OSPAR COMMISSION

Assessment on Impact of Anthropogenic sources of radioactive substances on marine biota

Radioactive Substances Series

2008

The Convention for the Protection of the Marine Environment of the North-East Atlantic (the "OSPAR Convention") was opened for signature at the Ministerial Meeting of the former Oslo and Paris Commissions in Paris on 22 September 1992. The Convention entered into force on 25 March 1998. It has been ratified by Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, Netherlands, Norway, Portugal, Sweden, Switzerland and the United Kingdom and approved by the European Community and Spain.

La Convention pour la protection du milieu marin de l'Atlantique du Nord-Est, dite Convention OSPAR, a été ouverte à la signature à la réunion ministérielle des anciennes Commissions d'Oslo et de Paris, à Paris le 22 septembre 1992. La Convention est entrée en vigueur le 25 mars 1998. La Convention a été ratifiée par l'Allemagne, la Belgique, le Danemark, la Finlande, la France, l'Irlande, l'Islande, le Luxembourg, la Norvège, les Pays-Bas, le Portugal, le Royaume-Uni de Grande Bretagne et d'Irlande du Nord, la Suède et la Suisse et approuvée par la Communauté européenne et l'Espagne.

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Executive summary

Under Annex IV to the OSPAR Convention, OSPAR is required to produce periodic assessments of the quality status of the maritime area covered by the Convention. A general assessment of the whole of the North-East Atlantic was produced in 2000, supported by five sub-regional reports. A further general assessment is planned to be produced in 2010, which will concentrate on the extent to which the aims of the thematic strategies of the OSPAR Commission have been delivered. In preparation for this, it is planned to produce in relation to the OSPAR Radioactive Substances Strategy four thematic assessments: RA-1 related to reduction of radioactive substances discharges, RA-2 related to concentrations of radioactive substances in the environment and the associated doses for human, RA-3 related to impact on marine biota of anthropogenic sources (past and present) of radioactive substances (that is, this report), and RA-4 being an overall assessment of radionuclides in the OSPAR maritime area.

This report, entirely devoted to the impact assessment of anthropogenic sources of radioactive substances on marine biota, is based on 3 elements: (1) a brief state-of-the-art on methodologies and associated knowledge for performing ecological impact and risk assessment for radioactive substances, (2) the selected assessment method to demonstrate to which extent the progress that the Contracting Parties to the OSPAR Convention are making in reducing anthropogenic inputs of radioactive substances to the North-East Atlantic, is propagated to doses or dose rates to biota living in the exposed marine ecosystems, (3) the application of the method for the OSPAR regions where needed data are available. This assessment is fully conducted in a consistent way with regard to the two previous periodic evaluations (RA-1 and RA-2).

The review of the state-of-the-art leads to the conclusion that an environmental impact and risk assessment can be easily implemented for a list of radionuclides potentially released in the marine ecosystems within the OSPAR maritime area. The calculated total dose rates can be interpreted by comparison to a screening dose rate such as the one from the European project ERICA (10 µGy/h for a generic ecosystem, this value being highly conservative and the lowest of any recommended screening values). The calculated dose rates need therefore to be interpreted as incremental dose rates above the dose rate from the natural background. It can also be directly compared to the dose rate delivered by the natural background.

To implement the demonstration, the proposed method needs input data such as measured environmental activity concentrations for the selected radioactive substances, combined with modelling of the absorbed radiological dose rates delivered to living organisms representative of the marine ecosystems within the OSPAR area. This has been done by using the ERICA approach, the only European reference project that allows an Integrated Assessment of doses to biota. Moreover, this flexible approach may be adapted to the user needs, especially in terms of organisms and radionuclides. It was then selected as corresponding to the RA-3 requirements. The justification of this choice is argued for each decisive criterion, on an inter-comparison basis. From the available similar approaches, two of the most recent ones have been selected in this objective, RESRAD-BIOTA (DOE, 2002) and the Environment Agency R&D 128 (Copplestone et al, 2001). Considering the knowledge related to discharges of radioactive substances, more especially in relation with the significance of the radionuclides in terms of radiological dose, a restricted list of radionuclides is taken into consideration in OSPAR (i.e. ^{3}H, ^{99}Tc, $^{239,240}Pu$, ^{210}Po, ^{226}Ra, ^{228}Ra, and ^{210}Pb).

For the past period (1995-2001) and each year of the assessment period, the radionuclide-specific dose rates were added per compartment and highest dose rates were estimated. For radionuclides from the nuclear sector, the highest estimated dose rate was 0.1 µGy/h in macroalgae and invertebrates. ^{137}Cs and ^{99}Tc are generally the most important contributors to the dose rate. For regions where ^{3}H and ^{137}Cs data were available, ^{137}Cs gives rise to dose rate higher than ^{3}H does. For radionuclides from the non-nuclear sector (^{210}Po, ^{226}Ra, ^{228}Ra, ^{210}Pb), very few data were available and it was not possible to perform the assessment for each year. When considering the years where data were available, the highest dose rate was observed in 1976 in crustaceans with a value of 2.74 µGy/h, ^{210}Po being the most important contributor.

Including only a few radionuclides in the assessment may lead to its misinterpretation in terms of the biological effect of ionising radiation in the OSPAR region. However, although the conclusion of such comparison is robust only when input data on source term is exhaustive, it is possible to compare the dose rates summed for the selected radionuclides to the screening value of 10 µGy/h to characterize the potential risk to the structure and function of the marine ecosystems in each OSPAR region. Such an assessment indicates that the partial calculated dose rates to marine biota from the radionuclides from the nuclear sector considered are low and are below the lowest levels at which any effects are likely to occur.

Récapitulatif

Dans le cadre de l'annexe IV de la Convention OSPAR, OSPAR est tenue de réaliser des évaluations périodiques de l'état de santé de la zone maritime couverte par la Convention. Une évaluation générale de l'ensemble de l'Atlantique du Nord-est a été effectuée en 2000, étayée par cinq rapports sous-régionaux. Une nouvelle évaluation générale est prévue en 2010. Elle se concentrera sur la mesure dans laquelle les objectifs des stratégies thématiques de la Commission OSPAR ont été réalisés. Il est prévu, dans ce sens, de réaliser quatre évaluations thématiques dans le cadre de la Stratégie OSPAR substances radioactives. Il s'agit du RA-1 concernant la réduction des rejets de substances radioactives, du RA-2 concernant les concentrations de substances radioactives dans l'environnement et des doses correspondantes pour l'homme, du RA-3 concernant l'impact sur le milieu vivant marin des sources anthropiques de substances radioactives (passées et présentes) (le présent rapport) et du RA-4, un bilan général des radionucléides dans la zone maritime OSPAR.

