Environment Agency

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Impact of radioactive substances on Ribble and Alt estuarine habitats

Better regulation science programme
Science report: SC060083/SR2

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- **Delivering information, advice, tools and techniques**, by making appropriate products available to our policy and operations staff.

Steve Killeen

Head of Science

Executive summary

The UK has a duty to comply with the EU Birds and Habitats Directives (Council Directives 79/409/EEC on the conservation of wild birds and 92/43/EEC on the conservation of natural habitats and wild flora and fauna) when planning and undertaking all of its regulatory and operational activities. These European Directives were introduced into UK legislation by the Conservation (Natural Habitats & c.) Regulations 1994. These Directives established and protect a network of conservation areas across the EU called 'Natura 2000'.

Under the Habitats Regulations, the Environment Agency has obligations to review relevant existing authorisations, permits, consents, licences and permissions (collectively referred to as permits) to ensure that no Environment Agency authorised activity or permission results in an adverse effect, either directly or indirectly, on the integrity of Natura 2000 sites. The Environment Agency is also required to ensure that any new or varied permits do not have an adverse effect on the integrity of the Natura 2000 sites.

The Environment Agency has adopted a staged approach to reviewing existing permits:

- Stage 1 – identify the relevant permits.
- Stage 2 – determine which permits have a potential significant effect.
- Stage 3 – undertake appropriate assessment for permits with significant effects.
- Stage 4 – revise permits to ensure no adverse effects (e.g. by changing the type, amount and location of discharges).

Doses to reference organisms and feature species were calculated for authorised discharges under the Radioactive Substances Act 1993 (RSA 93) in the Stage 3 assessment. These doses were compared to a threshold of 40 microgray/h, below which the Environment Agency and Natural England agreed there would be no adverse affect to the integrity of a Natura 2000 site. For one Natura 2000 site in England and Wales, the Ribble and Alt Estuaries SPA, it was not possible to conclude that there was no adverse effect on the integrity of the site from authorised discharges of radioactive substances. The primary reason was potential releases at the authorised discharge limits from the Springfields Fuels Ltd site.

The Environment Agency and Natural England have agreed a habitats protection objective for the Ribble and Alt Estuaries SPA and have considered how this objective can be met. The objective includes meeting the agreed dose threshold of 40 microgray/h. For operational reasons, new lower RSA 93 authorisation limits came into force on 1 January 2008 for the Springfields Fuels Ltd site. A reassessment has been made of discharges at these new limits using the newly available EU funded ERICA (Environmental Impact of Ionising Contaminants: Assessment and management) assessment tool.

The reassessed dose rates to reference organisms and feature species in the Ribble and Alt Estuaries SPA for discharges at the new Springfields Fuels Ltd authorisation limits are less than 40 microgray/h. A variability and uncertainty assessment has been carried out which shows that, for phytoplankton only, doses above 40 microgray/h might occur in some circumstances. However, the dose threshold above which populations of phytoplankton would suffer adverse affects is much higher than 40 microgray/h.

Overall, it is concluded that the environmental outcomes objectives for the Ribble and Alt Estuaries SPA will be met through the introduction of the new authorisation limits for the Springfields Fuels Ltd site.

It is recommended that, if practicable, a small campaign of phytoplankton monitoring should be undertaken for thorium-228, thorium-230, thorium-232 and thorium-234 to reduce the uncertainty in the dose assessment for this reference organism. Alternatively, it may be possible to study uptake of these radionuclides by phytoplankton in the laboratory.

Contents

1 Introduction

The UK has a duty to comply with the EU Birds and Habitats Directives (Council Directives 79/409/EEC on the conservation of wild birds and 92/43/EEC on the conservation of natural habitats and wild flora and fauna) when planning and undertaking all of its regulatory and operational activities. These European Directives were introduced into UK legislation by the Conservation (Natural Habitats & c.) Regulations 1994. The aim of the Habitats Directive is to contribute towards ensuring biodiversity through conserving natural habitats and wild fauna and flora. It provides measures to maintain or restore, at favourable conservation status, natural habitats and species of European Community interest.

These Directives established and protect a network of conservation areas across the EU called 'Natura 2000'. Natura 2000 is made up of sites designated as Special Areas of Conservation (SACs) and Special Protection Areas (SPAs). SACs can be marine or terrestrial and support rare, endangered or vulnerable natural habitats, plant and animal species. SPAs support significant numbers of wild birds, for example wintering wildfowl, and their habitats. The designation of SAC or SPA shows the value of the site on an international level.

Natural England and the Countryside Council for Wales (CCW) are responsible for reporting the condition of Natura 2000 sites and providing advice on conservation objectives to government. Competent authorities, including the Environment Agency, have duties to protect Natura 2000 sites under the Habitats Regulations.

Under the Habitats Regulations the Environment Agency has obligations to review relevant existing authorisations, permits, consents, licences and permissions (collectively referred to as permits) to ensure that no Environment Agency authorised activity or permission results in an adverse effect, either directly or indirectly, on the integrity of Natura 2000. The Environment Agency is also required to ensure that any new or varied permits do not have an adverse effect on the integrity of the Natura 2000 sites.

The Environment Agency has adopted a staged approach to reviewing existing permits:

- Stage 1 – identify the relevant permits.
- Stage 2 – determine which permits have a potential significant effect.
- Stage 3 – undertake appropriate assessment for permits with significant effects.
- Stage 4 – revise permits to ensure no adverse effects (e.g. by changing the type, amount and location of discharges).

The timescales to complete Stages 3 and 4 for high, medium and low priority Natura 2000 sites are as follows:

Site priority	**Complete Stage 3 by:**	**Complete Stage 4 by:**
High	March 2004	March 2006
Medium	March 2006	March 2008
Low	March 2008	March 2010

Environmental outcomes for Natura 2000 sites are recorded by Natural England and the Countryside Council for Wales. They set out the targets that need to be met to maintain each site in a favourable condition (see Section 3).

The Environment Agency authorises discharges of radioactive waste to the environment under the Radioactive Substances Act 1993 (RSA 93) from a variety of premises, including hospitals, universities, pharmaceutical companies and nuclear sites. These disposals include discharges to air and water. The Environment Agency has assessed the impact of discharges of authorised radioactive substances to air and water on Natura 2000 sites, as reported in Allott et al. (2009) (Stage 3 assessment).

For one Natura 2000 site in England and Wales, the Ribble and Alt Estuaries SPA, it could not be concluded as a result of the Stage 3 assessment that there is no adverse effect on the integrity of the site from authorised discharges of radioactive substances.

This report presents the results of the Stage 4 process, including the agreed environmental objective for the Ribble and Alt Estuaries SPA, plans to meet this objective and a reassessment of authorised discharges of radioactive substances to ensure the objective will be met in the future.

2 Stage 3 habitats assessment

The Stage 3 assessment methodology involved the calculation of dose rates to reference organisms and feature species using the total discharges of radionuclides at RSA 93 authorisation limits multiplied by dose rate per unit release factors. These dose rate per unit release factors were derived from dose rate per unit concentration data in air, soil and water (Copplestone et al. 2003) combined with concentration per unit discharge data. The methodology is described in more detail in Allott et al. (2009).

Assessments were made of the impact of radioactive discharges to water on coastal/marine and freshwater features of the Natura 2000 site and the impact of radioactive discharges to air on the terrestrial features of the site. For the coastal assessment, this includes the impact of discharges into a local compartment around the Natura 2000 site as well as the impact of discharges from more remote regional authorisations. These regions are based on modelling compartments and are not Environment Agency regions (see Allott et al. (2009) for more details about local and regional compartments).

The total discharges at authorisation limits in force up to 31 December 2007 which can impact on the Ribble and Alt Estuaries SPA are shown in Table 1 and the overall summary dose rate results for the worst affected organism in Table 2. The total dose rate for the worst affected organism was assessed as 520 microgray/h. The Stage 3 assessment process was designed to give cautious estimates of dose rates.

The dose rates to coastal and freshwater features are the most significant, and the contributions from different radionuclides to the dose rate for different reference organisms in the marine and freshwater assessments are shown in Tables 3 and 4 respectively. The dose rates to reference organisms are also shown in Figures 1 and 2.

The assessment predicts that the most affected marine organisms are seabirds and marine mammals. The predicted most affected freshwater organisms are amphibians and ducks. In both cases, thorium-234 and alpha-emitting radionuclides contribute the most to the dose rates (Figures 3 and 4). Within the vicinity of the Ribble and Alt Estuaries SPA, these radionuclides are discharged entirely by Springfields Fuels Ltd (see Table 5).

The Environment Agency, Natural England and the Countryside Council for Wales have agreed a dose rate threshold of 40 microgray/h, below which it can be concluded that there will be no adverse effect on the integrity of a Natura 2000 site. This has been derived as follows:

- Research from the Euratom FP5 Project ‘FASSET’ (Larsson et al. 2004) indicated that, in general and from the available data, there appear to be no significant adverse effects in biota exposed at levels of up to 100 microgray/h.
- A review paper from the FASSET Project (Brown et al. 2004) indicated that wildlife might receive up to 60 microgray/h from natural sources in European ecosystems.
- The threshold of 40 microgray/h for authorised discharges of radioactive substances is the difference between these two values.

This threshold of 40 microgray/h is the same as the lower 1992 guideline level for terrestrial animals published by the International Atomic Energy Agency (IAEA 1992). The

IAEA stated that it is unlikely that there would be any significant effect on populations of organisms which are chronically exposed at these levels.

Clearly, the predicted total dose rate for the worst affected organism for the Ribble/Alt Estuaries is greater than this threshold. Hence, the Ribble and Alt Estuaries SPA went forward into the Stage 4 process. The dose rates are dominated by discharges from the Springfields Fuels Ltd site at its pre-January 2008 RSA 93 authorisation limits.

3 Determination of permissions (Stage 4)

Where there is the potential for Environment Agency permissions to lead to an adverse effect on the integrity of a Natura 2000 site, the Environment Agency and Natural England will agree environmental outcomes for that site. The Environment Agency and Natural England will then identify options to enable the outcomes to be met. The Environment Agency is required to determine permissions to achieve the preferred option. This may include one of the following:

- reduce permission limits
- require re-location of discharge point
- revoke permission.

The potential impact of radioactive substances on the integrity of the Ribble and Alt Estuaries SPA is due almost entirely to discharges from the Springfields Fuels Ltd site into the Ribble Estuary. Hence, it was only necessary to consider discharges from this site. Springfields Fuels Ltd already had plans to reduce discharges to the River Ribble for operational reasons.

Natural England and the Environment Agency have agreed that the objective for the Ribble and Alt Estuaries SPA should be:

> ***To ensure that radioactive substances do not accumulate in Littoral Sediment (Coastal Saltmarsh), Littoral Sediment (Mudflats), Coastal Grazing Marsh (Reclaimed Saltmarshes) at levels which compromise the supply of invertebrate prey used by birds identified as SPA interest features in English Nature's Regulation 33 (2) advice, or which pose a significant risk of direct toxicity to these birds. The agreed radioactivity dose rate threshold levels should not be breached.***

Natural England and the Environment Agency have agreed a threshold of 40 microgray/h for determining whether the integrity of a Natura 2000 site may be adversely affected. We can be confident that there will be no adverse effect on the integrity of populations, if the predicted dose rates are below this value.

The limits used in the Stage 3 assessment for the Springfields Fuels Ltd site are shown in Table 6. These limits applied until 31 December 2007 with new limits to be applied from 1 January 2008. This was to remove headroom as a result of planned reductions in discharges. These new authorisation limits are also shown in Table 6 along with the actual discharges during 2006.

It can be seen in Figures 5 and 6 that the discharges of total alpha and total beta from the Springfields Fuels Ltd site in 2006 have either met or are below the new January 2008 limits.

It is necessary to reassess the impact of discharges of radioactive substances into the Ribble and Alt Estuaries SPA to determine whether these new authorisation limits will enable the objective for the Ribble and Alt Estuaries SPA to be met.

Springfields Fuels Ltd has made its own assessment of dose rates to organisms in the Ribble and Alt Estuaries SPA (Retburg 2007). The assessment approach and data have been reviewed and used to help formulate the assessment approach reported in this document.

4 Reassessment method

4.1 New ERICA assessment tool

The methods used for the Stage 3 radioactive substances habitat assessments (Allott et al. 2009) were based on work undertaken for the EU FASSET Project. In the intervening period, there has been a successor project, EU ERICA (Beresford et al. 2007a), which has extended the work of FASSET. The ERICA project has delivered an assessment tool (available from http://www.project.facilia.se/erica/download.html) which is now 'good practice' for radioactive substance habitat assessments and has been compared positively through the IAEA Environmental Modelling for Radiation Safety Programme to other models for predicting dose rates to biota. The Environment Agency has used this new tool to reassess discharges at the January 2008 authorisation limits for the Springfields Fuels Ltd site.

Full details on the application of the ERICA Integrated Approach and the use of the ERICA assessment tool are provided in Beresford et al. (2007a). However, a brief outline of the ERICA Integrated Approach is provided below.

The ERICA Integrated Approach is based on generalised ecosystem representations, termed reference organisms. Reference organisms are defined as: 'a series of entities that provide a basis for the estimation of radiation dose rate to a range of organisms which are typical, or representative, of a contaminated environment. These estimates, in turn, would provide a basis for assessing the likelihood and degree of radiation effects'. They have been defined and used for the derivation of geometric relationships between radiation sources and organisms, as well as for considerations of the dosimetry of both external and internal exposure. The reference organisms can be grouped into three general ecosystem categories, namely terrestrial, freshwater and marine ecosystems. Furthermore, they can be used for pooling some of the effects data generated for a range of species. The selection of reference organisms makes it possible to address all protected species within Europe.

The ERICA Integrated Approach is supported by the ERICA tool, which is a software programme that guides the user through the assessment process, keeps records and performs the necessary calculations to estimate dose rates to selected biota. The inputs required include details of the reference organisms (and any user-specific organism geometry that can be used to define feature species of interest in a particular assessment), the radionuclides of interest, media or biota activity concentration values, concentration ratios for radionuclide transfer between the media and the biota of interest, and dose rate conversion coefficients (which convert the radionuclide concentrations to dose rates).

The ERICA Integrated Approach follows a tiered assessment which increases in complexity, data and resource requirements as the user progresses from Tier 1 (a simple, highly conservative assessment that requires minimal data input) to Tier 3 (which is a full site-specific assessment that requires expert input, probabilistic and sensitivity analyses).

The Ribble and Alt Estuaries SPA reassessment was conducted using ERICA Tier 2, which requires realistic data as an input and allows the user to define geometries of interest (i.e. to represent the feature species present in the SPA), estimates the whole body absorbed dose rate directly, and provides some information on exposure to naturally

occurring radionuclides and also on the likely biological consequences of exposure based on available information in the scientific literature.

The Tier 2 ERICA assessment module has been used with environmental monitoring data (sediment, shrimp and mollusc data). Discharges have been reviewed to select the year when discharges have been closest to the January 2008 limits (see Section 4.2 below). Environmental monitoring data have been collated from this year (2006) and modified to take account of actual discharges compared to the January 2008 limits (see Section 4.3 below).

The new ERICA assessment tool has also been used to assess discharges at the pre-January 2008 limits to compare to the Stage 3 assessment (see Appendix 1). This has shown that there were a few pessimistic assumptions in the Stage 3 assessment for the Ribble and Alt Estuaries SPA which has led to an over-prediction of dose rates.

4.2 Discharge limits and discharges

The authorisation limits for Springfields Fuels Ltd include general limits for total alpha and total beta-emitting radionuclides and also a number of radionuclide or radioelement-specific limits (see Table 6).

There are a number of radionuclide (or radioelement) specific limits for alpha-emitting radionuclides, as well as the overall total alpha limit. These individual limits do not include all alpha-emitting radionuclides that are discharged. Key alpha-emitting radionuclides without a specific limit are radium-226, radium-228 and thorium-228. Although, there are not individual radionuclide limits in place, their discharges are limited by the overall alpha limit.

The discharges of beta-emitting radionuclides are dominated by thorium-234 (Retburg 2007), which has a relatively short half-life of 24 days, and its daughter protoactinium-234m, which has a half-life of 1.2 minutes.

Figures 5 and 6 show the discharges of total alpha activity and total beta activity over the last 5 years compared to the pre- and post-January 2008 limits. Discharges during 2006 were closest to the limits applied from January 2008.

Discharges of total alpha activity and total beta activity in 2006 were 80% and 104% respectively of the January 2008 limits. This has been taken into account to modify the monitoring data used in this reassessment.

4.3 Environmental monitoring data

The Environment Agency, Food Standards Agency and Springfields Fuels Ltd have radiological monitoring programmes in the Ribble Estuary. Monitoring data are available for sediments, shrimps and mussels. Monitoring data for 2006 have been used for assessing discharges at the January 2008 limits.

Sediment monitoring data for 2006 are shown in Table 7. Monitoring data have been selected for monitoring locations closest to the Ribble and Alt Natura sites (see Figure 7). These are monitoring locations down-estuary from the Springfields Fuels Ltd outfall.

Mean sediment concentrations have been used in the assessment and these are shown in Table 8. There are a few results below the detection limit and these have been treated

as positive results. A number of radionuclides are present in sediments in the estuary as a result of historical discharges from the Sellafield nuclear reprocessing site in Cumbria. These include caesium-137 and plutonium-239. The contributions of these radionuclides have been included in the assessment for completeness.

The discharges from Springfields Fuels Ltd are mainly naturally occurring radionuclides from long decay series. Not all radionuclides in the decay chain are analysed or reported, in particular those which are in equilibrium with their parent (or grandparent, etc.). Monitoring data were available for the key radionuclides which are not in equilibrium with their parents. The ERICA assessment tool takes account of some radionuclide daughters, by assuming the activity concentrations are the same as for the parent. This is shown in brackets in Table 8. For other key daughters, where monitoring data are not available, assumptions about the concentrations have been made and these are also shown in Table 8.

Since many radionuclides have natural background concentrations, these have been taken into account when deriving activity concentrations for use in the ERICA assessment. Natural background concentrations for Irish Sea sediment have been used (DOE 1993). Natural background concentrations for the freshwater sediments in the River Ribble catchment (Beresford et al. 2007b) are higher than these Irish Sea sediment natural background concentrations. The boundary between freshwater and coastal sediments within an estuary can be estimated from the distribution of cohesive and non-cohesive sediment. Cohesive sediments are those which have more shear stress strength than non-cohesive sediments. One of the reasons for this is electrostatic attraction between unweathered clay particles. Hence, cohesive sediments tend to be dominated by freshwater-derived sediments as these are less weathered than coastal sediments. In the Ribble Estuary, the boundary between cohesive and non-cohesive sediments is at the point the River Douglas enters the estuary (personal communication, Paul Simmons, Environment Agency). The Ribble and Alt Estuaries SPA is mainly to the east (marine) side of this point and hence the sediments are more likely to be marine in nature.

The 2006 monitoring data have been modified to take account of the fact that discharge of total alpha was not at 100% of the January 2008 limit. A correction factor of 1.3 has been applied to alpha-emitting radionuclides originating from Springfields Fuels Ltd. Discharges of beta-emitting radionuclides in 2006 were at the January 2008 limit. There was no need to scale the concentrations for radionuclides which mainly originate from historical discharges from Sellafield (Environment Agency et al. 2007).

Monitoring data for shrimps and mussels are shown in Tables 9 and 10 for 2006. The mean concentrations used in the assessment are shown in Tables 11 and 12. Only radionuclides with positive monitoring results (above the detection limit) for shrimps and mussels have been used in the assessment. Where there are only detection limit data reported, the actual concentrations may be much lower than the detection limits. The assessment could be severely pessimistic if the detection limit data were assumed to be actual results. Monitoring data have been scaled to take account of the fact that discharges of total alpha during 2006 were not at the January 2008 limits.

Where there are overlapping monitoring data between the different monitoring programmes, the monitoring results are in general agreement with the exception of thorium-228, thorium-230, thorium-232 and neptunium-237 in shrimp. For these radionuclides, the Springfields Fuels Ltd results are up to a factor of 1000 higher than the Food Standards Agency results. The effect of this variability in the environmental monitoring data on the assessment results is considered in the variability and uncertainty assessment.

4.4 Use of ERICA assessment tool

Neither the Stage 3 assessment process or the ERICA tool specifically address estuarine environments. Both tools have marine and freshwater assessment modules. Both of these modules have been used for the assessment of an estuarine environment. The ERICA tool has default data for reference organisms and these have been used in the assessment. Dosimetric data for the Ribble and Alt Estuaries SPA feature species have been created using ERICA so that these feature species can be included in the assessment. Parameter data (e.g. occupancy factor on water and sediment) for these feature species are shown in Table 13. The reference organism (bird) has an occupancy factor of 1 for water and does not take account of occupancy on sediment. Hence, a modified bird reference organism has been included with occupancy factors of 0.5 for water and 0.5 for sediment surface.

The ERICA assessment tool can accommodate a variety of input data: water activity concentrations, sediment activity concentrations, and biota activity concentrations. The tool uses these data to calculate internal and external dose rates to the reference organisms and feature species. Where data are not available, the tool will backcalculate a water concentration from a sediment concentration, using an appropriate sediment partitioning coefficient. Alternatively, it can backcalculate a water concentration from a biota activity concentration using a concentration factor. ERICA uses a defined rule set to decide how to calculate an 'average' water concentration when more than one set of data is available.

There is far more sediment monitoring data available for the Ribble Estuary than biota data. The sediment monitoring data are above the detection limit in all but a few results, which is not the case for the biota data. Also, there are major discrepancies between the biota data from the Food Standards Agency monitoring programme and the Springfields Fuels Ltd monitoring programme. The thorium-228, thorium-230, thorium-232 and neptunium-237 monitoring results for shrimp are a factor of up to 1000 higher for the Springfields monitoring programme. For these reasons, the biota monitoring data have only been used to calculate dose rates to those biota and the sediment monitoring data have been used to calculate dose rates to all organisms.

These ERICA assessments have been made:

- Marine assessment – sediment data only to assess dose rates for all organisms except crustacean and benthic mollusc.
- Marine assessment – sediment, mussel and shrimp environmental monitoring data to assess dose rates to crustacean and benthic mollusc.
- Freshwater assessment – sediment data only to assess dose rates for all organisms except crustacean and benthic mollusc.
- Freshwater assessment – sediment, mussel and shrimp environmental monitoring data to assess dose rates to crustacean and benthic mollusc.

Default parameters have been used in the ERICA assessment tool, with the exception of the sediment partitioning coefficient for thorium. ERICA uses the partitioning coefficient to calculate water activity concentrations from sediment activity concentrations. The default sediment partitioning coefficient for thorium is $3\ 10^6$ Bq/kg per Bq/l, but the mean observed value based on measurements for the Ribble Estuary is $3.5\ 10^5$ Bq/kg per Bq/l (see Table 14). Using the higher default sediment partitioning coefficient for thorium could lead to an underestimation of water concentrations and hence dose rate. So the observed value has been used.

ERICA uses excessively cautious default organism concentration factors for neptunium-237, as there are limited data for this radionuclide. Hence, it was decided to use plutonium-239 as a surrogate for neptunium-237, since the data will be more realistic.

4.5 Summary of key assumptions

The key assumptions in this assessment are as follows:

- ***Mix of radionuclides*** – The mix of radionuclides discharged in 2006 will continue to be discharged in the future.
- ***Discharges at authorisation limits*** – Environmental monitoring data have been scaled to correct for the fact that discharges of alpha-emitting radionuclides were less than the discharge limit.
- ***Mean environmental monitoring results*** – Mean sediment, shrimp and mussel environmental monitoring data have been used.
- ***Location of environmental monitoring data*** – Environmental monitoring results have been selected for samples collected from the outfall of the Springfields Fuels Ltd discharge pipeline to the mouth of the Ribble Estuary, as this area is closest to the Natura 2000 site.
- ***Sediment/biota monitoring data*** – Sediment, mussel and shrimp monitoring data have been used for assessing dose rates to crustacean and benthic mollusc; only sediment data have been used for all other organisms.
- ***Background concentrations*** – Corrections have been made for naturally occurring background concentrations.
- ***Source of radionuclides*** – Radionuclides have been included which arise from sources other than the Springfields Fuels Ltd site (e.g. Sellafield).
- ***Marine and freshwater assessments*** – Marine and freshwater assessments have been undertaken using the ERICA assessment tool as there is no estuarine assessment module.
- ***Thorium sediment partitioning coefficient*** – A Ribble Estuary specific sediment partitioning coefficient has been used in the assessment.
- ***ERICA assessment parameters*** – All other parameters in the ERICA assessment tool were default parameters.

