}
Springfields	2.2 10^{-13}	2.6 10^{-13}	2.6 10^{-13}	1.1 10^{-9}	4.5 10^{-11}	4.4 10^{-13}
Torness	1.2 10^{-14}	1.3 10^{-14}	1.3 10^{-14}	9.7 10^{-10}	2.5 10^{-11}	2.2 10^{-14}
Trawsfynydd	2.5 10^{-13}	2.5 10^{-13}	2.5 10^{-13}	1.1 10^{-9}	3.7 10^{-11}	4.3 10^{-13}
Winfrith	2.2 10^{-14}	2.5 10^{-14}	2.5 10^{-14}	1.7 10^{-9}	4.9 10^{-11}	4.3 10^{-14}
Wylfa	1.6 10^{-14}	2.6 10^{-14}	2.6 10^{-14}	7.6 10^{-10}	4.8 10^{-12}	4.5 10^{-14}

Table 5 Activity concentration per unit continuous release (Bq y^{-1}) in local compartment (Proposed data) in the 50th year

	Unfiltered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Site	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
Aldermaston, Amersham and Harwell	$3.9\ 10^{-14}$	$4.0\ 10^{-14}$	$4.0\ 10^{-14}$	$1.8\ 10^{-10}$	$5.0\ 10^{-11}$	$6.9\ 10^{-14}$
Barrow	$1.8\ 10^{-13}$	$1.9\ 10^{-13}$	$1.9\ 10^{-13}$	$8.4\ 10^{-10}$	$3.4\ 10^{-11}$	$3.4\ 10^{-13}$
Oldbury/Berkeley	$5.5\ 10^{-14}$	$5.6\ 10^{-14}$	$5.6\ 10^{-14}$	$2.5\ 10^{-10}$	$7.1\ 10^{-11}$	$9.6\ 10^{-14}$
Bradwell	$1.4\ 10^{-13}$	$1.4\ 10^{-13}$	$1.4\ 10^{-13}$	$6.1\ 10^{-10}$	$1.7\ 10^{-10}$	$2.4\ 10^{-13}$
Capenhurst	$4.7\ 10^{-14}$	$5.8\ 10^{-14}$	$5.8\ 10^{-14}$	$4.2\ 10^{-10}$	$1.0\ 10^{-11}$	$1.0\ 10^{-13}$
Cardiff bay	$6.0\ 10^{-14}$	$6.0\ 10^{-14}$	$6.0\ 10^{-14}$	$2.7\ 10^{-10}$	$7.6\ 10^{-11}$	$1.0\ 10^{-13}$
Chapelcross	$9.0\ 10^{-15}$	$1.8\ 10^{-14}$	$1.8\ 10^{-14}$	$4.4\ 10^{-10}$	$3.3\ 10^{-12}$	$3.1\ 10^{-14}$
Devonport	$7.8\ 10^{-13}$	$7.8\ 10^{-13}$	$7.9\ 10^{-13}$	$6.9\ 10^{-9}$	$1.2\ 10^{-9}$	$1.4\ 10^{-12}$
Dounreay	$7.5\ 10^{-15}$	$1.3\ 10^{-14}$	$1.3\ 10^{-14}$	$3.9\ 10^{-9}$	$2.5\ 10^{-11}$	$2.2\ 10^{-14}$
Dungeness	$2.3\ 10^{-14}$	$2.7\ 10^{-14}$	$2.7\ 10^{-14}$	$1.8\ 10^{-9}$	$5.2\ 10^{-11}$	$4.6\ 10^{-14}$
Hartlepool	$5.0\ 10^{-14}$	$5.0\ 10^{-14}$	$5.0\ 10^{-14}$	$2.2\ 10^{-10}$	$6.2\ 10^{-11}$	$8.6\ 10^{-14}$
Heysham	$2.3\ 10^{-14}$	$5.7\ 10^{-14}$	$5.7\ 10^{-14}$	$1.1\ 10^{-9}$	$1.1\ 10^{-11}$	$9.9\ 10^{-14}$
Hinkley Point	$5.0\ 10^{-14}$	$5.0\ 10^{-14}$	$5.0\ 10^{-14}$	$2.2\ 10^{-10}$	$6.3\ 10^{-11}$	$8.6\ 10^{-14}$
Hunterston	$3.7\ 10^{-14}$	$4.9\ 10^{-14}$	$5.0\ 10^{-14}$	$2.8\ 10^{-9}$	$9.6\ 10^{-11}$	$8.6\ 10^{-14}$
Sizewell	$7.1\ 10^{-14}$	$7.3\ 10^{-14}$	$7.4\ 10^{-14}$	$7.6\ 10^{-10}$	$1.2\ 10^{-10}$	$1.3\ 10^{-13}$
Springfields	$6.5\ 10^{-14}$	$7.7\ 10^{-14}$	$7.8\ 10^{-14}$	$3.1\ 10^{-10}$	$1.4\ 10^{-11}$	$1.3\ 10^{-13}$
Torness	$1.2\ 10^{-14}$	$1.3\ 10^{-14}$	$1.3\ 10^{-14}$	$9.7\ 10^{-10}$	$2.5\ 10^{-11}$	$2.2\ 10^{-14}$
Trawsfynydd	$2.6\ 10^{-14}$	$2.7\ 10^{-14}$	$2.7\ 10^{-14}$	$1.1\ 10^{-10}$	$4.0\ 10^{-12}$	$4.6\ 10^{-14}$
Winfrith	$3.7\ 10^{-14}$	$4.9\ 10^{-14}$	$5.0\ 10^{-14}$	$2.9\ 10^{-9}$	$9.7\ 10^{-11}$	$8.6\ 10^{-14}$
Wylfa	$1.8\ 10^{-14}$	$3.3\ 10^{-14}$	$3.3\ 10^{-14}$	$8.7\ 10^{-10}$	$6.0\ 10^{-12}$	$5.6\ 10^{-14}$

Table 6 Ratio of activity concentration per unit continuous release (Bq y^{-1}) in local compartment (Proposed data : current DORIS data) in the 50th year

	Unfiltered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Site	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
Aldermaston, Amersham and Harwell	0.2	0.2	0.2	0.2	0.2	0.2
Barrow harbour	0.8	0.8	0.8	0.8	0.8	0.8
Oldbury/Berkeley	0.2	0.2	0.2	0.2	0.2	0.2
Bradwell	0.6	0.6	0.6	0.6	0.6	0.6
Capenhurst	3.7	2.9	2.9	3.7	2.9	2.9
Cardiff bay	0.2	0.2	0.2	0.2	0.2	0.2
Chapelcross	1.3	1.3	1.3	1.3	1.3	1.3
Devonport	3.2	3.2	3.2	3.2	3.2	3.2
Dounreay	1.5	2.0	2.0	1.4	2.0	2.0
Dungeness	1.9	2.1	2.1	1.9	2.1	2.1
Hartlepool	0.2	0.2	0.2	0.2	0.2	0.2
Heysham	0.2	0.4	0.4	0.2	0.4	0.4
Hinkley Point	5.0	4.8	4.8	4.9	4.8	4.8
Hunterston	4.3	4.9	4.9	4.1	4.9	5.0
Sizewell	0.8	0.8	0.8	0.8	0.8	0.8
Springfields	0.3	0.3	0.3	0.3	0.3	0.3
Torness	1.0	1.0	1.0	1.0	1.0	1.0
Trawsfynydd	0.1	0.1	0.1	0.1	0.1	0.1
Winfrith	1.7	2.0	2.0	1.6	2.0	2.0
Wylfa	1.1	1.3	1.3	1.1	1.3	1.3

Table 7 Activity concentrations in the 50th year in selected regional compartments per unit continuous release (1 Bq y^{-1}) from Hinkley Point

	Unfiltered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Compartment	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
DORIS current data						
Bristol Channel	$6.6\ 10^{-17}$	$4.8\ 10^{-16}$	$4.9\ 10^{-16}$	$3.2\ 10^{-11}$	$9.6\ 10^{-13}$	$8.4\ 10^{-16}$
Celtic Sea	$4.2\ 10^{-19}$	$5.1\ 10^{-18}$	$5.0\ 10^{-18}$	$1.9\ 10^{-13}$	$1.0\ 10^{-14}$	$8.6\ 10^{-18}$
English Channel West	$1.4\ 10^{-19}$	$5.0\ 10^{-18}$	$5.0\ 10^{-18}$	$5.7\ 10^{-14}$	$9.9\ 10^{-15}$	$8.5\ 10^{-18}$
Proposed						
Bristol Channel	$6.5\ 10^{-17}$	$4.8\ 10^{-16}$	$4.9\ 10^{-16}$	$3.1\ 10^{-11}$	$9.5\ 10^{-13}$	$8.4\ 10^{-16}$
Celtic Sea	$4.2\ 10^{-19}$	$5.1\ 10^{-18}$	$5.0\ 10^{-18}$	$1.9\ 10^{-13}$	$1.0\ 10^{-14}$	$8.6\ 10^{-18}$
English Channel West	$1.4\ 10^{-19}$	$5.0\ 10^{-18}$	$5.0\ 10^{-18}$	$5.5\ 10^{-14}$	$9.9\ 10^{-15}$	$8.5\ 10^{-18}$

Table 8 Activity concentrations in the 50th year in selected regional compartments per unit continuous release (1 Bq y^{-1}) from Trawsfynydd

	Unfiltered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Compartment	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
DORIS current data						
Irish Sea West	$1.3\ 10^{-16}$	$6.7\ 10^{-16}$	$6.4\ 10^{-16}$	$7.5\ 10^{-12}$	$1.1\ 10^{-13}$	$1.1\ 10^{-15}$
Irish Sea South	$3.0\ 10^{-16}$	$7.1\ 10^{-16}$	$6.9\ 10^{-16}$	$2.1\ 10^{-11}$	$1.1\ 10^{-13}$	$1.2\ 10^{-15}$
Celtic Sea	$8.5\ 10^{-19}$	$2.3\ 10^{-18}$	$2.2\ 10^{-18}$	$5.8\ 10^{-14}$	$3.5\ 10^{-16}$	$3.7\ 10^{-18}$
Proposed						
Irish Sea West	$1.3\ 10^{-16}$	$6.7\ 10^{-16}$	$6.4\ 10^{-16}$	$7.5\ 10^{-12}$	$1.1\ 10^{-13}$	$1.1\ 10^{-15}$
Irish Sea South	$3.0\ 10^{-16}$	$7.1\ 10^{-16}$	$7.0\ 10^{-16}$	$2.1\ 10^{-11}$	$1.1\ 10^{-13}$	$1.2\ 10^{-15}$
Celtic Sea	$8.5\ 10^{-19}$	$2.3\ 10^{-18}$	$2.2\ 10^{-18}$	$5.8\ 10^{-14}$	$3.5\ 10^{-16}$	$3.7\ 10^{-18}$

2.2 Local compartment sedimentation parameters

2.2.1 Review of data and recommendations

The sedimentation model in the marine dispersion code DORIS of PC-CREAM 08 accounts for the remobilisation of activity from the top sediment layer to the water column and the transfer of activity to deep sediments. The model comprises 3 compartments representing the upper, middle and deep sediments located beneath the water column of the local and each regional compartment. The transfer factors between these compartments and the water column take account of the key dispersion processes of sedimentation, particle scavenging, molecular diffusion, pore water mixing and particle mixing (Smith and Simmonds, 2009). The parameters used to model these processes include the suspended sediment load, sedimentation rate, sediment density and diffusion rate. All these parameters have been reviewed in the EA report for each local compartment.

The EA report took suspended sediment loads from a database of experimental sediment load determinations collated by CEFAS as part of the Clean Safe Seas Environmental Monitoring Programme (CSEMP). In cases where fewer than 20 sediment samples were available in the local compartment additional samples were included from a larger region that extended outside the local compartment by a distance of 10 km in each direction along the coast. The values presented are the mean values of individual measurements from each compartment.

In the EA report the sedimentation rate was calculated assuming the relationship:

$$SR = 10 \times \left(\frac{SSL}{500} \right) \qquad (1)$$

where the sedimentation rate SR is in kg m^{-2} y^{-1} and the suspended sediment load (SSL) is in mg l^{-1}. The justification for this approach was that the sedimentation rate is likely to be proportional to the suspended sediment load and to ensure that a sediment load of around 500 mg l^{-1} gives a sedimentation rate at the upper end of the suggested range. Sedimentation rates around the UK range from about 0 to 10 kg m^{-2} y^{-1} (0 – 0.01 t m^{-2} y^{-1}) (Brownless et al, 2001).

Tables 9 and 10 present the suspended sediment loads and sedimentation rates currently used in DORIS for the regional and local compartments and those reported by EA (Dewar et al, 2011). It can be seen that the SSLs for local compartments are generally one or 2 orders of magnitude greater than for the regional compartment. This is to be expected particularly in the vicinity of an estuary but also more generally along the coast due to the action of tides and a reduced sea depth. Sedimentation rates tend to be similar between the local and regional compartments although some notably high values are reported by EA for some sites.

Report NRPB-R119 (Camplin et al, 1982) suggests a value for the suspended sediment load of 2 10^{-4} t m^{-3} for most estuarine locations and 1 10^{-5} t m^{-3} for sheltered and exposed coastal sites. In addition, a site specific value of 1 10^{-4} t m^{-3} is suggested for Capenhurst. In the current version of DORIS the SSLs are based on those from NRPB-R119 but also include some site specific values for Devonport (1 10^{-4} t m^{-3}), Dounreay (1 10^{-6} t m^{-3}) and Sizewell (8 10^{-5} t m^{-3}). These site specific values can be traced back to the MARINA II study (European Commission, 2002) although it is not clear how they were derived.

There are some significant differences between the current DORIS values and the EA values, most notably for some estuarine environments. For example, the SSL reported by the EA for Solway Firth is 20 times greater than the PC CREAM 08 value, while the SSL for Devonport is about 20 times lower.

For sedimentation rates NRPB-R119 (Camplin et al, 1982) recommends that the local compartment value should be the same as that for the regional compartment. However, this general rule was not followed for all sites. The report also acknowledges the fact that sedimentation rates tend to increase closer to the shore. The sedimentation rates currently used in DORIS appear to have been derived in 3 ways: taken directly from NRPB-R119, using the value of the nearest regional compartment or by adopting new values. The justification for the values currently used in DORIS is not clear but they date back to PC-CREAM 98 and the accompanying methodology report (Simmonds et al, 1995). There are some significant differences between the sedimentation rates adopted in the current version of DORIS, those reported in NRPB-R119 and those in the EA report (Dewar et al, 2011). For example, the EA report gives a value for the Severn Estuary that is 140 times greater than the current DORIS value.

The EA report also considered sediment densities and diffusion rates. A sediment grain density of 2.65 t m^{-3} was reported as typical of quartz based sediment and was used in the EA report to calculate the densities of wet sediments according to how well packed the sediment particles are likely to be. In the DORIS model of PC-CREAM 08 a sediment grain density of 2.6 t m^{-3} is used for all model compartments and packing density is accounted for using a porosity factor. Comparing the wet sediment density values in the EA Report with those calculated using DORIS defaults for sediment density and porosity suggests that the porosity used in DORIS for the local compartment may be a little high but not significantly so.

The values for the diffusion rate given in the EA report are many orders of magnitude larger than the default values for the sediment diffusion coefficient given in DORIS. The parameter as used in DORIS represents the pore water diffusion coefficient as originally defined in (Chartier et al, 1987). However, the parameter reported in (Dewar et al, 2011) appears to represent an aggregate of the many turbulent processes acting on a water body and is consequently significantly greater and not considered to be compatible with DORIS.

It is recommended that, where available, the values of suspended sediment load and sedimentation rate from the EA report (Dewar et al, 2011) should be used for the sites considered in this section. Where such data are not available it is recommended that default values for SSL of 1 10^{-5} t m^{-3} and 2 10^{-4} t m^{-3} are used for coastal and estuarine sites, respectively (Camplin et al, 1982), and corresponding values of 2 10^{-4} t m^{-2} y^{-1} and 4 10^{-3} t m^{-2} y^{-1} are used for SR based on equation (1) above. However, there are 2 exceptions to this rule. For Heysham, data from the EA report (Dewar et al, 2011) and the current regional compartment value in DORIS both suggest a SR value higher than the coastal default of 2 10^{-4} t m^{-2} y^{-1}. Even though the EA data are for the Morecambe Bay area a higher value of 1 10^{-3} t m^{-2} y^{-1} is recommended. Similarly, for Hinkley Point, data from the EA report (Dewar et al, 2011) and from NRPB-R119 (Camplin et al, 1982) suggest a SSL value higher than the coastal default of 1 10^{-5} t m^{-3}. Again, the EA data are slightly outside the discharge location, nevertheless, a value of 1 10^{-4} t m^{-3} is recommended for SSL and equation (1) is used to calculate the value of SR. A summary of recommended values is presented in Table 11.

It is also recommended that the DORIS default values for sediment density and pore water diffusion coefficient are retained.

Table 9 Comparison of suspended sediment loads (SSL, t m^{-3})

			Local compartment		
Sites in DORIS	EA locations	Regional compartment	EA report	DORIS current	EA report / DORIS current
Aldermaston	Thames estuary (outer)	$6\ 10^{-6}$	$3.0\ 10^{-5}$	$2.0\ 10^{-4}$	0.2
Amersham	Thames estuary (outer)	$6\ 10^{-6}$	$3.0\ 10^{-5}$	$2.0\ 10^{-4}$	0.2
Barrow	Walney Channel/Barrow Harbour	$3\ 10^{-6}$	$6.4\ 10^{-5}$	$2.0\ 10^{-4}$	0.3
Berkeley	Severn Estuary (inner)	$1\ 10^{-6}$	$6.9\ 10^{-4}$	$2.0\ 10^{-4}$	3.5
Bradwell	Blackwater estuary	$6\ 10^{-6}$	$3.8\ 10^{-5}$	$2.0\ 10^{-4}$	0.2
Capenhurst	Mersey estuary (outer)	$3\ 10^{-6}$	$7.8\ 10^{-5}$	$1.0\ 10^{-4}$	0.8
Cardiff	Cardiff Bay	$1\ 10^{-6}$	$1.8\ 10^{-4}$	$2.0\ 10^{-4}$	0.9
Chapelcross	Solway Firth (inner)	$3\ 10^{-6}$	$1.8\ 10^{-4}$	$1.0\ 10^{-5}$	18.0
Devonport	Tamar Estuary	$1\ 10^{-6}$	$4.6\ 10^{-6}$	$1.0\ 10^{-4}$	0.05
Dounreay	Not considered	$1\ 10^{-6}$	-	$1.0\ 10^{-6}$	-
Dungeness	Dungeness coast	$5\ 10^{-6}$	$6.1\ 10^{-5}$	$1.0\ 10^{-5}$	6.1
Hartlepool	Tees estuary	$6\ 10^{-6}$	$8.7\ 10^{-6}$	$2.0\ 10^{-4}$	0.04
Harwell	Thames estuary (outer)	$6\ 10^{-6}$	$3.0\ 10^{-5}$	$2.0\ 10^{-4}$	0.2
Heysham	Morecambe Bay	$3\ 10^{-6}$	$8.1\ 10^{-5}$	$1.0\ 10^{-5}$	8.1
Hinkley Point	Parrett estuary	$1\ 10^{-6}$	$9.7\ 10^{-5}$	$2.0\ 10^{-4}$	0.5
Hunterston	Not considered	$1\ 10^{-6}$	-	$1.0\ 10^{-5}$	-
Oldbury	Severn Estuary (inner)	$1\ 10^{-6}$	$6.9\ 10^{-4}$	$2.0\ 10^{-4}$	3.5
Sizewell	Aldeburgh coast	$6\ 10^{-6}$	$3.6\ 10^{-5}$	$8.0\ 10^{-5}$	0.5
Springfields	Ribble estuary (outer)	$3\ 10^{-6}$	$9.4\ 10^{-5}$	$2.0\ 10^{-4}$	0.5
Torness	Not considered	$6\ 10^{-6}$	-	$1.0\ 10^{-5}$	-
Trawsfynydd	Tremadog Bay	$1\ 10^{-6}$	$1.3\ 10^{-5}$	$2.0\ 10^{-4}$	0.1
Winfrith	Weymouth Bay	$3\ 10^{-6}$	$4.0\ 10^{-6}$	$1.0\ 10^{-5}$	0.4
Wylfa	Cemaes coast	$3\ 10^{-6}$	$4.9\ 10^{-6}$	$1.0\ 10^{-5}$	0.5