Le présent rapport, entièrement consacré à l'évaluation de l'impact des sources anthropiques de substances radioactives sur le milieu vivant marin, se fonde sur trois éléments (1) une revue brève de l'état de l'art des toutes dernières méthodes, et des connaissances correspondantes, en ce qui concerne l'évaluation des risques et de l'impact écologique des substances radioactives, (2) la méthode d'évaluation sélectionnée pour démontrer dans quelle mesure les progrès réalisés par les Parties contractantes à la Convention OSPAR, dans le sens de la réduction des apports anthropiques de substances radioactives dans l'Atlantique du Nord-est, ont des répercutions sur les débits de dose dans le milieu vivant des écosystèmes marins exposés à ces substances, (3) l'application de la méthode pour les régions OSPAR sur lesquelles les données nécessaires sont disponibles. Cette évaluation est totalement réalisée en cohérence avec les deux évaluations périodiques précédentes (RA-1 et RA-2).

On peut tirer de la revue de l'état de l'art la conclusion que l'on peut facilement mettre en œuvre une évaluation des risques et de l'impact écologique pour une liste de radionucléides potentiellement relâchés dans les écosystèmes marins de la zone maritime OSPAR. On peut interpréter les débits de dose totaux calculés par rapport à un débit de dose de filtrage tel que celui du projet européen ERICA (10 µGy/h pour un écosystème générique, cette valeur étant extrêmement conservative et la plus faible de toutes les valeurs de filtrage recommandées). Il est donc nécessaire d'interpréter les débits de dose calculés comme des débits de dose progressifs supérieurs au débit de dose provenant de l'ambiance naturelle. On peut également les comparer directement au débit de dose produit par l'ambiance naturelle.

Pour réaliser la démonstration il est nécessaire d'avoir, pour la méthode proposée, des données telles que les concentrations d'activité environnementales pour les substances sélectionnées, en conjonction avec la modélisation du débit de dose radiologique absorbée par des organismes vivants représentatifs des écosystèmes marins dans la zone OSPAR. Ceci a été effectué en utilisant l'approche ERICA, qui représente le seul projet de référence européen permettant une évaluation intégrée des doses dans le milieu vivant. De plus on peut adapter cette approche flexible aux besoins de l'utilisateur, en particulier en matière d'organismes et de radionucléides. Elle a alors été sélectionnée car elle correspond aux exigences du RA-3. Ce choix est justifié en soutenant chaque critère décisif, sur la base d'une intercomparaison. Deux approches similaires les plus récentes, parmi celles disponibles, ont été sélectionnées dans ce but. Il s'agit de RESRAD-BIOTA (DOE, 2002) et de R&D 128 de l'Agence pour l'environnement (Copplestone *et*

al, 2001). OSPAR envisage une liste restreinte de radionucléides (c'est-à-dire ^{3}H, ^{99}Tc, ^{239,240}Pu, ^{210}Po, ^{226}Ra, ^{228}Ra, et ^{210}Pb), étant données les connaissances sur les rejets de substances radioactives et en particulier relatives à l'importance des radionucléides en matière de dose radiologique.

Les débits de dose propres aux radionucléides ont été ajoutés par compartiment et on a estimé les débits de dose les plus élevés, et ce pour la période écoulée (1995-2001) et chaque année de la période d'évaluation. Le débit de dose estimé le plus élevé est 0.1 µGy/h dans les macroalgues et les invertébrés, en ce qui concerne les radionucléides provenant du secteur nucléaire. Le ^{137}Cs et le ^{99}Tc sont en général les plus importants contributeurs au débit de dose. Le ^{137}Cs accuse une augmentation du débit de dose supérieure à celle du ^{3}H, dans les régions pour lesquelles on dispose de données sur ces substances. En ce qui concerne les radionucléides provenant du secteur non nucléaire (^{210}Po, ^{226}Ra, ^{228}Ra, ^{210}Pb), très peu de données sont disponibles et il n'a pas été possible d'effectuer une évaluation pour chaque année. Lorsqu'on étudie les années pour lesquelles on dispose de données, on relève le débit de dose le plus élevé en 1976 chez les crustacés, avec une valeur de 2.74 µGy/h et le ^{210}Po étant le contributeur le plus important.

On risque de mal interpréter l'évaluation des radionucléides, en ce qui concerne les effets biologiques de la radiation ionisante dans la région OSPAR, si l'évaluation ne porte que sur quelques radionucléides. Cependant, bien que les conclusions d'une telle comparaison ne soient solides que lorsque les données sur le terme source sont exhaustives, il est possible de comparer la somme des débits de dose pour les radionucléides sélectionnés avec la valeur de filtrage 10 µGy/h afin de déterminer le risque potentiel pour la structure et la fonction des écosystèmes marins dans chaque région OSPAR. Cette évaluation indique que les débits de dose calculés partiellement, pour le milieu vivant marin, des radionucléides provenant du secteur nucléaire étudiés sont faibles et se situent en dessous des niveaux les plus bas susceptibles d'entraîner des effets.

Chapter 1 – Introduction

This report aims to demonstrate to which extent the progress the Contracting Parties to the OSPAR Convention are making in reducing anthropogenic inputs of radioactive substances to the North-East Atlantic, is propagated to doses or dose rates to biota living in the exposed marine ecosystems,, in line with the commitments that they have made in the OSPAR Radioactive Substances Strategy.

The possibility of harm to the marine environment and its users (including the consumers of food produced from the marine environment) from inputs of radionuclides caused by human activities was always a subject with which the 1972 Oslo and 1974 Paris Conventions were concerned – a concern taken over by the 1992 OSPAR Convention and taken forward in the work of implementing it. When international action to protect the marine environment from all kinds of pollution was first agreed in 1972, the Oslo Convention[1] acknowledged that radioactive substances were one of the forms of wastes and other matter to be addressed, and committed the Contracting Parties to working in the appropriate UN specialised agencies and other international bodies to promote measures to protect the marine environment against them. When the Paris Convention[2] was adopted in 1974, in order to provide for international action against land-based sources of marine pollution, the Contracting Parties undertook "to adopt measures to forestall and, as appropriate, eliminate pollution of the maritime area from land-based sources by radioactive substances"[3].

When the Oslo and Paris Conventions were up-dated and unified in 1992 to form the OSPAR Convention, stringent restrictions were included not merely on the dumping of any radioactive waste or matter (which was then temporarily halted under an international moratorium) but also on any possibility of resuming such dumping, and radioactivity was included as one of the factors against which the need for control measures on discharges from land-based sources would be judged.

When the first Ministerial meeting under the 1992 Convention of the OSPAR Commission was held in 1998 at Sintra, Portugal, agreement was reached on both:

a. a complete and permanent ban on all dumping of radioactive waste and other matter; and

b. a strategy to guide the future work of the OSPAR Commission on protecting the marine environment of the North-East Atlantic against radioactive substances arising from human activities.