The assumptions which most affect the results have been considered in the variability and uncertainty assessment.

5 Results of reassessment

The ERICA marine and freshwater assessment results for the January 2008 limits are shown in Tables 15 and 16 and Figures 8 and 9 respectively for the reference organisms. Total dose rates to the feature species for the Ribble and Alt Estuaries SPA for the marine and freshwater assessments are shown in Table 17 and Figures 10 and 11. The highest dose rate for the marine assessment is 16 microgray/h to phytoplankton and the highest dose rate for the freshwater assessment is 27 microgray/h for vascular plants. The total dose rates to the feature species are all less than 1 microgray/h. The dose rate for the modified bird reference organism is in the mid-point of the range of dose rates to the feature species.

There is an additional dose rate from potential exposure to terrestrial discharges. This was conservatively assessed as 3.6 microgray/h in the Stage 3 assessment (Table 2). Hence the highest total dose rates are 20 microgray/h to phytoplankton for the marine assessment and 31 microgray/h to vascular plants for the freshwater assessment.

The radionuclides with the greatest contribution to the phytoplankton dose rate are thorium-228, thorium-230 and plutonium-239/neptunium-237 (see Table 15 and Figure 12). Although there are discharges of thorium-228 from Springfields Fuels Ltd, the monitored sediment activity concentrations are close to and probably not in excess of the natural background.

The radionuclides with the greatest contribution to the vascular plants dose rate are uranium-234 and uranium-238 (see Table 16 and Figure 13). Again these are discharged in small quantities from the Springfields Fuels Ltd site, but it is also probable that the monitored sediment activity concentrations are actually background concentrations.

The dose rates to marine and freshwater reference organisms and feature species using the ERICA assessment tool are below 40 microgray/h.

6 Variability and uncertainty in reassessment

The key elements of variability and uncertainty in the reassessment of dose rates to reference organisms and feature species in the Ribble and Alt Estuaries SPA arise in the following parameters:

- ***Mix of radionuclides in the discharge*** – There is uncertainty in assumption that the mix of radionuclides discharged in 2006 will continue in the future. A greater proportion of radionuclides with higher or lower dose rate per unit concentrations could be discharged.
- ***Environmental monitoring results*** – There is variability in the environmental monitoring results, as can be seen in Tables 7, 9 and 10.
- ***Sediment partitioning coefficients*** – There is uncertainty in the selection of appropriate sediment partitioning coefficients for the Ribble and Alt Estuaries SPA as well as variability for different sediment types within the estuary. A lower sediment partitioning coefficient will lead to the calculation of a higher water concentration which is used with the concentration factor to calculate the uptake of radionuclides into organisms.
- ***Concentration factors*** – There is uncertainty in the selection of appropriate concentration factors for reference organisms and feature species in the Ribble and Alt Estuaries SPA as well as variability within the organism populations.

A variability and uncertainty assessment has been carried out for these parameters as described in Appendix 2. The total dose rates to marine organisms from the variability and uncertainty assessment are shown in Figures 14–17. It is not realistic to combine all worst case scenarios or all best case scenarios together, hence the variability and uncertainty assessment results have been kept separate for each scenario.

Phytoplankton is the organism with the highest dose rate for each variability and uncertainty scenario. The maximum dose rates to all other organisms for these scenarios were less than 40 microgray/h. The range of dose rates to phytoplankton for each scenario are:

- Best/worst case discharge profiles 13–47 microgray/h
- Minimum/maximum environmental concentrations 5.1–63 microgray/h
- High/low thorium sediment partitioning coefficient 4.8–420 microgray/h
- Low/high concentration factors 1.4–50 microgray/h

The radionuclides that provide the dominant contribution to the dose rate for phytoplankton are thorium-228, thorium-230, thorium-232 and thorium-234 (Figure 18).

Although phytoplankton is not a feature species, it is part of the food chain for feature species and hence populations of phytoplankton need to be protected. However, the dose rate threshold above which there is likely to be an adverse affect on the integrity of populations of phytoplankton is much higher than 40 microgray/h. In the literature, effects that might lead to a reduction in the population have only been observed under laboratory conditions at dose rates in excess of 10000 microgray/h (Woodhead and Zinger 2003).

The confidence in the assessment of dose rates to phytoplankton could be increased by a better understanding of concentrations of thorium isotopes in phytoplankton in the Ribble and Alt Estuaries SPA. For this reason it is recommended that a small programme of phytoplankton monitoring is undertaken.

7 Conclusions

Under the Habitats Regulations, the Environment Agency has obligations to review relevant existing authorisations, permits, consents, licences and permissions (collectively referred to as permits) to ensure that no Environment Agency authorised activity or permission results in an adverse effect, either directly or indirectly, on the integrity of Natura 2000 sites.

The Environment Agency has adopted a staged approach to reviewing existing permits:

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- Stage 3 – undertake appropriate assessment for permits with significant effects.
- Stage 4 – revise permits to ensure no adverse effects (e.g. by changing the type, amount and location of discharges).

Dose rates to reference organisms and feature species were calculated for authorised discharges under RSA 93 in the Stage 3 assessment. These dose rates were compared to a threshold of 40 microgray/h, below which the Environment Agency and Natural England agreed there would be no adverse effect on the integrity of a Natura 2000 site. For one Natura 2000 site, the Ribble and Alt Estuaries SPA, it could not be concluded as a result of the Stage 3 assessment that there was no adverse effect on the integrity of the site from authorised discharges of radioactive substances. The primary reason was discharges from the Springfields Fuels Ltd RSA 93 authorisation limits.

The Environment Agency and Natural England have agreed a habitats protection objective for the Ribble and Alt Estuaries SPA. This includes meeting the agreed dose rate threshold of 40 microgray/h. The RSA 93 authorisation for the Springfields Fuels Ltd site includes new lower authorisation limits which came into force on 1 January 2008. A reassessment has been made of discharges at these January 2008 limits using the newly available EU-funded ERICA assessment tool.

The reassessed dose rates to reference organisms and feature species in the Ribble and Alt Estuaries SPA for discharges at the January 2008 Springfields Fuels Ltd authorisation limits are less than 40 microgray/h.

A variability and uncertainty assessment has been carried out. This shows that for phytoplankton only, dose rates above 40 microgray/h could occur in some circumstances. However, the dose rate threshold above which populations of phytoplankton would suffer adverse affects is much higher than 40 microgray/h, probably as high as 10000 microgray/h. The uncertainty in the assessment of phytoplankton dose rates could be reduced with some monitoring results.

Overall, it is concluded that the environmental outcomes for the Ribble and Alt Estuaries SPA will be met through the introduction of the January 2008 authorisation limits for the Springfields Fuels Ltd site.

8 Recommendations

It is recommended that, if practicable, phytoplankton samples should be obtained from the Ribble and Alt Estuaries SPA and monitored for thorium-228, thorium-230, thorium-232 and thorium-234 to reduce the uncertainty in the dose assessment for these organisms, given their importance in the food chain. Alternatively, it may be possible to study uptake of these radionuclides by phytoplankton in the laboratory.

Before a new permit is authorised or an existing permit varied which has the potential to impact on the Ribble and Alt Estuaries SPA, it is recommended that the dose assessment be reviewed to ensure that any combination effects from multiple discharge sources of radioactive substances continues to achieve the required environmental outcome. A process now exists to ensure that this review is undertaken if and when an application for a new or varied authorisation is received.

9 References

Allott, R., Copplestone, D., Merrill, P. and Oliver, S. 2009. *Habitats Assessments for Radioactive Substances*. Environment Agency Technical Report NMA/TR/2008/05.

Beresford, N.A., Brown, J., Copplestone, D., Garnier-Laplace, J., Howard, B.J., Larsson, C-M., Oughton, D., Pröhl, G. and Zinger, I. 2007a. *D-ERICA: An Integrated Approach to the Assessment and Management of Environmental Risks from Ionising Radiation. Description of Purpose, Methodology and Application*, 82pp. Deliverable of the Environmental Risk from Ionising Contaminants: Assessment and Management (ERICA) Project EC Contract No. FI6R-CT-2004-508847.

Beresford, N.A., Appleton, J.D., Barnett, C.L., Bescoby, M.W., Breward, N., Jones, D.G., MacKenzie, A.C., Scheib, C., Thørring, H. and Wood, M.D. 2007b. *Assessment of Naturally Occurring Radionuclides in England and Wales*. Environment Agency Science Report SC030283/SR.

Brown, J.E., Jones, S.R., Saxén, R., Thørring, H. and Vives i Batlle, J. 2004. Radiation doses to aquatic organisms from natural radionuclides. *Journal of Radiological Protection* 24, A63–A77.

Chambers, N. and Punt, A. 2002. *Investigation of ^{137}Cs and Thorium Behaviour in the Ribble Estuary in Support of the Calibration and Validation of VERSE*. Westlakes Scientific Consulting.

Copplestone, D., Wood, M.D., Bielby, S., Jones, S.R., Vives, J. and Beresford, N.A. 2003. *Habitats Regulations for Stage 3 Assessments: Radioactive Substances Authorisations*. Environment Agency R&D Technical Report P3-101/SP1a. ISBN: 1844321754.

DOE (Department of the Environment) 1993. *Natural Radionuclides in Environmental Media*. DOE Report No. DOE/HMIP/RR/93/063.

Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency 2005. *Radioactivity in Food and the Environment, 2004 (RIFE-10)*.

Environment Agency, Environment and Heritage Service, Food Standards Agency and Scottish Environment Protection Agency 2007. *Radioactivity in Food and the Environment, 2006 (RIFE-12)*.

IAEA 1992. *Effects of Ionising Radiation on Plants and Animals at Levels Implied by Current Radiation Protection Standards*. Technical Report Series No. 332, International Atomic Energy Agency, Vienna.

IAEA 2004. *Sediment Distribution Coefficients and Concentration Factors for Biota in the Marine Environment*. IAEA Technical Report Series No. 422.

Larsson, C-M., Jones, C., Gomez-Ros, J.M. and Zinger, I. 2004. *Deliverable 6: Framework for Assessment of Environmental Impact of Ionising Radiation in Major European Ecosystems*, 74pp. Framework for Assessment of Environmental Impact (FASSET) Project EC Contract No. FIGE-CT-2000-00102.

Retburg, C. 2007. *Springfields Habitats Dose Assessment* (draft August 2007), 16pp.

Woodhead, D. and Zinger, I. (2003) *Deliverable D4: Radiation Effects on Plants and Animals*. Framework for Assessment of Environmental Impact (FASSET) Project EC Contract No. FIGE-CT-2000-00102.

Table 1: Discharges at pre-January 2008 limits affecting Ribble/Alt Estuaries used in Stage 3 assessment (Bq/y)

Radionuclide	Total discharges at limits to water affecting coastal features		Total discharges at limits to water affecting freshwater features	Total discharges at limits to air affecting terrestrial features
	Local compartment	Regional compartment[a]		
Tritium (not OBT)	-	2.4E+15	-	-
Carbon-14	-	4.0E+11	-	-
Phosphorus-32/33	2.4E+09	7.0E+09	2.4E+09	-
Sulphur-35	-	5.1E+12	-	-
Cobalt-60	-	6.0E+10	-	-
Strontium-90	-	4.8E+08	-	-
Technetium-99	6.0E+11	1.0E+09	6.0E+11	-
Technetium-99m	3.6E+11	1.8E+12	3.6E+11	-
Iodine-125	-	2.5E+11	-	-
Iodine-131	8.2E+10	1.1E+12	8.2E+10	-
Caesium-137	-	8.4E+06	-	-
Thorium-234	1.4E+14	-	1.4E+14	-
Uranium-alpha	1.0E+11	2.7E+10	1.0E+11	8.6E+08
Plutonium-alpha	4.0E+10	-	4.0E+10	-
Other alpha	4.4E+11	1.8E+11	4.4E+11	-
Other beta/gamma (t1/2 >10 days)	1.7E+11	8.6E+12	1.7E+11	-

[a]Regional compartment is only included for the coastal assessment.

Table 2: Stage 3 summary dose rates to the worst affected organism for Ribble/Alt Estuaries

Feature of Natura 2000 site	Dose rate (microgray/h)
Coastal	
Local compartment	5.1E+02
Regional compartment	1.6E+00
Total coastal	5.1E+02
Freshwater	2.6E+02
Maximum water	**5.1E+02**
Terrestrial	**3.6E+00**
TOTAL DOSE RATE	**5.2E+02**

Table 3: Organism dose rates for Stage 3 Ribble/Alt marine assessment (microgray/h)

Radionuclide	Bacteria	Benthic fish	Benthic mollusc	Fish egg	Large b. crust.	Macro-phyte	Pelagic fish	Phyto-plankton	Seabird	Seal	Small b. crust.	Whale	Zoo-plankton
Phosphorus-32/33	3.4E-04	8.3E-04	6.9E-04	2.2E-04	7.2E-04	5.1E-04	8.3E-04	1.3E-07	8.5E-04	8.5E-04	4.0E-04	8.7E-04	7.2E-05
Technetium-99m	2.0E-03	5.9E-04	1.2E-03	2.5E-03	4.7E-03	2.0E-03	5.9E-04	1.7E-06	5.6E-03	7.4E-03	1.2E-03	8.9E-03	3.7E-05
Iodine-131	1.9E-05	1.4E-05	1.3E-05	1.6E-03	1.3E-05	5.8E-04	1.4E-05	3.2E-06	2.7E-03	3.8E-03	1.3E-05	4.7E-03	1.8E-03
Thorium-234	1.4E+02	4.4E+00	2.4E+01	8.8E+01	1.9E+01	1.0E+02	4.4E+00	6.1E-03	3.4E+02	3.6E+02	5.0E+01	3.6E+02	5.8E-01
Uranium-alpha	1.0E+00	2.6E-03	7.5E-02	2.5E+00	2.5E-02	2.5E-01	2.6E-03	4.9E-02	2.5E+00	2.5E+00	2.6E-02	2.5E+00	1.2E-02
Plutonium-alpha	5.2E+00	5.2E-03	4.0E-01	1.3E+01	4.0E-02	2.6E-01	5.2E-03	1.3E+01	1.3E+01	1.3E+01	4.0E-02	1.3E+01	1.3E-01
Other alpha	5.7E+01	5.7E-02	4.4E+00	1.4E+02	4.4E-01	2.8E+00	5.7E-02	1.4E+02	1.4E+02	1.4E+02	4.4E-01	1.4E+02	1.4E+00
Other beta/gamma (t1/2 >10 days)	2.1E-02	6.7E-03	7.7E-03	1.0E-02	7.6E-03	1.7E-02	6.7E-03	1.8E-05	2.5E-02	7.1E-03	8.5E-03	2.2E-03	1.2E-04
Total	**2.0E+02**	**4.5E+00**	**2.9E+01**	**2.4E+02**	**2.0E+01**	**1.1E+02**	**4.5E+00**	**1.5E+02**	**5.0E+02**	**5.1E+02**	**5.0E+01**	**5.1E+02**	**2.1E+00**

Table 4: Organism dose rates for Stage 3 Ribble/Alt freshwater assessment (microgray/h)

Radionuclide	Amphib-ian	Aqu. mammal	Bacteria	Benthic fish	Benthic mollusc	Duck	Large b. crust.	Macro-phyte	Pelagic fish	Phyto-plankton	Small b. crust.	Zoo-plankton
Phosphorus-32/33	1.1E-02	9.8E-03	4.3E-03	1.1E-02	8.7E-03	1.1E-02	9.2E-03	3.8E-03	1.1E-02	2.7E-07	5.2E-03	1.5E-04
Technetium-99m	5.0E-02	4.4E-02	2.2E-04	1.9E-03	1.4E-03	5.5E-02	7.4E-04	4.9E-02	1.9E-03	5.6E-06	3.4E-04	5.5E-04
Iodine-131	1.5E-03	1.4E-03	3.0E-05	1.1E-04	3.7E-04	1.6E-03	3.9E-04	6.9E-04	1.1E-04	6.9E-06	3.1E-04	1.1E-03
Thorium-234	1.2E+02	1.1E+02	5.1E+01	2.7E+00	9.0E+00	1.2E+02	7.6E+00	4.7E+01	2.7E+00	9.7E-02	1.8E+01	8.2E+00
Uranium-alpha	1.6E+01	1.6E+01	5.2E-02	2.5E-02	4.5E-01	1.6E+01	4.5E-01	1.6E+01	2.5E-02	1.0E-02	4.5E-01	2.5E-03
Plutonium-alpha	1.1E+01	2.4E-02	4.3E+00	7.4E-03	8.9E-02	2.2E-04	1.5E-02	1.9E-01	7.4E-03	1.9E-02	1.5E-02	2.2E-03
Other alpha	1.2E+02	2.6E-01	4.7E+01	8.0E-02	9.7E-01	2.4E-03	1.6E-01	2.1E+00	8.0E-02	2.1E-01	1.6E-01	2.3E-02
Other beta/gamma (t1/2 >10 days)	7.1E-02	6.3E-02	7.2E-03	7.5E-02	5.5E-03	7.6E-02	5.9E-03	1.4E-02	7.5E-02	2.1E-05	2.2E-02	9.0E-05
Total	**2.6E+02**	**1.2E+02**	**1.0E+02**	**2.9E+00**	**1.1E+01**	**1.3E+02**	**8.3E+00**	**6.6E+01**	**2.9E+00**	**3.4E-01**	**1.9E+01**	**8.2E+00**

Table 5: Stage 3 discharge limits for Springfields Fuels Ltd

Radionuclide	Discharges at limits to water from Springfields (Bq/y)	% of total discharges to water
Tritium (not OBT)	0.0E+00	0%
Carbon-14	0.0E+00	0%
Phosphorus-32/33	0.0E+00	0%
Sulphur-35	0.0E+00	0%
Cobalt-60	0.0E+00	0%
Strontium-90	0.0E+00	0%
Technetium-99	6.0E+11	100%
Technetium-99m	0.0E+00	0%
Iodine-125	0.0E+00	0%
Iodine-131	0.0E+00	0%
Caesium-137	0.0E+00	0%
Thorium-234	1.4E+14	100%
Uranium-alpha	1.0E+11	100%
Plutonium-alpha	4.0E+10	100%
Other alpha	4.4E+11	100%
Other beta/gamma (t1/2 >10 days)	0.0E+00	0%

Table 6: Pre-January 2008 and January 2008 discharge limits for Springfields Fuels Ltd

Radioactive substance or category	Pre-January 2008 limits (TBq)	January 2008 limit (from 1/1/2008) (TBq)	2006 discharges (TBq)	2006 discharges as % of January 2008 limits
Overall limits				
Alpha	0.55	0.1	0.08	80%
Beta	140	20	20.7	104%
Limits on individual radionuclides and radioelements				
Technetium-99 (beta)	0.6	0.6	0.065	11%
Thorium-230 (alpha)	0.4	0.02	0.0119	60%
Thorium-232 (alpha)	0.015	0.015	0.00031	2%
Neptunium-237 (alpha)	0.04	0.04	0.00158	4%
Other transuranic radionuclides (alpha)	0.02	0.02	0.00235	12%
Uranium (alpha)	0.1	0.04	0.026	65%

Table 7: Sediment monitoring data for 2006 (Bq/kg dry weight)

Data source	Sample site	Date	^{60}Co	^{106}Ru	^{134}Cs	^{137}Cs	^{228}Th	^{230}Th	^{232}Th	^{234}Th	^{234}U	^{235}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu/ ^{240}Pu	^{241}Am
SEMP	FBY	Jan 06				339	37	208	41	66000				6.9			228
SEMP	FBY	Apr 06				237	36	133	35	4510				4.3			152
SEMP	FBY	Jul 06				303	35	103	39	2580				5.6			198
SEMP	FBY	Oct 06				315	29	95	35	229				4.3			185
SEMP	Outfall	Jan 06				69	20	53	30	7800				4.7			45
SEMP	Outfall	Apr 06				246	27	104	34	3380				4.2			85
SEMP	Outfall	Jul 06				280	25	65	30	2690				5.4			175
SEMP	Outfall	Oct 06				175	25	57	30	171				3.9			107
SEMP	BBY	Jan 06				231	29	99	29	32400				6.8			153
SEMP	BBY	Apr 06				96.1	27	65	34	860				4.9			60
SEMP	BBY	Jul 06				290	34	83	35	1590				4.4			177
SEMP	BBY	Oct 06				323	29	110	34	289				5.4			193
SEMP	GB	Jan 06				105	37	63	45	2200				3.8			76
SEMP	GB	Apr 06				150	40	60	31	1090				4.6			103
SEMP	GB	Jul 06				131	26	56	33	152				3.7			93
SEMP	GB	Oct 06				66.2	26	43	37	146				3.4			52
SEMP	WM	Jan 06				401	42	167	41	27500				7			271
SEMP	WM	Apr 06				464	40	199	37	2200				5.9			275
SEMP	WM	Jul 06				383	42	104	35	781				4.6			220
SEMP	WM	Oct 06				440	35	102	42	212				5.7			276
RIFE	BBY	2006	2.3	7	1.0	245	21	58	18	1895	24	1.0	22				105
RIFE	FBY	2006	2.9	6	0.8	350	12	40	13	1000	25	1.2	27				210
RIFE	HM	2006	1.0	5	0.5	500	57	400	53	200	28	1.3	28				160
RIFE	LM	2006	0.8	6	0.8	130	23	92	20	330	28	0.8	29				71
RIFE	LYC	2006	4.0	12	1.3	320	9.2	28	11	990	25	0.8	26				170
RIFE	Outfall	2006	1.5	8	0.9	165	18.5	97	17.5	878	21	1.1	20				104
RIFE	HMB	2006													12	67	
Mean activity conc.			**2.1**	**7.3**	**0.88**	**260**	**30**	**100**	**32**	**6200**	**25**	**1**	**25**	**5**	**12**	**67**	**150**

SEMP = Springfields Environmental Monitoring Programme (Retburg 2007); RIFE = Radioactivity in Food and the Environment (Environment Agency et al. 2007).
BBY = Becconsall boatyard; FBY = Freckleton boatyard; GB = Granny's Bay; HM = Hutton Marsh; HMB = Half Moon Bay; LM = Longton Marsh; LYC = Lytham Yacht Club; Outfall = Springfields pipeline outfall; WM = Warton Marsh.