Table 10 Comparison of local compartment sedimentation rates (SR, t m^{-2} y^{-1})

Sites in DORIS	EA locations	Regional compartment	Local compartment		
			EA report	DORIS current	EA report / DORIS current
Aldermaston	Thames estuary (outer)	$1.0\ 10^{-4}$	$6.0\ 10^{-4}$	$1.0\ 10^{-4}$	6.0
Amersham	Thames estuary (outer)	$1.0\ 10^{-4}$	$6.0\ 10^{-4}$	$1.0\ 10^{-4}$	6.0
Barrow	Walney channel/Barrow harbour	$6.0\ 10^{-3}$	$1.3\ 10^{-3}$	$5.0\ 10^{-3}$	0.3
Berkeley	Severn estuary (inner)	$1.0\ 10^{-4}$	$1.4\ 10^{-2}$	$1.0\ 10^{-4}$	140.0
Bradwell	Blackwater estuary	$1.0\ 10^{-4}$	$8.0\ 10^{-4}$	$1.0\ 10^{-4}$	8.0
Capenhurst	Mersey estuary (outer)	$6.0\ 10^{-3}$	$1.6\ 10^{-3}$	$5.0\ 10^{-3}$	0.3
Cardiff	Cardiff bay	$1.0\ 10^{-4}$	$3.6\ 10^{-3}$	$1.0\ 10^{-4}$	36.0
Chapelcross	Solway Firth (inner)	$1.0\ 10^{-4}$	$3.7\ 10^{-3}$	$5.0\ 10^{-3}$	0.7
Devonport	Tamar estuary	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	$2.0\ 10^{-4}$	0.5
Dounreay	Not considered	$1.0\ 10^{-4}$	-	$1.0\ 10^{-4}$	-
Dungeness	Dungeness coast	$1.0\ 10^{-4}$	$1.2\ 10^{-3}$	$1.0\ 10^{-4}$	12.0
Hartlepool	Tees estuary	$1.0\ 10^{-4}$	$2.0\ 10^{-4}$	$1.0\ 10^{-4}$	2.0
Harwell	Thames estuary (outer)	$1.0\ 10^{-4}$	$6.0\ 10^{-4}$	$1.0\ 10^{-4}$	6.0
Heysham	Morecambe Bay	$6.0\ 10^{-3}$	$1.6\ 10^{-3}$	$4.9\ 10^{-3}$	0.3
Hinkley Point	Parrett estuary	$1.0\ 10^{-4}$	$1.9\ 10^{-3}$	$1.0\ 10^{-4}$	19.0
Hunterston	Not considered	$1.0\ 10^{-4}$	-	$1.0\ 10^{-4}$	-
Oldbury	Severn estuary (inner)	$1.0\ 10^{-4}$	$1.4\ 10^{-2}$	$1.0\ 10^{-4}$	140.0
Sizewell	Aldeburgh coast	$1.0\ 10^{-4}$	$7.0\ 10^{-4}$	$1.0\ 10^{-4}$	7.0
Springfields	Ribble estuary (outer)	$6.0\ 10^{-3}$	$1.9\ 10^{-3}$	$5.0\ 10^{-3}$	0.4
Torness	Not considered	$1.0\ 10^{-4}$	-	$1.0\ 10^{-4}$	-
Trawsfynydd	Tremadog Bay	$1.0\ 10^{-4}$	$3.0\ 10^{-4}$	$1.0\ 10^{-4}$	3.0
Winfrith	Weymouth Bay	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	$1.0\ 10^{-4}$	1.0
Wylfa	Cemaes coast	$1.0\ 10^{-3}$	$1.0\ 10^{-4}$	$5.0\ 10^{-3}$	0.02

Table 11 Proposed new data for local compartment sedimentation parameters

Sites in DORIS	Locations	Regional compartment		Local compartment	
		SSL, t m^{-3}	SR, t m^{-2} y^{-1}	SSL, t m^{-3}	SR, t m^{-2} y^{-1}
Aldermaston	Thames estuary (outer)	6 10^{-6}	1.0 10^{-4}	3.0 10^{-5}	6.0 10^{-4}
Amersham	Thames estuary (outer)	6 10^{-6}	1.0 10^{-4}	3.0 10^{-5}	6.0 10^{-4}
Barrow	Walney channel/Barrow harbour	3 10^{-6}	6.0 10^{-3}	6.4 10^{-5}	1.3 10^{-3}
Berkeley	Severn estuary (inner)	1 10^{-6}	1.0 10^{-4}	6.9 10^{-4}	1.4 10^{-2}
Bradwell	Blackwater estuary	6 10^{-6}	1.0 10^{-4}	3.8 10^{-5}	8.0 10^{-4}
Capenhurst	Mersey estuary (outer)	3 10^{-6}	6.0 10^{-3}	7.8 10^{-5}	1.6 10^{-3}
Cardiff	Cardiff bay	1 10^{-6}	1.0 10^{-4}	1.8 10^{-4}	3.6 10^{-3}
Chapelcross	Solway Firth (inner)	3 10^{-6}	1.0 10^{-4}	1.8 10^{-4}	3.7 10^{-3}
Devonport	Tamar estuary	1 10^{-6}	1.0 10^{-4}	4.6 10^{-6}	1.0 10^{-4}
Dounreay	Exposed coast	1 10^{-6}	1.0 10^{-4}	1.0 10^{-5}	2.0 10^{-4}
Dungeness	Dungeness coast	5 10^{-6}	1.0 10^{-4}	6.1 10^{-5}	1.2 10^{-3}
Hartlepool	Sheltered coast	6 10^{-6}	1.0 10^{-4}	1.0 10^{-5}	2.0 10^{-4}
Harwell	Thames estuary (outer)	6 10^{-6}	1.0 10^{-4}	3.0 10^{-5}	6.0 10^{-4}
Heysham	Sheltered coast	3 10^{-6}	6.0 10^{-3}	1.0 10^{-5}	1.0 10^{-3}
Hinkley Point	Sheltered coast	1 10^{-6}	1.0 10^{-4}	1.0 10^{-4}	2.0 10^{-3}
Hunterston	Sheltered coast	1 10^{-6}	1.0 10^{-4}	1.0 10^{-5}	2.0 10^{-4}
Oldbury	Severn estuary (inner)	1 10^{-6}	1.0 10^{-4}	6.9 10^{-4}	1.4 10^{-2}
Sizewell	Aldeburgh coast	6 10^{-6}	1.0 10^{-4}	3.6 10^{-5}	7.0 10^{-4}
Springfields	Ribble estuary (outer)	3 10^{-6}	6.0 10^{-3}	9.4 10^{-5}	1.9 10^{-3}
Torness	Exposed coast	6 10^{-6}	1.0 10^{-4}	1.0 10^{-5}	2.0 10^{-4}
Trawsfynydd	Tremadog Bay	1 10^{-6}	1.0 10^{-4}	1.3 10^{-5}	3.0 10^{-4}
Winfrith	Sheltered coast	3 10^{-6}	1.0 10^{-4}	1.0 10^{-5}	2.0 10^{-4}
Wylfa	Cemaes coast	3 10^{-6}	1.0 10^{-3}	4.9 10^{-6}	1.0 10^{-4}

2.2.2 Model results using proposed values

The consequences of making the recommended changes to suspended sediment load and sedimentation rate have been investigated for a selection of sites. Chapelcross, Hartlepool, Hinkley Point, Oldbury, Sizewell and Wylfa have been chosen because some of the most significant changes to the parameter values of the sedimentation model are proposed for these sites. Tables 12 and 13 present environmental activity concentrations for 3 radionuclides (^{241}Am, ^{137}Cs and ^{3}H) calculated using DORIS with current default SSLs and SRs and proposed new values for these parameters. These radionuclides are used as examples only and may not actually be discharged from every site. Table 14 shows the ratio of the results presented in Tables 12 and 13. Activity concentrations for suspended sediments are not presented because the ratios were found to be very similar to those for filtered water.

This exercise shows that the relationship between SSL, SR and k_d is not simple and that it can be difficult to interpret the impact these parameters have on the partitioning of activity between seawater and sediments. However, it can be seen that activity concentrations of ^{241}Am, which has a high k_d and readily adsorbs onto sediments, are influenced most by changes to sedimentation parameter values, while radionuclides with low k_d, such a ^{3}H, are relatively unaffected.

For Chapelcross activity concentrations of ^{241}Am in unfiltered water increase when the proposed sedimentation parameters are used while concentrations in filtered water and seabed sediments decrease. This is primarily due to the increase in SSL by a factor of 18 and the high k_d of ^{241}Am which leads to more activity becoming associated with suspended sediments. Although the activity concentration on suspended sediments decreases in proportion to the activity concentration in filtered water the total mass of suspended sediments in the water column increases which gives rise to an increase in the unfiltered water concentration. For Hartlepool the opposite effect is seen for ^{241}Am as a consequence of the decrease in SSL by a factor of about 20.

The large increase in the SR by a factor of 140 for Oldbury reduces the activity concentrations of ^{137}Cs and ^{241}Am in unfiltered seawater, filtered seawater and seabed sediments. This is because a higher SR acts to remove activity from the water column to the lower sediment layers.

For Hinkley Point, Sizewell and Wylfa a reduction in the SSL by a factor of 2 and changes to the SR by factors of 20, 7 and 0.02, respectively, are proposed. Table 14 shows that the proposed changes give rise to similar activity concentration ratios for Hinkley Point and Sizewell when modelled using DORIS. For these 2 sites activity concentrations of ^{241}Am in filtered seawater and seabed sediments increase by a factor of about 2 due to the increase in SSL. Results for Wylfa are similar but the activity concentration for ^{241}Am in unfiltered seawater also increases which is due to the significant decrease in SR and the reduction in transfer of activity to lower seabed sediments. Also, for Wylfa the activity concentration for ^{137}Cs in seabed sediments decreases following the change in parameter values while that for ^{241}Am increases. This difference in behaviours is due to the difference in the k_d of the 2 radionuclides and how this, in conjunction with the change in the value of SR, affects the relative importance of the different transfer factors in the sedimentation model.

The evidence suggests that for some of the sites considered the proposed changes to the sedimentation parameters may have a significant impact on activity concentrations and subsequently doses for specific radionuclides and exposure pathways. Ingestion doses depend on activity concentrations in filtered seawater and uptake by marine biota, while external doses depend on activity concentrations in sediments. In general, it has been shown that for radionuclides that adsorb onto sediments an increase in suspended sediment load is likely to result in a decrease in dose from both ingestion and external exposure pathways. The impact of an increase in sedimentation rate is less clear and more dependent on the value of the radionuclide k_d. The consequences of recommendations made in Sections 2.1.2 and 2.2.1 for dose are investigated further in Section 2.3.

Table 12 Activity concentration per unit continuous release (Bq y^{-1}) in local compartment for selected sites (DORIS current data) in the 50th year

	Unfiltered seawater (Bq l^{-1})			Filtered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Site	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
Chapelcross	$6.9\ 10^{-15}$	$1.4\ 10^{-14}$	$1.4\ 10^{-14}$	$3.5\ 10^{-15}$	$1.4\ 10^{-14}$	$1.4\ 10^{-14}$	$3.4\ 10^{-10}$	$2.6\ 10^{-12}$	$2.4\ 10^{-14}$
Hartlepool	$2.5\ 10^{-13}$	$2.5\ 10^{-13}$	$2.5\ 10^{-13}$	$6.2\ 10^{-16}$	$1.5\ 10^{-13}$	$2.5\ 10^{-13}$	$1.1\ 10^{-09}$	$3.1\ 10^{-10}$	$4.3\ 10^{-13}$
Hinkley Point	$1.0\ 10^{-14}$	$1.0\ 10^{-14}$	$1.1\ 10^{-14}$	$2.5\ 10^{-17}$	$6.5\ 10^{-15}$	$1.1\ 10^{-14}$	$4.5\ 10^{-11}$	$1.3\ 10^{-11}$	$1.8\ 10^{-14}$
Oldbury	$2.5\ 10^{-13}$	$2.5\ 10^{-13}$	$2.5\ 10^{-13}$	$6.2\ 10^{-16}$	$1.6\ 10^{-13}$	$2.5\ 10^{-13}$	$1.1\ 10^{-09}$	$3.1\ 10^{-10}$	$4.3\ 10^{-13}$
Sizewell	$9.0\ 10^{-14}$	$9.1\ 10^{-14}$	$9.2\ 10^{-14}$	$5.6\ 10^{-16}$	$7.4\ 10^{-14}$	$9.2\ 10^{-14}$	$9.9\ 10^{-10}$	$1.5\ 10^{-10}$	$1.6\ 10^{-13}$
Wylfa	$1.6\ 10^{-14}$	$2.6\ 10^{-14}$	$2.6\ 10^{-14}$	$7.7\ 10^{-15}$	$2.6\ 10^{-14}$	$2.6\ 10^{-14}$	$7.6\ 10^{-10}$	$4.8\ 10^{-12}$	$4.5\ 10^{-14}$

Table 13 Activity concentration per unit continuous release (Bq y^{-1}) in local compartment for selected sites (proposed data) in the 50th year

	Unfiltered seawater (Bq l^{-1})			Filtered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Site	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
Chapelcross	$1.2\ 10^{-14}$	$1.4\ 10^{-14}$	$1.4\ 10^{-14}$	$6.1\ 10^{-16}$	$1.4\ 10^{-14}$	$1.4\ 10^{-14}$	$5.9\ 10^{-11}$	$2.4\ 10^{-12}$	$2.4\ 10^{-14}$
Hartlepool	$1.8\ 10^{-13}$	$2.5\ 10^{-13}$	$2.5\ 10^{-13}$	$8.6\ 10^{-15}$	$2.4\ 10^{-13}$	$2.5\ 10^{-13}$	$1.4\ 10^{-8}$	$4.9\ 10^{-10}$	$4.3\ 10^{-13}$
Hinkley Point	$9.6\ 10^{-15}$	$1.0\ 10^{-14}$	$1.1\ 10^{-14}$	$4.8\ 10^{-17}$	$8.0\ 10^{-15}$	$1.1\ 10^{-14}$	$9.1\ 10^{-11}$	$1.8\ 10^{-11}$	$1.8\ 10^{-14}$
Oldbury	$2.3\ 10^{-13}$	$2.3\ 10^{-13}$	$2.5\ 10^{-13}$	$1.6\ 10^{-16}$	$7.6\ 10^{-14}$	$2.5\ 10^{-13}$	$3.3\ 10^{-10}$	$2.1\ 10^{-10}$	$4.3\ 10^{-13}$
Sizewell	$8.4\ 10^{-14}$	$9.1\ 10^{-14}$	$9.2\ 10^{-14}$	$1.2\ 10^{-15}$	$8.2\ 10^{-14}$	$9.2\ 10^{-14}$	$2.1\ 10^{-9}$	$1.8\ 10^{-10}$	$1.6\ 10^{-13}$
Wylfa	$2.3\ 10^{-14}$	$2.6\ 10^{-14}$	$2.6\ 10^{-14}$	$1.6\ 10^{-14}$	$2.6\ 10^{-14}$	$2.6\ 10^{-14}$	$1.3\ 10^{-9}$	$4.0\ 10^{-12}$	$4.5\ 10^{-14}$

Table 14 Ratio of activity concentration per unit continuous release (Bq y^{-1}) in local compartment for selected sites (proposed data : current DORIS default values) in the 50th year

	Unfiltered seawater (Bq l^{-1})			Filtered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Site	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
Chapelcross	1.7	1.0	1.0	0.2	1.0	1.0	0.2	0.9	1.0
Hartlepool	0.7	1.0	1.0	13.9	1.6	1.0	12.7	1.6	1.0
Hinkley Point	1.0	1.0	1.0	1.9	1.2	1.0	2.0	1.4	1.0
Oldbury	0.9	0.9	1.0	0.3	0.5	1.0	0.3	0.7	1.0
Sizewell	0.9	1.0	1.0	2.1	1.1	1.0	2.1	1.2	1.0
Wylfa	1.4	1.0	1.0	2.1	1.0	1.0	1.7	0.8	1.0

2.3 Implications for radiological impact assessments

2.3.1 Dose per unit discharge

The implications of the recommendations made in Sections 2.1.2 and 2.2.1 for dose assessments have been investigated for 6 sites: Chapelcross, Hartlepool, Hinkley Point, Oldbury, Sizewell and Wylfa. Individual and collective doses per unit discharge have been calculated for ^{3}H, ^{137}Cs and ^{241}Am. These radionuclides are used as examples only and may not actually be discharged from every site.

Table 15 presents the habit data used for the dose assessments and Tables 16 to 21 show the impact that the proposed changes to the local compartment parameter values have on the individual dose. For these calculations it was assumed that 10% of the fish consumed was caught from the local compartment and the remaining 90% was from the adjacent regional compartment and that all the shellfish came from the local compartment. It was also assumed that individuals spend 2000 hours each year on the beaches of the local compartment. These assumptions are reflected in the difference in doses calculated using the 2 sets of parameter values – for example there is a greater difference in the doses from ingestion of shellfish than in those from ingestion of fish. Differences in total dose for a given radionuclide can vary quite significantly depending on the site, with the greatest difference being an increase by a factor of about 10 for a unit discharge of ^{241}Am from Hinkley Point.

In Tables 22 and 27 it can be seen that the proposed changes to local compartment parameter values have a smaller impact on the collective dose to 500 years for the chosen radionuclides. This can be explained by the fact that most of the collective dose is derived from the consumption of seafood caught in regional compartments that are quite distant from the discharge point. Therefore, modifications to local dispersion conditions would not be expected to have a significant impact on these doses.