This strategy was revised and confirmed by the second Ministerial meeting of the OSPAR Commission at Bremen in 2003. The OSPAR Radioactive Substances Strategy thus now provides that

"In accordance with the general objective [of the OSPAR Convention], the objective of the Commission with regard to radioactive substances, including waste, is to prevent pollution of the maritime area from ionizing radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances, with the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances. In achieving this objective, the following issues should, *inter alia*, be taken into account:

a. legitimate uses of the sea;

b. technical feasibility;

c. radiological impacts on man and biota."

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1 Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft, Oslo, 15 February 1972.

2 Convention for the Prevention of Marine Pollution from Land-Based Sources, Paris, 4 June, 1974.

3 Article 5(1).

The Strategy further provides that:

"This strategy will be implemented in accordance with the Program for More Detailed Implementation of the Strategy with regard to Radioactive Substances[4] in order to achieve by the year 2020 that the Commission will ensure that discharges, emissions and losses of radioactive substances are reduced to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero."

The logic underlying these commitments is the same as the logic underlying the similar objective and time-frame for hazardous substances. The starting point is the principle enunciated by the 1972 UN Stockholm Conference on the Human Environment: "States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction." There is no generally accepted evidence that the current levels of discharges of radioactive substances by the OSPAR Contracting Parties are causing actual harm to the marine environment. However, given that the marine environment is a common resource of the Contracting Parties, there is a common wish to go, as soon as reasonably practicable, beyond the principle of merely not causing damage. The commitment to reductions in discharges of radioactive substances aims to ensure that such discharges do not add to the load which the marine environment must bear, and thereby to increase the likelihood that the marine environment will be healthy and sustainable.

The Program for More Detailed Implementation of the Strategy with regard to Radioactive Substances (the "RSS Implementation Program")[5] and the agreements made at the second OSPAR Ministerial meeting, in effect, provide that

a. the Contracting Parties will each prepare a national plan for achieving the objective of the Strategy,

b. they will monitor and report on progress in implementing those plans, and

c. the OSPAR Commission will periodically evaluate progress against an agreed baseline.

This report contains the first of these evaluations.

Under Annex IV to the OSPAR Convention, OSPAR is required to produce periodic assessments of the quality status of the maritime area covered by the Convention. A general assessment of the whole of the North-East Atlantic was produced in 2000, supported by five sub-regional reports. A further general assessment is planned to be produced in 2010, which will concentrate on the extent to which the aims of the thematic strategies of the OSPAR Commission have been delivered. In preparation for this, it in planned to produce in relation to the OSPAR Radioactive Substances Strategy the following thematic assessments:

2006: RA-1 First Periodic Evaluation of Progress towards the Objective of the Radioactive Substances Strategy (concerning progressive and substantial reductions in discharges of radioactive substances, as compared with the agreed baseline).

2007: RA-2 Second Periodic Evaluation of the Progress towards the Objective of the Radioactive Substances Strategy concerning concentrations in the environment as compared with the agreed baseline and including an assessment (for those regions where information is available) of the exposure of humans to radiation from pathways involving the marine environment.

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4 OSPAR agreement reference number: 2001-3.

5 Adopted by the OSPAR Commission in 2000, and slightly revised in 2001, the Program for the More Detailed Implementation of the OSPAR Strategy with regard to Radioactive Substances is OSPAR Agreement 2001/3.

2008: RA-3 An assessment (for those regions where information is available) of the impact on marine biota of anthropogenic sources (past and present) of radioactive substances (that is, this report).

2009: RA-4 Third Periodic Evaluation of the Progress towards the Objective of the Radioactive Substances Strategy (being an overall assessment of radionuclides in the OSPAR maritime area).

This report is entirely devoted to the impact assessment of anthropogenic radioactive substances on marine biota. This assessment is based on 3 elements: (1) a brief state-of-the-art on methodologies and associated knowledge that have been recently developed for performing ecological impact and risk assessment for radioactive substances, (2) the selected method to demonstrate to which extent the progress the Contracting Parties to the OSPAR Convention are making in reducing anthropogenic inputs of radioactive substances to the North-East Atlantic, is propagated to doses or dose rates to biota living in the exposed marine ecosystems, (3) the application of the method for the OSPAR regions where needed data are available, (4) the conclusion underlying limitations associated to gaps both in data and scientific knowledge. This assessment is fully conducted in a consistent way with regard to the two previous periodic evaluations (RA-1 and RA-2).

Chapter 2 – Brief state-of-the-art

2.1 Introduction and international context

Until now, ecological impact or risk assessment devoted to radioactive substances released into ecosystems has been exclusively viewed implicitly through the human radioprotection, under the umbrella of the statement of the International Commission on Radiological Protection (ICRP) [ICRP 1991]: "The Commission believes that the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk. Occasionally, individual members of non-human species might be harmed, but not to the extent of endangering whole species or creating imbalance between species". Although one purpose of the Euratom Treaty is to guarantee high safety standards from the effects of ionizing radiation, the Treaty and its subsidiary legislation are focused on protecting the health of workers and the general public, rather than non-human species. However, a range of other international legislation and binding agreements includes requirements to protect the environment more broadly – including protection against the harmful effects of radioactive substances [NEA 2007].

Although assessment methodologies have existed for some years [IAEA, 1979, 1988; NCRP, 1991], the need for a system to protect the environment from ionizing radiation was only recently recognized internationally [IAEA 2003; ICRP 2003]. There is a gap to be filled, such that radiological protection approaches will be brought up to date with current environmental protection regulation, arguing for consistency between the approaches to be applied in regulating radioactive substances with those applied for chemicals [IAEA 2003; ICRP 2003]. Although there are a number of key differences between chemical and radioactive stressors - *e.g.*, for radioactive substances, the effects analysis is dependent on the amount of radiation energy absorbed by the body of the living organism rather than the concentration to which it is exposed to -, there is no compelling argument for radioactive substances to be considered in a different way than that used for conventional chemicals. Consequently, a similar approach can be adopted for both categories of stressors. An Environmental Risk Assessment (ERA)-type method has been recently conceived and adopted within a 6th European Commission project (Environmental Risk from Ionising Contaminants: Assessment and management – ERICA), with an integrated approach to assess and manage environmental risk from radioactive substances [ERICA 2007]. This ERA-type method comprises *inter alia* the traditional components: problem formulation, exposure analysis, effects analysis and risk characterization. This method is generally applied according to a tiered approach, from screening level, simplistic and conservative assessment to full, site-specific and detailed assessment.

Previously, the European Commission (EC) supported the Framework for ASSessment of Environmental impacT of ionising radiation (FASSET) project within the 5^{th} framework program [Larsson et al. 2004] and the Environmental Protection from Ionising Contaminants in the Artic (EPIC) project [Brown et al. 2003] within the EC Inco-Copernicus program. FASSET formulated a generic framework for assessments, elaborated on the reference organism concept and guidelines for pathways, exposure and effects analyses. EPIC dealt with the protection of artic environment from the effects of ionizing radiation. It developed an environmental impact assessment framework compatible with systems being developed elsewhere including the one's from FASSET, the MARINA II study [EC 2003a] and those for chemicals [EPIC 2003].