Table 8: Mean 2006 sediment activity concentrations used in habitats assessment

Radionuclide	Mean activity conc. (Bq/kg dry weight)	Natural background conc. (Bq/kg dry weight)	Correction factor for discharges below limits	Corrected mean activity conc. (Bq/kg dry weight)	Comment on mean result and background
Cobalt-60	2.1	0	1[b]	2.1	See Table 7 for mean result; zero background
Ruthenium-106 (+rhodium-106)	7.3	0	1[b]	7.3	See Table 7 for mean result; zero background
Caesium-134	0.88	0	1[b]	0.88	See Table 7 for mean result; zero background
Caesium-137 (+barium-137m)	260	0	1[b]	260	See Table 7 for mean result; zero background
Polonium-210 (+Bismuth-210)	25	19	1.3	7.8	Mean result and background same as uranium-238
Radium-226 (+radon-222, astatine-218, polonium-218, lead-214, bismuth-214, polonium-214)	25	19	1.3	7.8	Mean result and background same as uranium-238
Radium-228	32	20	1	12	Mean result and background same as thorium-232
Thorium-228 (+radium-224, radon-220, polonium-216, lead-212, bismuth-212, polonium-212, thallium-208)	30	20	1.3	13	See Table 7 for mean result; background same as thorium-232
Thorium-230	100	35	1.3	85	See Table 7 for mean result; background DOE 1993
Thorium-232	32	20	1.3	16	See Table 7 for mean result; background DOE 1993
Thorium-234 (+protactinium-234m and protactinium-234)	6200	18	1	6200	See Table 7 for mean result; background same as uranium-234
Uranium-234	25	18	1.3	9.1	See Table 7 for mean result; background DOE 1993
Uranium-235 (+thorium-231)	1	0.79	1.3	0.27	See Table 7 for mean result; background calculated from ratio uranium-234 to uranium-235 in natural uranium
Uranium-238	25	19	1.3	7.8	See Table 7 for mean result; background DOE 1993
Neptunium-237[a]	5	-	1.3	6.5	See Table 7 for mean result; no background data
Plutonium-238	12	0	1	12	See Table 7 for mean result; zero background
Plutonium-239 + Plutonium-240	67	0	1	67	See Table 7 for mean result; zero background
Americium-241	150	0	1.3	200	See Table 7 for mean result; zero background

[a]Assessed as plutonium-239.
[b]Dominated by discharges from Sellafield.

Table 9: Shrimp monitoring data for 2006 (Bq/kg wet weight)

Data source	Sample site	Date	^{60}Co	^{99}Tc	^{106}Ru	^{134}Cs	^{137}Cs	^{228}Th	^{230}Th	^{232}Th	^{234}Th	^{237}Np	^{238}Pu	^{239}Pu/ ^{240}Pu	^{241}Am
SEMP	Ribble	Feb-06					2.4	1.9	1.7	0.61	12	1.9			0.58
SEMP	Ribble	Sep-06					3.1	1.7	1.5	0.53	18	9.8			0.8
RIFE	Ribble	2006	<0.05	0.64	<0.49	<0.05	2.2	0.012	0.012	0.0027		0.00026	0.0017	0.011	0.022
Mean activity conc.			**0.05**	**0.64**	**0.49**	**0.05**	**2.6**	**1.2**	**1.1**	**0.38**	**15**	**3.9**	**0.0017**	**0.011**	**0.47**

SEMP = Springfields Environmental Monitoring Programme (Retburg 2007); RIFE = Radioactivity in Food and the Environment (Environment Agency et al. 2007).

Table 10: Mussel monitoring data for 2006 (Bq/kg wet weight)

Data Source	Sample Site	Date	^{60}Co	^{99}Tc	^{106}Ru	^{134}Cs	^{137}Cs	^{228}Th	^{230}Th	^{232}Th	^{234}Th	^{237}Np	^{238}Pu	^{239}Pu/ ^{240}Pu	^{241}Am
SEMP	Ribble	Feb-06					2	1.2	1.06	0.38	41				1.15
SEMP	Ribble	Sep-06					1.6	1.3	1.12	0.4	36				0.59
RIFE	Ribble	2006	<0.13		<0.53	<0.05	1.2	0.27	0.29	0.089					1.4
Mean activity conc.			**0.13**	**-**	**0.53**	**0.05**	**1.6**	**0.92**	**0.82**	**0.29**	**39**	**-**	**-**	**-**	**1**

SEMP = Springfields Environmental Monitoring Programme (Retburg 2007); RIFE = Radioactivity in Food and the Environment (Environment Agency et al. 2007).

Table 11: Mean 2006 activity concentrations in shrimp used in habitats assessment

Radionuclide	Mean activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected mean activity conc. Bq/kg wet weight)	Comment on mean result and background
Technetium-99	0.64	0	1[b]	0.64	See Table 9 for mean result; zero background
Caesium-137	2.6	0	1[b]	2.6	See Table 9 for mean result; zero background
Thorium-228	1.2	0.0096	1.3	1.5	See Table 9 for mean result; background DOE 1993
Thorium-230	1.1	0.0026	1.3	1.4	See Table 9 for mean result; background DOE 1993
Thorium-232	0.38	0.0014	1.3	0.49	See Table 9 for mean result; background DOE 1993
Thorium-234	15	0.0026	1	15	See Table 9 for mean result; background same as thorium-230
Neptunium-237[a]	3.9	0	1.3	5.1	See Table 9 for mean result; zero background
Plutonium-238	0.0017	0	1[b]	0.0017	See Table 9 for mean result; zero background
Plutonium-239/240	0.011	0	1[b]	0.011	See Table 9 for mean result; zero background
Americium-241	0.47	0	1.3	0.61	See Table 9 for mean result; zero background

[a]Assessed as plutonium-239.
[b]Dominated by discharges from Sellafield.

Table 12: Mean 2006 activity concentrations in mussels used in habitats assessment

Radionuclide	Mean activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected mean activity conc. Bq/kg wet weight)	Comment on mean result and background
Technetium-99	-	0	N/A	N/A	No data
Caesium-137	1.6	0	1[b]	1.6	See Table 10 for mean result; zero background
Thorium-228	0.92	0.37	1.3	0.72	See Table 10 for mean result; background DOE 1993
Thorium-230	0.82	0.19	1.3	0.82	See Table 10 for mean result; background DOE 1993
Thorium-232	0.29	0.28	1.3	0.013	See Table 10 for mean result; background DOE 1993
Thorium 234	39	0.19	1	39	See Table 10 for mean result; background same as thorium-230
Neptunium-237[a]	-	0	N/A	N/A	No data
Plutonium-238	-	0	N/A	N/A	No data
Plutonium-239/240	-	0	N/A	N/A	No data
Americium-241	1.0	0	1.3	1.3	See Table 10 for mean result; zero background

[a]Assessed as plutonium-239. [b]Dominated by discharges from Sellafield.

Table 13: Parameter data for feature species

Feature species	Occupancy				Height (m)	Width (m)	Length (m)	Mass (kg)
	Water-surface	Water	Sediment-Surface	Sediment				
Bird	0	1.0	0	0	Default	Default	Default	Default
Bird (revised occupancy)	0	0.5	0.5	0	Default	Default	Default	Default
Bar-tailed godwit (female)	0.05	0.05	0.70	0.00	4.9E-02	4.9E-02	2.9E-01	3.7E-01
Bar-tailed godwit (male)	0.05	0.05	0.70	0.00	4.0E-02	4.0E-02	2.9E-01	2.5E-01
Bewick's swan (female)	0.25	0.25	0.30	0.00	1.3E-01	1.3E-01	6.1E-01	5.3E+00
Bewick's swan (male)	0.25	0.25	0.30	0.00	1.4E-01	1.4E-01	6.1E-01	6.4E+00
Black-tailed godwit (female)	0.05	0.05	0.70	0.00	4.5E-02	4.5E-02	3.2E-01	3.4E-01
Black-tailed godwit (male)	0.05	0.05	0.70	0.00	4.0E-02	4.0E-02	3.2E-01	2.8E-01
Common scoter (female)	0.25	0.25	0.30	0.00	7.5E-02	7.5E-02	3.3E-01	9.5E-01
Common scoter (male)	0.25	0.25	0.30	0.00	8.0E-02	8.0E-02	3.3E-01	1.1E+00
Cormorant	0.25	0.25	0.30	0.00	2.2E-01	3.0E-01	7.8E-01	2.7E+00
Curlew (female)	0.05	0.05	0.70	0.00	6.7E-02	6.7E-02	4.3E-01	1.0E+00
Curlew (male)	0.05	0.05	0.70	0.00	5.9E-02	5.9E-02	4.3E-01	7.7E-01
Dunlin	0.25	0.25	0.20	0.00	9.0E-02	9.0E-02	1.6E-01	6.8E-02
Golden plover	0.05	0.05	0.70	0.00	1.1E-01	1.2E-01	2.4E-01	2.2E-01
Grey plover	0.05	0.05	0.70	0.00	1.2E-01	1.3E-01	2.5E-01	2.4E-01
Knot	0.05	0.05	0.70	0.00	1.6E-01	1.0E-01	2.0E-01	1.4E-01
Lapwing	0.05	0.05	0.70	0.00	1.3E-01	1.4E-01	2.6E-01	2.3E-01
Lesser black-backed gull (female)	0.05	0.05	0.70	0.00	5.0E-02	5.0E-02	5.3E-01	6.9E-01
Lesser black-backed gull (male)	0.05	0.05	0.70	0.00	5.4E-02	5.4E-02	5.3E-01	8.1E-01
Oystercatcher	0.05	0.05	0.70	0.00	5.5E-02	5.5E-02	3.4E-01	5.4E-01
Pink-footed goose	0.05	0.05	0.70	0.00	3.7E-01	2.8E-01	6.2E-01	2.6E+00
Pintail (female)	0.25	0.25	0.30	0.00	5.9E-02	5.9E-02	3.9E-01	7.0E-01
Pintail (male)	0.25	0.25	0.30	0.00	6.6E-02	6.6E-02	3.9E-01	9.0E-01
Redshank (female)	0.05	0.05	0.70	0.00	3.2E-02	3.2E-02	2.4E-01	1.3E-01
Redshank (male)	0.05	0.05	0.70	0.00	2.9E-02	2.9E-02	2.4E-01	1.1E-01
Sanderling	0.05	0.05	0.70	0.00	9.0E-02	7.0E-02	1.7E-01	6.0E-02
Scaup	0.25	0.25	0.30	0.00	1.7E-01	1.7E-01	4.3E-01	1.0E+00
Shelduck (female)	0.25	0.25	0.30	0.00	6.8E-02	6.8E-02	4.2E-01	1.0E+00
Shelduck (male)	0.25	0.25	0.30	0.00	7.5E-02	7.5E-02	4.2E-01	1.2E+00
Teal (female)	0.25	0.25	0.30	0.00	4.9E-02	4.9E-02	2.4E-01	3.0E-01
Teal (male)	0.25	0.25	0.30	0.00	5.3E-02	5.3E-02	2.4E-01	3.5E-01
Whooper swan (female)	0.25	0.25	0.30	0.00	1.5E-01	1.5E-01	7.6E-01	9.3E+00
Whooper swan (male)	0.25	0.25	0.30	0.00	1.5E-01	1.5E-01	7.6E-01	9.3E+00
Wigeon (female)	0.25	0.25	0.30	0.00	6.2E-02	6.2E-02	3.2E-01	6.5E-01
Wigeon (male)	0.25	0.25	0.30	0.00	6.9E-02	6.9E-02	3.2E-01	8.0E-01

Table 14: Thorium partitioning coefficient

Radioactive substance or category	Water conc.[a] (Bq/l)	Particulate conc.[a] (Bq/kg)	Kd[b] (Bq/kg per Bq/l)
Thorium-228	0.00021	49	$2.3\ 10^5$
Thorium-230	0.0059	810	$1.4\ 10^5$
Thorium-232	0.000057	52	$9.1\ 10^5$
Thorium-234	1.5	180000	$1.2\ 10^5$
Average			**$3.5\ 10^5$**

[a]Chambers and Punt (2002).
[b]Ratio of sediment concentration to water concentration.

Table 15: Dose rate to marine reference organisms using ERICA assessment tool for January 2008 limits (microgray/h)

Nuclide	Benthic fish	Crust-acean[a]	Mammal	Pelagic fish	Phyto-plankton	Vascular plant	Zoo-plankton	(Wading) bird	Benthic mollusc[a]	Macro-algae	Poly-chaete worm	Reptile	Sea anemones or true corals – colony	Sea anemones or true corals – polyp
Cobalt-60	1.4E-03	1.4E-03	2.7E-06	7.5E-06	1.0E-06	1.5E-03	1.9E-06	8.5E-07	1.5E-03	1.5E-03	2.9E-03	2.7E-06	1.4E-03	1.5E-03
Technetium-99	5.2E-08	3.7E-05	4.0E-08	5.2E-08	6.6E-09	5.1E-05	1.6E-07	5.2E-08	1.5E-05	5.0E-05	3.7E-05	5.2E-08	3.6E-05	3.6E-05
Ruthenium-106	8.1E-04	6.3E-04	4.2E-06	3.7E-06	2.2E-03	1.1E-03	1.3E-03	3.8E-06	1.2E-03	1.9E-03	2.7E-03	4.2E-06	8.8E-04	1.6E-03
Caesium-134	3.6E-04	3.5E-04	2.7E-05	3.8E-06	1.7E-06	3.8E-04	2.2E-06	2.2E-05	3.8E-04	4.0E-04	7.8E-04	5.9E-05	3.6E-04	4.0E-04
Caesium-137	4.0E-02	3.8E-02	4.5E-03	1.0E-03	6.0E-04	4.2E-02	8.8E-04	5.7E-03	4.2E-02	4.5E-02	8.7E-02	9.6E-03	4.1E-02	4.6E-02
Polonium-210	2.1E-04	7.3E-04	1.2E-04	2.1E-04	3.1E-04	1.2E-05	9.2E-04	1.2E-04	4.2E-04	1.2E-05	2.4E-04	1.2E-04	7.3E-04	7.3E-04
Radium-226	1.5E-01	8.7E-02	3.3E-02	1.5E-01	5.4E-01	5.1E-02	4.3E-02	1.6E-01	3.8E-02	5.2E-02	8.8E-02	1.5E-01	5.3E-01	5.3E-01
Radium-228	3.7E-03	3.3E-03	2.2E-04	6.1E-04	7.7E-04	3.5E-03	1.1E-04	6.4E-04	3.5E-03	3.7E-03	7.1E-03	1.0E-03	5.2E-03	5.1E-03
Thorium-228	9.8E-03	2.8E-01	1.3E-03	4.1E-03	5.1E+00	2.0E-02	5.2E-02	2.2E-04	1.4E-01	2.1E-02	1.6E-02	2.3E-04	2.4E-02	2.5E-02
Thorium-230	3.9E-03	3.8E-02	1.2E-03	3.9E-03	4.8E+00	1.3E-02	4.9E-02	2.2E-04	2.2E-02	1.3E-02	3.4E-03	2.2E-04	1.8E-02	1.8E-02
Thorium-232	6.3E-04	1.1E-02	1.9E-04	6.3E-04	7.7E-01	2.1E-03	7.9E-03	3.5E-05	3.0E-04	2.1E-03	5.4E-04	3.5E-05	2.8E-03	2.8E-03
Thorium-234	1.6E-01	1.0E-01	1.7E-03	5.2E-03	1.2E+00	2.2E-01	3.1E-02	2.9E-04	2.4E-01	5.4E-01	6.2E-01	3.0E-04	2.2E-01	4.2E-01
Uranium-234	3.6E-03	2.5E-03	1.0E-04	3.6E-03	3.6E-02	5.9E-02	7.6E-03	1.0E-03	8.2E-03	3.1E-02	8.2E-03	1.0E-03	2.5E-01	2.5E-01
Uranium-235	1.1E-04	8.1E-05	2.7E-06	9.7E-05	9.8E-04	1.6E-03	2.1E-04	2.8E-05	2.4E-04	8.5E-04	2.5E-04	2.7E-05	6.9E-03	7.0E-03
Uranium-238	2.6E-03	1.9E-03	7.5E-05	2.6E-03	2.6E-02	4.3E-02	5.6E-03	7.5E-04	6.0E-03	2.2E-02	6.0E-03	7.5E-04	1.9E-01	1.9E-01
Plutonium-238	1.3E-02	5.5E-05	1.1E-03	1.3E-02	4.6E-01	1.6E-02	3.0E-02	5.8E-04	3.8E-04	1.6E-02	5.8E-03	5.8E-04	1.0E-02	1.0E-02
Plutonium-239 & neptunium-237	7.7E-02	1.5E-01	6.2E-03	7.7E-02	2.6E+00	9.0E-02	1.7E-01	3.3E-03	1.1E+00	9.0E-02	3.3E-02	3.3E-03	6.0E-02	6.0E-02
Americium-241	1.4E-03	2.0E-02	8.9E-04	1.8E-04	6.7E-01	4.1E-03	1.3E-02	4.8E-04	4.3E-02	4.3E-03	2.9E-02	4.8E-04	1.1E-03	1.9E-03
Total	**4.7E-01**	**7.4E-01**	**5.0E-02**	**2.6E-01**	**1.6E+01**	**5.7E-01**	**4.1E-01**	**1.7E-01**	**1.6E+00**	**8.4E-01**	**9.1E-01**	**1.7E-01**	**1.4E+00**	**1.6E+00**

[a]The dose assessments for crustacean and mollusc have been derived from a separate ERICA assessment which has included the monitoring data for these species.

Table 16: Dose rate to freshwater reference organisms using ERICA assessment tool for January 2008 limits (microgray/h)

Nuclide	Benthic fish	Crust-acean[a]	Mammal	Pelagic fish	Phyto-plankton	Vascular plant	Zooplankton	Amphib-ian	Bird	Bivalve mollusc[a]	Gastro-pod	Insect larvae
Cobalt-60	1.4E-03	1.5E-03	2.9E-06	1.8E-06	9.0E-07	1.5E-03	7.0E-07	3.3E-07	2.1E-06	1.5E-03	1.5E-03	3.0E-03
Technetium-99	1.1E-04	3.5E-05	1.1E-04	1.1E-04	2.1E-05	3.3E-03	5.0E-05	1.1E-04	1.1E-04	6.9E-05	6.9E-05	3.5E-05
Ruthenium-106	5.5E-04	3.2E-03	3.0E-06	2.9E-06	2.6E-06	2.7E-03	8.3E-05	2.6E-06	2.9E-06	2.1E-03	2.4E-03	6.2E-03
Caesium-134	3.5E-04	4.1E-04	1.7E-05	9.6E-06	1.4E-06	4.1E-04	5.9E-07	7.8E-06	4.2E-06	3.7E-04	3.9E-04	8.1E-04
Caesium-137	3.9E-02	4.8E-02	3.7E-03	2.4E-03	5.6E-04	4.8E-02	2.3E-04	2.6E-03	1.1E-03	4.1E-02	4.4E-02	9.8E-02
Polonium-210	2.9E-06	1.2E-04	2.9E-06	2.9E-06	3.3E-04	4.8E-05	3.3E-04	2.9E-06	2.9E-06	4.6E-04	2.7E-04	1.2E-04
Radium-226	9.4E-03	1.1E-01	5.9E-03	5.9E-03	7.8E-02	1.3E-01	7.8E-02	5.5E-03	5.9E-03	1.1E-01	6.9E-02	1.2E-01
Radium-228	3.0E-03	4.4E-03	2.7E-05	2.4E-05	1.0E-04	4.2E-03	1.2E-04	2.1E-05	2.4E-05	3.6E-03	3.6E-03	8.4E-03
Thorium-228	6.1E-03	2.9E-01	7.5E-04	7.5E-04	2.8E-02	1.7E-02	1.4E-02	7.6E-04	7.5E-04	1.4E-01	7.1E-03	1.8E-02
Thorium-230	7.3E-04	3.8E-02	7.2E-04	7.2E-04	2.6E-02	8.3E-03	1.3E-02	7.2E-04	7.2E-04	2.2E-02	6.8E-04	7.3E-04
Thorium-232	1.2E-04	1.1E-02	1.2E-04	1.2E-04	4.2E-03	1.3E-03	2.1E-03	1.2E-04	1.2E-04	3.0E-04	1.1E-04	1.2E-04
Thorium-234	9.1E-02	1.2E+00	9.7E-04	9.7E-04	5.8E-03	9.4E-01	4.1E-03	9.0E-04	9.7E-04	1.8E-01	3.4E-01	2.3E+00
Uranium-234	1.5E-01	2.5E+00	1.5E-01	1.5E-01	6.1E-01	1.5E+01	2.4E-01	1.5E-01	1.5E-01	9.2E-01	9.2E-01	2.5E+00
Uranium-235	4.2E-03	7.0E-02	4.1E-03	4.2E-03	1.6E-02	4.1E-01	6.7E-03	4.2E-03	4.2E-03	2.5E-02	2.5E-02	7.0E-02
Uranium-238	1.1E-01	1.9E+00	1.1E-01	1.1E-01	4.5E-01	1.1E+01	1.8E-01	1.1E-01	1.1E-01	6.7E-01	6.7E-01	1.9E+00
Plutonium-238	1.7E-05	6.0E-05	6.4E-05	1.7E-05	1.6E-03	7.2E-04	1.2E-04	6.4E-05	5.5E-07	4.2E-05	2.3E-04	3.2E-04
Plutonium-239 & neptunium-237	9.8E-05	1.5E-01	3.6E-04	9.5E-05	9.4E-03	4.1E-03	7.1E-04	3.6E-04	3.2E-06	1.1E-01	1.3E-03	1.8E-03
Americium-241	5.3E-03	2.1E-02	2.4E-05	2.2E-05	4.8E-01	5.2E-02	4.8E-03	2.4E-05	2.4E-05	4.3E-02	3.8E-03	2.4E-01
Total	**4.3E-01**	**6.4E+00**	**2.8E-01**	**2.8E-01**	**1.7E+00**	**2.7E+01**	**5.5E-01**	**2.8E-01**	**2.8E-01**	**2.3E+00**	**2.1E+00**	**7.3E+00**

[a]The dose assessments for crustacean and mollusc have been derived from a separate ERICA assessment which has included the monitoring data for these species.