Table 15 Habits of adult marine food consumer

Food	Intake rate (kg y^{-1})
Fish	100
Crustaceans	20
Molluscs	20
Location	**Occupancy rate (h y^{-1})**
Local compartment	2000

Table 16 Chapelcross individual adult dose (μSv) in 50th year due to continuous unit discharges (1 Bq y^{-1})

				External beta		External gamma			
Radionuclide	Crustaceans	Fish	Molluscs	Beaches	Fishing gear	Beaches	Fishing gear	Sea spray inhalation	Total
Current DORIS parameters									
^{241}Am	$6.9\ 10^{-12}$	$2.5\ 10^{-12}$	$2.8\ 10^{-10}$	$2.0\ 10^{-17}$	$3.0\ 10^{-14}$	$1.3\ 10^{-12}$	$1.3\ 10^{-14}$	$8.4\ 10^{-15}$	$2.9\ 10^{-10}$
^{137}Cs	$1.1\ 10^{-13}$	$6.7\ 10^{-13}$	$1.1\ 10^{-13}$	$4.6\ 10^{-15}$	$1.1\ 10^{-15}$	$2.8\ 10^{-13}$	$2.8\ 10^{-15}$	$3.9\ 10^{-19}$	$1.2\ 10^{-12}$
^{3}H	$5.1\ 10^{-18}$	$9.2\ 10^{-18}$	$5.1\ 10^{-18}$	–	–	–	–	$2.3\ 10^{-21}$	$1.9\ 10^{-17}$
Proposed DORIS parameters									
^{241}Am	$1.6\ 10^{-12}$	$3.1\ 10^{-12}$	$6.3\ 10^{-11}$	$4.6\ 10^{-18}$	$6.9\ 10^{-15}$	$2.9\ 10^{-13}$	$2.9\ 10^{-15}$	$1.8\ 10^{-14}$	$6.8\ 10^{-11}$
^{137}Cs	$1.3\ 10^{-13}$	$7.1\ 10^{-13}$	$1.3\ 10^{-13}$	$5.4\ 10^{-15}$	$1.3\ 10^{-15}$	$3.3\ 10^{-13}$	$3.3\ 10^{-15}$	$4.9\ 10^{-19}$	$1.3\ 10^{-12}$
^{3}H	$6.4\ 10^{-18}$	$9.9\ 10^{-18}$	$6.4\ 10^{-18}$	–	–	–	–	$2.9\ 10^{-21}$	$2.3\ 10^{-17}$

Table 17 Hartlepool individual adult dose (μSv) in 50th year due to continuous unit discharges (1 Bq y^{-1})

				External beta		External gamma			
Radionuclide	Crustaceans	Fish	Molluscs	Beaches	Fishing gear	Beaches	Fishing gear	Sea spray inhalation	Total
Current DORIS parameters									
^{241}Am	$1.2\ 10^{-12}$	$1.3\ 10^{-13}$	$4.9\ 10^{-11}$	$6.7\ 10^{-17}$	$9.9\ 10^{-14}$	$4.2\ 10^{-12}$	$4.2\ 10^{-14}$	$3.0\ 10^{-13}$	$5.5\ 10^{-11}$
^{137}Cs	$1.2\ 10^{-12}$	$2.0\ 10^{-12}$	$1.2\ 10^{-12}$	$5.6\ 10^{-13}$	$1.4\ 10^{-13}$	$3.3\ 10^{-11}$	$3.3\ 10^{-13}$	$6.9\ 10^{-18}$	$3.9\ 10^{-11}$
^{3}H	$9.0\ 10^{-17}$	$4.5\ 10^{-17}$	$9.0\ 10^{-17}$	–	–	–	–	$4.1\ 10^{-20}$	$2.2\ 10^{-16}$
Proposed DORIS parameters									
^{241}Am	$3.4\ 10^{-12}$	$3.5\ 10^{-13}$	$1.4\ 10^{-10}$	$1.7\ 10^{-16}$	$2.5\ 10^{-13}$	$1.1\ 10^{-11}$	$1.1\ 10^{-13}$	$4.4\ 10^{-14}$	$1.5\ 10^{-10}$
^{137}Cs	$3.7\ 10^{-13}$	$6.3\ 10^{-13}$	$3.7\ 10^{-13}$	$1.7\ 10^{-13}$	$4.2\ 10^{-14}$	$1.0\ 10^{-11}$	$1.0\ 10^{-13}$	$1.4\ 10^{-18}$	$1.2\ 10^{-11}$
^{3}H	$1.8\ 10^{-17}$	$9.1\ 10^{-18}$	$1.8\ 10^{-17}$	–	–	–	–	$8.2\ 10^{-21}$	$4.5\ 10^{-17}$

Table 18 Hinkley Point individual adult dose (µSv) in 50th year due to continuous unit discharges (1 Bq y^{-1})

				External beta		External gamma			
Radionuclide	Crustaceans	Fish	Molluscs	Beaches	Fishing gear	Beaches	Fishing gear	Sea spray inhalation	Total
Current DORIS parameters									
^{241}Am	5.0 10^{-14}	4.4 10^{-14}	2.0 10^{-12}	2.7 10^{-18}	4.0 10^{-15}	1.7 10^{-13}	1.7 10^{-15}	1.2 10^{-14}	2.3 10^{-12}
^{137}Cs	5.1 10^{-14}	1.4 10^{-13}	5.1 10^{-14}	2.3 10^{-14}	5.7 10^{-15}	1.4 10^{-12}	1.4 10^{-14}	2.9 10^{-19}	1.7 10^{-12}
^{3}H	3.8 10^{-18}	2.7 10^{-18}	3.8 10^{-18}	–	–	–	–	1.7 10^{-21}	1.0 10^{-17}
Proposed DORIS parameters									
^{241}Am	4.5 10^{-13}	8.0 10^{-14}	1.8 10^{-11}	2.6 10^{-17}	3.9 10^{-14}	1.6 10^{-12}	1.6 10^{-14}	5.5 10^{-14}	2.0 10^{-11}
^{137}Cs	2.9 10^{-13}	5.4 10^{-13}	2.9 10^{-13}	1.5 10^{-13}	3.8 10^{-14}	9.3 10^{-12}	9.3 10^{-14}	1.4 10^{-18}	1.1 10^{-11}
^{3}H	1.8 10^{-17}	9.9 10^{-18}	1.8 10^{-17}	–	–	–	–	8.2 10^{-21}	4.6 10^{-17}

Table 19 Oldbury individual adult dose (µSv) in 50th year due to continuous unit discharges (1 Bq y^{-1})

				External beta		External gamma			
Radionuclide	Crustaceans	Fish	Molluscs	Beaches	Fishing gear	Beaches	Fishing gear	Sea spray inhalation	Total
Current DORIS parameters									
^{241}Am	1.2 10^{-12}	1.6 10^{-13}	4.9 10^{-11}	6.7 10^{-17}	9.9 10^{-14}	4.2 10^{-12}	4.2 10^{-14}	3.0 10^{-13}	5.5 10^{-11}
^{137}Cs	1.2 10^{-12}	2.1 10^{-12}	1.2 10^{-12}	5.6 10^{-13}	1.4 10^{-13}	3.3 10^{-11}	3.3 10^{-13}	6.9 10^{-18}	3.9 10^{-11}
^{3}H	9.0 10^{-17}	4.6 10^{-17}	9.0 10^{-17}	–	–	–	–	4.1 10^{-20}	2.3 10^{-16}
Proposed DORIS parameters									
^{241}Am	7.8 10^{-14}	4.6 10^{-14}	3.1 10^{-12}	4.7 10^{-18}	6.9 10^{-15}	3.0 10^{-13}	3.0 10^{-15}	6.5 10^{-14}	3.6 10^{-12}
^{137}Cs	1.4 10^{-13}	2.9 10^{-13}	1.4 10^{-13}	8.7 10^{-14}	2.1 10^{-14}	5.2 10^{-12}	5.2 10^{-14}	1.5 10^{-18}	6.0 10^{-12}
^{3}H	2.0 10^{-17}	1.1 10^{-17}	2.0 10^{-17}	–	–	–	–	9.2 10^{-21}	5.1 10^{-17}

Table 20 Sizewell individual adult dose (μSv) in 50th year due to continuous unit discharges (1 Bq y^{-1})

				External beta		External gamma			
Radionuclide	Crustaceans	Fish	Molluscs	Beaches	Fishing gear	Beaches	Fishing gear	Sea spray inhalation	Total
Current DORIS parameters									
^{241}Am	$1.1\ 10^{-12}$	$1.6\ 10^{-13}$	$4.5\ 10^{-11}$	$6.0\ 10^{-17}$	$8.9\ 10^{-14}$	$3.8\ 10^{-12}$	$3.8\ 10^{-14}$	$1.1\ 10^{-13}$	$5.0\ 10^{-11}$
^{137}Cs	$5.7\ 10^{-13}$	$1.1\ 10^{-12}$	$5.7\ 10^{-13}$	$2.6\ 10^{-13}$	$6.5\ 10^{-14}$	$1.6\ 10^{-11}$	$1.6\ 10^{-13}$	$2.5\ 10^{-18}$	$1.9\ 10^{-11}$
^{3}H	$3.3\ 10^{-17}$	$1.8\ 10^{-17}$	$3.3\ 10^{-17}$	–	–	–	–	$1.5\ 10^{-20}$	$8.4\ 10^{-17}$
Proposed DORIS parameters									
^{241}Am	$1.7\ 10^{-12}$	$2.0\ 10^{-13}$	$6.6\ 10^{-11}$	$8.9\ 10^{-17}$	$1.3\ 10^{-13}$	$5.6\ 10^{-12}$	$5.6\ 10^{-14}$	$7.4\ 10^{-14}$	$7.4\ 10^{-11}$
^{137}Cs	$5.1\ 10^{-13}$	$9.6\ 10^{-13}$	$5.1\ 10^{-13}$	$2.5\ 10^{-13}$	$6.0\ 10^{-14}$	$1.5\ 10^{-11}$	$1.5\ 10^{-13}$	$2.0\ 10^{-18}$	$1.7\ 10^{-11}$
^{3}H	$2.7\ 10^{-17}$	$1.5\ 10^{-17}$	$2.7\ 10^{-17}$	–	–	–	–	$1.2\ 10^{-20}$	$6.8\ 10^{-17}$

Table 21 Wylfa individual adult dose (μSv) in 50th year due to continuous unit discharges (1 Bq y^{-1})

				External beta		External gamma			
Radionuclide	Crustaceans	Fish	Molluscs	Beaches	Fishing gear	Beaches	Fishing gear	Sea spray inhalation	Total
Current DORIS parameters									
^{241}Am	$1.5\ 10^{-11}$	$1.9\ 10^{-12}$	$6.2\ 10^{-10}$	$4.6\ 10^{-17}$	$6.8\ 10^{-14}$	$2.9\ 10^{-12}$	$2.9\ 10^{-14}$	$1.9\ 10^{-14}$	$6.4\ 10^{-10}$
^{137}Cs	$2.0\ 10^{-13}$	$4.5\ 10^{-13}$	$2.0\ 10^{-13}$	$8.5\ 10^{-15}$	$2.1\ 10^{-15}$	$5.1\ 10^{-13}$	$5.1\ 10^{-15}$	$7.2\ 10^{-19}$	$1.4\ 10^{-12}$
^{3}H	$9.3\ 10^{-18}$	$6.2\ 10^{-18}$	$9.3\ 10^{-18}$	–	–	–	–	$4.2\ 10^{-21}$	$2.5\ 10^{-17}$
Proposed DORIS parameters									
^{241}Am	$3.8\ 10^{-11}$	$4.2\ 10^{-12}$	$1.5\ 10^{-9}$	$9.6\ 10^{-17}$	$1.4\ 10^{-13}$	$6.0\ 10^{-12}$	$6.0\ 10^{-14}$	$3.4\ 10^{-14}$	$1.6\ 10^{-9}$
^{137}Cs	$2.5\ 10^{-13}$	$5.3\ 10^{-13}$	$2.5\ 10^{-13}$	$8.8\ 10^{-15}$	$2.2\ 10^{-15}$	$5.3\ 10^{-13}$	$5.3\ 10^{-15}$	$9.0\ 10^{-19}$	$1.6\ 10^{-12}$
^{3}H	$1.2\ 10^{-17}$	$7.3\ 10^{-18}$	$1.2\ 10^{-17}$	–	–	–	–	$5.2\ 10^{-21}$	$3.0\ 10^{-17}$

Table 22 Collective dose (manSv) over 500 years to the UK population due to unit discharges (1 Bq y^{-1}) for a single year from Chapelcross

Radionuclide	Fish	Crustaceans	Molluscs	Beach sediment gamma	Global circulation	Total
Current DORIS parameters						
^{241}Am	$1.1\ 10^{-14}$	$3.4\ 10^{-14}$	$1.9\ 10^{-12}$	$4.9\ 10^{-17}$	–	$1.9\ 10^{-12}$
^{137}Cs	$4.3\ 10^{-15}$	$6.9\ 10^{-16}$	$7.9\ 10^{-16}$	$1.0\ 10^{-17}$	–	$5.8\ 10^{-15}$
^{3}H	$5.5\ 10^{-20}$	$3.1\ 10^{-20}$	$3.6\ 10^{-20}$	–	$2.0\ 10^{-19}$	$3.2\ 10^{-19}$
Proposed DORIS parameters						
^{241}Am	$1.8\ 10^{-14}$	$5.1\ 10^{-14}$	$2.6\ 10^{-12}$	$6.8\ 10^{-17}$	–	$2.6\ 10^{-12}$
^{137}Cs	$4.3\ 10^{-15}$	$7.1\ 10^{-16}$	$8.4\ 10^{-16}$	$1.1\ 10^{-17}$	–	$5.9\ 10^{-15}$
^{3}H	$5.5\ 10^{-20}$	$3.2\ 10^{-20}$	$3.9\ 10^{-20}$	–	$2.0\ 10^{-19}$	$3.3\ 10^{-19}$

Table 23 Collective dose (manSv) over 500 years to the UK population due to unit discharges (1 Bq y^{-1}) for a single year from Hartlepool

Radionuclide	Fish	Crustaceans	Molluscs	Beach sediment gamma	Global circulation	Total
Current DORIS parameters						
^{241}Am	$1.3\ 10^{-15}$	$3.1\ 10^{-15}$	$1.8\ 10^{-14}$	$1.9\ 10^{-17}$	–	$2.3\ 10^{-14}$
^{137}Cs	$2.0\ 10^{-15}$	$2.0\ 10^{-15}$	$2.1\ 10^{-16}$	$9.0\ 10^{-17}$	–	$4.3\ 10^{-15}$
^{3}H	$2.9\ 10^{-20}$	$1.4\ 10^{-19}$	$1.5\ 10^{-20}$	–	$2.0\ 10^{-19}$	$3.9\ 10^{-19}$
Proposed DORIS parameters						
^{241}Am	$1.2\ 10^{-15}$	$7.4\ 10^{-15}$	$3.5\ 10^{-14}$	$4.5\ 10^{-17}$	–	$4.3\ 10^{-14}$
^{137}Cs	$2.0\ 10^{-15}$	$6.7\ 10^{-16}$	$8.4\ 10^{-17}$	$3.1\ 10^{-17}$	–	$2.8\ 10^{-15}$
^{3}H	$2.9\ 10^{-20}$	$3.3\ 10^{-20}$	$4.1\ 10^{-21}$	–	$2.0\ 10^{-19}$	$2.7\ 10^{-19}$

Table 24 Collective dose (manSv) over 500 years to the UK population due to unit discharges (1 Bq y^{-1}) for a single year from Hinkley Point

Radionuclide	Fish	Crustaceans	Molluscs	Beach sediment gamma	Global circulation	Total
Current DORIS parameters						
^{241}Am	$1.0\ 10^{-15}$	$2.6\ 10^{-15}$	$6.1\ 10^{-14}$	$7.5\ 10^{-17}$	–	$6.5\ 10^{-14}$
^{137}Cs	$6.0\ 10^{-16}$	$1.2\ 10^{-16}$	$7.5\ 10^{-17}$	$2.7\ 10^{-17}$	–	$8.3\ 10^{-16}$
^{3}H	$8.4\ 10^{-21}$	$7.0\ 10^{-21}$	$4.3\ 10^{-21}$	–	$2.0\ 10^{-19}$	$2.2\ 10^{-19}$
Proposed DORIS parameters						
^{241}Am	$9.2\ 10^{-16}$	$2.5\ 10^{-15}$	$6.0\ 10^{-14}$	$7.4\ 10^{-17}$	–	$6.3\ 10^{-14}$
^{137}Cs	$6.0\ 10^{-16}$	$1.7\ 10^{-16}$	$1.0\ 10^{-16}$	$4.0\ 10^{-17}$	–	$9.0\ 10^{-16}$
^{3}H	$8.4\ 10^{-21}$	$9.2\ 10^{-21}$	$5.6\ 10^{-21}$	–	$2.0\ 10^{-19}$	$2.3\ 10^{-19}$

Table 25 Collective dose (manSv) over 500 years to the UK population due to unit discharges (1 Bq y^{-1}) for a single year from Oldbury

Radionuclide	Fish	Crustaceans	Molluscs	Beach sediment gamma	Global circulation	Total
Current DORIS parameters						
^{241}Am	$1.0\ 10^{-15}$	$3.0\ 10^{-15}$	$7.1\ 10^{-14}$	$8.8\ 10^{-17}$	–	$7.5\ 10^{-14}$
^{137}Cs	$6.0\ 10^{-16}$	$4.4\ 10^{-16}$	$2.7\ 10^{-16}$	$1.0\ 10^{-16}$	–	$1.4\ 10^{-15}$
^{3}H	$8.4\ 10^{-21}$	$3.1\ 10^{-20}$	$1.9\ 10^{-20}$	–	$2.0\ 10^{-19}$	$2.6\ 10^{-19}$
Proposed DORIS parameters						
^{241}Am	$9.7\ 10^{-16}$	$2.5\ 10^{-15}$	$6.0\ 10^{-14}$	$7.4\ 10^{-17}$	–	$6.4\ 10^{-14}$
^{137}Cs	$5.7\ 10^{-16}$	$1.8\ 10^{-16}$	$1.1\ 10^{-16}$	$4.8\ 10^{-17}$	–	$9.0\ 10^{-16}$
^{3}H	$7.9\ 10^{-21}$	$1.8\ 10^{-20}$	$1.1\ 10^{-20}$	–	$2.0\ 10^{-19}$	$2.4\ 10^{-19}$

Table 26 Collective dose (manSv) over 500 years to the UK population due to unit discharges (1 Bq y^{-1}) for a single year from Sizewell

Radionuclide	Fish	Crustaceans	Molluscs	Beach sediment gamma	Global circulation	Total
Current DORIS parameters						
^{241}Am	$1.3\ 10^{-15}$	$1.7\ 10^{-15}$	$2.2\ 10^{-13}$	$5.9\ 10^{-17}$	–	$2.2\ 10^{-13}$
^{137}Cs	$2.5\ 10^{-15}$	$2.5\ 10^{-16}$	$8.3\ 10^{-16}$	$6.8\ 10^{-17}$	–	$3.6\ 10^{-15}$
^{3}H	$3.6\ 10^{-20}$	$1.3\ 10^{-20}$	$4.5\ 10^{-20}$	–	$2.0\ 10^{-19}$	$3.0\ 10^{-19}$
Proposed DORIS parameters						
^{241}Am	$1.2\ 10^{-15}$	$1.7\ 10^{-15}$	$2.2\ 10^{-13}$	$5.8\ 10^{-17}$	–	$2.2\ 10^{-13}$
^{137}Cs	$2.6\ 10^{-15}$	$2.3\ 10^{-16}$	$7.6\ 10^{-16}$	$6.4\ 10^{-17}$	–	$3.6\ 10^{-15}$
^{3}H	$3.9\ 10^{-20}$	$1.2\ 10^{-20}$	$3.9\ 10^{-20}$	–	$2.0\ 10^{-19}$	$2.9\ 10^{-19}$

Table 27 Collective dose (manSv) over 500 years to the UK population due to unit discharges (1 Bq y^{-1}) for a single year from Wylfa

Radionuclide	Fish	Crustaceans	Molluscs	Beach sediment gamma	Global circulation	Total
Current DORIS parameters						
^{241}Am	$1.0\ 10^{-14}$	$5.3\ 10^{-14}$	$9.2\ 10^{-13}$	$2.3\ 10^{-17}$	–	$9.8\ 10^{-13}$
^{137}Cs	$4.2\ 10^{-15}$	$9.4\ 10^{-16}$	$5.2\ 10^{-16}$	$6.6\ 10^{-18}$	–	$5.7\ 10^{-15}$
^{3}H	$5.4\ 10^{-20}$	$4.2\ 10^{-20}$	$2.3\ 10^{-20}$	–	$2.0\ 10^{-19}$	$3.2\ 10^{-19}$
Proposed DORIS parameters						
^{241}Am	$1.6\ 10^{-14}$	$1.1\ 10^{-13}$	$1.8\ 10^{-12}$	$4.4\ 10^{-17}$	–	$1.9\ 10^{-12}$
^{137}Cs	$4.2\ 10^{-15}$	$1.0\ 10^{-15}$	$5.4\ 10^{-16}$	$6.6\ 10^{-18}$	–	$5.8\ 10^{-15}$
^{3}H	$5.4\ 10^{-20}$	$4.6\ 10^{-20}$	$2.4\ 10^{-20}$	–	$2.0\ 10^{-19}$	$3.3\ 10^{-19}$

2.3.2 Doses to people residing near Hinkley Point from actual discharges

Doses to adults were calculated for key radionuclides using actual discharge data for 2017 for Hinkley Point taken from the RIFE report (Environment Agency et al, 2018). The generic habit data used for the assessment is as described in Section 2.3.1. The results are shown in Table 28. It can be seen that the total annual dose estimated using the proposed DORIS model parameter values has increased by a factor of about 7 to 0.15 µSv. This is considerably less than the annual dose constraint for a single source of 300 µSv and also less than the 10 µSv annual dose that the Environment Agency considers to be potentially of no regulatory concern.