Concomitantly, the EC funded MARINA II project with a main objective to provide input to be used in implementing the OSPAR strategy with regard to radioactive substances and their radiological potential impact on man and marine biota, was developed [EC 2003a]. A working sub-group worked exclusively on addressing the radiological aspects relating to biota.

ERICA was built on the FASSET assessment framework, focusing particularly on risk characterization as the link between assessment and management, and addressing the possible effects of radioactive contaminants predominantly at the level of populations and ecosystems. Throughout ERICA there was emphasis on disseminating the progress of the work through continuous interaction with potential end-users. The development of the ERICA Integrated

Approach has coincided with the work of the International Commission on Radiological Protection (ICRP) in the field of protection of the environment against the harmful effects of ionizing radiation [ICRP 2003, 2007]. The ERICA Integrated Approach and the ICRP approach are consistent. The databases are developed around certain ecosystem representatives (Reference Organisms, ROs, in ERICA; Reference Animals and Plants, RAPs, in ICRP). The dosimetric characterisation of RAPs', being a subset of ROs, is identical in many cases, but their transfer parameterisation may be different [ICRP, 2008].

The ICRP has directly addressed environmental protection as an element of its last recommendations [ICRP 2007]. Since 2005, the ICRP has appointed a new Committee, Committee 5, to make recommendations for the establishment of an environmental protection system that: takes into account the current ethical debate; corroborates systems developed in other areas of environmental protection (*e.g.,* for hazardous substances); and can be operated in conjunction with the system for radiological protection of humans.

The International Conference on the Protection of the Environment from Ionizing Radiation (Stockholm 2003) organised by the International Atomic Energy Agency (IAEA) clearly recommended Member States to support international actions within the IAEA structure to consider protection of the environment in the further development of safety guidelines in accordance with the IAEA action plan approved in 2005 (http://www-ns.iaea.org/tech-areas/waste-safety/enviro-protection.htm). In 2004, the IAEA established a Biota Working Group under their Environmental Modelling for Radiation Safety (EMRAS) program with the objective of comparing and validating approaches being used and developed by Member States for biota dose assessment [Beresford and Howard 2005; Beresford et al. 2005]. In July 2007, the IAEA launched the Basic Safety Standards revision while including a section devoted to the radioprotection of the environment.

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) regularly publishes broad reviews of the sources and effects of ionizing radiation. In 1996, UNSCEAR published its first report on the effects of ionizing radiation on plants and animals in the environment as a separate Annex to the UNSCEAR 1996 Report to the General Assembly of the United Nations (UN). An updated Annex on biota will be included in the forthcoming UNSCEAR report to be released at the end of 2008 [UNSCEAR in preparation].

Finally, there has been a considerable international and national effort to consider the issue of protection of the environment from radioactive substances. Much of the focus has been on collating relevant information and on developing different approaches to enable regulatory assessments (*e.g.,* within Europe to comply with conservation legislation, namely the Habitats and Birds Directives) to be carried out. The 6th framework EC coordinated Action PROTection of the Environment from ionising radiation in a regulatory ContexT (PROTECT) is currently evaluating the feasibility of different approaches that are being used and developed. The primary objectives of this coordinated action are to evaluate the practicability and relative merits of different approaches to protection of the environment from ionizing radiation. It also aims to compare these with methods used for non-radioactive contaminants, particularly on the adequacy with respect to the European framework defined for chemicals. This will provide a basis on which the EC could develop protection policies and revise its Basic Safety Standards.

2.2 The key components of an Environmental Impact or Risk Assessment

A number of national bodies have already developed assessment methodologies which they are now using to regulate sites. These include the US Department of Energy [USDOE 2002], Canadian agencies [Environment Canada 2000] and the England and Wales Environment Agency/English Nature [Copplestone et al. 2001].

In Europe, the ERICA tool and associated databases constitute the elements of the only Integrated Approach existing and yet tested for a number of case studies. More than 60 European scientists, regulators, policy makers and environmental experts have contributed to the ERICA Integrated Approach through the ERICA project [ERICA 2007]. In addition, a large number of experts in different areas have contributed views on the Integrated Approach and its associated Tool from the user's perspective, through participation in the End Users Group.

Whatever the method/approach previously cited, they all have the following key components in common. They proposed to use an Ecological Risk Assessment (ERA) methodology to demonstrate the provision of an appropriate level of protection for ecosystems. ERA is a process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors. According to this methodology, any risk assessment applicable to biota from exposure to radionuclides is to be associated with (1) the problem formulation composed of the source-term characterization and environmental release scenario, the ecological object to be protected (e.g., a given ecosystem, a given species), any question to be answered (2) the exposure analysis, (3) the effects analysis at different levels of individual or ecosystem organisation, resulting in the derivation of no-effect values and finally, (4) the risk characterization where for instance risk can be calculated in the simplest way as the ratio between predicted concentrations in the source of exposure and estimated no-effect concentrations [FASSET 2004; ERICA 2007]. This sub-division is similar to the one adopted for chemical substances recommended by the European Commission [EC 2003]. The following paragraphs will mainly focus on the ERICA Integrated Approach as this is the most recent and complete of existing ERA approaches although reference will be made to other main approaches that are available and that have been involved in the IAEA EMRAS Biota Working Group intercomparison exercises.

Risk Characterization includes estimation of the probability and magnitude of adverse effects in biota, together with identification of uncertainties. The method to calculate the risk has been developed within the ERICA project and constitutes an element of the ERICA Integrated Approach. Risk characterization is performed by evaluating the output data from the exposure analysis or assessment (estimates of exposure) against an effects analysis. The latter is done on the basis of published effects data, gathered into the FRED-ERICA[6] radiation effects database, which is a compilation of the scientific literature on radiation effect experiments and field studies, organised around different wildlife groups and, for most data, broadly categorized according to four effect umbrella endpoints: morbidity, mortality, reproduction, and mutation.

The ERICA Integrated Approach is organised in three separate tiers, where satisfying certain criteria in Tiers 1 and 2 allows the assessor to exit the assessment process while being confident that the effects on biota are low or negligible, and that the situation requires no further action. Where the effects are not shown to be negligible, the assessment should continue to Tiers 2 and 3. Situations of concern should be assessed further in Tier 3, by making full use of all relevant information available through the Integrated Approach or elsewhere. As such, the ERICA Integrated Approach (Figure 2.1) attempts to strike a balance between the simplification required for the method to be workable, and the complexity needed to generate useful information. This enables the early screening out of situations of negligible radiological concern, leaving only those of potential or real concern for more in-depth assessment [ERICA 2007].