Table 17: Dose rate to feature species reference for January 2008 limits (microgray/h)

Feature species	Total dose rate for marine assessment	Total dose rate for freshwater assessment
(Wading) bird	1.7E-01	2.8E-01
(Wading) bird (revised occupancy)	2.4E-01	3.5E-01
Bar-tailed godwit (female)	2.9E-01	4.0E-01
Bar-tailed godwit (male)	3.0E-01	4.1E-01
Bewick's swan (female)	2.0E-01	3.1E-01
Bewick's swan (male)	2.0E-01	3.1E-01
Black-tailed godwit (female)	2.9E-01	4.0E-01
Black-tailed godwit (male)	3.0E-01	4.1E-01
Common scoter (female)	2.1E-01	3.2E-01
Common scoter (male)	2.1E-01	3.2E-01
Cormorant	2.0E-01	3.0E-01
Curlew (female)	2.7E-01	3.8E-01
Curlew (male)	2.8E-01	3.9E-01
Dunlin	2.1E-01	3.1E-01
Golden plover	2.9E-01	3.7E-01
Grey plover	2.9E-01	3.7E-01
Knot	3.0E-01	3.7E-01
Lapwing	2.9E-01	3.6E-01
Lesser black-backed gull (female)	2.9E-01	4.0E-01
Lesser black-backed gull (male)	2.8E-01	3.9E-01
Oystercatcher	2.8E-01	3.9E-01
Pink-footed goose	2.5E-01	3.3E-01
Pintail (female)	2.1E-01	3.2E-01
Pintail (male)	2.1E-01	3.2E-01
Redshank (female)	3.1E-01	4.3E-01
Redshank (male)	3.2E-01	4.3E-01
Sanderling	3.2E-01	3.8E-01
Scaup	2.1E-01	3.1E-01
Shelduck (female)	2.1E-01	3.2E-01
Shelduck (male)	2.1E-01	3.2E-01
Teal (female)	2.2E-01	3.3E-01
Teal (male)	2.2E-01	3.3E-01
Whooper swan	2.0E-01	3.1E-01
Wigeon (female)	2.1E-01	3.2E-01
Wigeon (male)	2.1E-01	3.2E-01

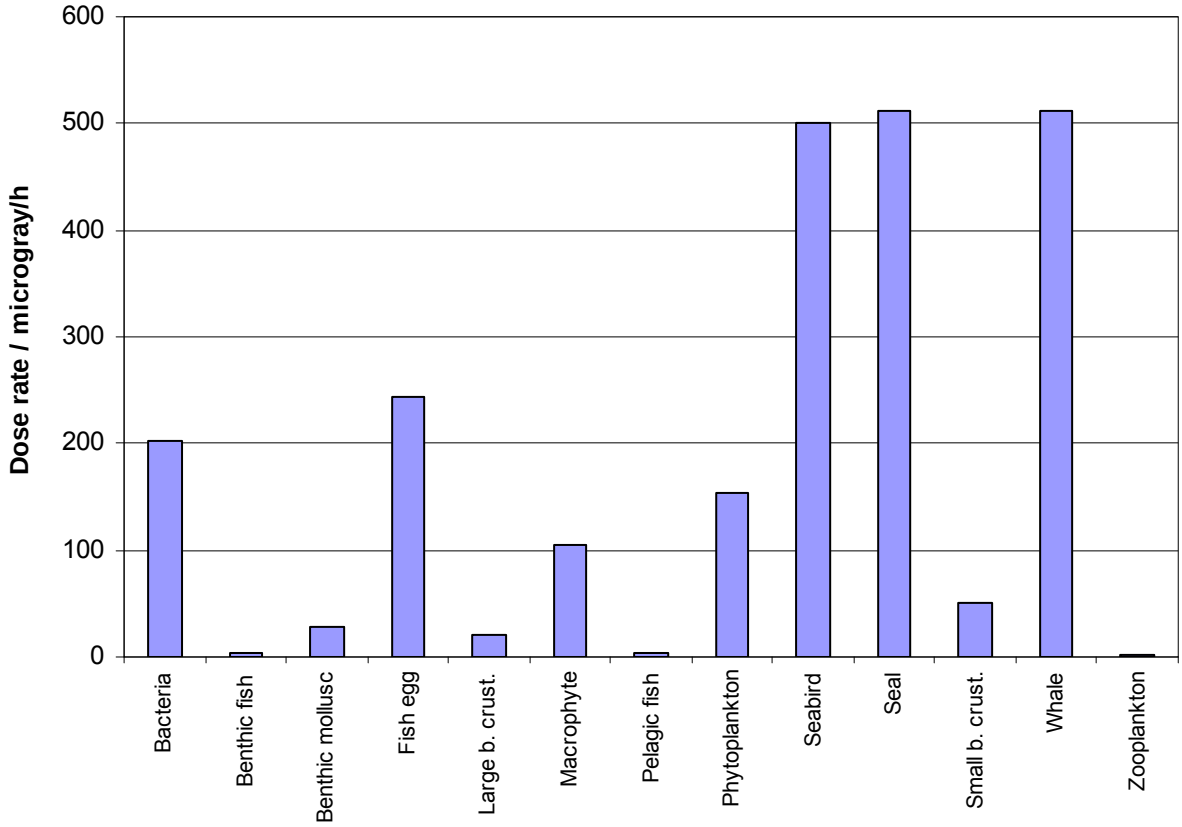

Figure 1: Pre-January 2008 limits – Stage 3 marine assessment – Total dose rates to reference organisms

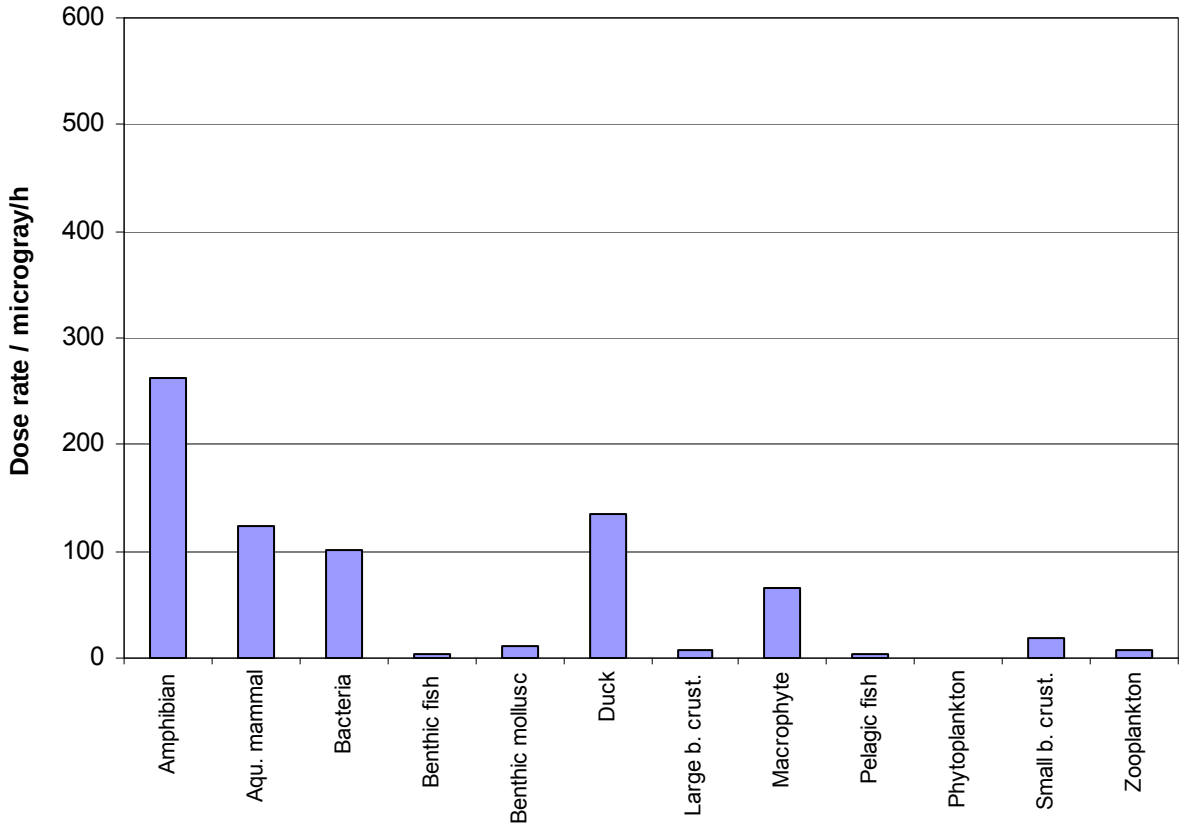

Figure 2: Pre-January 2008 limits – Stage 3 freshwater assessment – Total dose rates to reference organisms

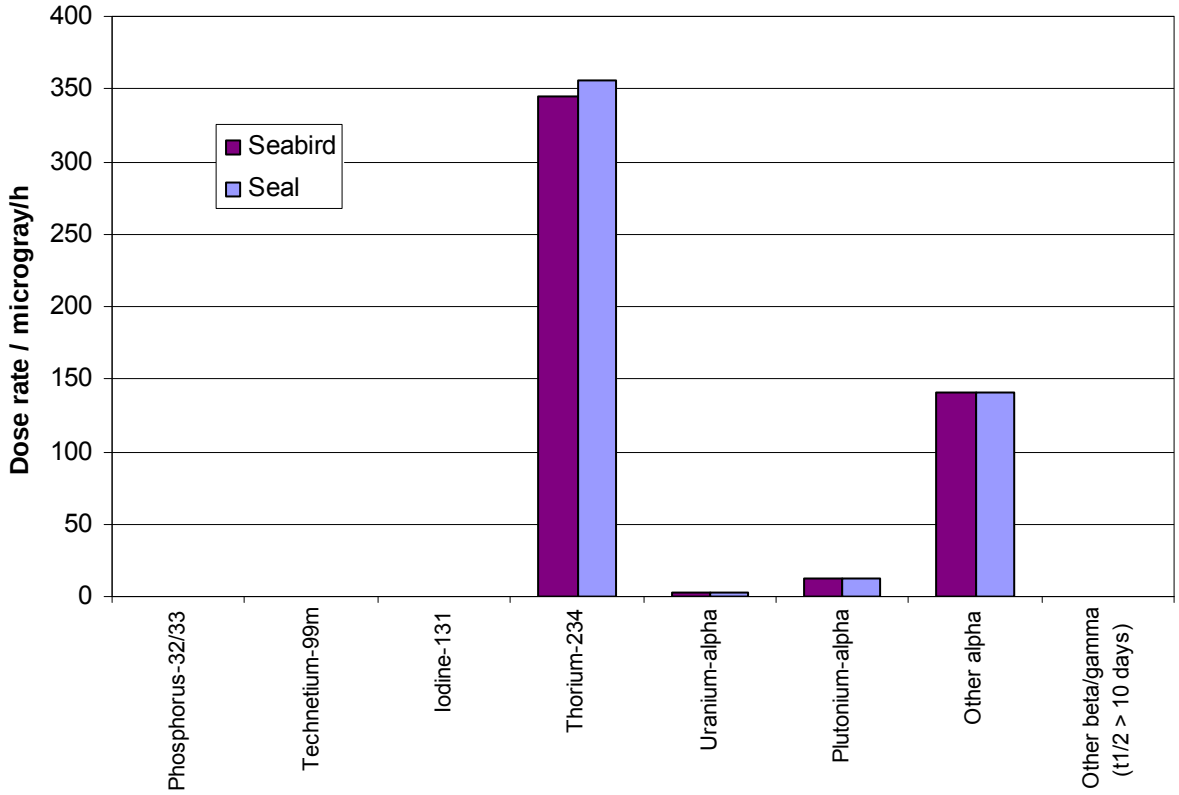

Figure 3: Pre-January 2008 limits – Stage 3 marine assessment – Radionuclide contributions to dose rate for worst affected organisms

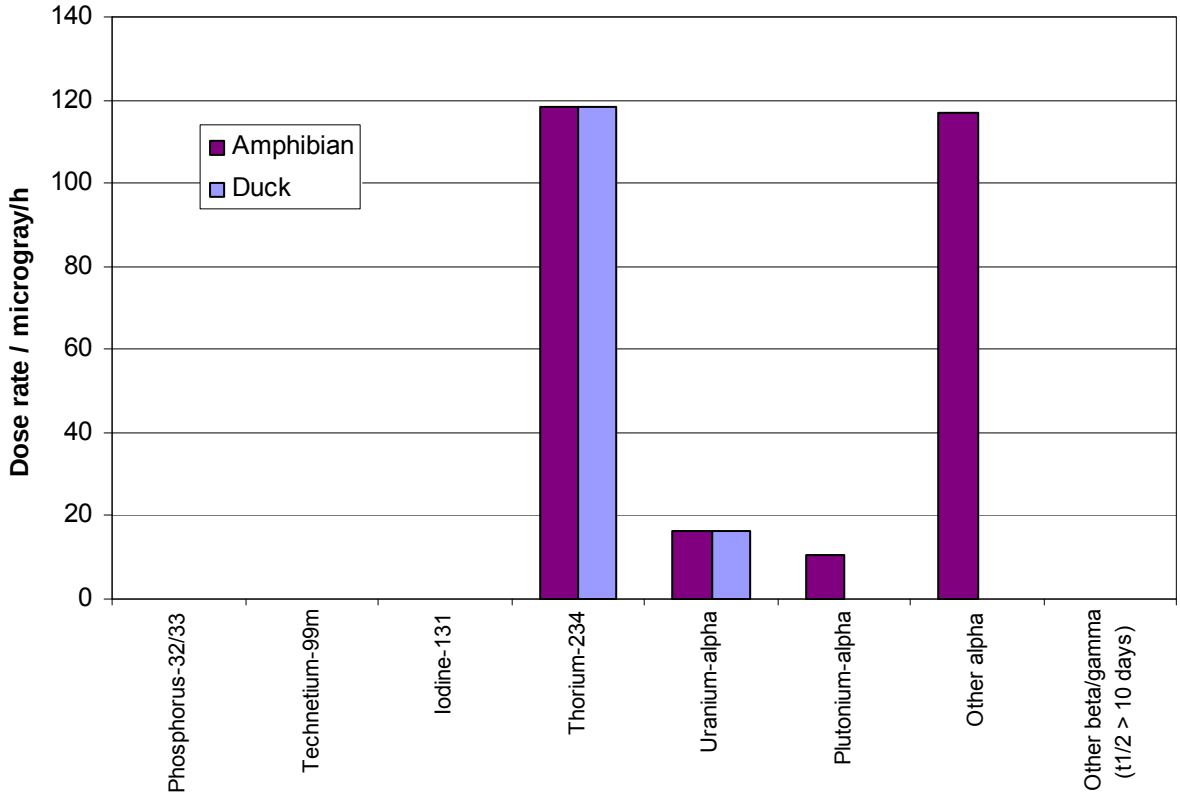

Figure 4: Pre-January 2008 limits – Stage 3 freshwater assessment – Radionuclide contributions to dose rate for worst affected organisms

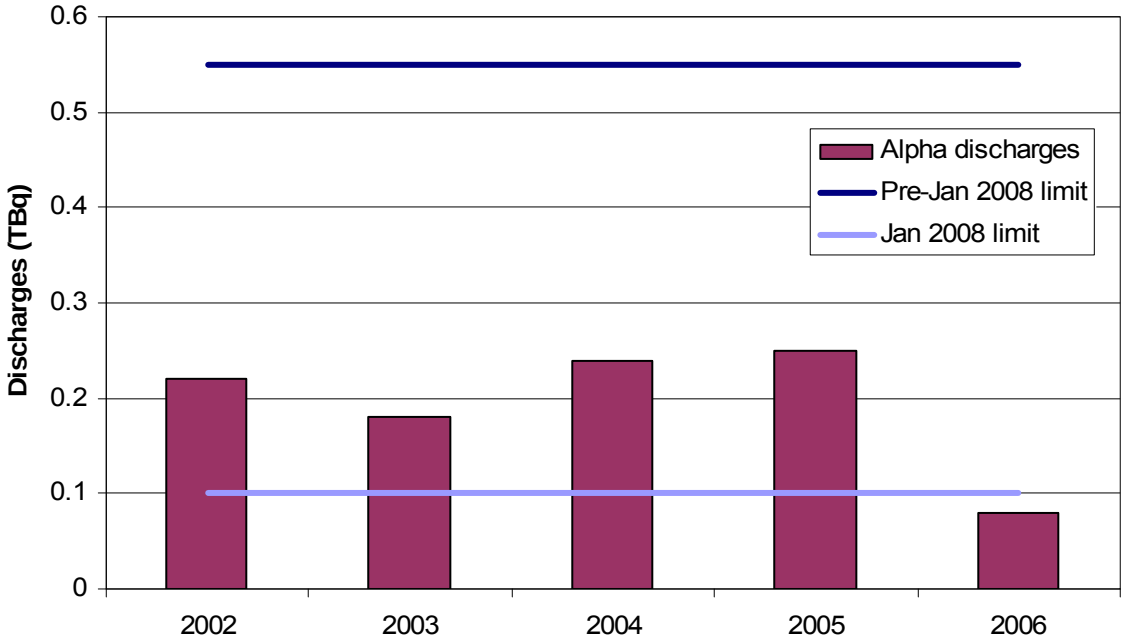

Figure 5: Total alpha discharges from Springfields compared to pre-January 2008 and January 2008 limits

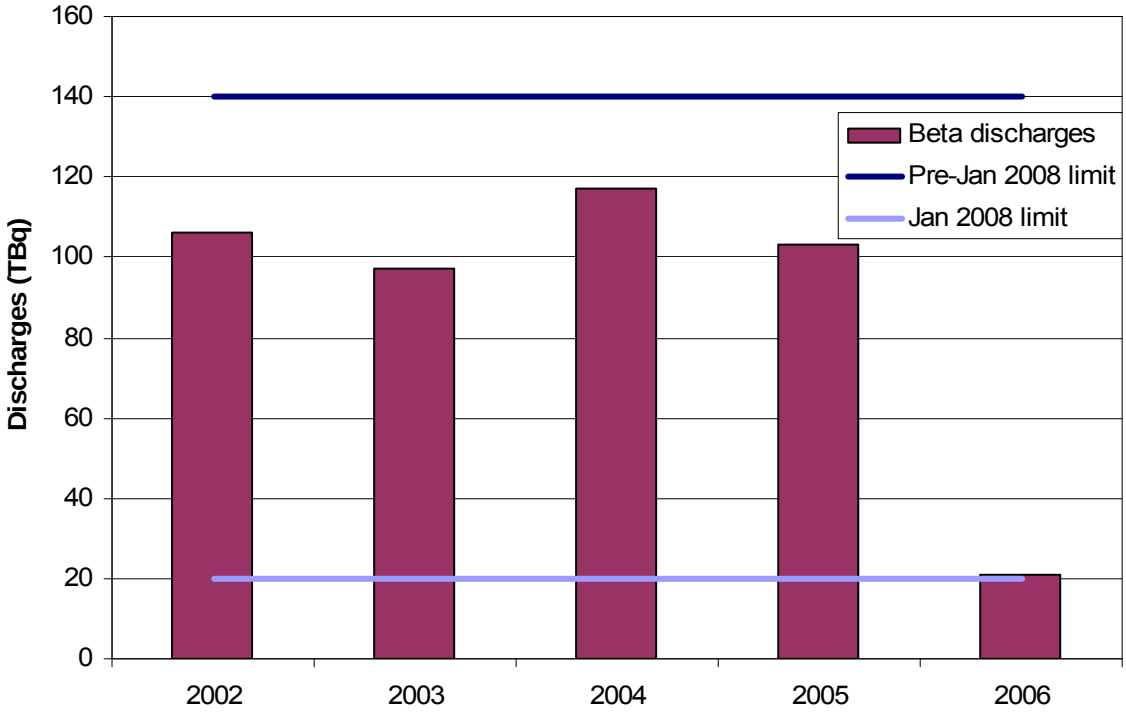

Figure 6: Total beta discharges from Springfields compared to pre-January 2008 and January 2008 limits

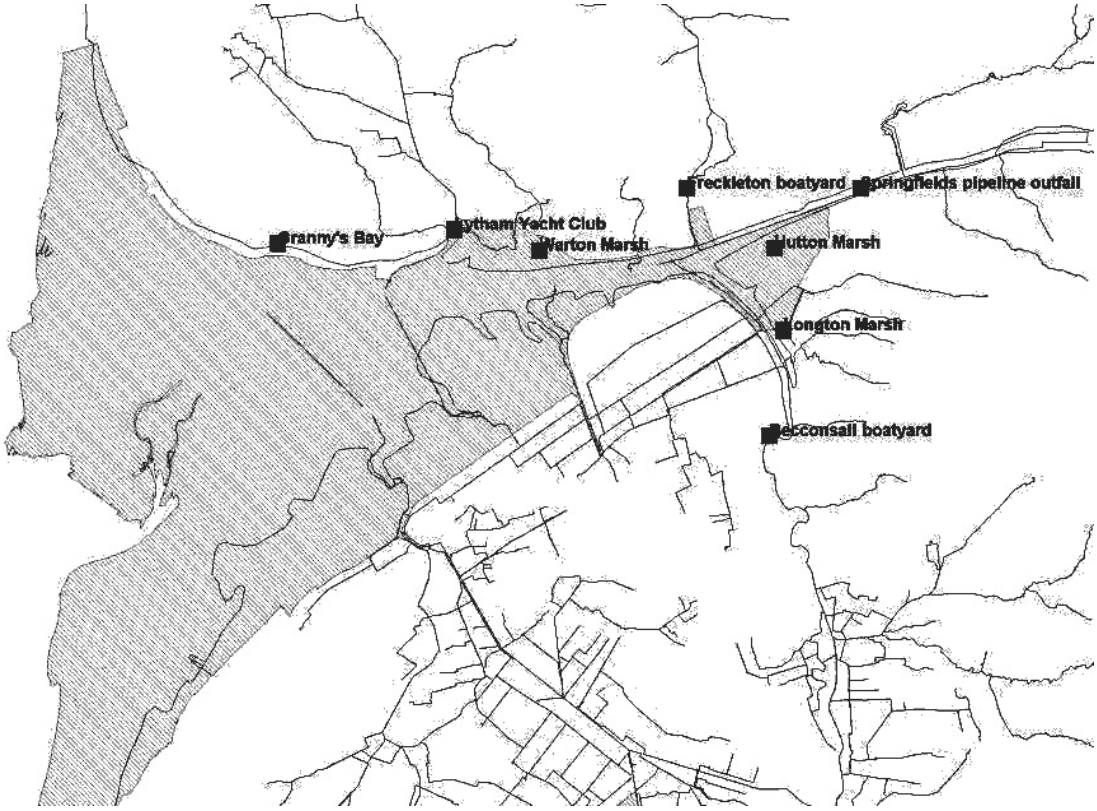

Figure 7: Ribble and Alt Natura 2000 site (shaded area) and sediment monitoring locations (squares)

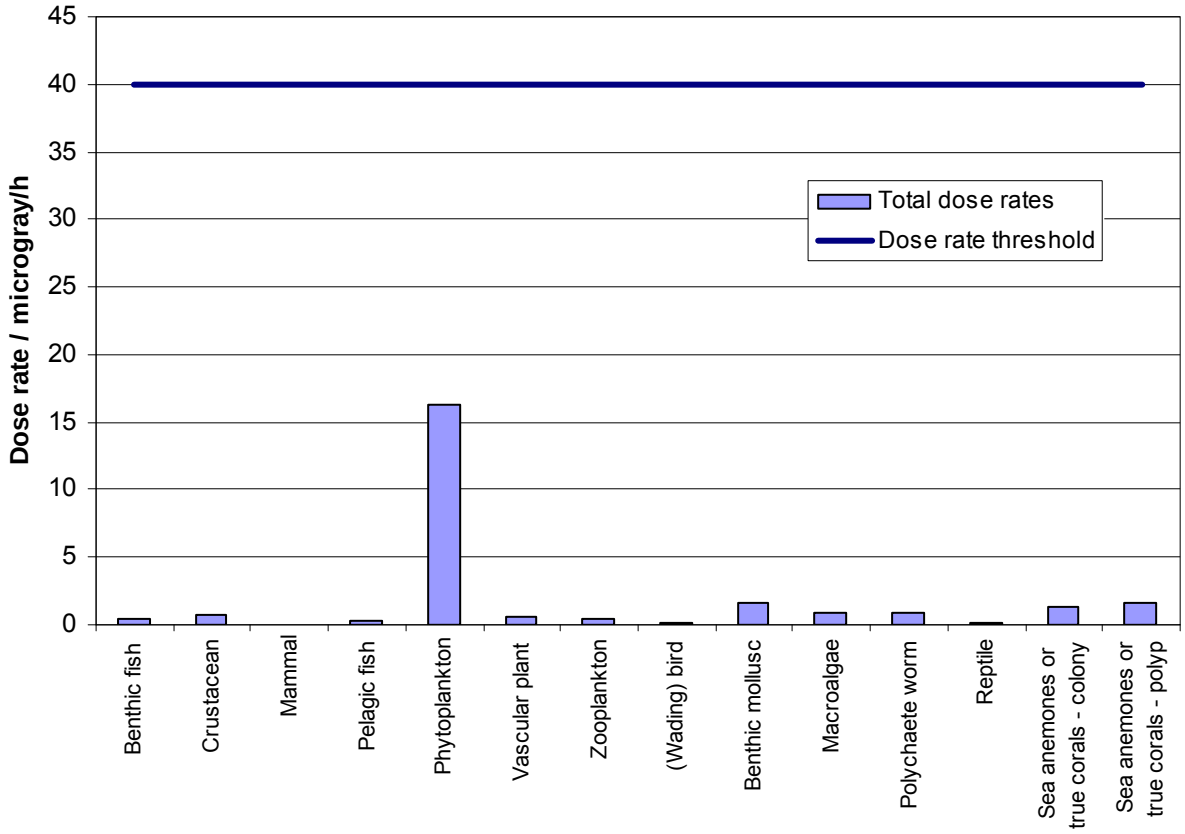

Figure 8: January 2008 limits – ERICA marine assessment – Total dose rates to reference organisms