Table 28 Indicative individual annual doses to adults living near Hinkley Point (μSv) in 50th year due to continuous discharges at 2017 levels

Radionuclide	Annual discharge 2017 (Bq y^{-1})	Crustaceans	Fish	Molluscs	External beta		External gamma		Sea spray inhalation	Total
					Beaches	Fishing gear	Beaches	Fishing gear		
Current DORIS parameters										
^{60}Co	$6.71\ 10^{8}$	$1.1\ 10^{-4}$	$2.2\ 10^{-5}$	$5.4\ 10^{-5}$	$3.1\ 10^{-6}$	$1.5\ 10^{-6}$	$4.0\ 10^{-3}$	$4.0\ 10^{-5}$	$4.0\ 10^{-10}$	$4.3\ 10^{-3}$
^{134}Cs	$3.99\ 10^{9}$	$2.9\ 10^{-4}$	$7.4\ 10^{-4}$	$2.9\ 10^{-4}$	$1.2\ 10^{-5}$	$2.9\ 10^{-6}$	$2.9\ 10^{-3}$	$2.9\ 10^{-5}$	$1.6\ 10^{-9}$	$4.2\ 10^{-3}$
^{137}Cs	$5.13\ 10^{9}$	$2.6\ 10^{-4}$	$7.2\ 10^{-4}$	$2.6\ 10^{-4}$	$1.2\ 10^{-4}$	$2.9\ 10^{-5}$	$7.2\ 10^{-3}$	$7.2\ 10^{-5}$	$1.5\ 10^{-9}$	$8.6\ 10^{-3}$
^{55}Fe	$1.18\ 10^{9}$	$3.5\ 10^{-5}$	$5.0\ 10^{-6}$	$2.1\ 10^{-4}$	0.0	0.0	$2.7\ 10^{-6}$	$2.7\ 10^{-8}$	$2.7\ 10^{-11}$	$2.5\ 10^{-4}$
^{3}H	$2.55\ 10^{14}$	$9.6\ 10^{-4}$	$6.8\ 10^{-4}$	$9.6\ 10^{-4}$	0.0	0.0	0.0	0.0	$4.4\ 10^{-7}$	$2.6\ 10^{-3}$
^{35}S	$2.68\ 10^{11}$	$3.7\ 10^{-5}$	$4.3\ 10^{-5}$	$1.5\ 10^{-4}$	$3.5\ 10^{-8}$	$1.4\ 10^{-7}$	0.0	0.0	$2.0\ 10^{-8}$	$2.3\ 10^{-4}$
^{90}Sr	$1.48\ 10^{10}$	$1.4\ 10^{-4}$	$1.1\ 10^{-4}$	$7.2\ 10^{-5}$	$6.5\ 10^{-4}$	$5.6\ 10^{-5}$	$2.6\ 10^{-8}$	$2.6\ 10^{-10}$	$3.4\ 10^{-8}$	$1.0\ 10^{-3}$
Total		$1.8\ 10^{-3}$	$2.3\ 10^{-3}$	$2.0\ 10^{-3}$	$7.8\ 10^{-4}$	$9.0\ 10^{-5}$	$1.4\ 10^{-2}$	$1.4\ 10^{-4}$	$5.0\ 10^{-7}$	$2.1\ 10^{-2}$
Proposed DORIS parameters										
^{60}Co	$6.71\ 10^{8}$	$9.1\ 10^{-4}$	$5.9\ 10^{-5}$	$4.5\ 10^{-4}$	$3.5\ 10^{-5}$	$1.7\ 10^{-5}$	$4.6\ 10^{-2}$	$4.6\ 10^{-4}$	$1.7\ 10^{-9}$	$4.8\ 10^{-2}$
^{134}Cs	$3.99\ 10^{9}$	$1.7\ 10^{-3}$	$3.0\ 10^{-3}$	$1.7\ 10^{-3}$	$9.7\ 10^{-5}$	$2.4\ 10^{-5}$	$2.4\ 10^{-2}$	$2.4\ 10^{-4}$	$7.5\ 10^{-9}$	$3.0\ 10^{-2}$
^{137}Cs	$5.13\ 10^{9}$	$1.5\ 10^{-3}$	$2.8\ 10^{-3}$	$1.5\ 10^{-3}$	$7.9\ 10^{-4}$	$1.9\ 10^{-4}$	$4.8\ 10^{-2}$	$4.8\ 10^{-4}$	$7.0\ 10^{-9}$	$5.5\ 10^{-2}$
^{55}Fe	$1.18\ 10^{9}$	$2.7\ 10^{-4}$	$1.6\ 10^{-5}$	$1.6\ 10^{-3}$	0.0	0.0	$3.0\ 10^{-5}$	$3.0\ 10^{-7}$	$1.1\ 10^{-10}$	$2.0\ 10^{-3}$
^{3}H	$2.55\ 10^{14}$	$4.6\ 10^{-3}$	$2.5\ 10^{-3}$	$4.6\ 10^{-3}$	0.0	0.0	0.0	0.0	$2.1\ 10^{-6}$	$1.2\ 10^{-2}$
^{35}S	$2.68\ 10^{11}$	$1.8\ 10^{-4}$	$1.9\ 10^{-4}$	$7.2\ 10^{-4}$	$1.7\ 10^{-7}$	$6.9\ 10^{-7}$	0.0	0.0	$1.0\ 10^{-7}$	$1.1\ 10^{-3}$
^{90}Sr	$1.48\ 10^{10}$	$7.5\ 10^{-4}$	$4.1\ 10^{-4}$	$3.8\ 10^{-4}$	$3.8\ 10^{-3}$	$3.3\ 10^{-4}$	$1.5\ 10^{-7}$	$1.5\ 10^{-9}$	$1.6\ 10^{-7}$	$5.7\ 10^{-3}$
Total		$9.9\ 10^{-3}$	$9.0\ 10^{-3}$	$1.1\ 10^{-2}$	$4.8\ 10^{-3}$	$5.7\ 10^{-4}$	$1.2\ 10^{-1}$	$1.2\ 10^{-3}$	$2.4\ 10^{-6}$	$1.5\ 10^{-1}$

3. Sellafield

3.1 Local compartment dimensions and flows

3.1.1 Review of data and recommendations

Table 29 contains local marine compartment parameter values for Sellafield currently used in DORIS and those taken from the EA report (Dewar et al., 2011). Although the EA report does not include data for the coastal region immediately adjacent to the Sellafield site, data are presented for the coastal region near Whitehaven and Workington. It is notable that the volumetric exchange rate for the Whitehaven/Workington coastal compartment (4.1 10^{10} m^3 y^{-1}) is an order of magnitude lower than that currently used in DORIS (5.0 10^{11} m^3 y^{-1}) even though the 2 compartment volumes are similar. The dilution factors calculated using these VERs are 8.9 10^{-9} Bq m^{-3} per Bq d^{-1} and 7.3 10^{-10} Bq m^{-3} per Bq d^{-1}, respectively; these factors compare with a value based on measurements of about 3 10^{-9} Bq m^{-3} per Bq d^{-1} (Baxter and Camplin, 1993). The current DORIS value was derived from an internal review of flow rates in an earlier version of the marine dispersion model in which it was assumed that the flow rate from the local compartment to the Cumbrian waters compartment was the same as the net flow out of the Cumbrian waters compartment, meaning 4.8 10^{11} m^3 y^{-1}, hence the high VER (5 10^{11} m^3 y^{-1}) currently used in the DORIS model for the Sellafield local compartment. However, the net flow out of the Cumbrian waters compartment in (Smith and Simmonds, 2009) is 1.1 10^{11} m^3 y^{-1}. The calculated residual flow for the Sellafield local compartment using the DORIS default data (Table 29) suggests a value of 0.16 m s^{-1} which is high when compared to the typical range for the UK coast (0.01 and 0.05 m s^{-1}) (Aldridge, 2006; Round, 1998). Using the EA data from Table 29 a value of 0.012 m s^{-1} can be derived which is at the lower end of the typical range.

In addition, normalised activity concentrations (NACs) of about 7 mBq l^{-1} per TBq y^{-1} of ^{3}H discharged, ie 2.6 10^{-9} Bq m^{-3} per Bq d^{-1}, were calculated by (Hunt et al, 2013). Comparing this value with the dilution factor based on proposed parameter values in Table 29 (meaning 3.6 10^{-9} Bq m^{-3} per Bq d^{-1}) the new model might be expected to predict activity concentrations in filtered seawater that are almost 50% greater than measured values, all other factors being equal. NACs for ^{99}Tc and ^{137}Cs are also reported by Hunt et al. (2013) as about 5 and 6 mBq l^{-1} per TBq y^{-1}, respectively. The NACs reported by Hunt are in good agreement with the value reported in (Baxter and Camplin, 1993).

In the European Commission report Radiation Protection 72 (Simmonds et al, 1995) a VER of 8 10^{10} m^3 y^{-1} is given for the local Windscale compartment. This value was derived in NRPB-R119 (Camplin et al, 1982) based on assumptions about the number of exchanges per year and the size of the local compartment.

It is recommended that a volumetric exchange rate of 1 10^{11} m^3 y^{-1}, equivalent to the net flow out of the Cumbrian waters compartment, is used for Sellafield. In addition, it is proposed that the volume and the depth of the Sellafield local compartment should not change from the current defaults but the coastline length should decrease by a factor of 2 which means the new compartment extends to 10 km off shore rather than 5 km. These changes imply a dilution factor of 3.6 10^{-9} Bq m^{-3} per Bq d^{-1} and a residual flow of about 0.016 m s^{-1}. The impact of the proposed parameter values on model predictions is investigated below.

Table 29 Local marine compartment parameter values for Sellafield (Smith and Simmonds, 2009)

Type	Depth (m)	Volume (m^3)	Volumetric exchange rate (m^3 y^{-1})	Coastline length (m)	Dilution factor (Bq m^{-3} per Bq d^{-1})	Residual flow (m s^{-1})
Current DORIS data	2.0 10^1	2.0 10^9	5.0 10^{11}	2.0 10^4	7.3 10^{-10}	1.6 10^{-1}
EA report (Workington/Whitehaven coast)	1.1 10^1	1.1 10^9	4.1 10^{10}	1.0 10^4	8.9 10^{-9}	1.2 10^{-2}
Proposed	2.0 10^1	2.0 10^9	1.0 10^{11}	1.0 10^4	3.6 10^{-9}	1.6 10^{-2}

3.1.2 Model results using proposed values

An investigation of the impact of using the proposed local compartment parameter values for the Sellafield site was carried out for 3 radionuclides. Table 30 shows the activity concentrations of ^{241}Am, ^{137}Cs and ^{3}H in unfiltered seawater and seabed sediments in the 50th year of a continuous discharge of 1 Bq y^{-1} from Sellafield, calculated using the current DORIS default parameter values and proposed new values. Table 30 also shows the ratios between the activity concentrations calculated using the 2 sets of data. For a given radionuclide the ratios are essentially the same for both media. The ratios are also similar for different radionuclides in the same media. It is interesting to note that the ratio between the 2 sets of values is about 2.3 whereas the ratio of the dilution factors is 5. This is because as the VER increases the activity concentration in the local compartment approaches that in the regional compartment. A point is reached where the local and regional compartments are in equilibrium and any further increase in VER has little effect on activity concentrations in the local compartment.

It is important to make sure that model predictions using the proposed local compartment parameter values are consistent with environmental measurements. A comparison of activity concentrations in some regional compartments has been carried out for a continuous discharge of 1 Bq y^{-1} from Sellafield for 50 years (see Table 31). This shows that for ^{3}H and ^{137}Cs the proposed changes have very little effect on model predictions. For ^{241}Am, which has a much higher k_d, the difference is a decrease by about 30%.

Table 30 Activity concentration in the 50th year in the local compartment per unit continuous release (1 Bq y^{-1}) from Sellafield

	Unfiltered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Parameter values	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
Current DORIS data	2.8 10^{-15}	6.2 10^{-15}	6.2 10^{-15}	1.8 10^{-10}	1.2 10^{-12}	1.1 10^{-14}
Proposed	6.5 10^{-15}	1.4 10^{-14}	1.4 10^{-14}	4.3 10^{-10}	2.8 10^{-12}	2.5 10^{-14}
Ratio	2.3	2.3	2.3	2.3	2.3	2.3

Table 31 Activity concentrations in the 50th year in selected regional compartments per unit continuous release (1 Bq y^{-1}) from Sellafield

	Unfiltered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
Compartment	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
Current DORIS data						
Cumbrian waters	1.1 10^{-15}	4.2 10^{-15}	4.2 10^{-15}	5.5 10^{-11}	7.9 10^{-13}	7.2 10^{-15}
Irish Sea NE	5.0 10^{-16}	2.9 10^{-15}	2.9 10^{-15}	3.0 10^{-11}	4.4 10^{-13}	4.9 10^{-15}
L&M Bay	4.2 10^{-17}	1.7 10^{-15}	1.7 10^{-15}	3.1 10^{-12}	3.2 10^{-13}	2.9 10^{-15}
Proposed						
Cumbrian waters	7.8 10^{-16}	4.2 10^{-15}	4.2 10^{-15}	3.9 10^{-11}	7.9 10^{-13}	7.2 10^{-15}
Irish Sea NE	3.5 10^{-16}	2.9 10^{-15}	2.9 10^{-15}	2.1 10^{-11}	4.4 10^{-13}	4.9 10^{-15}
L&M Bay	2.9 10^{-17}	1.7 10^{-15}	1.7 10^{-15}	2.2 10^{-12}	3.2 10^{-13}	2.9 10^{-15}

3.2 Local compartment sedimentation parameters

3.2.1 Review of data and recommendations

The current default suspended sediment load (SSL) for the Sellafield local compartment in DORIS is 6-times lower than the value reported by the EA (Dewar et al, 2011), although the EA measurements were made some 20 km further along the coast at Workington and Whitehaven which is considered to be outside of the Sellafield local compartment. It is also notable that the DORIS SSL value for the local compartment is lower than that for the regional compartment (Table 32). In general sedimentation loads are expected to be at least as great in the local compartment as the regional compartment due to the greater degree of turbulence in the sea along the coast. The value presented in the EA report (Dewar et al, 2011) for Workington / Whitehaven is 3-times greater than the current DORIS value for the regional compartment. Therefore, it is concluded that the SSL for the Sellafield local compartment should be increased and a value of 3.1 10^{-5} t m^{-3} is recommended. Although this value is based on that given in the EA report which is derived from measurements from the Workington/Whitehaven region it is considered to be more consistent with the regional compartment value used in DORIS.

The sedimentation rate (SR) for the Sellafield local compartment in DORIS is 1 10^{-2} t m^{-2} y^{-1} while the value given in the EA report for Workington / Whitehaven is significantly less at 6 10^{-4} t m^{-2} y^{-1}. The expectation is that the sedimentation rate should increase as distance from the coast decreases which suggests that in this case the EA value is inconsistent with the value used for the regional compartment. Therefore, if the value for the regional compartment is not going to be changed the SR for the Sellafield local compartment should be greater than 6 10^{-3} t m^{-2} y^{-1}. It is recommended that a sedimentation rate of 7.0 10^{-3} t m^{-2} y^{-1} is used.

It is also recommended that the DORIS default values for sediment density and pore water diffusion coefficient are retained meaning 2.6 t m^{-3} and 3.2 10^{-2} m^2 y^{-1}, respectively.

Table 32 Comparison of local compartment suspended sediment loads (SSL, t m^{-3}) and sedimentation rates (SR, t m^{-2} y^{-1}) for Sellafield

Parameter	DORIS regional compartment	Local compartment		
		EA report	Current DORIS	Proposed
SSL	1.0 10^{-5}	3.1 10^{-5}	5.0 10^{-6}	3.1 10^{-5}
SR	6.0 10^{-3}	6.0 10^{-4}	1.0 10^{-2}	7.0 10^{-3}

3.2.2 Model results using proposed values

The sensitivity of the model results to changes in these parameters has been investigated for 3 representative radionuclides. Table 33 shows that activity concentrations of ^{241}Am in unfiltered water increase when the proposed sedimentation parameters are used while concentrations in filtered water and seabed sediments decrease. This is primarily due to the increase in SSL by a factor of 6 and the high k_d of ^{241}Am which leads to more activity becoming associated with suspended sediments. Although the activity concentration on suspended sediments decreases in proportion to the activity concentration in filtered water the total mass of suspended sediments in the water column increases which gives rise to an increase in the unfiltered water concentration.

Table 33 Activity concentration in the 50th year in Sellafield local compartment per unit continuous release (1 Bq y^{-1}) from Sellafield

Parameter values	Unfiltered seawater (Bq l^{-1})			Filtered seawater (Bq l^{-1})			Seabed sediment (Bq kg^{-1})		
	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H	^{241}Am	^{137}Cs	^{3}H
DORIS defaults	2.8 10^{-15}	6.2 10^{-15}	6.2 10^{-15}	1.8 10^{-15}	6.2 10^{-15}	6.2 10^{-15}	1.8 10^{-10}	1.2 10^{-12}	1.1 10^{-14}
Proposed	3.2 10^{-15}	6.2 10^{-15}	6.2 10^{-15}	7.8 10^{-16}	6.1 10^{-15}	6.2 10^{-15}	7.7 10^{-11}	1.2 10^{-12}	1.1 10^{-14}
Ratio	1.1	1.0	1.0	0.4	1.0	1.0	0.4	1.0	1.0

3.3 Implications for radiological impact assessments

The implications of the proposed changes to the DORIS model for the assessment of doses from Sellafield discharges were investigated further by calculating environmental activity concentrations using historical discharges and doses using both historical and unit discharges for some key radionuclides.

3.3.1 Environmental activity concentrations

The current default values for the DORIS parameters for the Sellafield site were previously selected by means of a validation exercise to ensure that the activity concentrations predicted by the model fit with the available measurement data (Jones et al, 2003). This validation exercise has been revisited in this review and the results from the original work have been recalculated with the current version of the model using both default parameter values and the proposed changes to these values (see Tables 29 and 31). The results, presented in

Figures 1 to 10, are based on historical discharges from Sellafield and have been compared with measured activity concentrations of ^{3}H, ^{60}Co ^{99}Tc, ^{137}Cs, ^{239}Pu and ^{241}Am in filtered sea water and seabed sediments taken from (Hunt et al, 2013). Model results for the regional compartment using current local compartment parameter values are very similar to those for the regional compartment using the proposed values and therefore have not been included in the figures.

In most cases using the proposed parameter values in the model overpredicts activity concentrations compared to the measurement data for both filtered seawater and seabed sediments. However, it should be noted that the measurements were not always taken in the immediate vicinity of the discharge point, although they have been used in previous work to represent local compartment concentrations. For example, some measurements were taken at St Bees which is located some 10 km north of Sellafield and outside the boundaries of the local compartment which can be considered to extend 5 km north and south of the Sellafield discharge point. It might be expected, therefore, that activity concentrations in the local compartment as calculated by the model should be higher than the measured values.

Activity concentrations of ^{3}H in filtered seawater in the local compartment calculated using the proposed parameter values are generally a factor of 2 to 3 higher than the measured values which were taken at St Bees, meaning outside the local compartment (Figure 1). Measurements at St Bees, taken in the mid-1990s (Hunt et al, 2013), suggest activity concentrations in seawater of about 10 to 20 Bq l^{-1}. However, measurements of tritium activity concentrations for 1993 taken near to the Sellafield site given in the Aquatic Environment Monitoring Report 42 (MAFF, 1994) are recorded as being greater than 20 Bq l^{-1}. This value compares to the model prediction of 32 Bq l^{-1} for 1993 using proposed parameter values. In general, the measurements from St Bees lie closer to the model predictions for the regional compartment based on proposed parameter values. Activity concentrations of ^{3}H in seabed sediments calculated using the proposed parameter values were also a factor of 2 to 3 higher than those predicted by the current version of the model (see Figure 2). It should be noted that all the model results include the activity in the pore water which accounts for about 50% of the activity in the seabed sediment for ^{3}H. Unfortunately, no measurement data for ^{3}H in seabed sediments were found in the literature.

Activity concentrations of ^{137}Cs in filtered seawater and seabed sediments calculated using the model with the proposed parameter values are also higher than those calculated using the current values. Any contribution to the activity in sediment from the pore water is not significant. For filtered seawater the activity concentrations are a factor of about 2 to 3 greater than the measurements taken at St Bees (Hunt et al, 2013) (see Figure 3). However, Hunt et al. (2013) also reports a peak activity concentration of ^{137}Cs in filtered seawater at Seascale of about 64 Bq l^{-1} for 1975 which is more consistent with the prediction of the model with the proposed parameter values. For sediments the predictions of the model with the proposed parameter values are reasonably consistent with the measurements taken at Newbiggin (Hunt et al, 2013), while the current model appears to underestimate these concentrations (see Figure 4). Other measurement datasets (MAFF, 1979) give activity concentrations of ^{137}Cs in seabed sediments of about 12 kBq kg^{-1} in 1977 at Whitehaven which is approximately 50% greater than the prediction using the proposed values (see Figure 4). The RIFE report for 2012 (Environment Agency et al, 2013) reports that an activity concentration of approximately 340 Bq kg^{-1} of ^{137}Cs was measured in dry sediment in 2012 at Newbiggin, while the model with proposed parameter values gives an activity concentration of about 50 Bq kg^{-1} for 2012. This suggests that DORIS may not represent the sedimentation process sufficiently well to model the long term build-up of radionuclides in sediments. However, it is reassuring to note that measurements generally lie between the modelled values for the local and regional compartments if proposed parameter values are used.