6 Extension of the initial FASSET database, FRED, during the ERICA project.

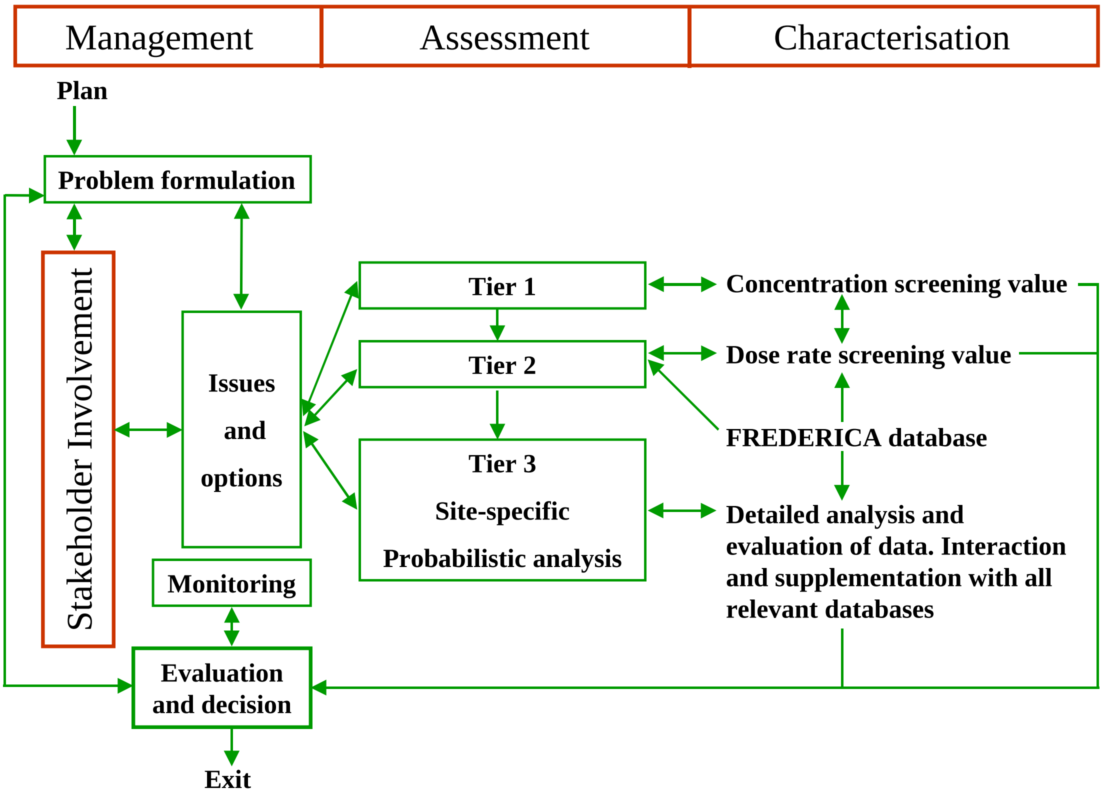

Figure 2.1: Overview of the ERICA Integrated Approach, outlining the interactions between assessment, risk characterization and management [ERICA 2007].

2.3 The two components of an Impact Assessment: problem formulation, exposure analysis or concentrations estimates and dosimetry

The problem formulation is intended to identify the scope, context and purpose of the assessment framework [Suter 1993]. This includes relevant ecological, political and societal issues, and integrates the process of choosing appropriate assessment endpoints, identifying sources and type of exposure situations (i.e. chronic or acute; past, present or future) and describing the receiving ecosystem. Commonly, a conceptual model is described at first to gather existing knowledge about the site/ecosystems (e.g., geographical limits, radionuclides of interest, natural background, pathways of exposure, receptors, the problem faced, and existing monitoring data).

The exposure analysis refers to the process of estimating exposure of biota, which involves estimating or measuring activity concentrations in environmental media and organisms, defining exposure conditions, and estimating radiation dose rates to selected biota.

Although dynamic models have been employed to describe the dispersion and dilution of radionuclides in marine ecosystems, the transfers to sediments and to living organisms are very often modelled as equilibrium processes, using simple distribution coefficients and concentration factors. Using equilibrium based values may be limited because temporal variation in concentrations and consequently in dose rate due to short-term fluctuations in discharge rate or in any short-term environmental processes (e.g. seasonality), is neglected. However using an equilibrium based approach, as used in the assessment reported here, is appropriate given that the input data to the dosimetric model is based on annually reported data and because this work is looking at long term changes in the activity concentrations of radioactive substances in the environment.

Figure 2.2 summarizes the main transfer pathways and reference organisms for a generic marine ecosystem. This reference organisms concept constitutes an attempt to strike a balance between the level of simplification required for the methodology to be workable, the level of complexity needed to provide useful information and the basic data that can be made available as input for the models. The biological environment includes then phytoplankton, zooplankton, macroinvertebrates, sessile aquatic plants, molluscs, crustaceans and vertebrates (fish, marine mammals and marine birds) and the physical environment includes tidal zones, coastal waters and marine sediments. Connections with terrestrial and/or freshwater ecosystems may be included in the conceptual model of interest. Implicitly, the corresponding exposure pathways include external irradiation from contaminated water and sediments as well as internal contamination resulting both from direct and trophic transfers.

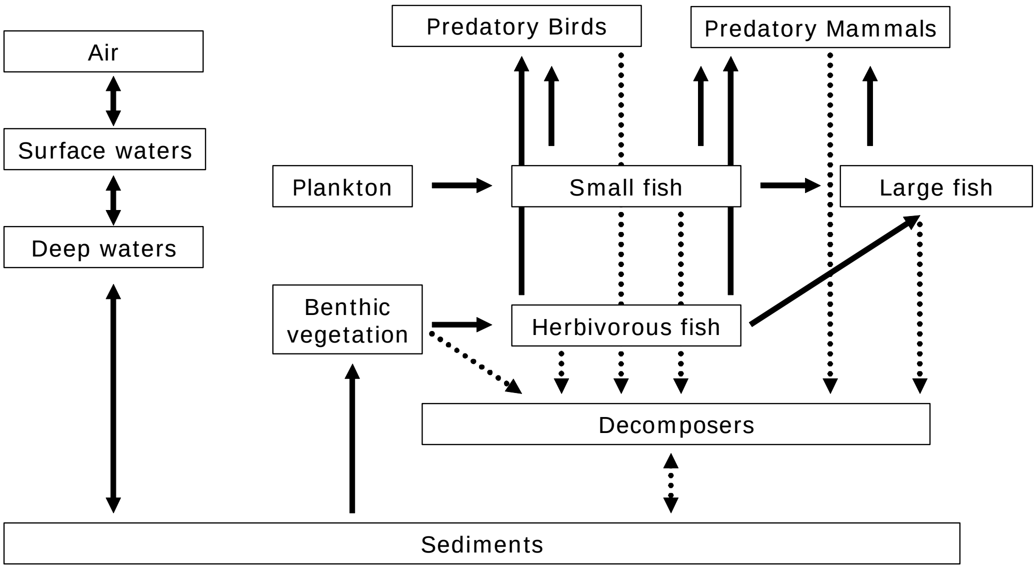

Figure 2.2: Example of a conceptual model for a marine generic ecosystem (from ERICA 2007).