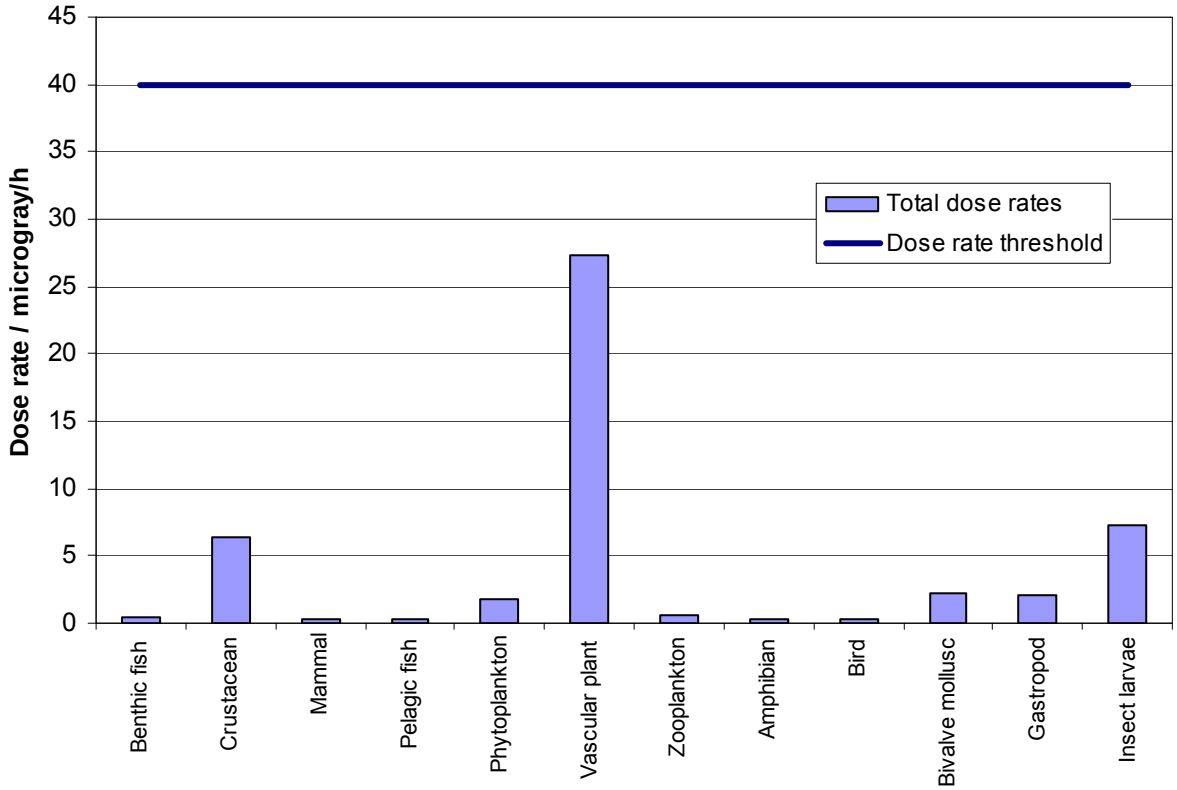

Figure 9:January 2008 limits – ERICA freshwater assessment – Total dose rates to reference organisms

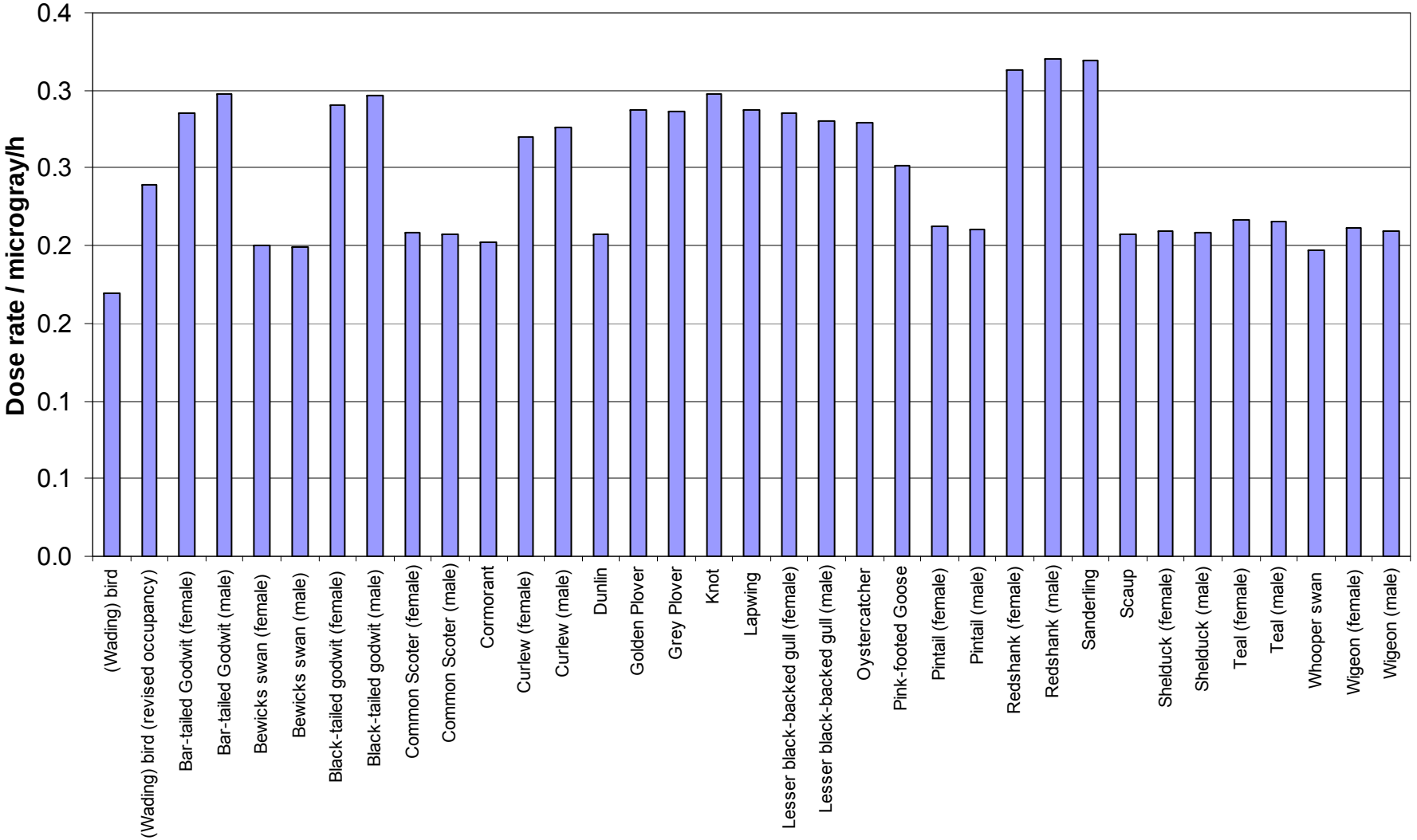

Figure 10: January 2008 limits – ERICA marine assessment – Total dose rates to feature species

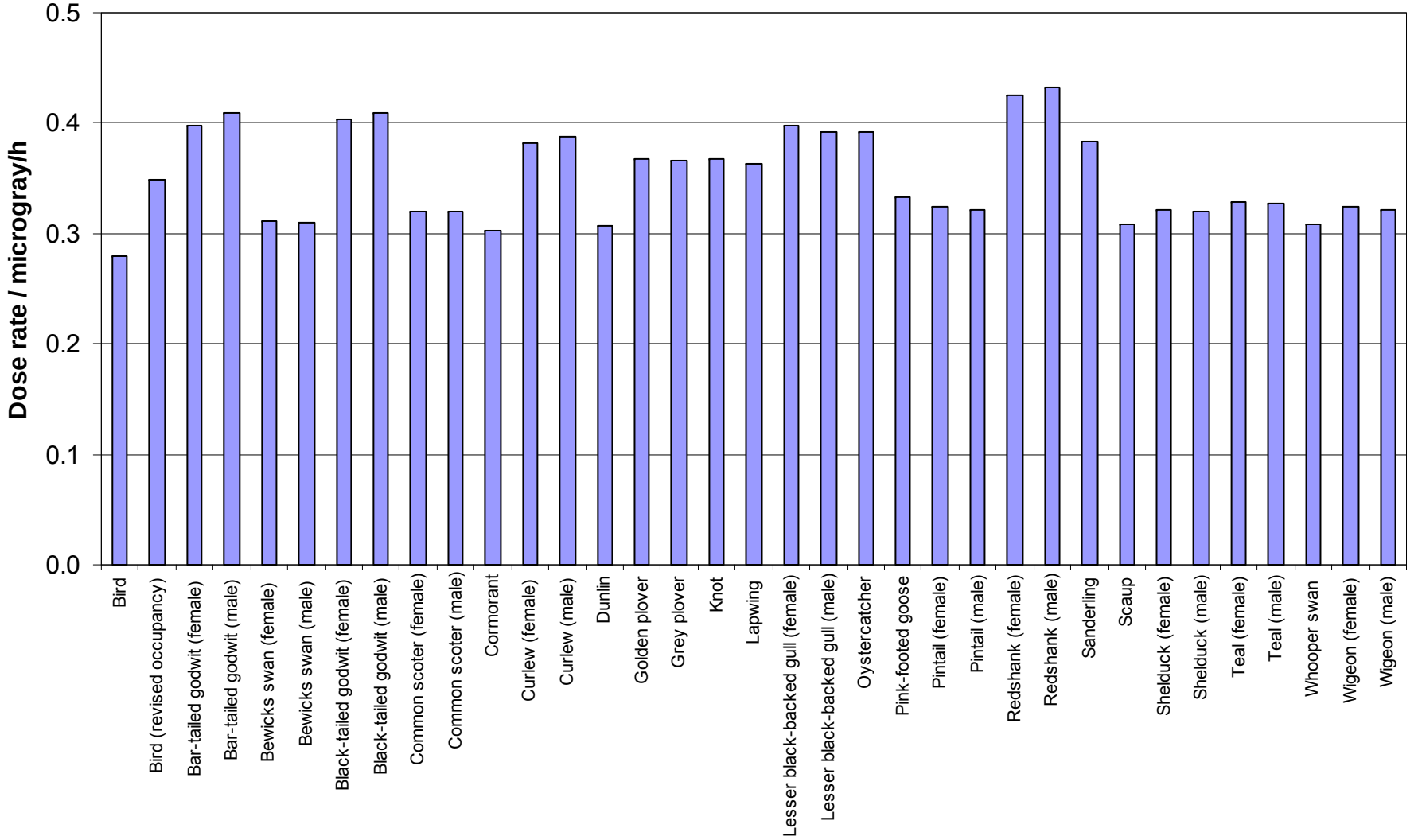

Figure 11: January 2008 limits – ERICA freshwater assessment – Total dose rates to feature species

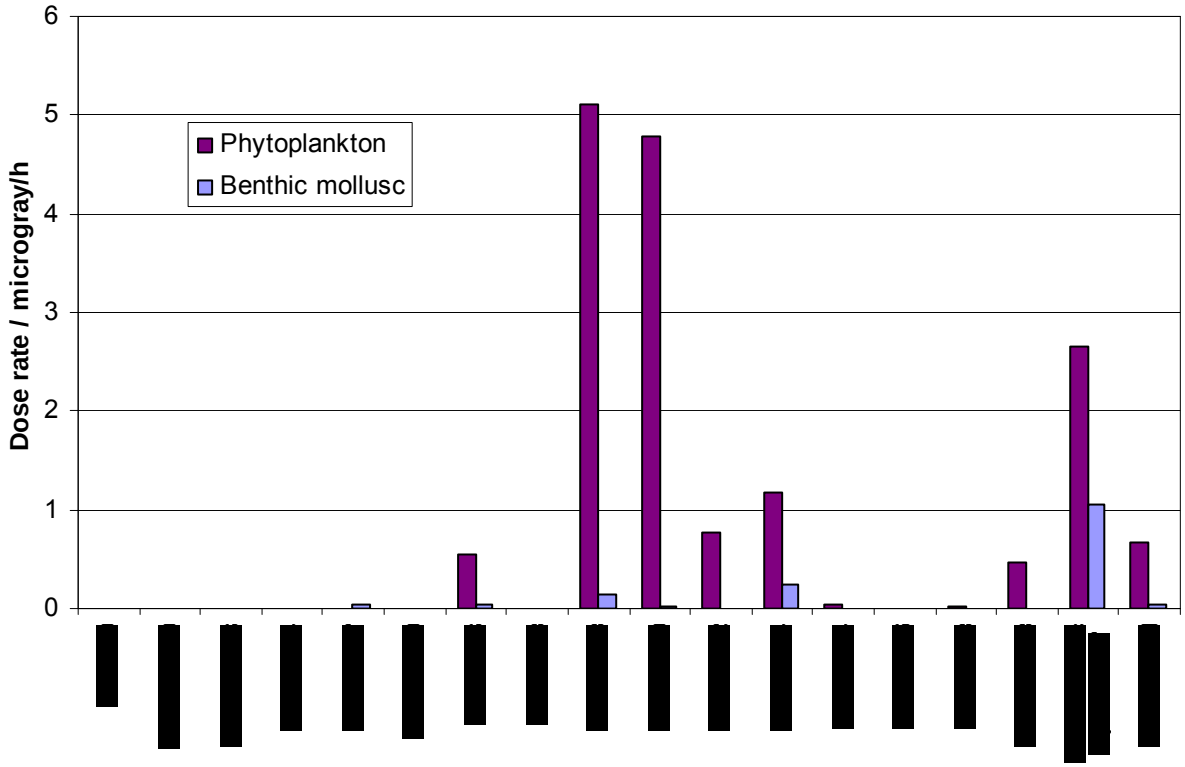

Figure 12: January 2008 limits – ERICA marine assessment – Radionuclide contribution to dose rates for worst affected organisms

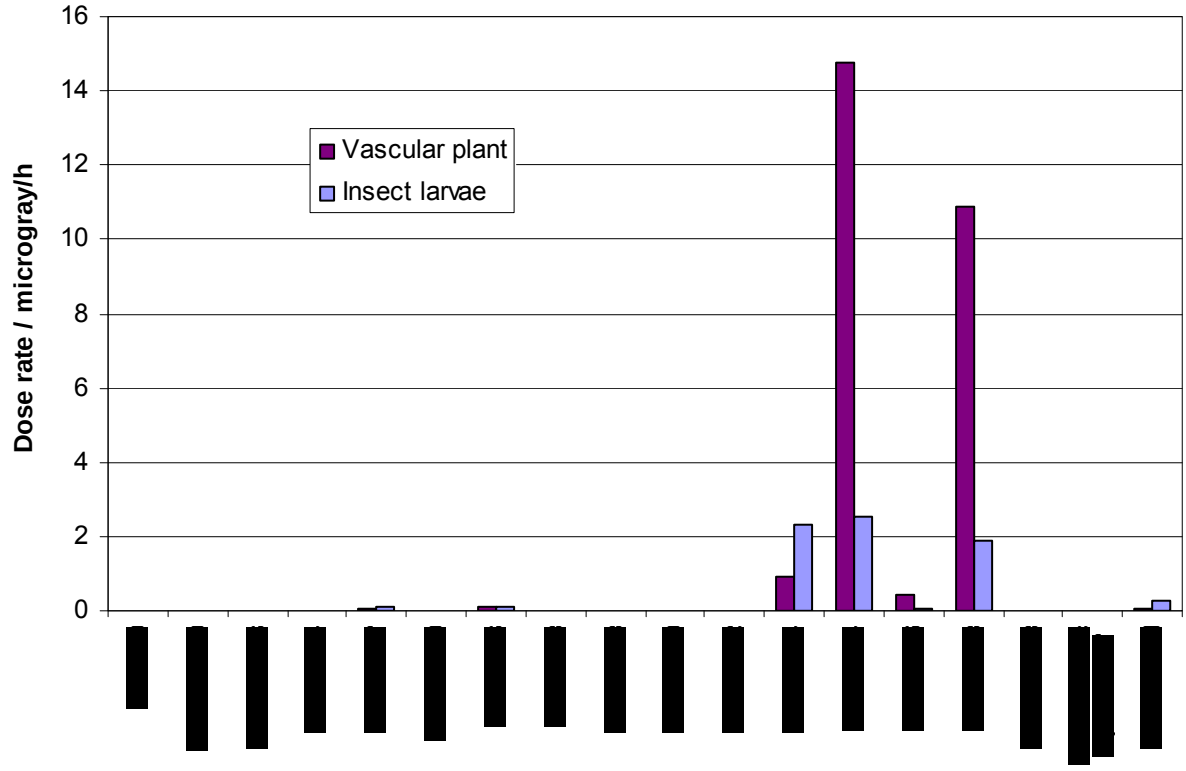

Figure 13: January 2008 limits – ERICA freshwater assessment – Radionuclide contribution to dose rates for worst affected organisms

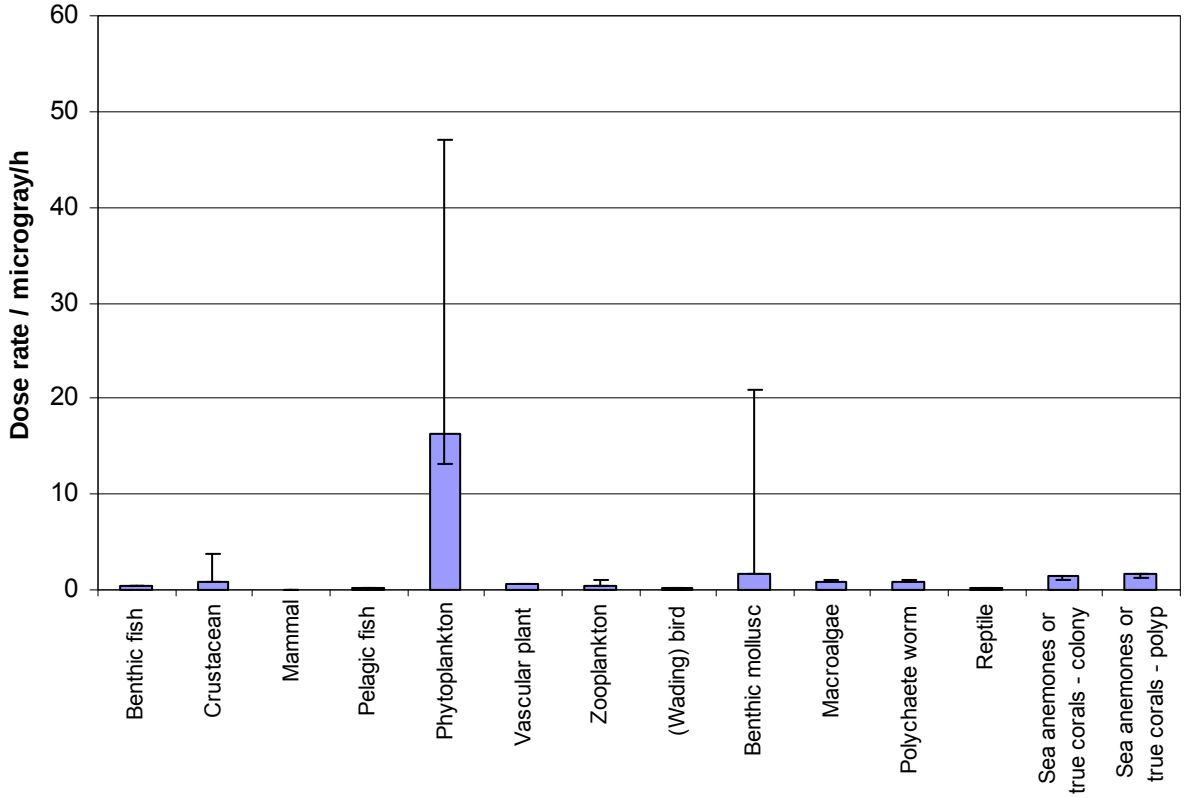

Figure 14: January 2008 limits – ERICA marine uncertainty/variability assessment – Worst/best discharge profile

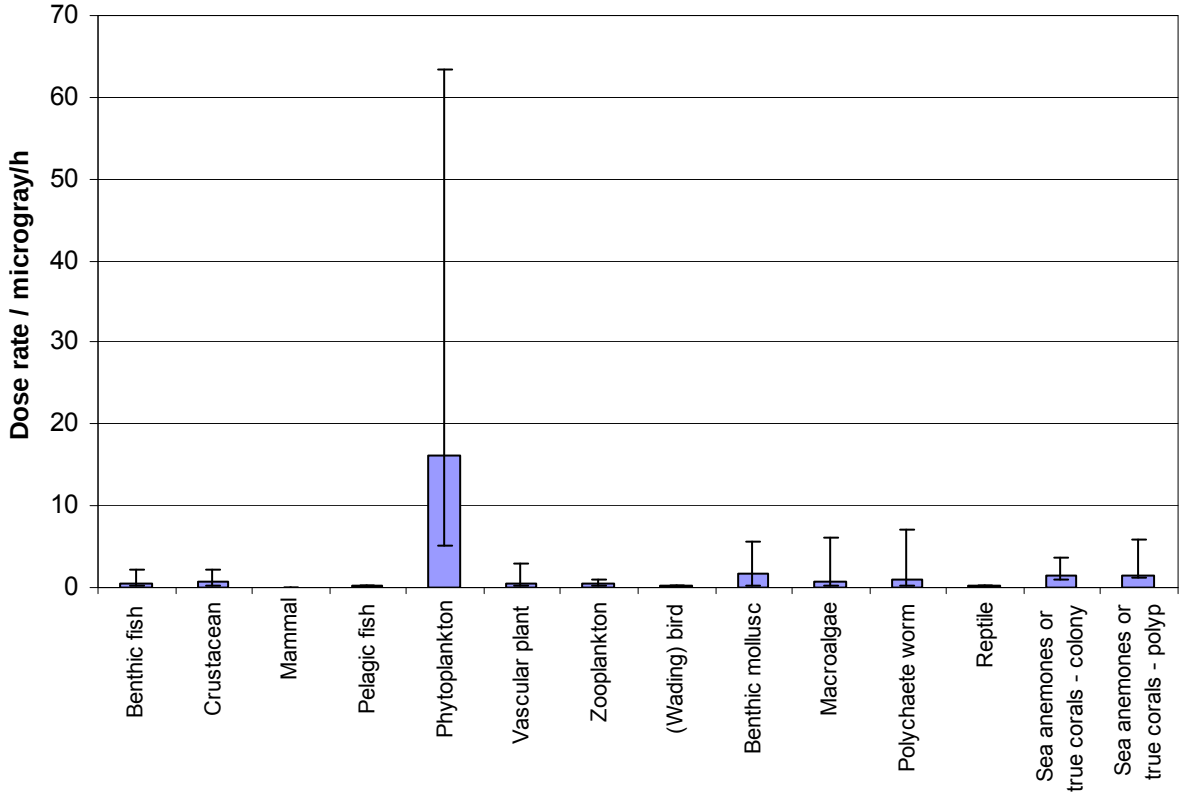

Figure 15: January 2008 limits – ERICA marine uncertainty/variability assessment – Maximum/minimum concentrations