For ^{239}Pu the activity concentrations in filtered seawater of the local compartment have been compared with measurements made at St Bees which is outside the local compartment (see Figure 5). The calculated activity concentrations using the proposed parameter values overestimate measurements by a factor of about 5 in 1978 but this decreases until the model underestimates measurements by almost a factor of 2 in 1998. This suggests that the model may not be accounting adequately for the remobilisation of activity from seabed sediments but unfortunately data for more recent years have not been found to test this further. It can also be seen that model predictions for the local compartment using the proposed parameter values are closer to those derived using the current values than was the case for ^{3}H or ^{137}Cs. Slightly higher values of ^{239}Pu activity concentrations in filtered seawater were reported by Leonard et al. (Leonard et al, 1999), who measured values of about 0.05 Bq l^{-l} near to the Sellafield site in the early 1970s. Activity concentrations in seabed sediments predicted by the model using the proposed parameter values consistently overestimate measurements by a factor of about 2 between 1978 and 1998 (Figure 6). More recently, the RIFE report for 2012 (Environment Agency et al, 2013) reports an average activity concentration of 640 Bq kg^{-1} in seabed sediments at Newbiggin which is greater than the model predictions using the proposed parameter values by a factor of about 5 and suggests once more that the model may not represent the sedimentation process sufficiently well to model long term build-up in sediments.

For ^{241}Am the model with the proposed parameter values predicts activity concentrations in filtered seawater that are about the same as those from the current model (see Figure 7). Measured values are about an order of magnitude lower than both proposed and current model predictions during the late 1970s and early 1980s although this difference decreases to such an extent that the model underpredicts measurements by a factor of almost 2 in 1998. Measurements of activity concentrations in filtered seawater post 1998 are only reported in RIFE as 'less than' values and as such cannot be used to investigate this trend further. For seabed sediments activity concentrations from the new model are about a factor of 2 to 3 greater than measurements for years 1975 to 1995 (see Figure 7). Thereafter, this difference decreases and by 2010 model predictions underestimate the measurements by a factor of about 3 (Figure 8). More recently, the RIFE report for 2012 (Environment Agency et al, 2013) reports that an activity concentration of approximately 1400 Bq kg^{-1} of ^{241}Am was measured in dry sediment at Newbiggin. This is about a factor of 7 greater than that predicted by the model with proposed parameter values and is further evidence that the activity concentrations in sediments predicted by the model are decreasing too quickly. It should be noted that measured and predicted activity concentrations of ^{241}Am include ingrowth from ^{241}Pu which, from the mid 1990s, accounts for about 50% of the total activity of ^{241}Am in filtered seawater and seabed sediments.

Figure 9 shows model predictions and measured activity concentrations of ^{99}Tc in filtered seawater. A peak concentration of 1.1 Bq l^{-1} is recorded by Hunt et al. (Hunt et al, 2013) for 1996. This compares with the calculated peak value of 2.6 Bq l^{-1} in 1995 from the model using proposed local compartment parameter values. Activity concentrations in seabed sediments from the model using proposed parameter values are about a factor of 2 greater than those from the current model. Measured activity concentrations of ^{99}Tc in seabed sediments are not reported by Hunt et al. (Hunt et al, 2013).

This comparison suggests that for those radionuclides that do not adsorb strongly to sediments the model with the proposed parameter values for the Sellafield local compartment predicts activity concentrations in filtered seawater within a factor of 2 to 3 of the current model setup. For seabed sediments the model results appear to fit the measurements quite well although there is some suggestion that the model underpredicts the build-up of activity in sediments in the longer term. However, care must be taken when making such comparisons to ensure that the measurements are representative of the region being modelled.

For radionuclides for which adsorption to sediments is important the model performs less well if the proposed parameter values for the Sellafield local compartment are adopted and tends to overpredict activity concentrations in seawater and seabed sediments in the short and medium term following the discharge. As discharges have reduced since the 1970s the remobilisation of activity from sediments has become a relatively more important source of radionuclides entering the water column and it would appear that the model tends to underpredict this contribution. Hunt et al. (2013) has shown that the NAC for such radionuclides in seawater is relatively small at about 0.6 mBq l^{-1} per TBq y^{-1} for ^{239}Pu (meaning 2.2 10^{-10} Bq m^{-3} per Bq d^{-1}). Given that the level of discharge in the late 1990s was about 0.1 TBq y^{-1} activity concentrations in filtered water from discharges alone are likely to be of the order of 0.06 mBq l^{-1} whereas measurements are of the order of 2 mBq l^{-1}. This suggests that much of the activity present in seawater since discharges were reduced is due to remobilisation.

Further results are presented and discussed in Appendix A, which includes a comparison of measured and predicted activity concentrations in seawater, sediments and biota in the Sellafield region for the 1990s. The measurements and model results from CSERAM (Aldridge, 1998) and MARINA II (European Commission, 2002) were taken from (Jones et al, 2003), while the DORIS results were calculated using the proposed Sellafield set of parameters given in Tables 29 and 31.

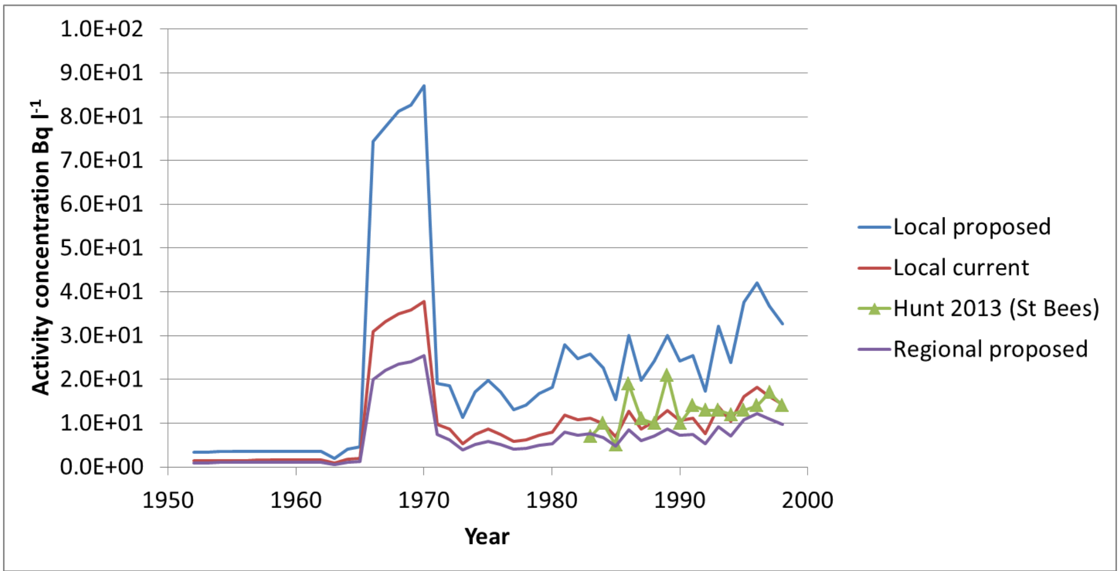

Figure 1 Activity concentrations (Bq l^{-1}) of ^{3}H in filtered seawater for Sellafield compartments

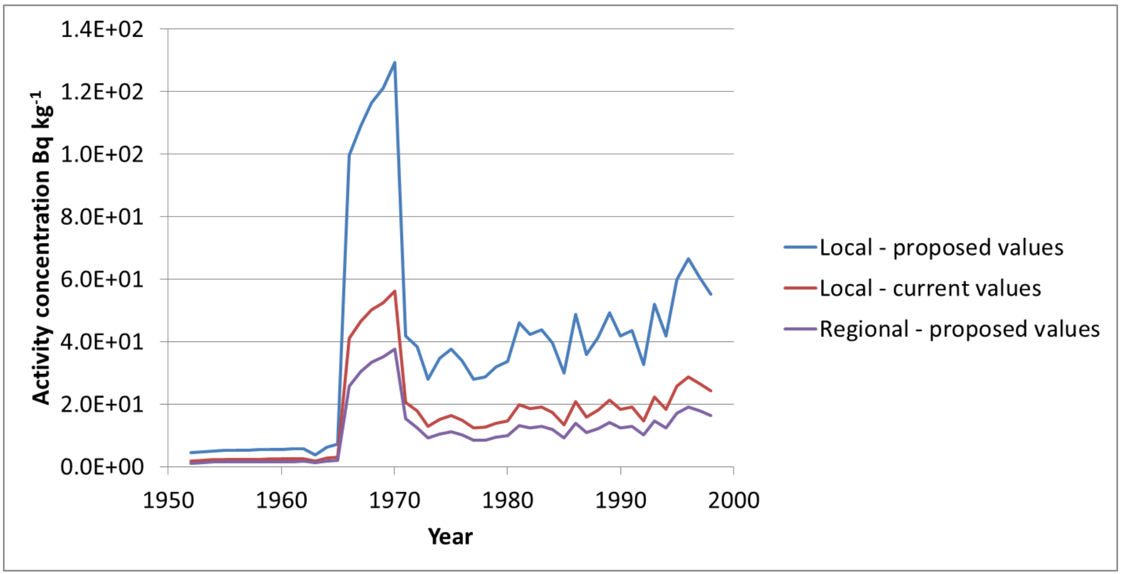

Figure 2 Activity concentrations (Bq kg^{-1}) of ^{3}H in seabed sediments for Sellafield compartments

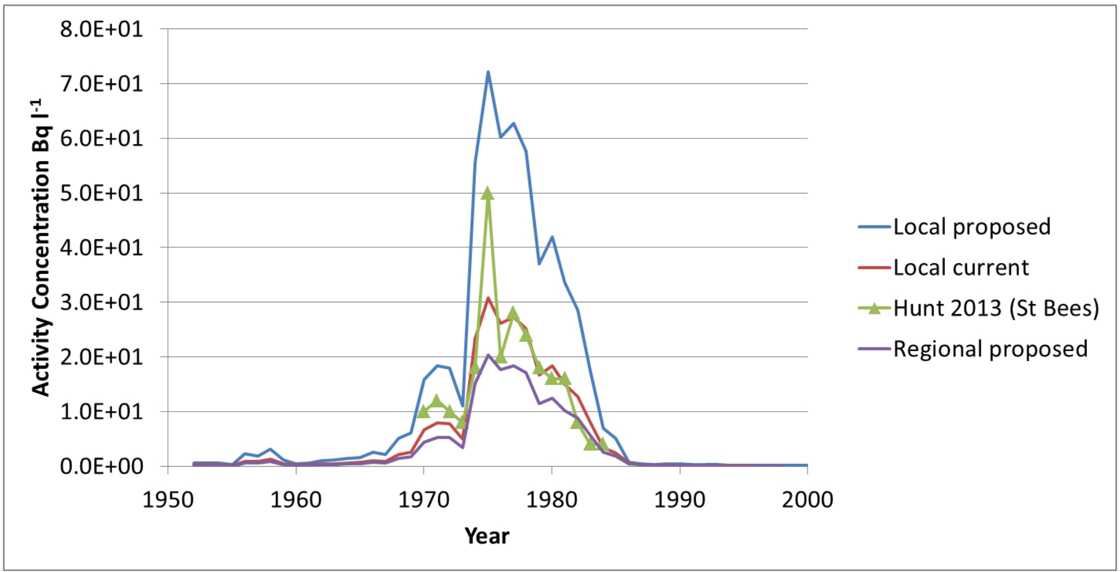

Figure 3 Activity concentrations (Bq l^{-1}) of ^{137}Cs in filtered seawater for Sellafield compartments

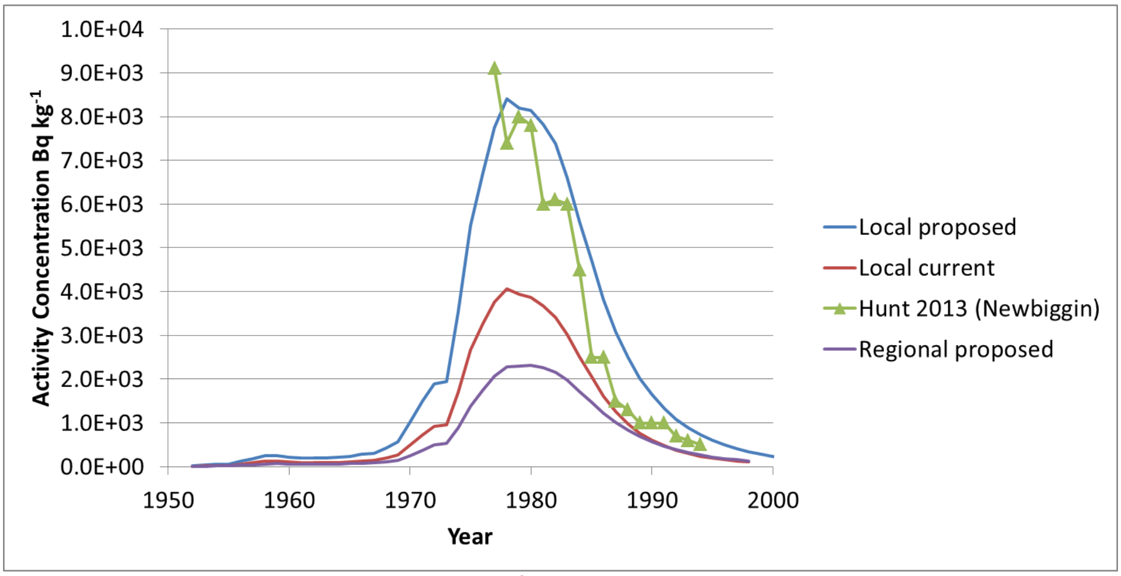

Figure 4 Activity concentrations (Bq kg^{-1}) of ^{137}Cs in seabed sediments for Sellafield compartments

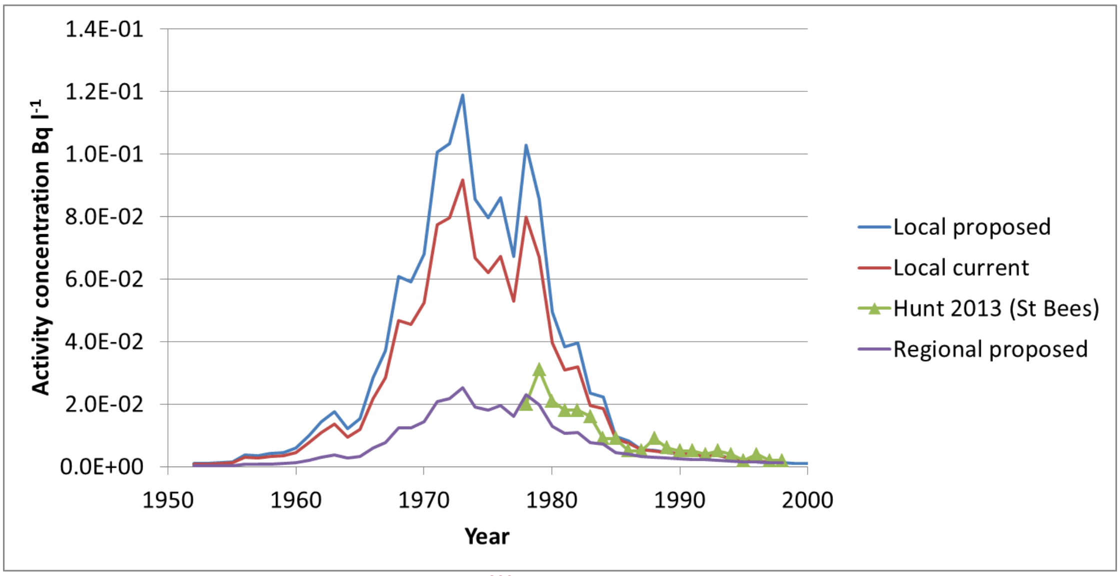

Figure 5 Activity concentrations (Bq l^{-1}) of ^{239}Pu in filtered seawater for Sellafield compartments

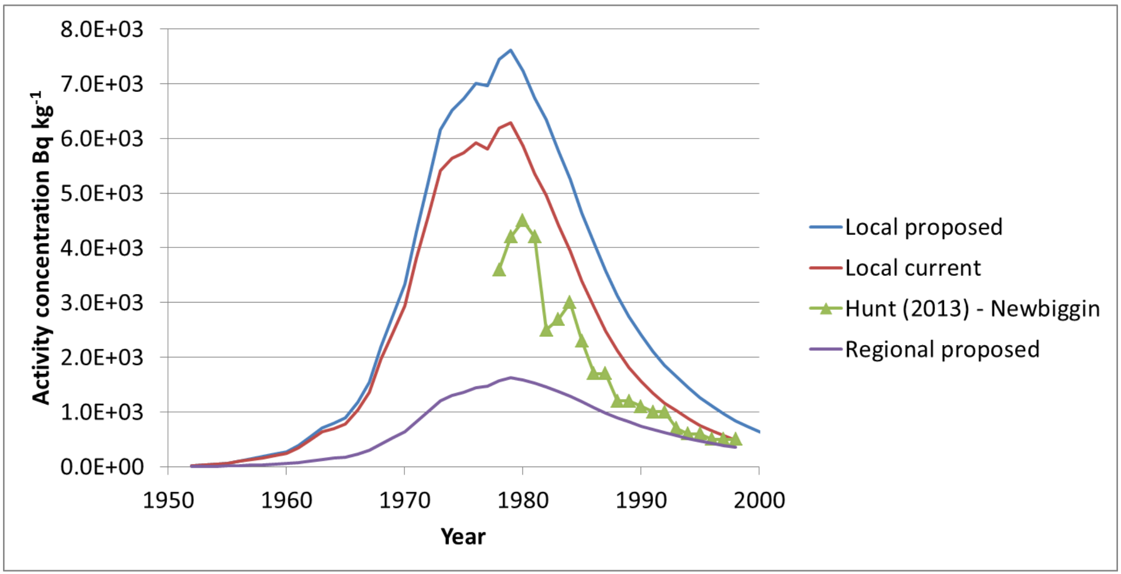

Figure 6 Activity concentrations (Bq kg^{-1}) of ^{239}Pu in seabed sediments for Sellafield compartments

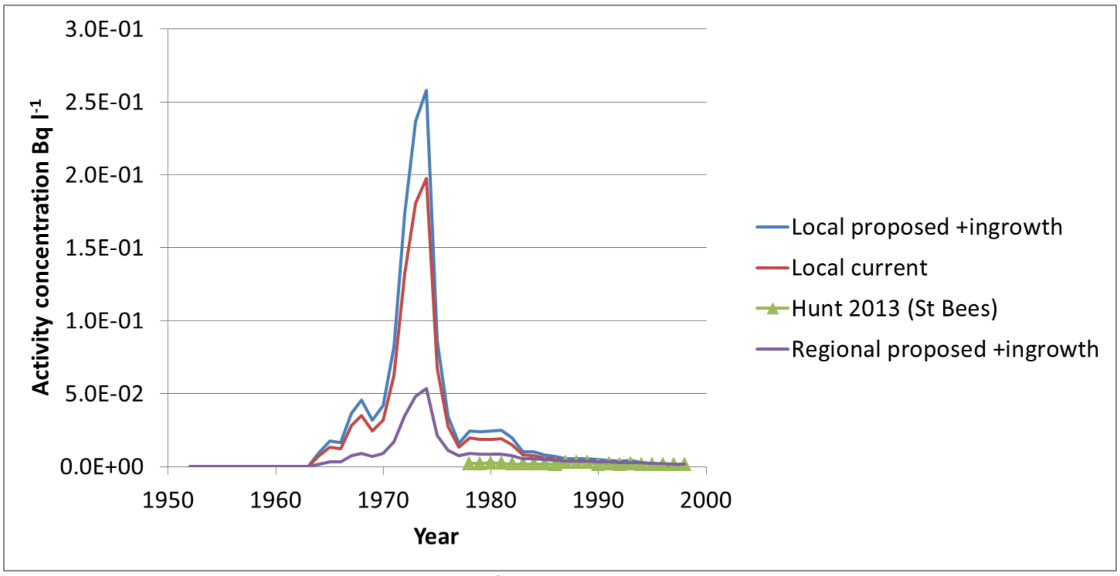

Figure 7 Activity concentrations (Bq l^{-1}) of ^{241}Am in filtered seawater for Sellafield compartments