Radioactivity in marine water is – in addition to radioactive decay - subject to several processes that lead to a modification of the activity concentrations in water. Of primary importance are (i) dilution due to convective and dispersive mixing effects during transport driven by local, regional and global currents, and (ii) sedimentation after binding to suspended particles.
Fractions of dissolved and the particle-bound radionuclides usually are determined by the distribution coefficient Kd, which is defined as the equilibrium ratio of radionuclide concentrations in normally filtered water and sorbed to particulate matter. Kd-values are element-dependent. Low Kd values and concentrations of suspended matter result in high dissolved fractions, whereas high Kd values and suspended load values cause a considerable sorption of radionuclides to particles and favour sedimentation. Once deposited, radionuclides are involved in remobilisation and resuspension processes. These processes may create additional sources or sinks with potential impact on the long-term behaviour.

For marine biota, activity concentrations can be estimated using a concentration ratio (CR) approach. This concentration ratio, also called concentration factor or bioaccumulation factor, is defined as the equilibrium ratio between the activity concentration within an organism and the activity concentration in normally filtered seawater. It may be calculated for a given organ (muscle) or for the whole body of the organism, as it is done in ERICA.

The radiation exposure received by a biota (or some organ or tissue of the biota) is the sum of both external and internal exposure. External exposures of biota are the result of complex and non-linear interactions of various factors, such as the levels of radionuclides in the habitat, the geometrical relationship between the radiation source and the target, the shielding properties of materials in the environment, the size of the organism and the radionuclide-specific decay properties (characterized by the radiation type, the energies emitted and their emission probabilities). Internal exposures of plants and animals are determined by the activity concentration in the organism, the size of the organism, the radionuclide distribution and the specific decay properties of the radionuclide. Factors to account for the relative biological effectiveness of alpha, beta and gamma radiation are applied. Some approaches, like ERICA, do consider a more precise description of the radiation categories, by distinguishing low and high beta radiation categories. The high beta radiation category is then treated in the same way as gamma radiation.

Dosimetric models are needed to convert concentrations expressed in Bq per unit of mass or volume into absorbed dose rates for living organisms, including both external and internal irradiation pathways. The absorbed dose measures the interaction of all types of radiation with any kind of material. These models take into account the radiation type, the specific geometry of the target, e.g. the whole body shape and composition, the geometry of the sources of exposure and their relative position with regards to the target. To reach this goal, it would be impossible to consider the whole diversity of life forms in an ecosystem. The reference organism concept then simplifies the approach and allows the basic data required as input for the models to be determined. Limitations are here given by additional sources of complexity such as those arising from the behaviour of mobile organisms in modifying the exposure from external sources and from occupation of different environmental niches at different stages of the life cycle. Finally, nuclide-specific dose conversion factors for internal and external exposure of reference organisms are provided in the literature (e.g., [ERICA 2007]) and some intercomparisons have been performed [Vives I Battle et al., 2007].

The various equivalent dose quantities (and the name of the unit, sievert (Sv)) are specific to human radiation protection. In the absence of corresponding dosimetric concepts and quantities for application to non-human species, the absorbed doses from low-linear energy transfer (LET) radiations (beta particles, x rays and gamma rays) and from high-LET radiation (alpha particles) are assessed separately and added for a given radionuclide if needed. The absorbed doses retain the SI unit joule per kilogram ($J\ kg^{-1}$) and the unit name gray (Gy) [UNSCEAR in preparation]. A radiation field that deposits 1 Joule of energy in 1 kg of material has an absorbed dose of 1 Gy. The old unit of measure for absorbed dose is rad (short for "radiation absorbed dose"). The relationship between the SI unit and the old unit is: 1 Gy = 100 rad.

The issue of using the concept of Relative Biological Effectiveness (RBE) and derived Radiation Weighting Factors (RWF) in assessing dose rate to non-human biota is still under debate. The question is whether it is relevant to modify the absorbed dose (rate) expressed as a physical quantity by the application of a properly derived RWF for each radiation type to estimate a biologically equivalent dose (rate). Even though it is widely accepted that a number of factors affect RBE values, e.g. the dose distribution in the targeted cells, organs or organisms, the dose-effect relationship, the LET, no consensus has been reached on the way to derive robust RWF at the individual level. Furthermore understanding of how its value could change for upper organisational level more relevant for ecosystems such as population for instance is still limited.

The considerations of RBE and RWF have been very critically examined for the purposes of human radiological protection, where each component of the absorbed dose to a tissue or organ is weighted according to the radiation quality. For UNSCEAR [UNSCEAR 1996] and most of the existing ERA approaches, it seems reasonable to apply a similar approach to radiation dosimetry for organisms other than man. In practice, however, there are circumstances that alter the detailed application of the approach. In the human case, the major concern has been with the induction of stochastic effects (principally cancer) at low doses and dose rates. For alpha radiation, experimental determinations of relative biological effectiveness (RBE) have led to a recommended radiation weighting factor of 20 for the purpose of human radiation protection. In the case of wild organisms, however, under the assumption that deterministic effects are of greatest significance, and considering alpha radiation, the experimental data for animals, mainly mammals, indicated that a lower weighting factor, perhaps 5, would be more appropriate; the weighting factors for beta and gamma radiation would remain unity [UNSCEAR in preparation; Chambers et al. 2006]. Moreover, it is well accepted that RBE depends on many factors, e.g. the endpoint, the species/tissue/cell, the type of particles and its LET distribution, the exposure pathway, the dose, the type of radiation used as reference. This has motivated some authors to consider this factor as a contributor to the uncertainty associated to the final dose estimates and to take it into account in a sensitivity analysis where its potential value varies within a given range [Avila et al. 2004] or as a statistical distribution.

Recently a systemic review of currently available literature has been conducted on the alpha radiation RBEs for non-human species [Chambers et al., 2005; Chambers et al., 2006]. Within the ERICA project, this data set was completed by an in depth examination of FRED-ERICA and an extension of the analysis to beta particles [ERICA, 2006]. In total, 145 RBE values were extracted from 66 papers; among which 84 were considered sufficiently robust (see Chambers et al., 2005) for detailed selection criteria) to be applied to non-human species. Since deterministic effects are of major importance in terms of demographic implication, only RBE values experimentally determined for survival, fecundity and reproduction were considered. A log-normal distribution was fitted to RBE values attributed to alpha particles and to beta particles. For alpha articles, the taxonomic group and endpoint are dominated by mammals. For beta particles, the RBE set is smaller: 11 data, 4 species, 3 taxonomic groups. Full details are given in Table 2.1 along with the median and associated 95 % CI together with a brief description of the biodiversity represented in each of the sub-set. Note that neither the reference radiation type nor the methodological approach for exposure (*i.e. in vitro* or *in vivo*) plays a major role in the RBE value sensitivity.