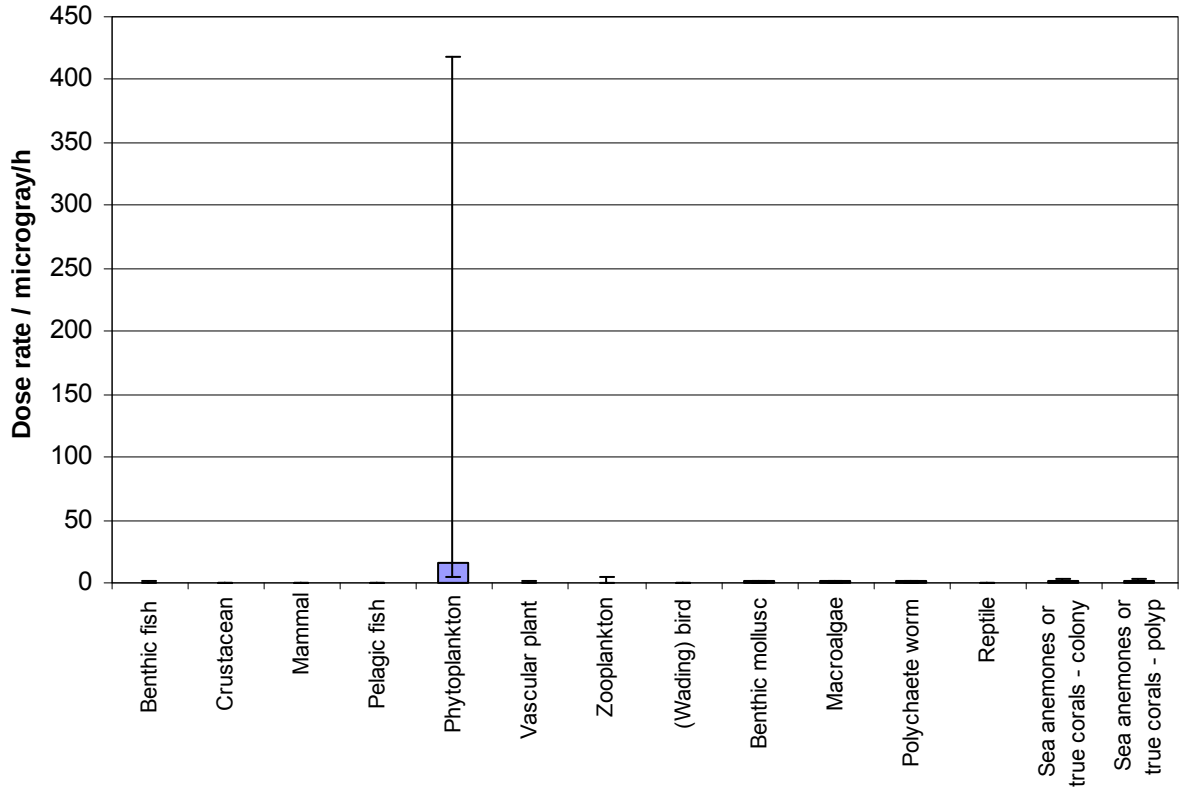

Figure 16: January 2008 limits – ERICA marine uncertainty/variability assessment – Low/high thorium sediment partitioning coefficients

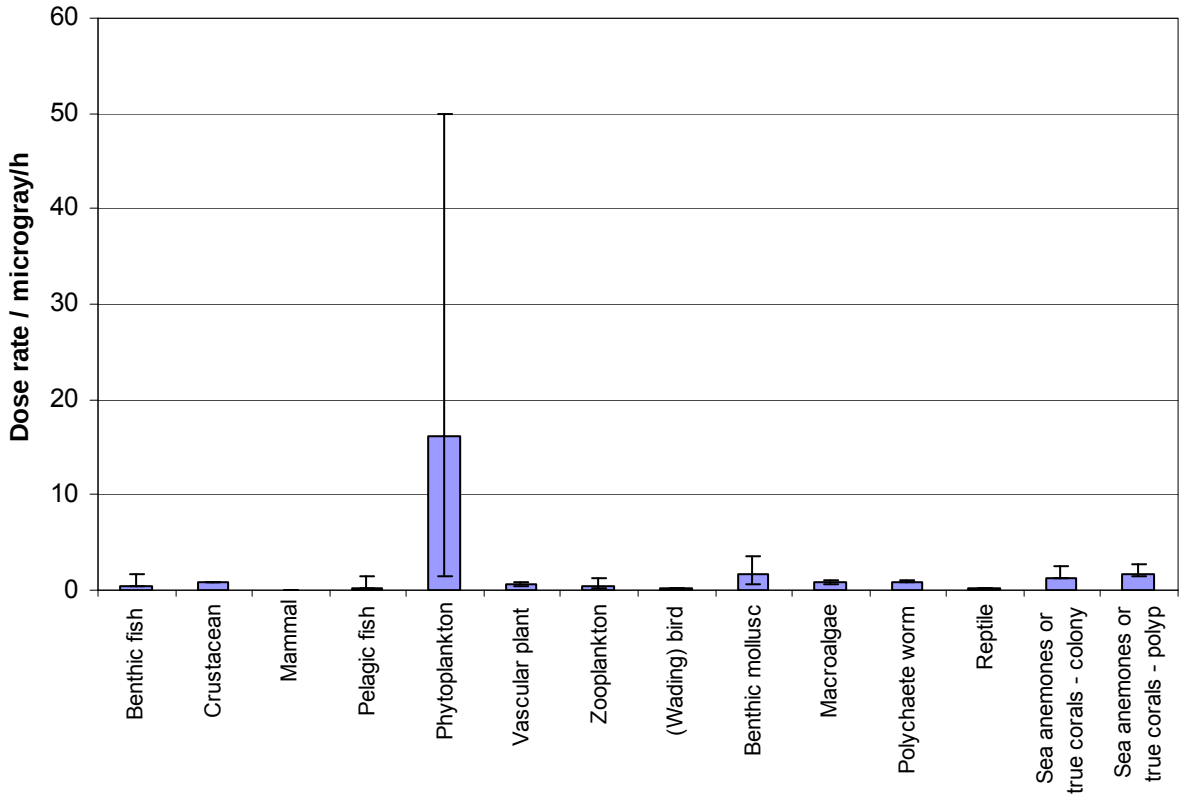

Figure 17: January 2008 limits – ERICA marine uncertainty/variability assessment – High/low concentration factors

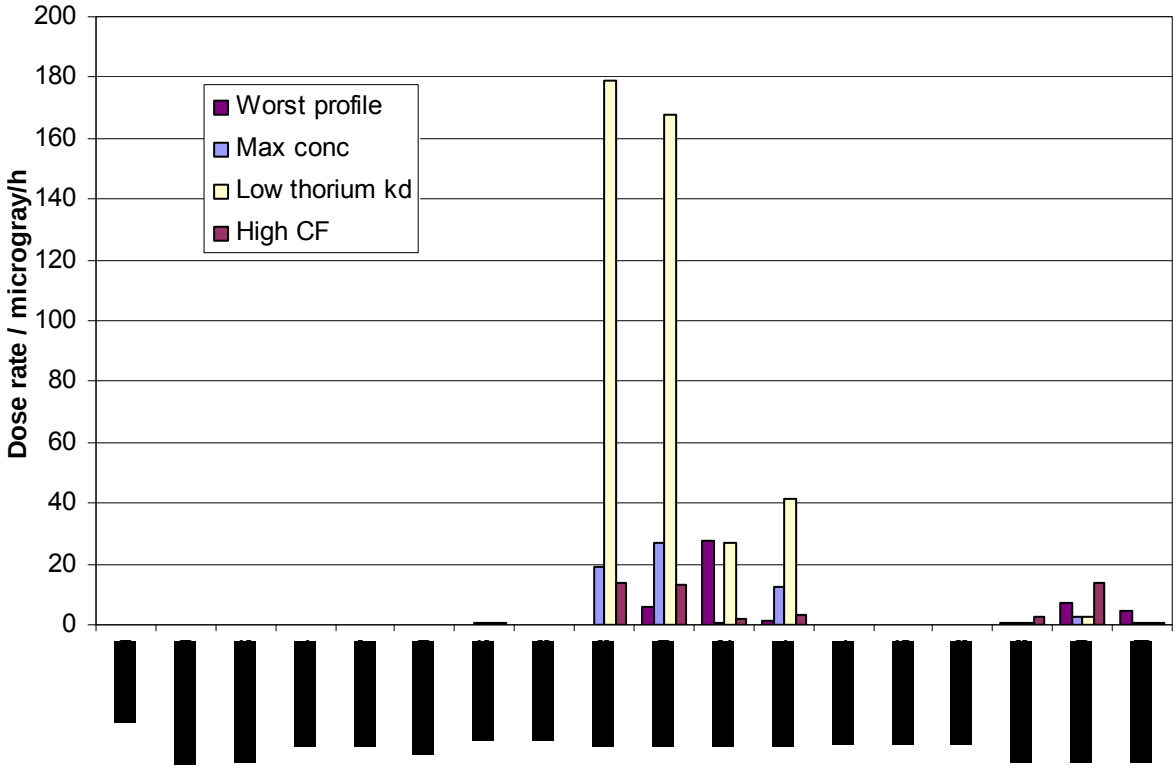

Figure 18: January 2008 limits – ERICA marine uncertainty/variability assessment – Radionuclide dose rates to phytoplankton for worst case scenarios

Appendix 1 – Comparison of Stage 3 assessment with ERICA assessment tool

Methodology

The ERICA assessment tool has been used to assess dose rate from discharges at pre-January 2008 limits for Springfields Fuels Ltd to compare to the Stage 3 assessment results. Environmental monitoring data for 2004 have been used in the assessment, as discharges were highest in this year during the last 5 years (see Figures 5 and 6).

These environmental monitoring data have been modified to take account of actual discharges compared to the pre-January 2008 discharge limits. Discharges of total alpha and total beta activity in 2004 were 44% and 84% respectively of the pre-January 2008 limits (Table A1.1).

Sediment monitoring data for 2004 are shown in Table A1.2. Mean sediment concentrations have been used in the assessment and these are shown in Table A1.3. There are a few results below the detection limit and these have been treated as positive results. The 2004 monitoring data have been modified to take account of the fact that discharges of total alpha and total beta were not at 100% of the pre-January 2008 limits. A correction factor of 2.3 has been applied to alpha-emitting radionuclides originating from Springfields Fuels Ltd and a factor of 1.2 for beta-emitting radionuclides. There was no need to scale the concentrations for radionuclides which mainly originate from historical discharges from Sellafield.

Monitoring data for shrimps and mussels are shown in Tables A1.4 and A1.5 for 2004. The mean concentrations used in the assessment are shown in Tables A1.6 and A1.7. Only radionuclides with positive monitoring results (above the detection limit) for shrimps and mussels have been used in the assessment. In these cases, actual concentrations may be well below the detection limit and it would make the assessment severely pessimistic if the detection limit was treated as a positive result. Monitoring data have been scaled to take account of the fact that discharges of total alpha and total beta during 2004 were not at the pre-January 2008 limits.

As for the reassessment for the January 2008 limits, the ERICA assessment tool has been used with default data, except for the thorium partitioning coefficient, where a Ribble Estuary specific value of 3.5 10^5 Bq/kg per Bq/l has been used.

These ERICA assessments have been made:

- Marine assessment – sediment data only to assess dose rates for all organisms except crustacean and benthic mollusc.
- Marine assessment – sediment, mussel and shrimp environmental monitoring data to assess dose rates to crustacean and benthic mollusc.
- Freshwater assessment – sediment data only to assess dose rates for all organisms except crustacean and benthic mollusc.
- Freshwater assessment – sediment, mussel and shrimp environmental monitoring data to assess dose rates to crustacean and benthic mollusc.

Comparison results

The marine and freshwater assessment results using the ERICA tool are shown in Tables A1.8 and A1.9 respectively. The dose rates are also shown in Figures A1.1 and A1.2. The highest dose rate is 58 microgray/h to phytoplankton for the marine assessment and 61 microgray/h to vascular plants in the freshwater assessment.

The dose rates to reference organisms from the Stage 3 assessment are compared to the ERICA assessment in Figures A1.3 and A1.4. In most cases, the Stage 3 dose rates are much higher than those for the ERICA assessment. The dose rates for freshwater plants and crustacean are similar (see Figure A1.4).

The highest dose rates in the Stage 3 assessment were to seabirds and sea mammals (up to 520 microgray/h). The dose rates to these organisms for the ERICA assessment are less than 1 microgray/h. In the Stage 3 assessment, the dominant dose contribution to seabirds and sea mammals was from internal dose as a result of uptake of thorium-234 and alpha-emitting radionuclides (e.g. thorium-230 and thorium-232).

The internal dose rate for thorium-234 is assessed using a concentration factor for thorium. There were no thorium concentration factor data available for these species when the Stage 3 assessment methodology was developed and pessimistic concentration factors were adopted. More realistic concentration factors are provided in the ERICA assessment tool.

The Stage 3 assessment methodology did not have assessment data for these alpha-emitting radionuclides and plutonium-239 was used as a surrogate. The ERICA assessment tool does have assessment data for thorium radionuclides, which give much lower dose rates than using plutonium-239 as a surrogate.

Conclusions of comparison

The ERICA assessment for pre-January 2008 limits gives a dose rate to the worst affected marine organism (phytoplankton) of 58 microgray/h and to the worst affected freshwater organism (vascular plants) of 61 microgray/h. These are above the 40 microgray/h threshold agreed with Natural England to determine whether there is the potential for an adverse affect on the integrity of a Natura 2000 site. However, the dose rate is much lower than that assessed for the worst affected organism in the Stage 3 assessment (520 microgray/h to seabirds and sea mammals).

The main causes of the difference in the assessment results are that a pessimistic concentration factor was used for thorium-234 in the Stage 3 assessment and that other alpha-emitting radionuclides (e.g. thorium-230 and thorium-232) were assessed using surrogate assessment data (for plutonium-239).

Table A1.1: Pre-January 2008 discharge limits and discharges in 2004 for Springfields

Radioactive substance or category	Pre-January 2008 limit (TBq)	2004 discharges (TBq)	2004 discharges as % of pre-January 2008 limits
Overall limits			
Alpha	0.55	0.221	44%
Beta	140	106	84%
Limits on individual radionuclides and radioelements			
Technetium-99 (beta)	0.6	0.0167	20%
Thorium-230 (alpha)	0.4	0.102	27%
Thorium-232 (alpha)	0.015	0.0025	7%
Neptunium-237 (alpha)	0.04	0.0014	4%
Other transuranic radionuclides (alpha)	0.02		0%
Uranium (alpha)	0.1	0.0496	46%

Table A1.2: Sediment monitoring data for 2004 (Bq/kg dry weight)

Data source	Sample site	Date	^{60}Co	^{106}Ru	^{134}Cs	^{137}Cs	^{228}Th	^{230}Th	^{232}Th	^{234}Th	^{234}U	^{235}U	^{238}U	^{237}Np	^{238}Pu	^{239}Pu/ ^{240}Pu	^{241}Am
SEMP	FBY	Feb-04				320	45	295	44.5	52000							214
SEMP	FBY	May-04				321	38	760	34.7	230000							275
SEMP	FBY	Aug-04				337	45	317	41.1	39100							243
SEMP	FBY	Nov-04				314	47	158	39.9	19100							198
SEMP	Outfall	Feb-04				213	41	124	36.2	22600							178
SEMP	Outfall	May-04				136	26	656	26	240000							116
SEMP	Outfall	Aug-04				197	41	246	36.3	60000							138
SEMP	Outfall	Nov-04				85	17.6	77	16.6	30200							51
SEMP	BBY	Feb-04				213	38	119	32	13000							145.3
SEMP	BBY	May-04				284	35	308	31.7	63000							225
SEMP	BBY	Aug-04				263	40	202	32.5	24400							184
SEMP	BBY	Nov-04				300	50	145	42.8	15000							191
SEMP	LYC	Feb-04				357	44	156	42.7	7400							282
SEMP	LYC	May-04				348	53	239	43.8	37200							282
SEMP	WM	Feb-04				367	48	232	42.4	43000							276
SEMP	WM	May-04				405	50	204	38.6	17700							284
SEMP	WM	Aug-04				332	43	198	39.5	13000							239
SEMP	WM	Nov-04				358	50	161	44.5	14700							228
RIFE	BBY	2004	<1.6	<11.7	<1.2	227	30	154	29	9500	26	1	26				138
RIFE	FBY	2004	<1.2	<10	<1.2	150	29	120	26	6200	25	1	23				100
RIFE	HM	2004	3	<14	<1.8	240	24	100	21	22000	25	1	19				130
RIFE	LM	2004	<1	<6.6	<1.2	64	18	29	25	200	17	1	19				27
RIFE	LYC	2004	<2.2	<18	<2.2	330	45	140	32	17000	28	1	30				200
RIFE	Outfall	2004	<3.8	<55	<9.9	230	23	203	22	154200	38	<1.6	29				133
RIFE	HMB	2004													11	63	
Mean activity conc.			**2.1**	**19**	**2.9**	**270**	**38**	**220**	**34**	**52000**	**27**	**1.1**	**24**	**-**	**11**	**63**	**190**

SEMP = Springfields Environmental Monitoring Programme (personal communication, Catherine Retberg, Springfields Fuels Ltd); RIFE = Radioactivity in Food and the Environment (Environment Agency et al. 2005).
BBY = Becconsall boatyard; FBY = Freckleton boatyard; HM = Hutton Marsh; HMB = Half Moon Bay; LM = Longton Marsh; LYC = Lytham Yacht Club; Outfall = Springfields pipeline outfall; WM = Warton Marsh

Table A1.3: Mean 2004 sediment activity concentrations used in habitats assessment

Radionuclide	Mean activity conc. (Bq/kg dry weight)	Natural background conc. (Bq/kg dry weight)	Correction factor for discharges below limits	Corrected mean activity conc. (Bq/kg dry weight)	Comment on mean result and background
Cobalt-60	2.1	0	1[a]	2.1	See Table A1.2 for mean result; zero background
Ruthenium-106 (+rhodium-106)	19	0	1[a]	19	See Table A1.2 for mean result; zero background
Caesium-134	2.9	0	1[a]	2.9	See Table A1.2 for mean result; zero background
Caesium-137 (+barium-137m)	270	0	1[a]	270	See Table A1.2 for mean result; zero background
Polonium-210 (+Bismuth-210)	24	19	2.3	12	Mean result and background same as uranium-238
Radium-226 (+radon-222, astatine-218, polonium-218, lead-214, bismuth-214, polonium-214)	24	19	2.3	12	Mean result and background same as uranium-238
Radium-228	34	20	1.2	17	Mean result and background same as thorium-232
Thorium-228 (+radium-224, radon-220, polonium-216, lead-212, bismuth-212, polonium-212, thallium-208)	38	20	2.3	41	See Table A1.2 for mean result; background same as thorium-232
Thorium-230	220	35	2.3	430	See Table A1.2 for mean result; background DOE 1993
Thorium-232	34	20	2.3	32	See Table A1.2 for mean result; background DOE 1993
Thorium-234 (+protactinium-234m and protactinium-234)	52000	18	1.2	58000	See Table A1.2 for mean result; background same as uranium-234
Uranium-234	27	18	2.3	21	See Table A1.2 for mean result; background DOE 1993
Uranium-235 (+thorium-231)	1.1	0.79	2.3	0.71	See Table A1.2 for mean result; background calculated from ratio uranium-234 to uranium-235 in natural uranium
Uranium-238	24	19	2.3	12	See Table A1.2 for mean result; background DOE 1993
Neptunium-237	-	-	-	-	No data
Plutonium-238	11	0	1[a]	11	See Table A1.2 for mean result; zero background
Plutonium-239 + Plutonium-240	63	0	1[a]	63	See Table A1.2 for mean result; zero background
Americium-241	190	0	2.3	440	See Table A1.2 for mean result; zero background

[a]Dominated by discharges from Sellafield.

Table A1.4: Shrimp monitoring data for 2004 (Bq/kg wet weight)

Data source	Sample site	Date	^{60}Co	^{99}Tc	^{106}Ru	^{134}Cs	^{137}Cs	^{228}Th	^{230}Th	^{232}Th	^{234}Th	^{237}Np	^{238}Pu	^{239}Pu/ ^{240}Pu	^{241}Am
SEMP	Ribble	May-04				2.3		1.7	1.5	0.53		3.3			0.48
SEMP	Ribble	Dec-04				2.2		1.7	1.5	0.53		4.5			0.8
RIFE	Ribble	2004	<0.05	1.5	<0.53	<0.06	2	0.014	0.025	0.0063	4.9	0.000057	0.0038	0.019	0.036
Mean activity conc.			<0.05	1.5	<0.53	<0.06	2.2	1.1	1.0	0.36	4.9	2.6	0.0038	0.019	0.44

SEMP = Springfields Environmental Monitoring Programme (personal communication, Catherine Retberg, Springfields Fuels Ltd); RIFE = Radioactivity in Food and the Environment (Environment Agency et al. 2005).

Table A1.5: Mussel monitoring data for 2004 (Bq/kg wet weight)

Data source	Sample site	Date	^{60}Co	^{99}Tc	^{106}Ru	^{134}Cs	^{137}Cs	^{228}Th	^{230}Th	^{232}Th	^{234}Th	^{237}Np	^{238}Pu	^{239}Pu/ ^{240}Pu	^{241}Am
SEMP	Ribble	Feb-04				1.2		1.3	1.18	0.42		4.6			0.58
SEMP	Ribble	Sep-04				1.6		1.1	0.94	0.34		1.1			0.53
RIFE	Ribble	2004	<0.06		<0.61	<0.06	1.5	0.25	0.43	0.15	40				1.4
Mean activity conc.			<0.06	-	<0.61	<0.06	1.4	0.88	0.85	0.3	40	2.9	-	-	0.84

SEMP = Springfields Environmental Monitoring Programme (personal communication, Catherine Retberg, Springfields Fuels Ltd); RIFE = Radioactivity in Food and the Environment (Environment Agency et al. 2005).

Table A1.6: Mean 2004 activity concentrations in shrimp used in habitats assessment

Radionuclide	Mean activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges below limits	Corrected mean activity conc. (Bq/kg wet weight)	Comment on mean result and background
Technetium-99	1.5	0	1[b]	1.5	See Table A1.4 for mean result; zero background
Caesium-137	2.2	0	1[b]	2.2	See Table A1.4 for mean result; zero background
Thorium-228	1.1	0.0096	2.3	2.5	See Table A1.4 for mean result; background DOE 1993
Thorium-230	1.0	0.0026	2.3	2.3	See Table A1.4 for mean result; background DOE 1993
Thorium-232	0.36	0.0014	2.3	0.82	See Table A1.4 for mean result; background DOE 1993
Thorium-234	4.9	0.0026	1.2	5.9	See Table A1.4 for mean result; background same as Th-230
Neptunium-237[a]	2.6	0	2.3	6	See Table A1.4 for mean result; zero background
Plutonium-238	0.0038	0	1[b]	0.0038	See Table A1.4 for mean result; zero background
Plutonium-239/240	0.019	0	1[b]	0.019	See Table A1.4 for mean result; zero background
Americium-241	0.44	0	2.3	1	See Table A1.4 for mean result; zero background

[a]Assessed as plutonium-239.
[b]Dominated by discharges from Sellafield.

Table A1.7: Mean 2004 activity concentrations in mussels used in habitats assessment

Radionuclide	Mean activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg dry weight)	Correction factor for discharges below limits	Corrected mean activity conc. (Bq/kg wet weight)	Comment on mean result and background
Technetium-99	-	0	N/A	N/A	No data
Caesium-137	1.4	0	1[b]	1.4	See Table A1.5 for mean result; zero background
Thorium-228	0.88	0.37	2.3	1.2	See Table A1.5 for mean result; background DOE 1993
Thorium-230	0.85	0.19	2.3	1.5	See Table A1.5 for mean result; background DOE 1993
Thorium-232	0.3	0.28	2.3	0.046	See Table A1.5 for mean result; background DOE 1993
Thorium-234	40	0.19	1.2	48	See Table A1.5 for mean result; background same as Th-230
Neptunium-237[a]	2.9	0	2.3	6.7	See Table A1.5 for mean result; zero background
Plutonium-238	-	0	N/A	N/A	No data
Plutonium-239/240	-	0	N/A	N/A	No data
Americium-241	0.84	0	2.3	1.9	See Table A1.5 for mean result; zero background

[a]Assessed as plutonium-239.[b]Dominated by discharges from Sellafield.