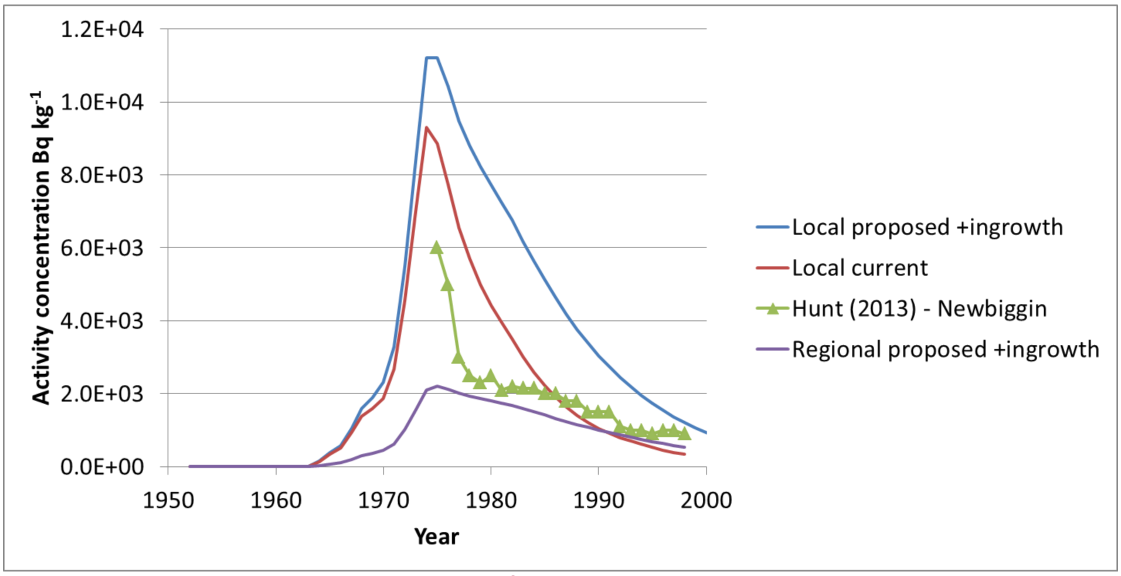

Figure 8 Activity concentrations (Bq kg^{-1}) of ^{241}Am in seabed sediments for Sellafield compartments

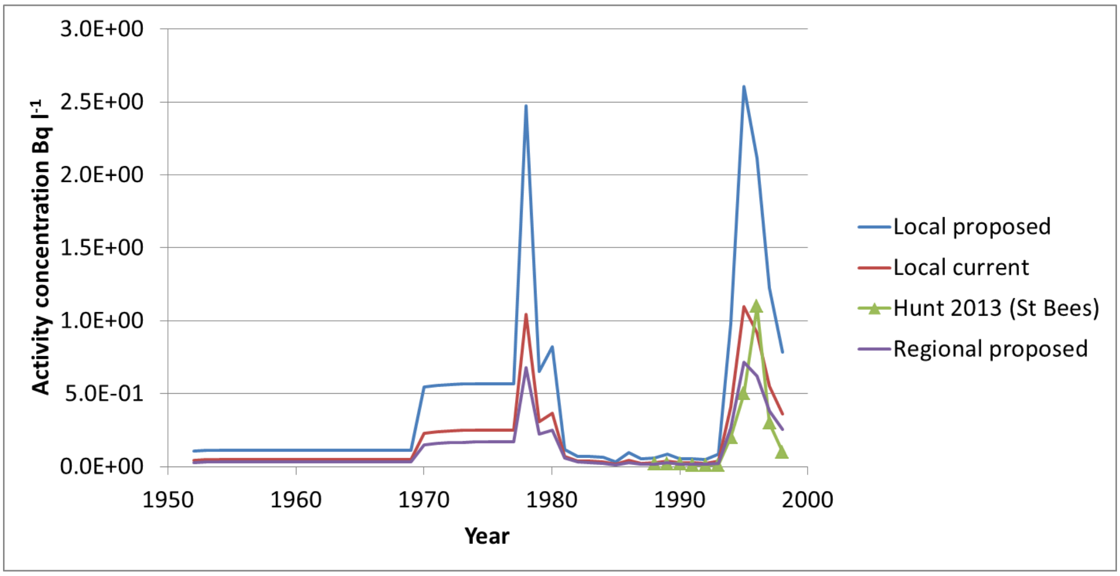

Figure 9 Activity concentrations (Bq l^{-1}) of ^{99}Tc in filtered seawater for Sellafield compartments

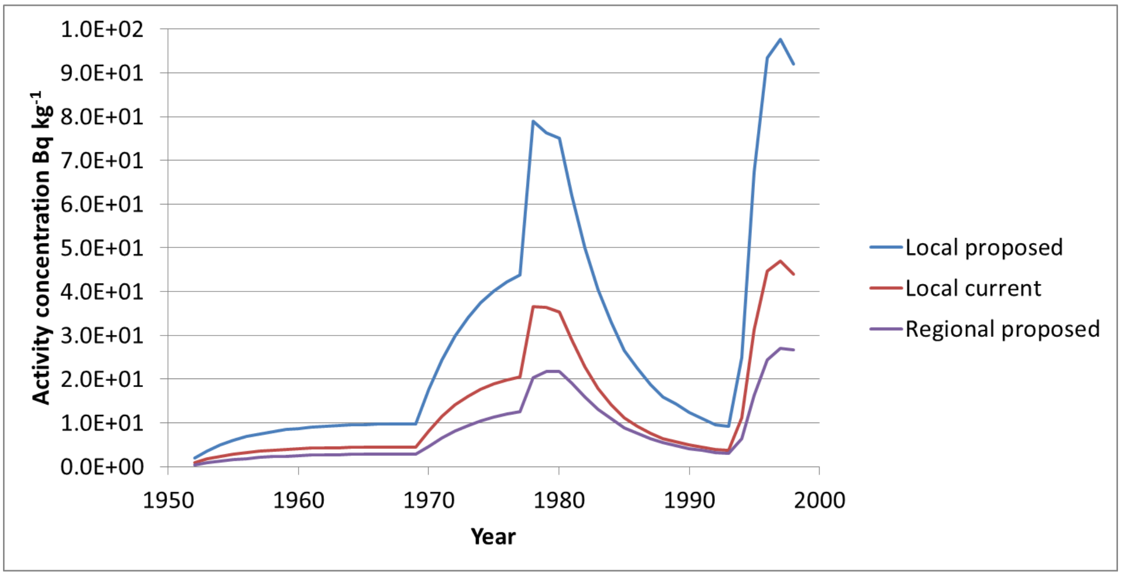

Figure 10 Activity concentrations (Bq kg $^{-1}$) of ^{99}Tc in seabed sediments for Sellafield compartments

3.3.2 Dose per unit discharge

Individual and collective doses per unit discharge have been calculated for ^{3}H, ^{137}Cs and ^{241}Am using the proposed local compartment parameter values for the Sellafield site. The model outputs presented here for Sellafield are the same as those presented in Section 2.3 for Chapelcross, Hartlepool, Hinkley Point, Oldbury, Sizewell and Wylfa.

Table 34 shows the impact of the proposed changes on individual dose. For these calculations the assumptions used regarding the location of locally caught fish and shellfish and the occupancy times of exposed individuals were the same as those used for Section 2.3 and as such the results for Sellafield confirm the previous findings. The differences in doses are within a factor of about 4 for all pathways and radionuclides considered.

From Table 35 it can be seen that the proposed changes to local compartment parameter values only have a small impact on the collective dose to 500 years for the reasons discussed in Section 2.3.

Table 34 Sellafield individual adult dose (μSv) in 50th year due to continuous unit discharges (1 Bq y^{-1})

Radionuclide	Crustaceans	Fish	Molluscs	External beta Beaches	External beta Fishing gear	External gamma Beaches	External gamma Fishing gear	Sea spray inhalation	Total
Current DORIS parameters									
^{241}Am	$3.7\ 10^{-12}$	$1.4\ 10^{-12}$	$1.5\ 10^{-10}$	$1.1\ 10^{-17}$	$1.6\ 10^{-14}$	$7.0\ 10^{-13}$	$6.9\ 10^{-15}$	$3.4\ 10^{-15}$	$1.5\ 10^{-10}$
^{137}Cs	$4.8\ 10^{-14}$	$5.7\ 10^{-13}$	$4.8\ 10^{-14}$	$2.2\ 10^{-15}$	$5.4\ 10^{-16}$	$1.3\ 10^{-13}$	$1.3\ 10^{-15}$	$1.7\ 10^{-19}$	$8.0\ 10^{-13}$
^{3}H	$2.2\ 10^{-18}$	$7.9\ 10^{-18}$	$2.2\ 10^{-18}$	–	–	–	–	$1.0\ 10^{-21}$	$1.2\ 10^{-17}$
Proposed DORIS parameters									
^{241}Am	$4.6\ 10^{-12}$	$1.5\ 10^{-12}$	$1.9\ 10^{-10}$	$1.4\ 10^{-17}$	$2.1\ 10^{-14}$	$8.8\ 10^{-13}$	$8.8\ 10^{-15}$	$1.2\ 10^{-14}$	$1.9\ 10^{-10}$
^{137}Cs	$1.1\ 10^{-13}$	$6.7\ 10^{-13}$	$1.1\ 10^{-13}$	$4.8\ 10^{-15}$	$1.2\ 10^{-15}$	$2.9\ 10^{-13}$	$2.9\ 10^{-15}$	$4.0\ 10^{-19}$	$1.2\ 10^{-12}$
^{3}H	$5.1\ 10^{-18}$	$9.3\ 10^{-18}$	$5.1\ 10^{-18}$	–	–	–	–	$2.3\ 10^{-21}$	$2.0\ 10^{-17}$

Table 35 Collective dose (manSv) over 500 years to the UK population due to unit discharges (1 Bq y^{-1}) for a single year from Sellafield

Radionuclide	Fish	Crustaceans	Molluscs	Beach sediment gamma	Global circulation	Total
Current DORIS parameters						
^{241}Am	$7.0\ 10^{-15}$	$2.5\ 10^{-14}$	$1.1\ 10^{-12}$	$2.9\ 10^{-17}$	–	$1.1\ 10^{-12}$
^{137}Cs	$4.3\ 10^{-15}$	$7.4\ 10^{-16}$	$7.4\ 10^{-16}$	$9.6\ 10^{-18}$	–	$5.8\ 10^{-15}$
^{3}H	$5.6\ 10^{-20}$	$3.3\ 10^{-20}$	$3.4\ 10^{-20}$	–	$2.0\ 10^{-19}$	$3.3\ 10^{-19}$
Proposed DORIS parameters						
^{241}Am	$7.2\ 10^{-15}$	$2.5\ 10^{-14}$	$1.1\ 10^{-12}$	$2.8\ 10^{-17}$	–	$1.1\ 10^{-12}$
^{137}Cs	$4.3\ 10^{-15}$	$7.6\ 10^{-16}$	$7.6\ 10^{-16}$	$9.9\ 10^{-18}$	–	$5.9\ 10^{-15}$
^{3}H	$5.6\ 10^{-20}$	$3.4\ 10^{-20}$	$3.5\ 10^{-20}$	–	$2.0\ 10^{-19}$	$3.3\ 10^{-19}$

3.3.3 Dose from historical discharges

Historical discharge data from 1951 to 1998 were used in PC-CREAM 08 to calculate doses to a group of marine food consumers. The group is categorised as Sellafield Group A in the RIFE 1998 report (MAFF and SEPA, 1999) and the habits are given in Table 36 below. Table 37 presents doses from the same RIFE report (MAFF and SEPA, 1999), which are based on measurements, as well as doses calculated using PC-CREAM 08 with local compartment parameter values based on the current default parameter values and the proposed parameter values. It can be seen that the annual dose estimate for the group considered from the RIFE report is about 0.2 mSv, whereas a calculation of the same dose using PC-CREAM 08 and the current parameter values gives a dose of 0.24 mSv. The radionuclide making the largest contribution (about 50%) to the dose predicted by PC-CREAM 08 is ^{241}Am and the key exposure pathway is the consumption of molluscs.

The total annual dose to the Sellafield consumers of marine food (Group A) for 1998 calculated with PC-CREAM 08 using the proposed local compartment parameters is 0.28 mSv. The main contribution to the dose (about 35%) comes once again from the consumption of ^{241}Am in molluscs. Doses based on measurements are broadly consistent with model estimates when proposed values are used; ^{14}C is the exception with ingestion dose predicted by the model being almost 6-times greater than the dose based on measurements.

Table 36 Habits of the Sellafield Group A marine food consumers

Food	Intake rate (kg y^{-1})
Fish	45
Crustaceans	28
Molluscs	15
Location	**Occupancy rate (h y^{-1})**
Sand and mollusc beds	1100

Table 37 Estimate of doses received by Group A in 1998

Source	Annual exposure (mSv)										
	Total	^{14}C	^{90}Sr	^{99}Tc	^{106}Ru	^{137}Cs	^{238}Pu	$^{239+240}$Pu	^{241}Pu	^{241}Am	Others
RIFE 1998*	0.2	0.006	0.003	0.023	0.006	0.008	0.007	0.034	0.008	0.060	<0.004
DORIS current data											
Ingestion	0.22	0.019	–	0.010	0.007	0.004	0.004	0.020	0.006	0.13	0.037
External	0.02	–	0.001	–	–	0.006	–	–	–	0.001	0.008
Total	0.24	0.019	0.001	0.010	0.007	0.010	0.004	0.020	0.006	0.13	0.045
DORIS proposed data											
Ingestion	0.24	0.034	0.001	0.022	0.017	0.006	0.004	0.017	0.006	0.10	0.055
External	0.035	–	0.002	–	–	0.020	–	–	–	0.002	0.010
Total	0.28	0.034	0.003	0.022	0.017	0.026	0.004	0.017	0.006	0.10	0.065

* Includes doses from γ exposure due to 1100 h y^{-1} occupancy over intertidal sediment ~ 0.05 mSv

4. Conclusions and summary of recommendations

A review has been carried out of the local compartment parameter values presented in the EA report (Dewar et al, 2011) to determine their suitability for use in the marine dispersion model DORIS as implemented in the radiological assessment tool PC-CREAM 08. Following the review, recommendations were made regarding the data to be used for 18 sites around the UK coast. These recommendations are summarised in Table 38.

Calculations of environmental activity concentrations and dose have been carried out using PC-CREAM 08 and the marine dispersion model DORIS to determine the consequences of using the recommended local compartment parameter values. For the majority of sites unit discharges were used and model results based on existing and proposed local compartment parameter values compared. Where data were available model results using historical discharges were also compared with measurements. This was done most comprehensively for Sellafield.

The consequences of changing the volumetric exchange rate (VER) and dimensions of the local compartment for all sites are discussed in this report. Activity concentrations in filtered seawater and seabed sediments were calculated using DORIS and the proposed and current local compartment parameter values. Table 6 shows that, for radionuclides with a low sediment distribution coefficient (k_d), there is a direct relationship between environmental activity concentrations and the VER, provided the VER is not so large that equilibrium exists between the local and regional compartments. For radionuclides with a high k_d this relationship is less well defined because of the influence of the sedimentation process. For a number of sites, namely Oldbury, Berkeley, Cardiff Bay, Heysham, Hinkley Point, Hunterston and sites discharging to the Thames estuary, changes to activity concentrations in filtered seawater and seabed sediments as a result of the proposed changes in model parameter values are expected to be as much as a factor of 5. These changes include both increases and decreases. For Trawsfynydd an increase by a factor of about 10 is expected.

Suspended sediment loads and sedimentation rates were also reviewed for all sites and values were recommended for use in DORIS. The consequences of using the recommended values for 6 nuclear sites where significant changes are proposed (Chapelcross, Hartlepool, Hinkley Point, Oldbury, Sizewell and Wylfa) were also investigated. The results of this investigation (see Table 14) show that large differences in environmental activity concentrations of ^{241}Am would be predicted for Chapelcross and Hartlepool if the proposed sedimentation parameters, particularly the suspended sediment load, are used.

A comparison of dose assessment results using PC-CREAM 08 and proposed values for all the local compartment parameters shows that differences in total dose for a given radionuclide can vary quite significantly depending on the site, with some of the more significant differences occurring for Hinkley Point (Table 18). However, an investigation of the impact of model changes on the dose calculations for Hinkley Point using annual discharges for 2017 shows that despite the increase doses remain extremely low (Table 28). Collective doses are less sensitive to the recommended changes in local compartment parameter values because much of the exposure of the UK population arises from the consumption of seafood that is caught well outside the local compartment.

The results of the review of all local compartment parameter values for the Sellafield site are reported in Section 3. The main conclusions from this review are:

a Results from the DORIS model, based on historical discharges, compare well with measured values of activity concentrations in filtered seawater and seabed sediments although it would appear that the model underpredicts the longer term accumulation and remobilisation of some radionuclides from seabed sediments.

b Individual doses are within a factor of about 4 and collective doses change very little when model results using proposed and current local compartment parameter values are compared.

c An assessment of doses using DORIS with proposed local compartment parameter values and historical discharges compares well with the doses reported in the 1998 RIFE report (MAFF and SEPA, 1999) which are based on measurements.

Considerable natural variability can occur in the model parameters considered in this report. It is therefore important to consider the sensitivity of model outputs to these parameters as part of any radiological impact assessment that uses the DORIS model.

This review of model parameter values has the potential to lead to both increases and decreases in the calculation of doses to members of the public depending on the location of the site and the radionuclides discharged. However, based on current discharges from UK nuclear sites the dose calculations carried out here, using the proposed changes to model parameter values, support the findings of previous assessments (Jones et al, 2014) that suggest public exposures are very low and not a concern for public health.

Table 38 Proposed data for local marine compartments for DORIS

Site	Location	Depth (m)	Volume (m^3)	Volumetric exchange rate (m^3 y^{-1})	Coastline length (m)*	SSL (t m^{-3})	SR (t m^{-2} y^{-1})
Aldermaston	Thames estuary (outer)	8.7 10^0	6.6 10^8	2.6 10^{10}	2.5 10^4	3.0 10^{-5}	6.0 10^{-4}
Amersham	Thames estuary (outer)	8.7 10^0	6.6 10^8	2.6 10^{10}	2.5 10^4	3.0 10^{-5}	6.0 10^{-4}
Barrow	Walney channel/Barrow harbour	1.3 10^0	1.5 10^7	5.4 10^9	6.0 10^3	6.4 10^{-5}	1.3 10^{-3}
Berkeley	Severn estuary (inner)	4.0 10^0	1.3 10^8	1.8 10^{10}	2.4 10^4	6.9 10^{-4}	1.4 10^{-2}
Bradwell	Blackwater estuary	4.0 10^0	1.0 10^8	7.3 10^9	1.4 10^4	3.8 10^{-5}	8.0 10^{-4}
Capenhurst	Mersey estuary (outer)	8.0 10^0	3.3 10^8	2.0 10^{10}	1.8 10^4	7.8 10^{-5}	1.6 10^{-3}
Cardiff	Cardiff bay	7.0 10^0	1.9 10^8	1.7 10^{10}	1.5 10^4	1.8 10^{-4}	3.6 10^{-3}
Chapelcross	Solway Firth (inner)	3.6 10^0	7.0 10^8	7.4 10^{10}	3.4 10^4	1.8 10^{-4}	3.7 10^{-3}
Devonport	Tamar estuary	1.0 10^1	5.0 10^7	1.3 10^9	6.0 10^3	4.6 10^{-6}	1.0 10^{-4}
Dounreay#	Exposed coast	2.0 10^1	2.0 10^9	8.0 10^{10}	1.0 10^4	1.0 10^{-5}	2.0 10^{-4}
Dungeness	Dungeness coast	2.5 10^1	2.5 10^9	3.8 10^{10}	1.0 10^4	6.1 10^{-5}	1.2 10^{-3}
Hartlepool	Sheltered coast	1.0 10^1	1.0 10^9	2.0 10^{10}	1.0 10^4	1.0 10^{-5}	2.0 10^{-4}
Harwell	Thames estuary (outer)	8.7 10^0	6.6 10^8	2.6 10^{10}	2.5 10^4	3.0 10^{-5}	6.0 10^{-4}
Heysham#	Sheltered coast	1.0 10^1	1.0 10^9	2.0 10^{10}	1.0 10^4	1.0 10^{-5}	1.0 10^{-3}
Hinkley Point#	Sheltered coast	1.0 10^1	1.0 10^9	2.0 10^{10}	1.0 10^4	1.0 10^{-4}	2.0 10^{-3}
Hunterston#	Sheltered coast	1.0 10^1	1.0 10^9	2.0 10^{10}	1.0 10^4	1.0 10^{-5}	2.0 10^{-4}
Oldbury	Severn estuary (inner)	4.0 10^0	1.3 10^8	1.8 10^{10}	2.4 10^4	6.9 10^{-4}	1.4 10^{-2}
Sellafield	Site specific	2.0 10^1	2.0 10^9	1.0 10^{11}	1.0 10^4	3.1 10^{-5}	7.0 10^{-3}
Sizewell	Aldeburgh coast	2.0 10^1	2.0 10^9	1.4 10^{10}	1.0 10^4	3.6 10^{-5}	7.0 10^{-4}
Springfields	Ribble estuary (outer)	3.0 10^0	1.1 10^8	1.4 10^{10}	1.3 10^4	9.4 10^{-5}	1.9 10^{-3}
Torness#	Exposed coast	2.0 10^1	2.0 10^9	8.0 10^{10}	1.0 10^4	1.0 10^{-5}	2.0 10^{-4}
Trawsfynydd	Tremadog bay	8.6 10^0	1.5 10^9	3.8 10^{10}	4.0 10^4	1.3 10^{-5}	3.0 10^{-4}
Winfrith#	Sheltered coast	1.0 10^1	1.0 10^9	2.0 10^{10}	1.0 10^4	1.0 10^{-5}	2.0 10^{-4}
Wylfa	Cemaes coast	2.7 10^1	2.7 10^9	3.2 10^{10}	1.0 10^4	4.9 10^{-6}	1.0 10^{-4}

* The coastline length in general relates to the linear distance from one end of the compartment to the other. However for bays and harbours it represents the total length of coastline in the compartment. For estuaries the total coastline length is double that presented here.