Table 2.1: RBE values allocation per radiation type or radionuclides and per wildlife group and effect category and their statistical distribution.

Radiation type/ Radionuclide	Number of data	Wildlife group (Number of species - Number of data)	Effect category (Number of data)	Distribution (R^2)	RBE median [95 %CI]	95th percentile [95 %CI]
All alpha particles	62	Algae (1 - 1) Micro-organisms (2 - 4) Fish (1 - 3) Mammals (4 - 54)	Mortality (55) Reproduction (6) Morbidity (1)	Log-normal (0.97)	3.9 [3.2; 4.7]	13 [9.4; 18.5]
All beta particles	11	Soil invertebrates (1 – 3) Fish (1 – 1) Mammals (2 – 7)	Mortality (3) Reproduction (8)	Log-normal (0.89)	1.1 [0.60; 1.8]	5.8 [3.3; 11.2]

To support the dosimetric calculations, the concept of using a limited set of reference organisms was developed within the FASSET project, based on some earlier papers [Pentreath 1999]. The 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". The main criteria for the selection of reference organisms within the FASSET project were the habitats and feeding habits of an organism that maximized its potential exposure to radionuclides, and the potential accumulation of radionuclides by an organism that were likely to maximize internal exposures. A similar approach is proposed by ICRP [ICRP 2003] which defines a "Reference Animal or Plant (RAP) as a hypothetical entity, with the assumed basic characteristics of a specific type of animal or plant, as described to the generality of the taxonomic level of Family, with precisely defined anatomical, physiological, and life-history properties that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism". The MARINA II has also defined a series of organisms for marine ecosystems adapted to the OSPAR area [EC 2003a]. Table 2.2 compares the marine reference organisms selected in the three approaches. They have been defined and used to fix the geometric relationships between radiation source and the organisms. Moreover they allow the diversity of both external and internal exposure scenarios in the dosimetric calculation to be accounted for. To address all protected species within Europe, some reference organisms may have been added, as for example in ERICA the marine reptile is used to represent the loggerhead turtle.

These entities are selected to be representative of large components of common ecosystems and for which models are adopted for the purpose of deriving dose and dose rates, mainly for whole organism, on which focus ERICA and MARINA II. It is possible that ICRP will go a step further by considering doses to tissues or organs (ICRP Dosimetry task group set up to look at this in 2008). The results of such dose assessments for pre-defined reference organisms will allow a basic assessment to be made concerning possible biological effects. This approach provides a strategy that allows the modelling effort to be reduced to a manageable size.

Table 2.2: ERICA reference organisms for marine ecosystem, the corresponding ICRP RAPs, and the MARINA II list.

FASSET-ERICA	ICRP RAPs	MARINA II
(Wading) bird	Duck	Bird (gull)
Benthic fish	Flat fish	Large fish (cod - mixed food; haddock – benthic food)
Bivalve mollusc		Bivalve mollusc (mussel)
		Gastropoda mollusc (winkle)
Crustacean	Crab	Large crustaceans (crab, shrimp)
Macroalgae	Brown seaweed	
Mammal		Mammal (seal)
Pelagic fish		Medium size fish (herring – planktinovorous; plaice – benthic food)
Phytoplankton		Small fish (sardine – planktinovorous)
Polychaete worm		Very small fish (sprat – planktinovorous)
Reptile		
Sea anemones/true corals		
Vascular plant		
Zooplankton		

2.4 Effects analysis or Dose effects relationships

Responses of individual functions to radiation exposure, e.g., growth, etc, can be traced to events at the cellular or sub cellular level in specific tissues or organs.

Even though mutational events in somatic cells are primarily responsible for cellular transformation, tumour formation hence inducing cancer, there is a strong agreement that cancer is still of low ecological relevance [Adam 2007]. Because most cancers (except leukaemia) are associated with older individuals, the effect on the population(s) following the removal of (a fraction of) this cohort is relatively small. On the contrary, mutational effects on germ cells may lead to reproductive impairment, which may affect the population in a more profound way [Anderson et al. 1998].

Whatever the stressor considered, population-level effects are valuable indicators of ecological hazard [Forbes and Calow 2002]. However, due to experimental constraints, most available data describe effects on individual traits. Many studies have documented the effects of radiation at the cellular, tissue and individual levels, and the likely consequences have been found to be increases in morbidity and mortality, decreases in fertility and fecundity, and increases in mutation rate [Woodhead 2003]. These types of effects observed at the individual level may have consequences on the dynamic of the population of the species.

Ionizing radiation does not appear to have any direct effects at the population or higher ecological levels (i.e. community or structure and function of ecosystems). All such effects are mediated by effects at the individual, or lower, levels. In addition, indirect effects through food-web mediated processes may occur [Garnier-Laplace et al. 2004], i.e. any detriment on the dynamic of a prey population may impact the population dynamics of its predators.

Even though several factors complicate extrapolations of individual level effects to populations, current knowledge supports the conclusion that measures intended to limit radiation damage in individuals to an acceptable degree will also provide a sufficient degree of protection for populations. Obviously, population level consequences of hereditary mutations might in some cases need to be allowed for in these extrapolations. If and how this is to be done requires additional research and scientific review [Garnier-Laplace et al. 2004].

The FASSET project organized a data base on radiation effects on non-human biota under four broad effects categories, referred to by FASSET as “umbrella effects”. These include: (i) morbidity (including growth rate, effects on the immune system, and the behavioural consequences of damage to the central nervous system from radiation exposure in the developing embryo); (ii) mortality (including stochastic effect of somatic mutation and its possible consequence of cancer induction, as well as deterministic effects in particular tissues or organs that would change the age-dependent death rate); (iii) reduced reproductive success (including fertility and fecundity); (iv) mutation (induced in germ and somatic cells).

Table 2.3 gives an overview of the quality and quantity of available data within FRED, adopting a simplified categorization (ecosystem type, exposure duration and irradiation pathway). Allocation of effects data is strongly weighted in favour of terrestrial ecosystems (73 % of all data) and for each ecosystem, the available data appears to be biased roughly 2:1 in favour of acute data and an external gamma irradiation exposure situation. As a consequence, chronic effect data information is limited and largely dominated by external gamma irradiation exposure conditions. This brief examination of the available knowledge on effects of radioactive substances on non-human species demonstrated that only data devoted to effects induced by external gamma irradiation pathway are quantitatively adequate to be mathematically processed in terms of dose-effect reconstruction [ERICA 2006; Garnier-Laplace et al. 2006]. Moreover, species from marine ecosystem were poorly investigated.

Table 2.3: Allocation of effects data within the FRED database to freshwater, terrestrial and marine ecosystems, and to the radiation exposure regimes (duration and irradiation pathways).