Table A1.8: Dose rate to marine reference organisms using ERICA assessment tool for pre-January 2008 limits

Nuclide	Benthic fish	Crust-acean[a]	Mammal	Pelagic fish	Phyto-plankton	Vascular plant	Zoo-plankton	(Wading) bird	Benthic mollusc[a]	Macro-algae	Poly-chaete worm	Reptile	Sea anemones or true corals – colony	Sea anemones or true corals – polyp
Cobalt-60	1.4E-03	1.4E-03	2.7E-06	7.5E-06	1.0E-06	1.5E-03	1.9E-06	8.5E-07	1.5E-03	1.5E-03	2.9E-03	2.7E-06	1.4E-03	1.5E-03
Technetium-99	1.2E-07	8.7E-05	9.5E-08	1.2E-07	1.5E-08	1.2E-04	3.8E-07	1.2E-07	3.5E-05	1.2E-04	8.7E-05	1.2E-07	8.6E-05	8.6E-05
Ruthenium-106	2.1E-03	1.6E-03	1.1E-05	9.6E-06	5.6E-03	3.0E-03	3.3E-03	9.8E-06	3.2E-03	4.9E-03	6.9E-03	1.1E-05	2.3E-03	4.3E-03
Caesium-134	1.2E-03	1.2E-03	9.0E-05	1.2E-05	5.5E-06	1.3E-03	7.4E-06	7.4E-05	1.3E-03	1.3E-03	2.6E-03	1.9E-04	1.2E-03	1.3E-03
Caesium-137	4.1E-02	4.0E-02	4.7E-03	1.1E-03	6.2E-04	4.3E-02	9.1E-04	5.9E-03	4.3E-02	4.7E-02	9.1E-02	9.9E-03	4.2E-02	4.8E-02
Polonium-210	3.2E-04	1.1E-03	1.9E-04	3.2E-04	4.8E-04	1.9E-05	1.4E-03	1.9E-04	6.5E-04	1.9E-05	3.7E-04	1.9E-04	1.1E-03	1.1E-03
Radium-226	2.3E-01	1.3E-01	5.1E-02	2.2E-01	8.3E-01	7.8E-02	6.6E-02	2.4E-01	5.9E-02	7.9E-02	1.3E-01	2.4E-01	8.1E-01	8.2E-01
Radium-228	5.3E-03	4.7E-03	3.1E-04	8.6E-04	1.1E-03	4.9E-03	1.6E-04	9.1E-04	4.9E-03	5.3E-03	1.0E-02	1.4E-03	7.3E-03	7.3E-03
Thorium-228	3.1E-02	4.7E-01	4.0E-03	1.3E-02	1.6E+01	6.2E-02	1.6E-01	7.1E-04	3.9E-01	6.6E-02	5.1E-02	7.3E-04	7.6E-02	7.9E-02
Thorium-230	2.0E-02	6.2E-02	6.0E-03	2.0E-02	2.4E+01	6.6E-02	2.5E-01	1.1E-03	5.4E-02	6.6E-02	1.7E-02	1.1E-03	9.0E-02	9.0E-02
Thorium-232	1.3E-03	1.9E-02	3.8E-04	1.3E-03	1.5E+00	4.2E-03	1.6E-02	6.9E-05	1.6E-02	4.2E-03	1.1E-03	6.9E-05	5.7E-03	5.7E-03
Thorium-234	1.5E+00	9.0E-01	1.6E-02	4.9E-02	1.1E+01	2.1E+00	2.9E-01	2.7E-03	2.1E+00	5.0E+00	5.8E+00	2.8E-03	2.1E+00	3.9E+00
Uranium-234	8.2E-03	5.9E-03	2.4E-04	8.2E-03	8.2E-02	1.4E-01	1.8E-02	2.4E-03	1.9E-02	7.1E-02	1.9E-02	2.4E-03	5.9E-01	5.9E-01
Uranium-235	2.9E-04	2.1E-04	7.2E-06	2.6E-04	2.6E-03	4.2E-03	5.5E-04	7.3E-05	6.2E-04	2.2E-03	6.5E-04	7.2E-05	1.8E-02	1.8E-02
Uranium-238	4.0E-03	2.9E-03	1.2E-04	4.0E-03	4.0E-02	6.6E-02	8.6E-03	1.2E-03	9.2E-03	3.5E-02	9.2E-03	1.2E-03	2.9E-01	2.9E-01
Plutonium-238	1.2E-02	1.2E-04	9.9E-04	1.2E-02	4.2E-01	1.4E-02	2.7E-02	5.3E-04	8.4E-04	1.4E-02	5.3E-03	5.3E-04	9.5E-03	9.5E-03
Plutonium-239 & neptunium-237	6.6E-02	1.8E-01	5.3E-03	6.6E-02	2.3E+00	7.7E-02	1.5E-01	2.8E-03	2.0E-01	7.7E-02	2.8E-02	2.8E-03	5.1E-02	5.1E-02
Americium-241	3.0E-03	3.4E-02	2.0E-03	4.0E-04	1.5E+00	9.1E-03	2.8E-02	1.0E-03	6.4E-02	9.5E-03	6.3E-02	1.0E-03	2.4E-03	4.1E-03
Total	**2.0E+00**	**1.9E+00**	**9.0E-02**	**4.0E-01**	**5.8E+01**	**2.7E+00**	**1.0E+00**	**2.6E-01**	**3.0E+00**	**5.5E+00**	**6.3E+00**	**2.6E-01**	**4.1E+00**	**6.0E+00**

[a]The dose assessments for crustacean and mollusc have been derived from a separate ERICA assessment which has included the monitoring data for these species.

Table A1.9: Dose rate to freshwater reference organisms using ERICA assessment tool for pre-January 2008 limits

Nuclide	Benthic fish	Crust-acean[a]	Mammal	Pelagic fish	Phyto-plankton	Vascular plant	Zooplankton	Amphib-ian	Bird	Bivalve mollusc[a]	Gastro-pod	Insect larvae
Cobalt-60	1.4E-03	1.5E-03	2.9E-06	1.8E-06	9.0E-07	1.5E-03	7.0E-07	3.3E-07	2.1E-06	1.5E-03	1.5E-03	3.0E-03
Technetium-99	2.7E-04	8.1E-05	2.7E-04	2.7E-04	4.8E-05	7.7E-03	1.2E-04	2.7E-04	2.7E-04	1.6E-04	1.6E-04	8.3E-05
Ruthenium-106	1.4E-03	8.4E-03	7.9E-06	7.5E-06	6.7E-06	7.0E-03	2.1E-04	6.7E-06	7.6E-06	5.5E-03	6.3E-03	1.6E-02
Caesium-134	1.2E-03	1.3E-03	5.5E-05	3.2E-05	4.7E-06	1.3E-03	1.9E-06	2.6E-05	1.4E-05	1.2E-03	1.3E-03	2.7E-03
Caesium-137	4.0E-02	5.0E-02	3.8E-03	2.5E-03	5.8E-04	5.0E-02	2.3E-04	2.7E-03	1.1E-03	4.2E-02	4.5E-02	1.0E-01
Polonium-210	4.5E-06	1.8E-04	4.5E-06	4.5E-06	5.0E-04	7.4E-05	5.0E-04	4.5E-06	4.5E-06	7.1E-04	4.1E-04	1.8E-04
Radium-226	1.5E-02	1.7E-01	9.0E-03	9.0E-03	1.2E-01	2.0E-01	1.2E-01	8.5E-03	9.0E-03	1.7E-01	1.1E-01	1.8E-01
Radium-228	4.2E-03	6.2E-03	3.8E-05	3.4E-05	1.5E-04	6.0E-03	1.7E-04	2.9E-05	3.5E-05	5.1E-03	5.1E-03	1.2E-02
Thorium-228	1.9E-02	5.0E-01	2.4E-03	2.4E-03	8.8E-02	5.2E-02	4.4E-02	2.4E-03	2.4E-03	2.4E-01	2.2E-02	5.6E-02
Thorium-230	3.7E-03	6.2E-02	3.6E-03	3.6E-03	1.3E-01	4.2E-02	6.6E-02	3.6E-03	3.6E-03	4.1E-02	3.4E-03	3.7E-03
Thorium-232	2.3E-04	1.9E-02	2.3E-04	2.3E-04	8.4E-03	2.7E-03	4.2E-03	2.3E-04	2.3E-04	1.1E-03	2.2E-04	2.3E-04
Thorium-234	8.5E-01	1.1E+01	9.1E-03	9.1E-03	5.5E-02	8.7E+00	3.8E-02	8.4E-03	9.1E-03	1.5E+00	3.2E+00	2.1E+01
Uranium-234	3.5E-01	5.9E+00	3.5E-01	3.5E-01	1.4E+00	3.4E+01	5.6E-01	3.5E-01	3.5E-01	2.1E+00	2.1E+00	5.9E+00
Uranium-235	1.1E-02	1.8E-01	1.1E-02	1.1E-02	4.3E-02	1.1E+00	1.8E-02	1.1E-02	1.1E-02	6.6E-02	6.6E-02	1.8E-01
Uranium-238	1.7E-01	2.9E+00	1.7E-01	1.7E-01	6.9E-01	1.7E+01	2.8E-01	1.7E-01	1.7E-01	1.0E+00	1.0E+00	2.9E+00
Plutonium-238	1.6E-05	1.3E-04	5.8E-05	1.5E-05	1.5E-03	6.6E-04	1.1E-04	5.8E-05	5.1E-07	9.2E-05	2.1E-04	2.9E-04
Plutonium-239 & neptunium-237	8.4E-05	1.8E-01	3.1E-04	8.2E-05	8.0E-03	3.5E-03	6.1E-04	3.1E-04	2.7E-06	2.0E-01	1.1E-03	1.5E-03
Americium-241	1.2E-02	3.6E-02	5.3E-05	4.7E-05	1.1E+00	1.1E-01	1.1E-02	5.3E-05	5.3E-05	6.3E-02	8.3E-03	5.3E-01
Total	**1.5E+00**	**2.1E+01**	**5.7E-01**	**5.6E-01**	**3.6E+00**	**6.1E+01**	**1.1E+00**	**5.6E-01**	**5.6E-01**	5.5E+00	**6.6E+00**	**3.1E+01**

[a]The dose assessments for crustacean and mollusc have been derived from a separate ERICA assessment which has included the monitoring data for these species.

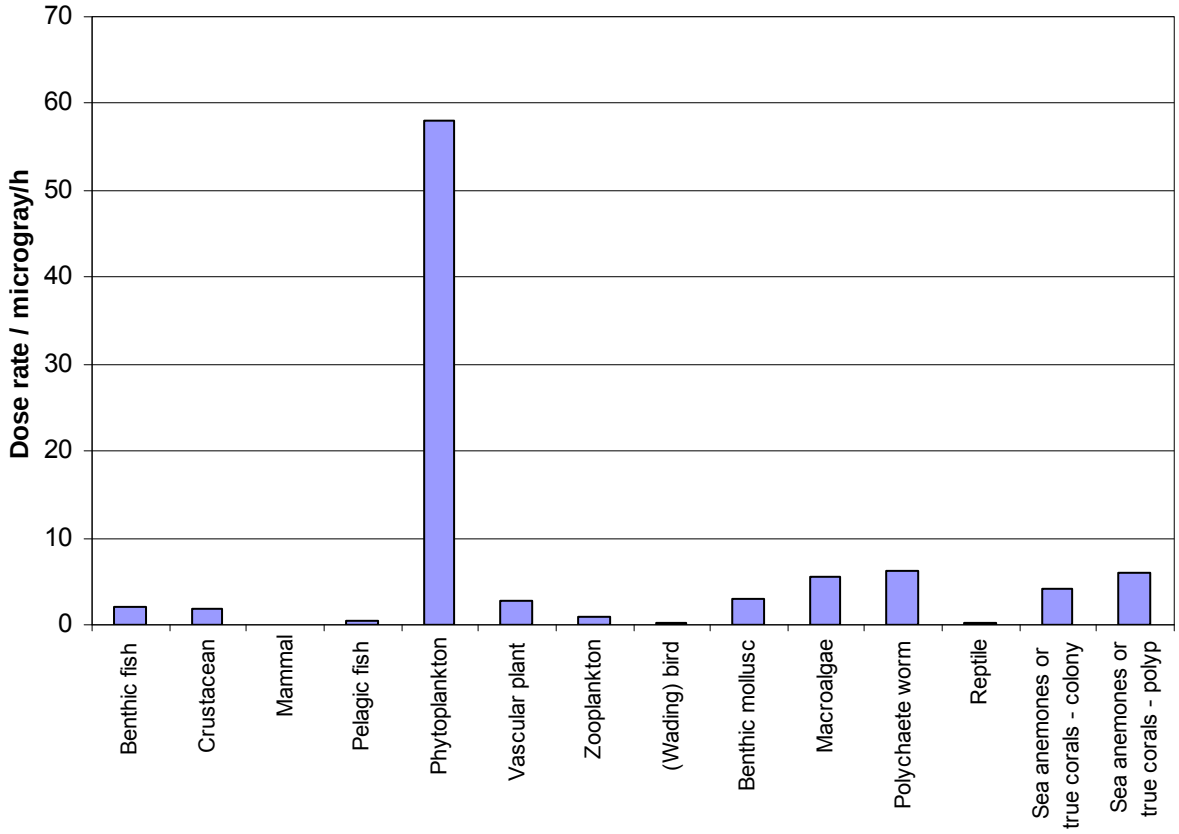

Figure A1.1: Pre-January 2008 limits – ERICA marine assessment – Total dose rates to reference organisms

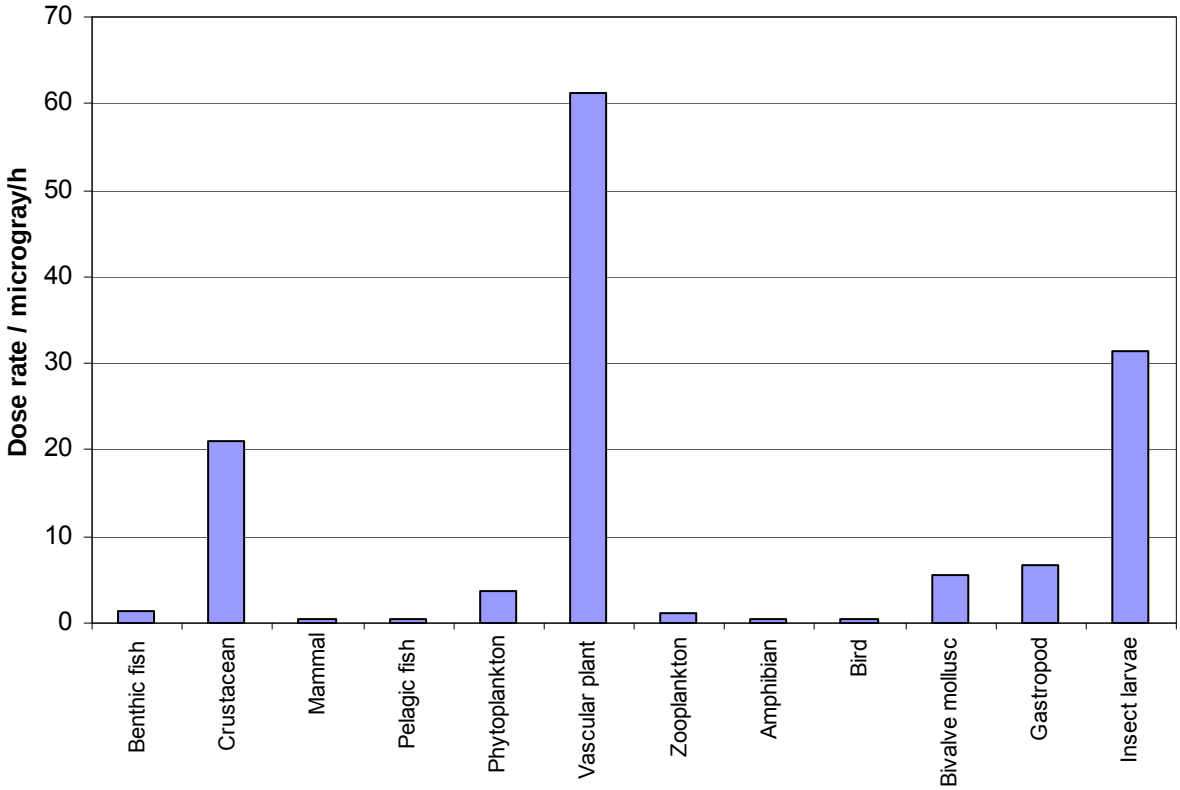

Figure A1.2: Pre-January 2008 limits – ERICA freshwater assessment – Total dose rates to reference organisms

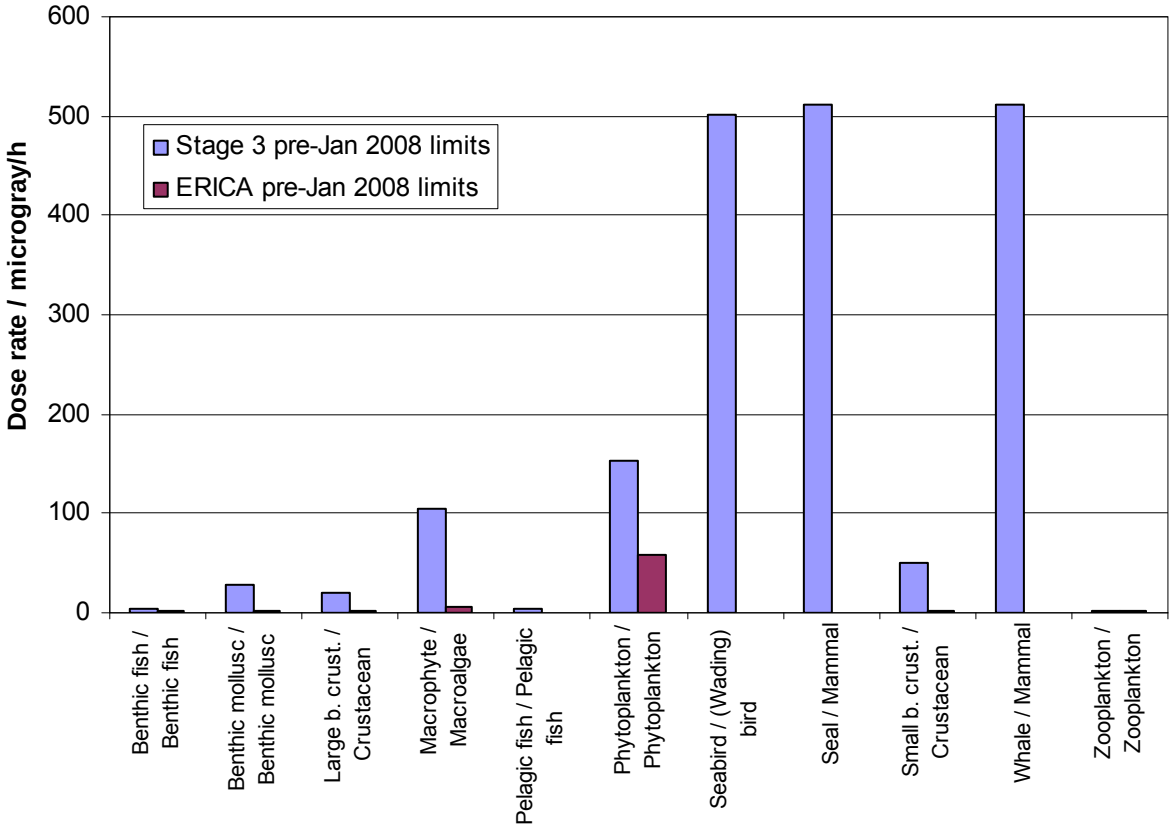

Figure A1.3: Comparison of Stage 3 and ERICA marine assessment for pre-January 2008 limits – Total dose rates to reference organisms

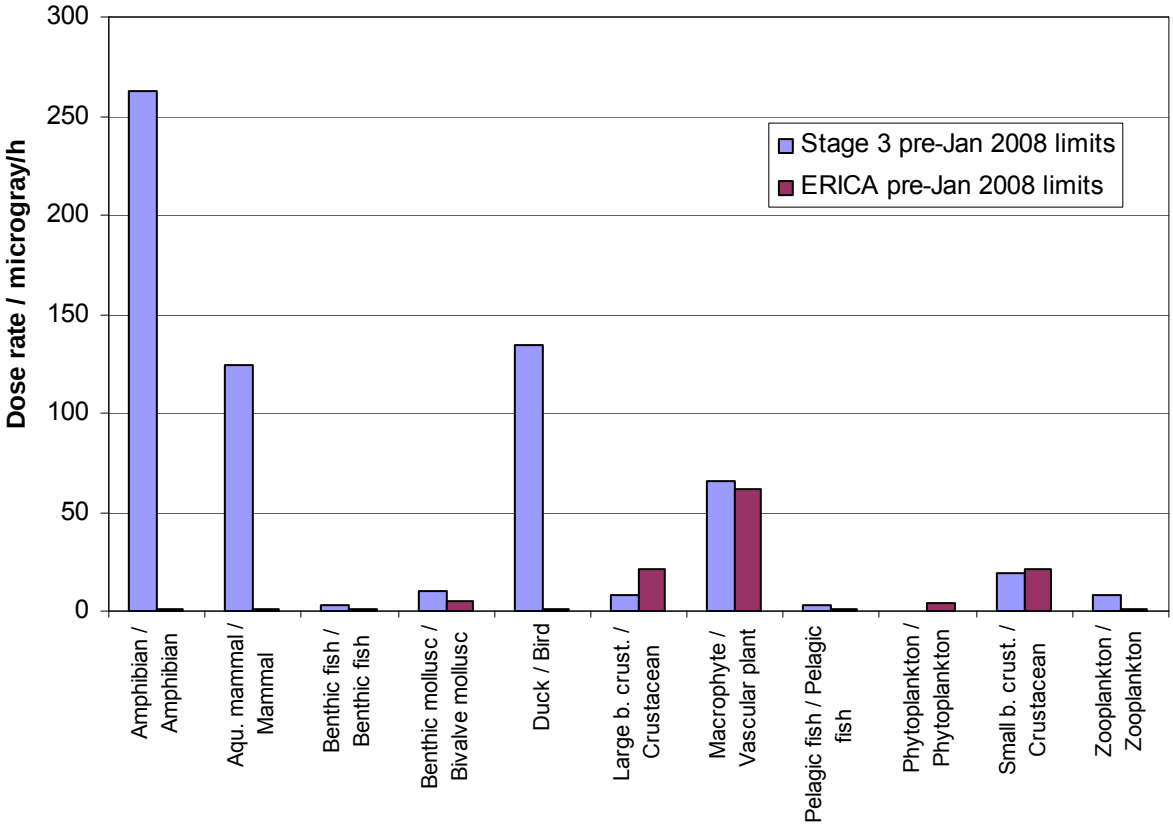

Figure A1.4: Comparison of Stage 3 and ERICA freshwater assessment for pre-January 2008 limits – Total dose rates to reference organisms

Appendix 2 – Variability and uncertainty in reassessment

Key assumptions

The key elements of variability and uncertainty in the reassessment of dose rates to reference organisms and feature species in the Ribble and Alt Estuaries SPA arise in the following parameters:

- Mix of radionuclides in the discharge.
- Environmental monitoring results.
- Sediment partitioning coefficients.
- Concentration factors.

It was assumed that the mix of radionuclides discharged in 2006 will continue to be discharged in the future. Discharges could be made of the radionuclides which give higher or lower dose rates to organisms. The discharge of beta-emitting radionuclides was assumed to be all thorium-234 and there are unlikely to be any other beta-emitting radionuclides dominating the discharge. However, there are a number of alpha-emitting radionuclides in the discharge with individual limits as shown in Table 6. These alpha-emitting radionuclides listed from highest dose rates to lowest dose rates per unit water concentration (see Allott et al. 2009) are:

a. Thorium-230
b. Thorium-232
c. Other transuranic radionuclides (assessed as americium-241)
d. Neptunium-237 (assessed as plutonium-239)
e. Uranium

There is variability in the environmental monitoring results for sediment and biota as can be seen in Tables 7, 9 and 10. There is uncertainty in the sediment partitioning coefficients for the different radionuclides which are used to calculate water concentrations from sediment concentrations. A lower sediment partitioning coefficient will lead to a higher water concentration as the water concentration is calculated from the sediment concentration. There is also uncertainty in the concentration factors which are used to calculate the transfer of radionuclides into organisms from the water concentrations. Higher concentration factors lead to calculation of higher internal dose rates for the organisms.