The coastline breadth of all these compartments is assumed to be 1 10^4 m.

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Appendix A Additional model comparisons

A1 Results of model comparison

Activity concentrations in various media following historical discharges from Sellafield have been calculated using DORIS and the local compartment parameter values recommended in this report (Table 38). Figures A2 to A19 compare model results and measurements taken from (Jones et al, 2003) which focussed on the period from 1990 to 2000. The MARINA II modelling results are based on the dispersion model developed under the MARINA II study (European Commission, 2002). This is essentially the same as the version of DORIS currently implemented in PC-CREAM 08 but includes additional regional compartments in remote locations that do not affect local compartment dispersion conditions. The CSERAM model (Aldridge, 1998) was developed by CEFAS. It is a numerical model that represents the underlying physical processes responsible for dispersion in a more realistic way than DORIS. Measurements were taken from CEFAS report (CEFAS, 2001) for locations along the Cumbrian coast (Figure A1) and are different to those used in Section 3.3.1.

Some model endpoints compare well with measurements, for example activity concentrations of ^{137}Cs in filtered seawater, fish and crustaceans, while others compare less well such as ^{14}C and ^{90}Sr in fish, ^{60}Co in molluscs and seaweed and ^{99}Tc in crustaceans. However, it must be noted that some of the measurements are taken outside the local compartment where the model predictions are made. Of the locations identified in Figure A1 just Coastal Area and Nethertown can be considered to be within the Sellafield local compartment. Consequently, the model would be expected to predict activity concentrations that are higher than the measurements taken at Maryport, St Bees and the Offshore Area. In addition, some fish species are very mobile and even if caught near to the discharge point may record lower than expected levels of activity because they are unlikely to have been continually subjected to locally elevated concentrations. The model predicts activity concentrations of ^{137}Cs in molluscs that are a factor of about 2 to 3 lower than measurements made at Nethertown. It also predicts activity concentrations that are within a factor of about 2 to 3 for ^{239}Pu and ^{241}Am in molluscs from Nethertown and ^{99}Tc in seaweed from St Bees. A comparison of modelled and measured activity concentrations in seabed sediments was included in Section 3.3.1. Additional figures included here generally support the previous finding that the model tends to underestimate activity concentrations in seabed sediments that arise as a result of historical discharges for radionuclides that readily adsorb onto sediments. However, ^{60}Co has a k_d that is similar to that of plutonium and americium and the model predictions for activity concentrations in seabed sediments for this radionuclide are quite good. It should be noted that the activity concentrations in sediments were measured at Maryport which is about 40 km north of the Sellafield discharge point and hence might be expected to be lower than model predictions for the local compartment.

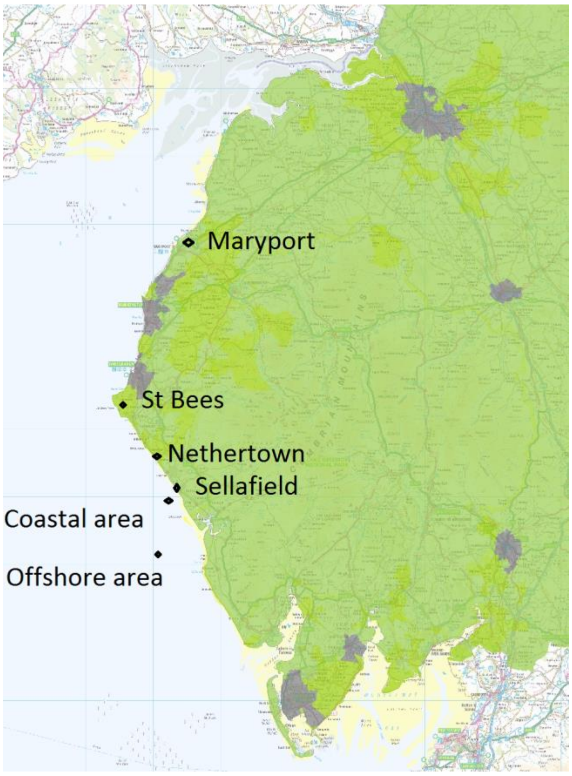

Figure A1 Guide to measurement locations

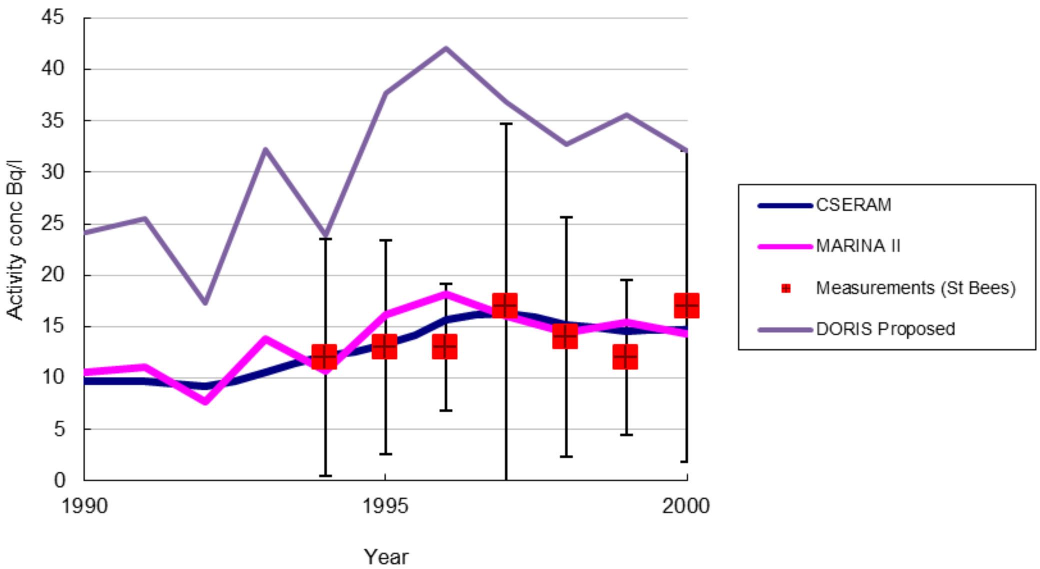

Figure A2 Activity concentrations (Bq l^{-1}) of ^{3}H in seawater for Sellafield local compartment

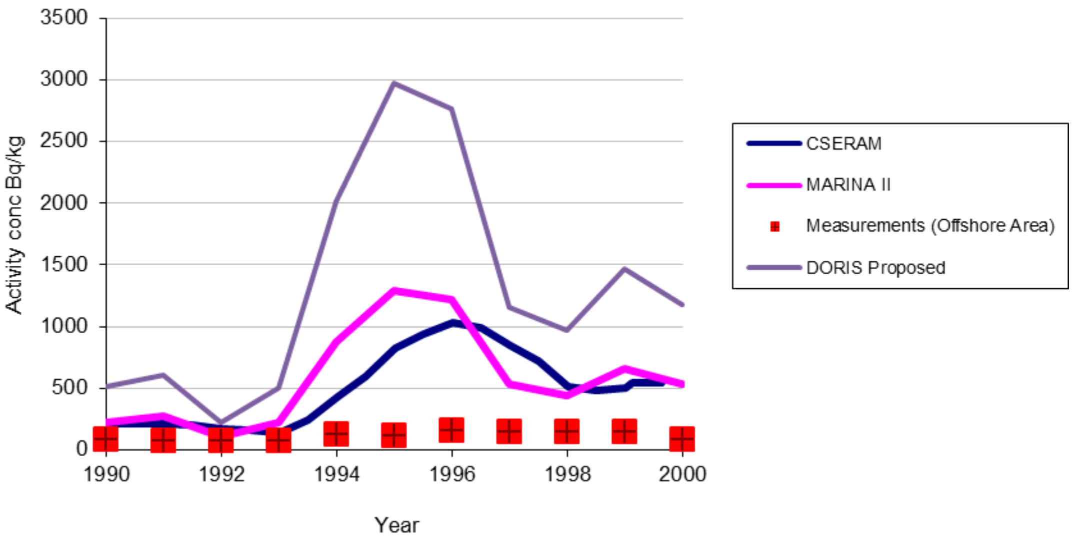

Figure A3 Activity concentrations (Bq kg $^{-1}$) of ^{14}C in fish for Sellafield local compartment

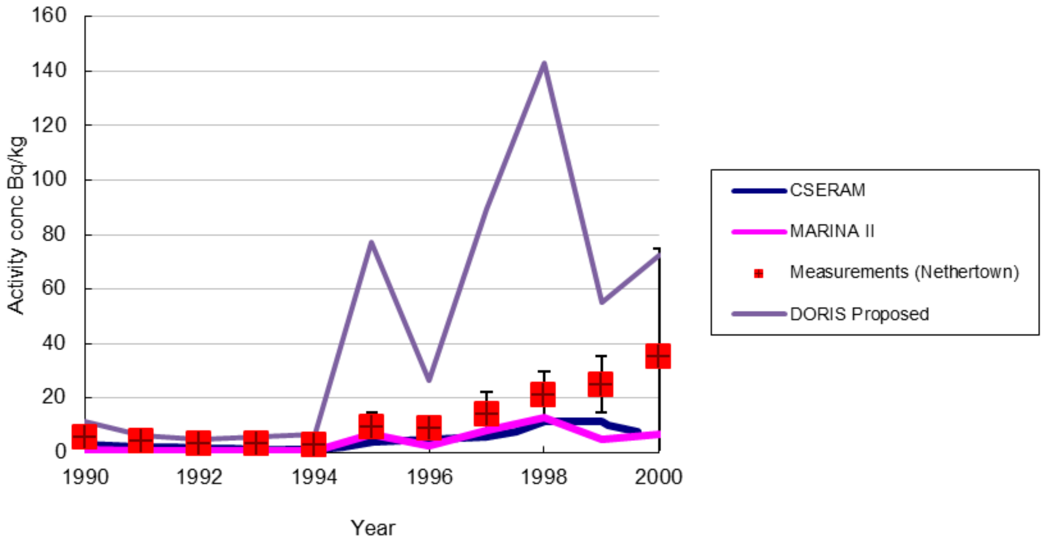

Figure A4 Activity concentrations (Bq kg $^{-1}$) of ^{60}Co in molluscs for Sellafield local compartment

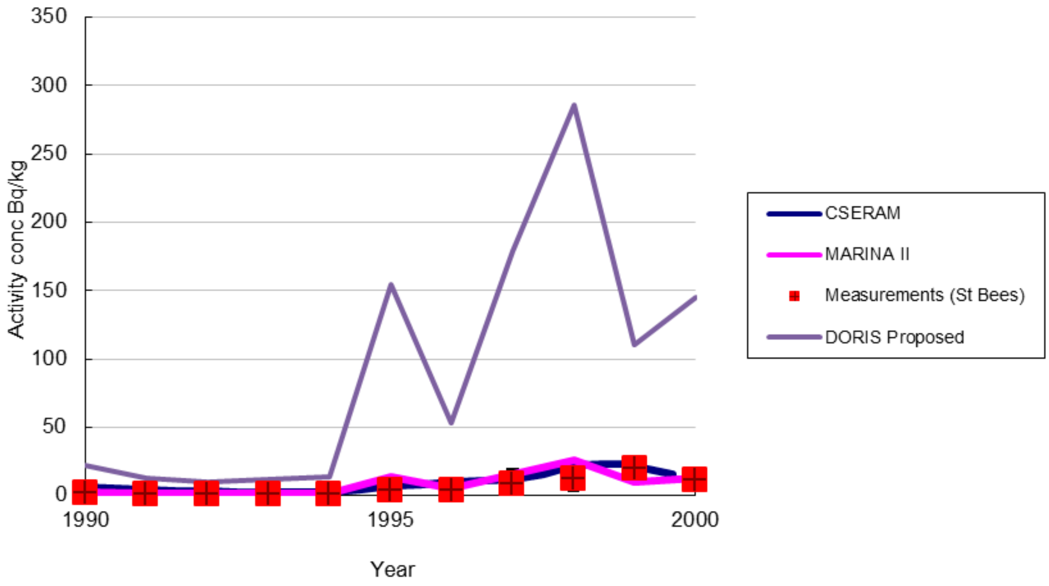

Figure A5 Activity concentrations (Bq kg $^{-1}$) of ^{60}Co in seaweed for Sellafield local compartment

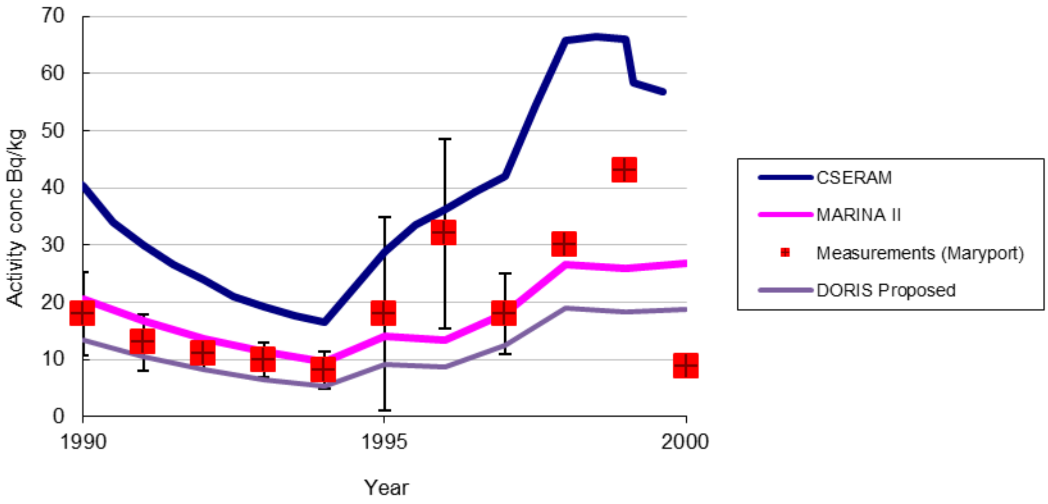

Figure A6 Activity concentrations (Bq kg $^{-1}$) of ^{60}Co in sediments for Sellafield local compartment

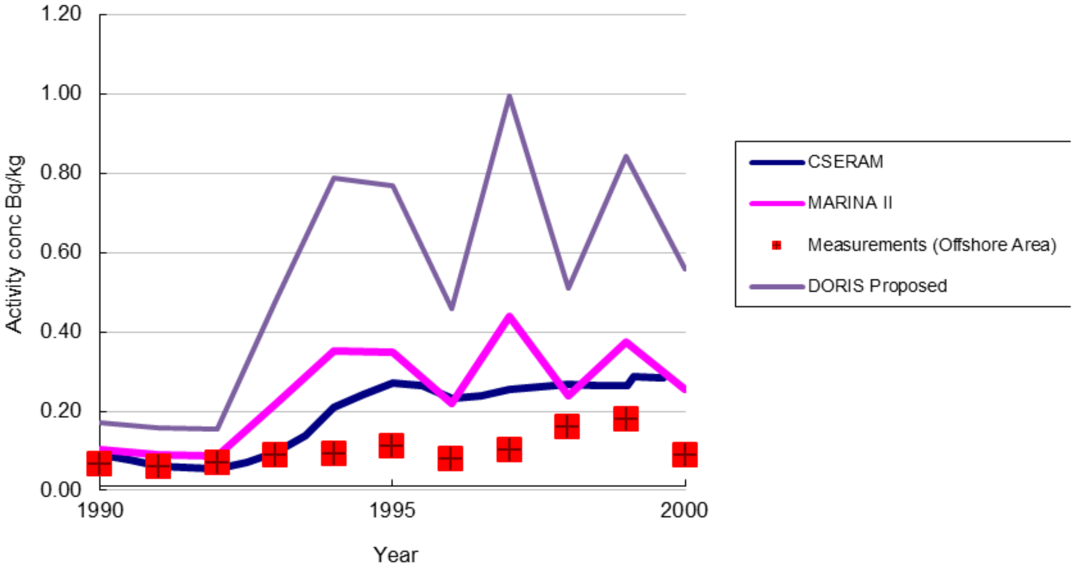

Figure A7 Activity concentrations (Bq kg^{-1}) of ^{90}Sr in fish for Sellafield local compartment

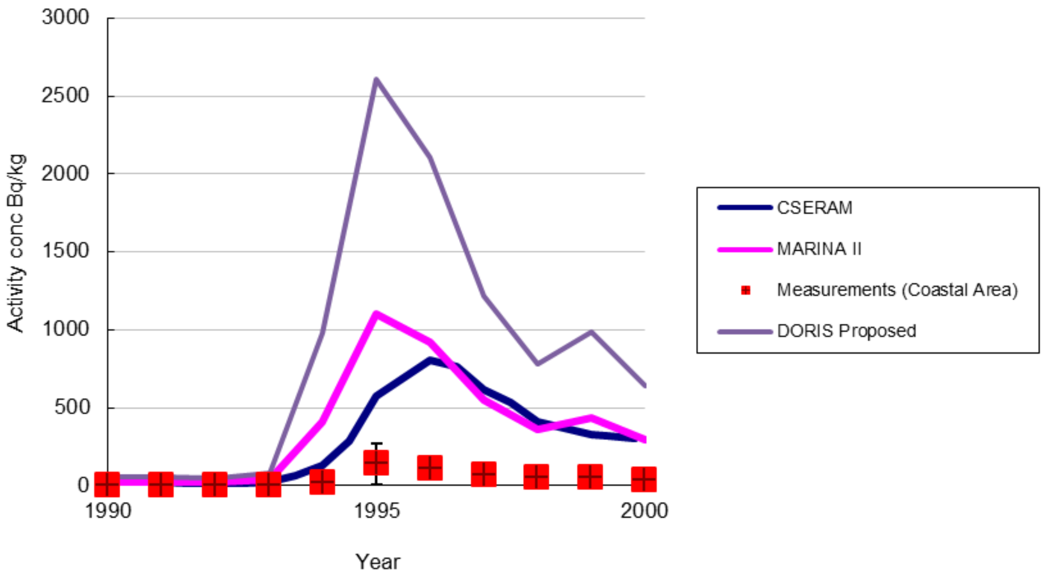

Figure A8 Activity concentrations (Bq kg^{-1}) of ^{99}Tc in crustaceans for Sellafield local compartment

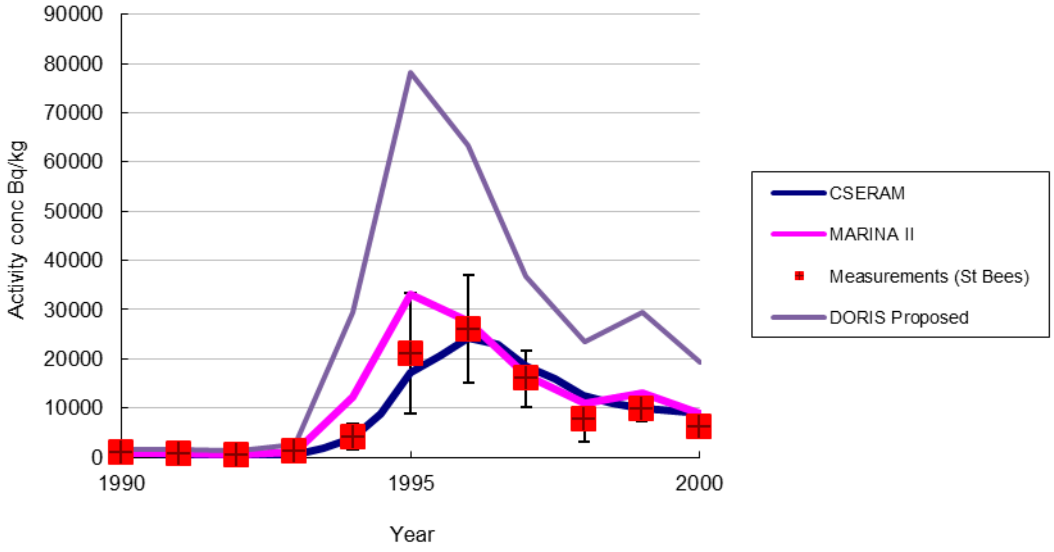

Figure A9 Activity concentrations (Bq kg^{-1}) of ^{99}Tc in seaweed for Sellafield local compartment