The most significant dose rates for the freshwater assessment arise from uranium-234 and uranium-238. However, it is probable that the environmental concentrations are dominated by naturally occurring uranium and an uncertainty/variability analysis has not been carried out for the freshwater assessment.

In the case of the marine assessment, thorium-228, thorium-230, thorium-234 and plutonium-239/neptunium-237 contribute the most significant dose rates to the organism with the highest dose rate (phytoplankton). An uncertainty assessment has been undertaken for these radionuclides.

Variability and uncertainty assessment method

The following marine scenarios have been assessed to examine the effect of uncertainty and variability:

- ***Worst case discharge profile*** – A worst case discharge profile was constructed by assuming the alpha-emitting radionuclides are discharged at their individual limits in order from highest to lowest dose rate per unit water concentration, while ensuring that the overall alpha limit was not exceeded (see Table A2.1). Ratios of these worst case discharges to the discharges in 2006 were calculated. These ratios were used to modify sediment and biota concentrations (see Tables A2.2–A2.4). All other parameters in the assessment remained the same.
- ***Best case discharge profile*** – A best case discharge profile was constructed by assuming the alpha-emitting radionuclides are discharged at their individual limits in order from lowest to highest dose rate per unit water concentration, while ensuring that the overall alpha limit was not exceeded (see Table A2.5). Ratios of these best case discharges to the discharges in 2006 were calculated. These ratios were used to modify sediment and biota concentrations (see Tables A2.6–A2.8).
- ***Maximum concentrations*** – Maximum sediment and biota concentrations for thorium-228, thorium-230, thorium-234 and neptunium-237 (see Tables A2.9–A2.11). Mean concentrations for all other radionuclides. All other parameters as for main assessment.
- ***Minimum concentrations*** – Minimum sediment and biota concentrations for thorium-228, thorium-230, thorium-234 and neptunium-237 (see Tables A2.12–A2.14). Mean concentrations for all other radionuclides. All other parameters as for main assessment.
- ***Low thorium sediment partitioning coefficient*** – A thorium sediment partitioning coefficient of $1\ 10^4$ Bq/kg per Bq/l was used which is at the low end of the range of values published by IAEA (2004). All other parameters as for main assessment.
- ***High thorium sediment partitioning coefficient*** – A thorium sediment partitioning coefficient of $1\ 10^7$ Bq/kg per Bq/l was used, which is at the high end of the range of values published by IAEA (IAEA 2004). All other parameters as for main assessment.
- ***High concentration factors*** – The maximum concentration factors for thorium and plutonium (to assess neptunium) in the ERICA database were used (Table A2.15). Where no maximum concentration factor was available, the maximum was assumed to be a factor of ten higher than the mean. All other parameters as for main assessment.
- ***Low concentration factors*** – The mean concentration factors for thorium and plutonium (to assess neptunium) in the ERICA database were used (Table A2.15). Where no minimum concentration factor was available, the minimum was assumed to be a factor of ten lower than the mean. All other parameters as for main assessment.

Variability and uncertainty assessment results

The total dose rates to marine organisms from the variability and uncertainty assessment are shown in Table A2.16 and Figures 14–18. It is not realistic to combine all worst case scenarios or all best case scenarios together; hence the variability and uncertainty assessment results have been kept separate for each scenario.

Table A2.1: Worst case discharge profile

Radioactive substance or category	January 2008 limit (TBq)	2006 discharges (TBq)	Revised discharge	Ratio
Thorium-230 (alpha)	0.02	0.0119	0.02	1.7
Thorium-232 (alpha)	0.015	0.00031	0.015	48
Other transuranic radionuclides (alpha)	0.02	0.00235	0.02	8.5
Neptunium-237 (alpha)	0.04	0.00158	0.04	25
Uranium (alpha)	0.04	0.026	0.005	0.19
Total alpha	0.1	0.08	0.1[a]	-

[a]Summed from revised alpha radionuclide discharges.

Table A2.2: 2006 Sediment activity concentrations used in uncertainty assessment for worst case discharges profile correction

Radionuclide	Mean activity conc. (Bq/kg dry weight)	Natural background conc. (Bq/kg dry weight)	Correction factor for discharges below limits	Corrected mean activity conc. (Bq/kg dry weight)	Comment on mean result and background
Cobalt-60	2.1	0	1[b]	2.1	See Table 7 for mean result; zero background
Ruthenium-106 (+rhodium-106)	7.3	0	1[b]	7.3	See Table 7 for mean result; zero background
Caesium-134	0.88	0	1[b]	0.88	See Table 7 for mean result; zero background
Caesium-137 (+barium-137m)	260	0	1[b]	260	See Table 7 for mean result; zero background
Polonium-210 (+bismuth-210)	25	19	0	0	Mean result and background same as uranium-238
Radium-226 (+radon-222, astatine-218, polonium-218, lead-214, bismuth-214, polonium-214)	25	19	0	0	Mean result and background same as uranium-238
Radium-228	32	20	0	0	Mean result and background same as thorium-232
Thorium-228 (+radium-224, radon-220, polonium-216, lead-212, bismuth-212, polonium-212, thallium-208)	30	20	0	0	See Table 7 for mean result; background same as thorium-232
Thorium-230	100	35	1.7	110	See Table 7 for mean result; background DOE 1993
Thorium-232	32	20	48	580	See Table 7 for mean result; background DOE 1993
Thorium-234 (+protactinium-234m and protactinium-234)	6200	18	1	6200	See Table 7 for mean result; background same as uranium-234
Uranium-234	25	18	0.19	1.3	See Table 7 for mean result; background DOE 1993
Uranium-235 (+thorium-231)	1	0.79	0.19	0.04	See Table 7 for mean result; background calculated from ratio uranium-234 to uranium-235 in natural uranium
Uranium-238	25	19	0.19	1.1	See Table 7 for mean result; background DOE 1993
Neptunium-237[a]	5	-	25	130	See Table 7 for mean result; no background data
Plutonium-238	12	0	1	12	See Table 7 for mean result; zero background
Plutonium-239 + Plutonium-240	67	0	1	67	See Table 7 for mean result; zero background
Americium-241	150	0	8.5	1300	See Table 7 for mean result; zero background

[a]Assessed as plutonium-239.
[b]Dominated by discharges from Sellafield.

Table A2.3: 2006 activity concentrations in shrimp used in uncertainty assessment for worst case discharges profile correction

Radionuclide	Mean activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected mean activity conc. Bq/kg wet weight)	Comment on mean result and background
Technetium-99	0.64	0	1[b]	0.64	See Table 9 for mean result; zero background
Caesium-137	2.6	0	1[b]	2.6	See Table 9 for mean result; zero background
Thorium-228	1.2	0.0096	0	0	See Table 9 for mean result; background DOE 1993
Thorium-230	1.1	0.0026	1.7	1.9	See Table 9 for mean result; background DOE 1993
Thorium-232	0.38	0.0014	48	18	See Table 9 for mean result; background DOE 1993
Thorium-234	15	0.0026	1	15	See Table 9 for mean result; background same as thorium-230
Neptunium-237[a]	3.9	0	25	98	See Table 9 for mean result; zero background
Plutonium-238	0.0017	0	1[b]	0.0017	See Table 9 for mean result; zero background
Plutonium-239/240	0.011	0	1[b]	0.011	See Table 9 for mean result; zero background
Americium-241	0.47	0	8.5	4	See Table 9 for mean result; zero background

[a]Assessed as plutonium-239.
[b]Dominated by discharges from Sellafield.

Table A2.4: 2006 activity concentrations in mussels used in uncertainty assessment for worst case discharges profile correction

Radionuclide	Mean activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected mean activity conc. Bq/kg wet weight)	Comment on mean result and background
Technetium-99	-	0	N/A	N/A	No data
Caesium-137	1.6	0	1[b]	1.6	See Table 10 for mean result; zero background
Thorium-228	0.92	0.37	0	0	See Table 10 for mean result; background DOE 1993
Thorium-230	0.82	0.19	1.7	1.1	See Table 10 for mean result; background DOE 1993
Thorium-232	0.29	0.28	48	0.48	See Table 10 for mean result; background DOE 1993
Thorium 234	39	0.19	1	39	See Table 10 for mean result; background same as thorium-230
Neptunium-237[a]	-	0	N/A	N/A	No data
Plutonium-238	-	0	N/A	N/A	No data
Plutonium-239/240	-	0	N/A	N/A	No data
Americium-241	1.0	0	8.5	8.5	See Table 10 for mean result; zero background

[a]Assessed as plutonium-239. [b]Dominated by discharges from Sellafield.

Table A2.5: Best case discharge profile

Radioactive substance or category	January 2008 limit (TBq)	2006 discharges (TBq)	Revised discharge	Ratio
Uranium (alpha)	0.04	0.026	0.04	1.5
Neptunium-237 (alpha)	0.04	0.00158	0.04	25
Other transuranic radionuclides (alpha)	0.02	0.00235	0.02	8.5
Thorium-232 (alpha)	0.015	0.00031	0	0
Thorium-230 (alpha)	0.02	0.0119	0	0
Total Alpha	0.1	0.08	0.1[a]	-

[a]Summed from revised alpha radionuclide discharges.

Table A2.6: 2006 Sediment activity concentrations used in uncertainty assessment for best case discharges profile correction

Radionuclide	Mean activity conc. (Bq/kg dry weight)	Natural background conc. (Bq/kg dry weight)	Correction factor for discharges below limits	Corrected mean activity conc. (Bq/kg dry weight)	Comment on mean result and background
Cobalt-60	2.1	0	1[b]	2.1	See Table 7 for mean result; zero background
Ruthenium-106 (+rhodium-106)	7.3	0	1[b]	7.3	See Table 7 for mean result; zero background
Caesium-134	0.88	0	1[b]	0.88	See Table 7 for mean result; zero background
Caesium-137 (+barium-137m)	260	0	1[b]	260	See Table 7 for mean result; zero background
Polonium-210 (+bismuth-210)	25	19	0	0	Mean result and background same as uranium-238
Radium-226 (+radon-222, astatine-218, polonium-218, lead-214, bismuth-214, polonium-214)	25	19	0	0	Mean result and background same as uranium-238
Radium-228	32	20	0	0	Mean result and background same as thorium-232
Thorium-228 (+radium-224, radon-220, polonium-216, lead-212, bismuth-212, polonium-212, thallium-208)	30	20	0	0	See Table 7 for mean result; background same as thorium-232
Thorium-230	100	35	0	0	See Table 7 for mean result; background DOE 1993
Thorium-232	32	20	0	0	See Table 7 for mean result; background DOE 1993
Thorium-234 (+protactinium-234m and protactinium-234)	6200	18	1	6200	See Table 7 for mean result; background same as uranium-234
Uranium-234	25	18	1.5	11	See Table 7 for mean result; background DOE 1993
Uranium-235 (+thorium-231)	1	0.79	1.5	0.31	See Table 7 for mean result; background calculated from ratio uranium-234 to uranium-235 in natural uranium
Uranium-238	25	19	1.5	9	See Table 7 for mean result; background DOE 1993
Neptunium-237[a]	5	-	25	130	See Table 7 for mean result; no background data
Plutonium-238	12	0	1	12	See Table 7 for mean result; zero background
Plutonium-239 + Plutonium-240	67	0	1	67	See Table 7 for mean result; zero background
Americium-241	150	0	8.5	1300	See Table 7 for mean result; zero background

[a]Assessed as plutonium-239.
[b]Dominated by discharges from Sellafield.

Table A2.7: 2006 activity concentrations in shrimp used in uncertainty assessment for best case discharges profile correction

Radionuclide	Mean activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected mean activity conc. Bq/kg wet weight)	Comment on mean result and background
Technetium-99	0.64	0	1[b]	0.64	See Table 9 for mean result; zero background
Caesium-137	2.6	0	1[b]	2.6	See Table 9 for mean result; zero background
Thorium-228	1.2	0.0096	0	0	See Table 9 for mean result; background DOE 1993
Thorium-230	1.1	0.0026	0	0	See Table 9 for mean result; background DOE 1993
Thorium-232	0.38	0.0014	0	0	See Table 9 for mean result; background DOE 1993
Thorium-234	15	0.0026	1	15	See Table 9 for mean result; background same as thorium-230
Neptunium-237[a]	3.9	0	25	98	See Table 9 for mean result; zero background
Plutonium-238	0.0017	0	1[b]	0.0017	See Table 9 for mean result; zero background
Plutonium-239/240	0.011	0	1[b]	0.011	See Table 9 for mean result; zero background
Americium-241	0.47	0	8.5	4.0	See Table 9 for mean result; zero background

[a]Assessed as plutonium-239.
[b]Dominated by discharges from Sellafield.

Table A2.8: 2006 activity concentrations in mussels used in uncertainty assessment for best case discharges profile correction

Radionuclide	Mean activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected mean activity conc. Bq/kg wet weight)	Comment on mean result and background
Technetium-99	-	0	N/A	N/A	No data
Caesium-137	1.6	0	1[b]	1.6	See Table 10 for mean result; zero background
Thorium-228	0.92	0.37	0	0	See Table 10 for mean result; background DOE 1993
Thorium-230	0.82	0.19	0	0	See Table 10 for mean result; background DOE 1993
Thorium-232	0.29	0.28	0	0	See Table 10 for mean result; background DOE 1993
Thorium 234	39	0.19	1	39	See Table 10 for mean result; background same as thorium-230
Neptunium-237[a]	-	0	N/A	N/A	No data
Plutonium-238	-	0	N/A	N/A	No data
Plutonium-239/240	-	0	N/A	N/A	No data
Americium-241	1.0	0	8.5	8.5	See Table 10 for mean result; zero background

[a]Assessed as plutonium-239. [b]Dominated by discharges from Sellafield.

Table A2.9: Maximum 2006 sediment activity concentrations used in variability assessment

Radionuclide	Max activity conc. (Bq/kg dry weight)	Natural background conc. (Bq/kg dry weight)	Correction factor for discharges below limits	Corrected max activity conc. (Bq/kg dry weight)	Comment on max result and background
Thorium-228	57	20	1.3	48	See Table 7 for max result; see Table 7 for background
Thorium-230	400	35	1.3	475	See Table 7 for max result; background DOE 1993
Thorium-234	66000	18	1	66000	See Table 7 for max result; see Table 7 for background
Neptunium-237[a]	7	-	1.3	9.1	See Table 7 for max result; no background data

[a]Assessed as plutonium-239.

Table A2.10: Maximum 2006 activity concentrations in shrimp used in variability assessment

Radionuclide	Max activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected max activity conc. Bq/kg wet weight)	Comment on max result and background
Thorium-228	1.9	0.0096	1.3	2.5	See Table 9 for max result; background DOE 1993
Thorium-230	1.7	0.0026	1.3	2.2	See Table 9 for max result; background DOE 1993
Thorium-234	18	0.0026	1	18	See Table 9 for max result; background same as thorium-230
Neptunium-237[a]	9.8	0	1.3	13	See Table 9 for max result; zero background

[a]Assessed as plutonium-239.

Table A2.11: Maximum 2006 activity concentrations in mussels used in variability assessment

Radionuclide	Max activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected max activity conc. Bq/kg wet weight)	Comment on max result and background
Thorium-228	1.3	0.37	1.3	1.2	See Table 10 for max result; background DOE 1993
Thorium-230	1.1	0.19	1.3	1.2	See Table 10 for max result; background DOE 1993
Thorium 234	41	0.19	1	41	See Table 10 for max result; background same as thorium-230
Neptunium-237[a]	-	0	N/A	N/A	No data

[a]Assessed as plutonium-239.

Table A2.12: Minimum 2006 sediment activity concentrations used in variability assessment

Radionuclide	Min activity conc. (Bq/kg dry weight)	Natural background conc. (Bq/kg dry weight)	Correction factor for discharges below limits	Corrected min activity conc. (Bq/kg dry weight)	Comment on min result and background
Thorium-228	9.2	20	1.3	0	See Table 7 for min result; see Table 7 for background
Thorium-230	28	35	1.3	0	See Table 7 for min result; background DOE 1993
Thorium-234	146	18	1	128	See Table 7 for min result; see Table 7 for background
Neptunium-237[a]	3.4	-	1.3	4.4	See Table 7 for min result; no background data

[a]Assessed as plutonium-239.

Table A2.13: Minimum 2006 activity concentrations in shrimp used in variability assessment

Radionuclide	Min activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected min activity conc. Bq/kg wet weight)	Comment on min result and background
Thorium-228	0.012	0.0096	1.3	0.0031	See Table 9 for min result; background DOE 1993
Thorium-230	0.012	0.0026	1.3	0.012	See Table 9 for min result; background DOE 1993
Thorium-234	12	0.0026	1	12	See Table 9 for min result; background same as thorium-230
Neptunium-237[a]	0.00026	0	1.3	0.00034	See Table 9 for min result; zero background

[a]Assessed as plutonium-239.

Table A2.14: Minimum 2006 activity concentrations in mussels used in variability assessment

Radionuclide	Min activity conc. (Bq/kg wet weight)	Natural background conc. (Bq/kg wet weight)	Correction factor for discharges limits	Corrected min activity conc. Bq/kg wet weight)	Comment on min result and background
Thorium-228	0.27	0.37	1.3	0	See Table 10 for min result; background DOE 1993
Thorium-230	0.29	0.19	1.3	0.13	See Table 10 for min result; background DOE 1993
Thorium 234	36	0.19	1	36	See Table 10 for min result; background same as thorium-230
Neptunium-237[a]	-	0	N/A	N/A	No data

[a]Assessed as plutonium-239.

Table A2.15: Maximum, mean and minimum concentration factors for thorium and plutonium isotopes

Concentration factor	Benthic fish	Crust-acean	Mammal	Pelagic fish	Phyto-plankton	Vascular plant	Zoo-plankton	(Wading) bird	Benthic mollusc	Macro-algae	Poly-chaete worm	Reptile	Sea anemones or true corals – colony	Sea anemones or true corals – polyp
Max thorium	6.0E+03	1.0E+04	1.8E+03	6.0E+03	2.0E+06	7.7E+03	2.0E+04	3.3E+02	7.0E+02	7.7E+03	7.0E+02	3.3E+02	2.7E+04	2.7E+04
Mean thorium	6.0E+02	1.0E+03	1.8E+02	6.0E+02	7.3E+05	2.0E+03	7.5E+03	3.3E+01	5.1E+02	2.0E+03	5.1E+02	3.3E+01	2.7E+03	2.7E+03
Min thorium	6.0E+01	1.0E+02	1.8E+01	6.0E+01	8.0E+03	2.3E+02	2.0E+01	3.3E+00	9.0E+01	2.3E+02	9.0E+01	3.3E+00	2.7E+02	2.7E+02
Max plutonium	4.5E+04	4.8E+02	4.4E+02	4.5E+04	6.3E+05	1.0E+04	2.8E+04	2.0E+02	9.2E+03	1.0E+04	4.1E+03	2.0E+02	2.7E+04	2.7E+04
Mean plutonium	3.5E+03	1.6E+02	2.8E+02	3.5E+03	1.2E+05	4.1E+03	7.8E+03	1.5E+02	1.1E+03	4.1E+03	1.5E+03	1.5E+02	2.7E+03	2.7E+03
Min plutonium	1.0E+00	3.7E+01	1.1E+02	1.0E+00	4.0E+02	8.5E+01	2.0E+03	1.0E+02	2.0E+00	8.5E+01	1.0E+02	1.0E+02	2.7E+02	2.7E+02

Table A2.16: Dose rates at January 2008 limits for marine variability and uncertainty assessment

Variability / uncertainty assessment	Benthic fish	Crust-acean	Mammal	Pelagic fish	Phyto-plankton	Vascular plant	Zoo-plankton	(Wading) bird	Benthic mollusc	Macro-algae	Poly-chaete worm	Reptile	Sea anemones or true corals – colony	Sea anemones or true corals – polyp
Mean	4.7E-01	7.4E-01	5.0E-02	2.6E-01	1.6E+01	5.7E-01	4.1E-01	1.7E-01	1.6E+00	8.4E-01	9.1E-01	1.7E-01	1.4E+00	1.6E+00
Worst discharge profile	4.7E-01	3.7E+00	5.0E-02	2.6E-01	**4.7E+01**	6.6E-01	9.6E-01	1.7E-01	2.1E+01	9.8E-01	1.0E+00	1.7E-01	1.4E+00	1.6E+00
Best discharge profile	4.4E-01	7.4E-01	3.0E-02	2.4E-01	1.3E+01	5.7E-01	4.1E-01	2.1E-02	1.6E+00	8.4E-01	9.1E-01	2.5E-02	9.7E-01	1.2E+00
Maximum concentrations	2.1E+00	2.1E+00	7.5E-02	3.4E-01	**6.3E+01**	2.8E+00	1.1E+00	1.7E-01	5.5E+00	6.2E+00	7.0E+00	1.8E-01	3.6E+00	5.8E+00
Minimum concentrations	3.0E-01	1.8E-01	4.6E-02	2.4E-01	5.1E+00	3.2E-01	2.8E-01	1.7E-01	1.7E-01	2.8E-01	2.8E-01	1.7E-01	1.1E+00	1.1E+00
Low thorium sediment kd	9.4E-01	7.4E-01	2.0E-01	7.3E-01	**4.2E+02**	2.1E+00	5.2E+00	2.0E-01	1.6E+00	2.3E+00	1.3E+00	2.0E-01	3.4E+00	3.5E+00
High thorium sediment kd	4.6E-01	7.4E-01	4.6E-02	2.5E-01	4.8E+00	5.3E-01	2.8E-01	1.7E-01	1.6E+00	8.0E-01	9.0E-01	1.7E-01	1.3E+00	1.5E+00
High concentration factors	1.7E+00	7.4E-01	9.3E-02	1.5E+00	**5.0E+01**	8.5E-01	1.2E+00	1.8E-01	3.5E+00	1.1E+00	9.9E-01	1.8E-01	2.5E+00	2.7E+00
Low concentration factors	3.7E-01	7.4E-01	4.2E-02	1.6E-01	1.4E+00	4.3E-01	1.2E-01	1.7E-01	5.6E-01	7.0E-01	8.7E-01	1.7E-01	1.2E+00	1.5E+00

Table A2.17: Dose rates to phytoplankton at January 2008 limits for worst case scenarios in marine variability and uncertainty assessment

Radionuclide	Worst discharge profile	Maximum concentrations	Low thorium sediment kd	High concentration factors
Cobalt-60	1.0E-06	1.0E-06	1.0E-06	1.0E-06
Technetium-99	6.6E-09	6.6E-09	6.6E-09	6.6E-09
Ruthenium-106	2.2E-03	2.2E-03	2.2E-03	2.2E-03
Caesium-134	1.7E-06	1.7E-06	1.7E-06	1.7E-06
Caesium-137	6.0E-04	6.0E-04	6.0E-04	6.0E-04
Polonium-210	0.0E+00	3.1E-04	3.1E-04	3.1E-04
Radium-226	0.0E+00	5.4E-01	5.4E-01	5.4E-01
Radium-228	0.0E+00	7.7E-04	7.7E-04	7.7E-04
Thorium-228	0.0E+00	1.9E+01	**1.8E+02**	1.4E+01
Thorium-230	6.2E+00	2.7E+01	**1.7E+02**	1.3E+01
Thorium-232	2.8E+01	7.7E-01	2.7E+01	2.1E+00
Thorium-234	1.2E+00	1.3E+01	**4.1E+01**	3.2E+00
Uranium-234	5.1E-03	3.6E-02	3.6E-02	3.6E-02
Uranium-235	1.5E-04	9.8E-04	9.8E-04	9.8E-04
Uranium-238	3.7E-03	2.6E-02	2.6E-02	2.6E-02
Plutonium-238	4.6E-01	4.6E-01	4.6E-01	2.4E+00
Plutonium-239	7.1E+00	2.7E+00	2.6E+00	1.4E+01
Americium-241	4.3E+00	6.7E-01	6.7E-01	6.7E-01

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