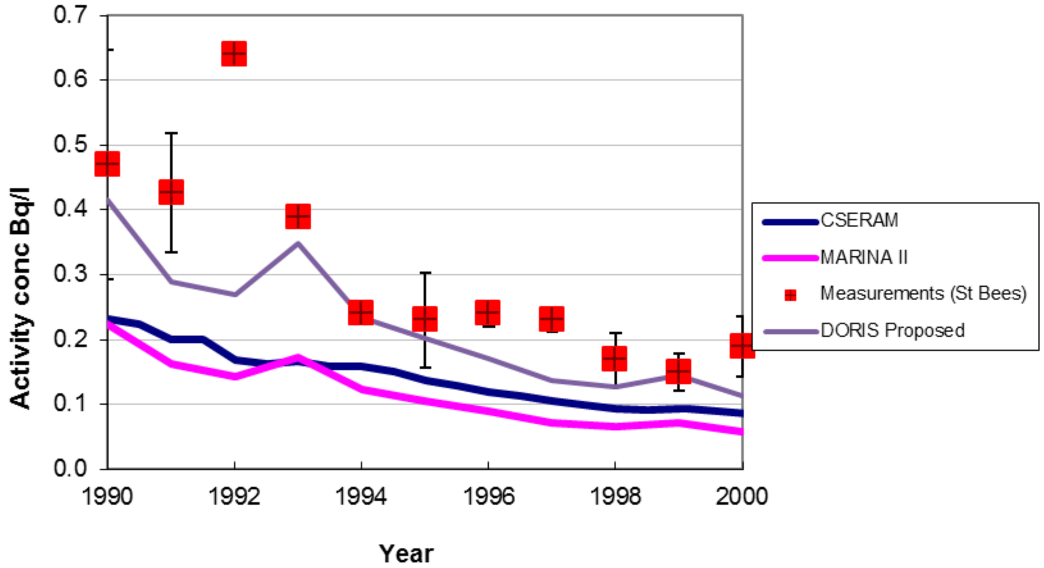

Figure A10 Activity concentrations (Bq l^{-1}) of ^{137}Cs in seawater for Sellafield local compartment

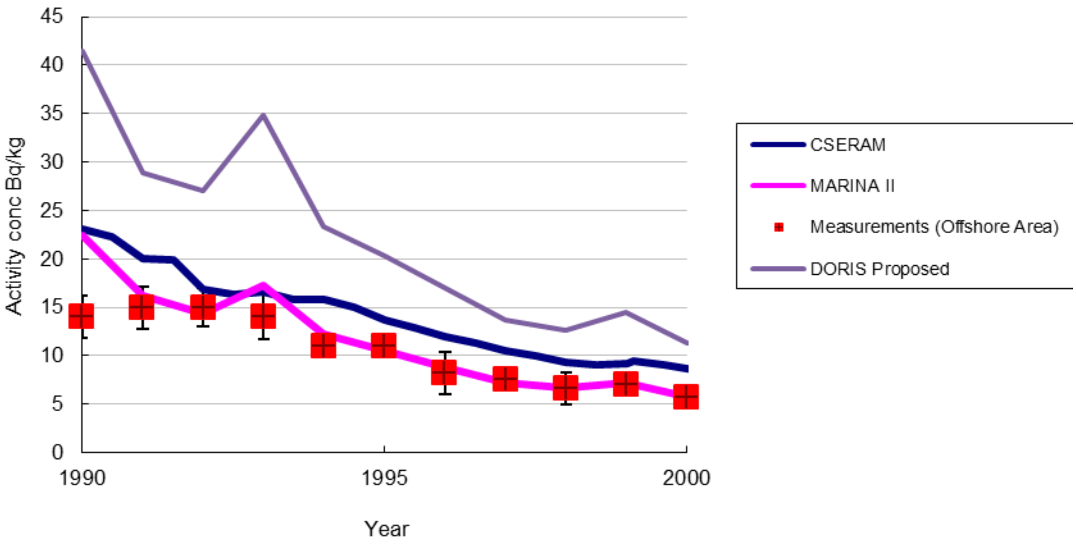

Figure A11 Activity concentrations (Bq kg^{-1}) of ^{137}Cs in fish for Sellafield local compartment

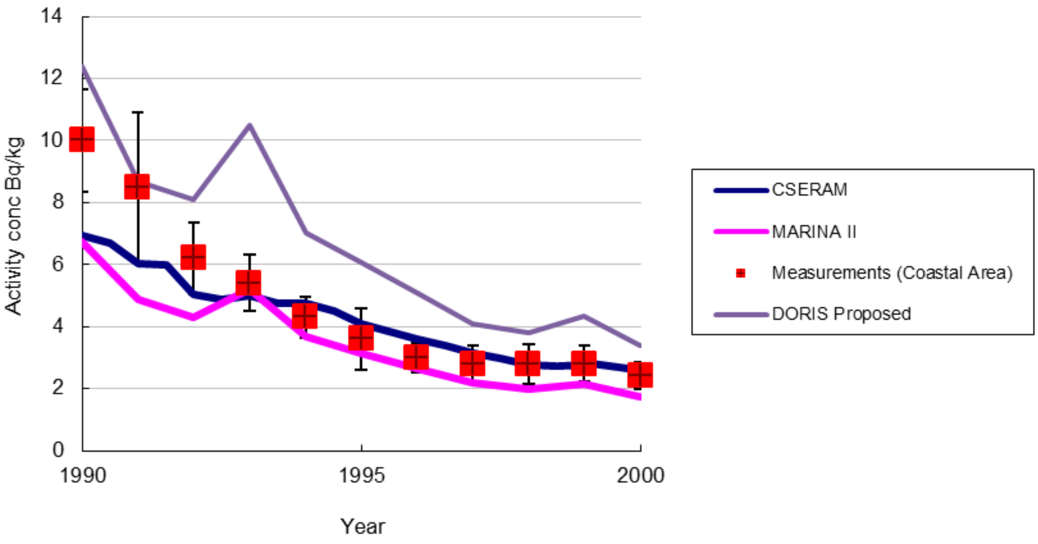

Figure A12 Activity concentrations (Bq kg^{-1}) of ^{137}Cs in crustaceans for Sellafield local compartment

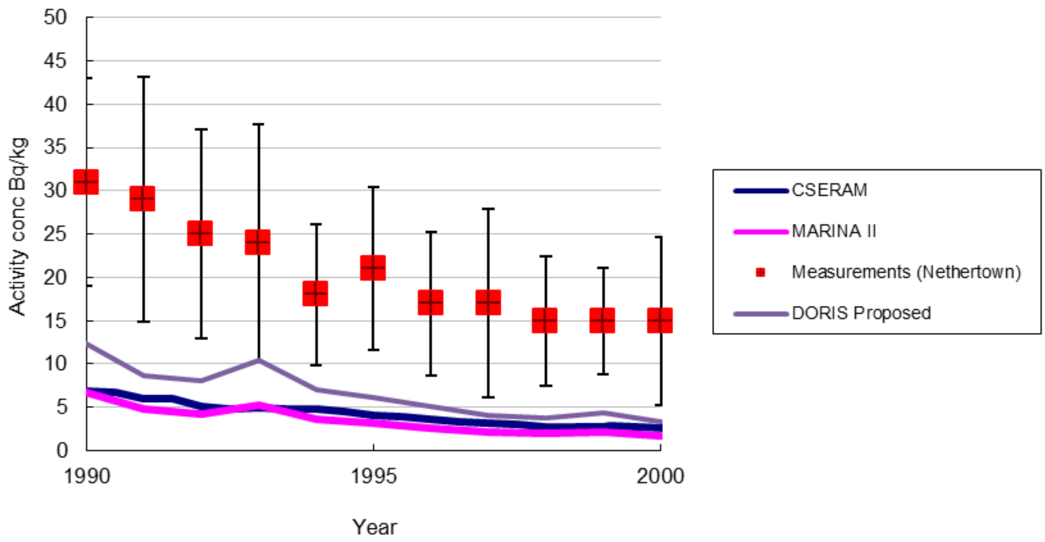

Figure A13 Activity concentrations (Bq kg^{-1}) of ^{137}Cs in molluscs for Sellafield local compartment

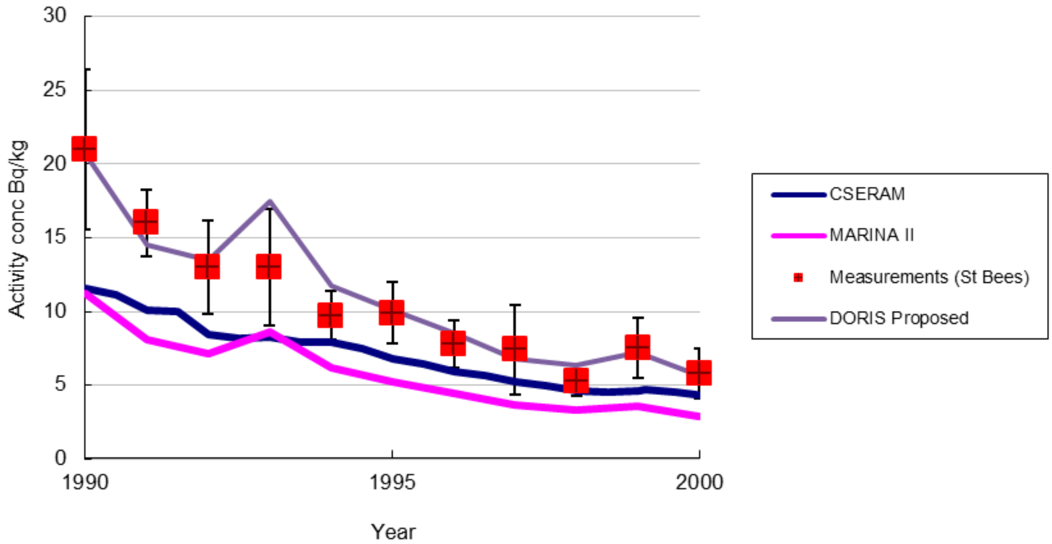

Figure A14 Activity concentrations (Bq kg^{-1}) of ^{137}Cs in seaweed for Sellafield local compartment

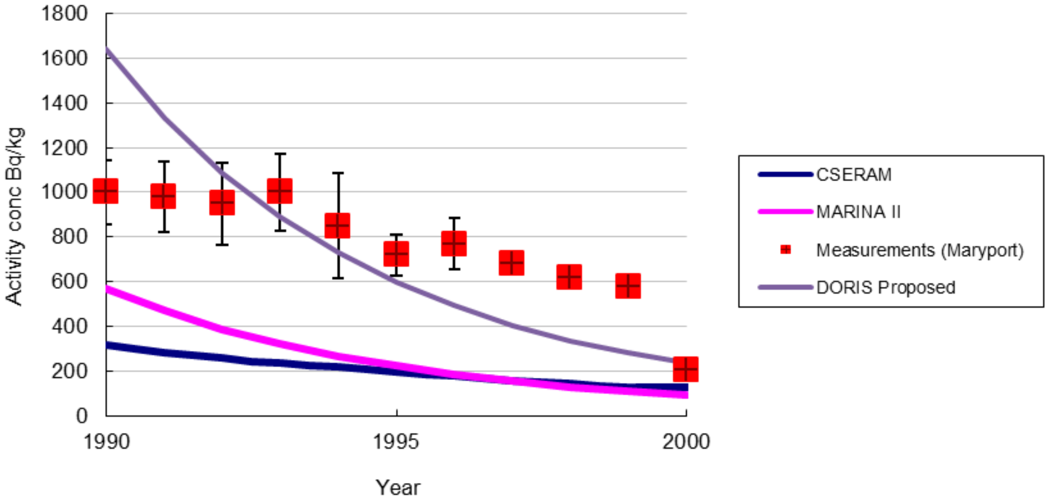

Figure A15 Activity concentrations (Bq kg^{-1}) of ^{137}Cs in sediments for Sellafield local compartment

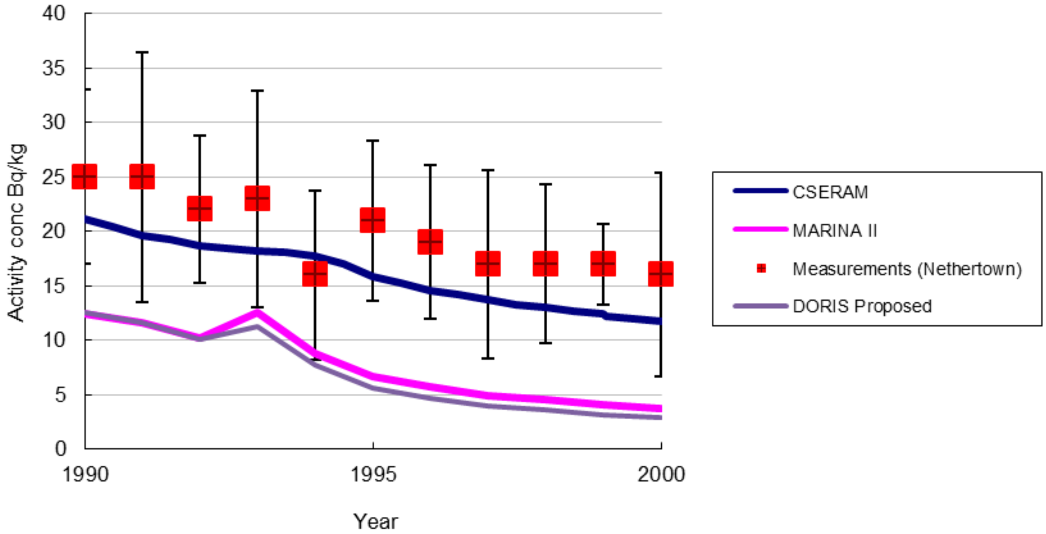

Figure A16 Activity concentrations (Bq kg^{-1}) of $^{239/240}$Pu in molluscs for Sellafield local compartment/coastal region

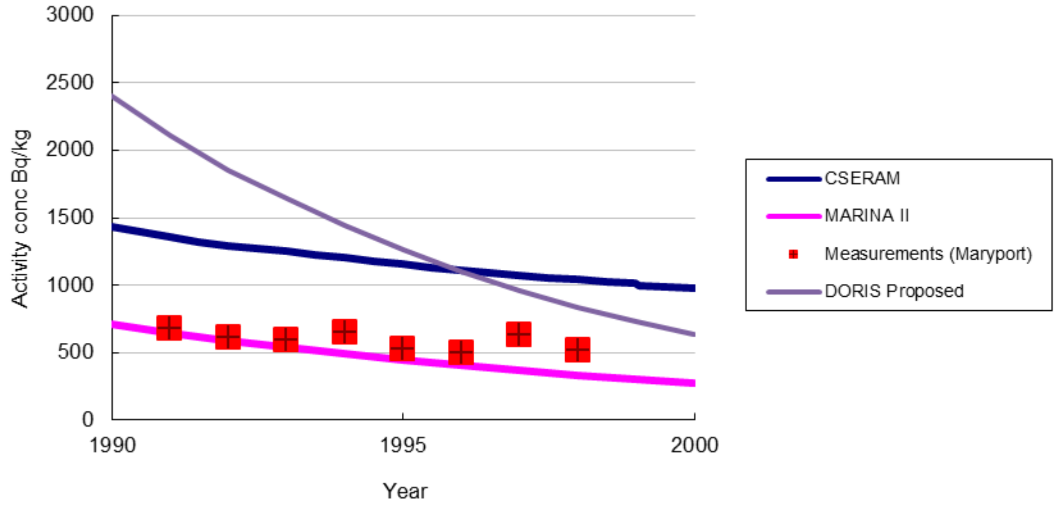

Figure A17 Activity concentrations (Bq kg^{-1}) of $^{239/240}$Pu in sediments for Sellafield local compartment/coastal region

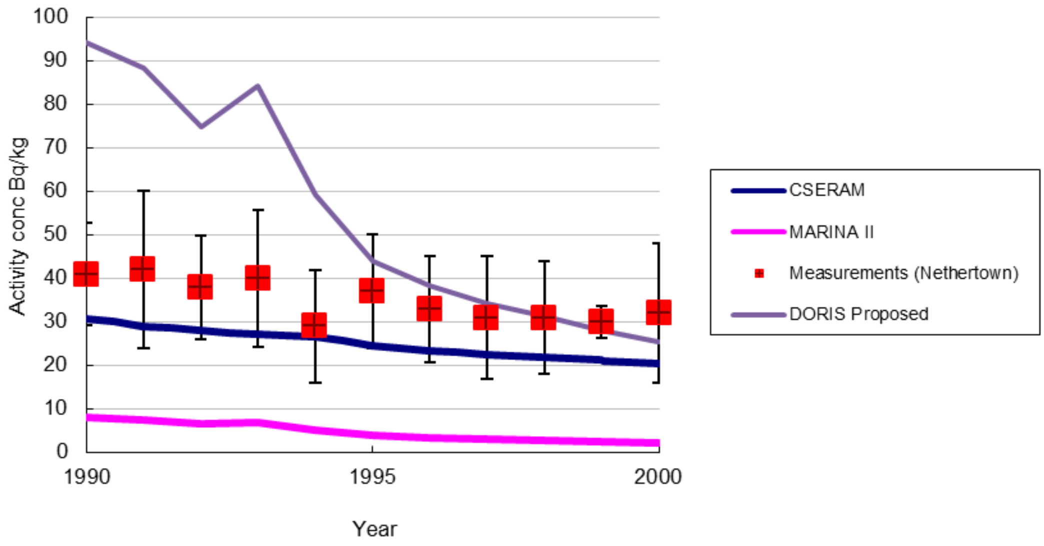

Figure A18 Activity concentrations (Bq kg^{-1}) of ^{241}Am in molluscs for Sellafield local compartment/coastal region (including in-growth)

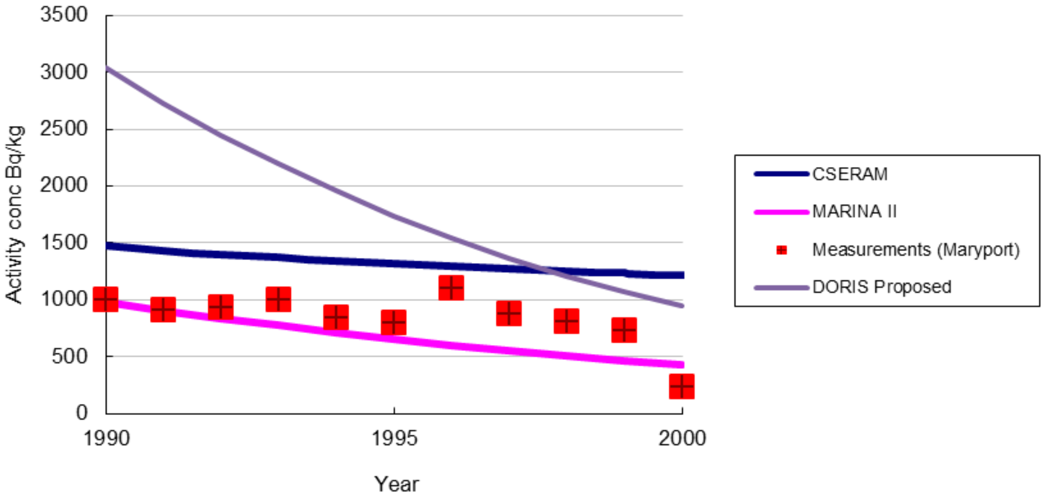

Figure A19 Activity concentrations (Bq kg^{-1}) of ^{241}Am in sediments for Sellafield local compartment/coastal region (including in-growth)

A2 References

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