Ecosystem (number of references)	Total number of data	(%)	Data per exposure duration			Data per exposure irradiation pathway		
				Total number	%	External	Internal	Other[a]
Terrestrial (579)	19983	(72.6)	acute	12273	61.4	11564	288	421
			chronic	6795	34.0	3449	344	3002
			transitory[b]	913	4.57	670	40	203
			not stated	2	0.03	0	0	2
Freshwater (195)	6067	(22.0)	acute	4526	74.6	4058	97	371
			chronic	1484	24.5	970	20	494
			transitory	54	0.89	12	2	40
			not stated	3	0.01	0	0	3
Marine (45)	1470	(5.4)	acute	1116	75.9	995	58	63
			chronic	353	24.1	286	0	67
			transitory	0	0	0	0	0
			not stated	1	0	0	0	1

[a] “Other“ means that the experiment reported in the literature was devoted to the study of effects involved by mixed irradiation pathways, and/or not well characterized to be used for the present analysis.

[b] “Transitory” means in between “acute” and “chronic” in terms of exposure duration.

The FASSET critical review of effects of ionizing radiation on flora and fauna concluded for chronic exposure conditions that “the reviewed effects data give few indications for readily observable effects at chronic dose rates below 100 µGy/h”. However, it was advised that “using this information for establishing environmentally “safe levels” of radiation should be done with caution, considering that the database contains large information gaps for environmentally relevant dose rates and ecologically important wildlife groups” [FASSET 2003; Réal et al. 2004].

The ERICA Integrated Approach has adopted an Ecological Risk Assessment tiered methodology that requires risk assessment screening dose rate values for the risk characterization within tiers 1 and 2. Those screening values were derived on the basis of data taken from the FASSET Radiation Effects Database (FRED) and compared from some key data from EPIC (making thus the best use of the FREDERICA database, issued from the merging of FRED with the EPIC database). The method applied follows EC recommendations for the estimation of PNEC for chemicals [EC 2003]. ERICA [ERICA 2006] and Garnier-Laplace et al. [Garnier-Laplace et al. 2006] described the methodology used to derive ERICA risk assessment predicted no effect dose (rate) values. This meta-analysis resulted in the ERICA Integrated Approach screening dose rate for incremental exposure of 10 µGy/h, corresponding to a safe level criterion to be applied only for protection of the structure and function of generic ecosystems, including marine ones, and associated with Tier 1 and Tier 2 assessments. This screening value is based on the HDR_5 of a SSD (Species Sensitivity Distribution, Figure 2.3), the Hazardous dose rate below which 95% of species in the ecosystem should be protected (in other words, the HDR_5 is the dose rate giving 10% effect to five % of species). To derive the final dose rate screening value (or PNEDR for

Predicted No Effect Dose Rate), an assessment factor of 5 was applied to account for the remaining extrapolation uncertainties and the resultant number rounded down to the nearest one significant digit (see [ERICA 2006] for details).

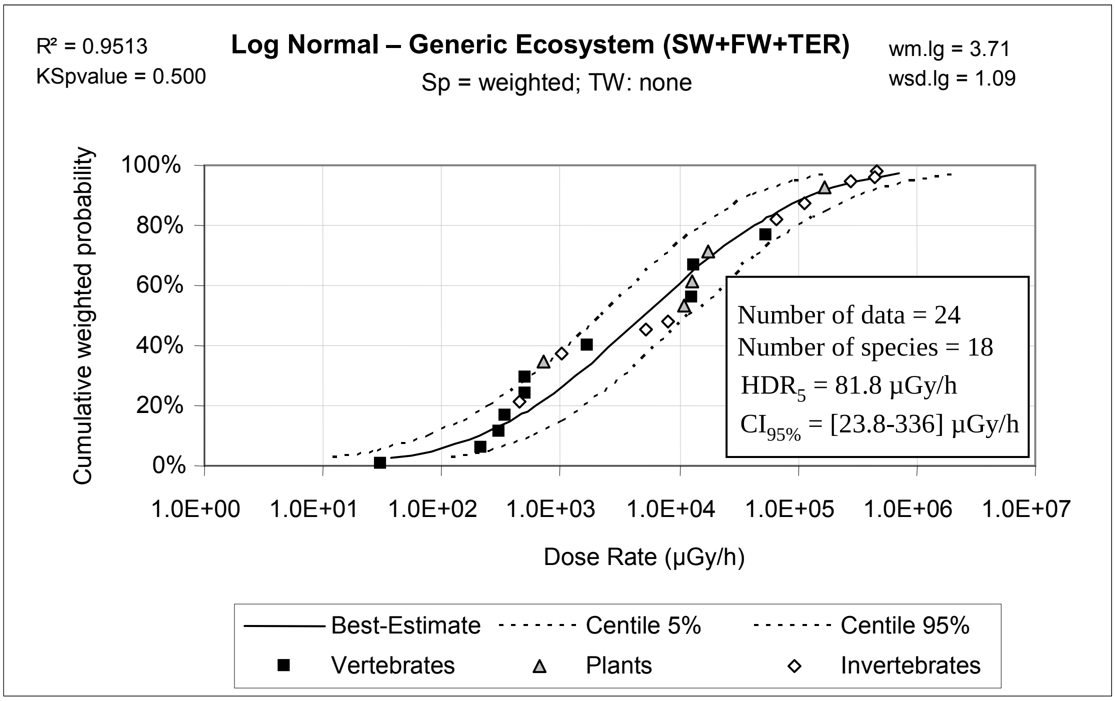

Figure 2.3: SSD for generic ecosystems (FW: FreshWaters+SW: SaltWaters+TER: Terrestrial) and chronic external γ irradiation exposure conditions. The log normal distribution with its associated 95 % confidence interval is fitted to geometric means per effect category for each species calculated on critical ecotoxicity data (*EDR_{10}* or Dose Rate giving 10% effect equivalent to a No Observed Effect Dose Rate). [ERICA 2006].

At the ecosystem level, the ERICA Integrated Approach screening dose rate value lies in the dose range giving rise to minor effects [FASSET 2003; ERICA 2006; Garnier-Laplace et al., 2006]. These minor effects are not expected to be directly relevant at higher organisational levels, such as the structure and function of ecosystems.

Whatever the recent literature review on ionizing radiation effect on non-human biota considered [Whicker 1997; Copplestone et al. 2001; FASSET 2003; Réal et al. 2004; Garnier-Laplace et al. 2004], the specificities of the environmental situations of interest (chronic low-level exposure regimes) emphasise the relevance of all reproductive parameters governing the demography of the population within a given ecosystem and as a consequence, the structure and functioning of that ecosystem. Concerning mutation, even though limits and constraints of radiation exposure at low dose rates have been explicitly defined for human radiation protection where the stochastic effects of cancer and mutation induction are of primary concern, these limits and constraints remain undefined for non-human biota due to the extreme paucity of effects data. These reviews clearly argue for the need of a research program to acquire specific data related to chronic low-level exposure and effects on reproductive capacity in such a way as to be able to shift from individual to population.

2.5 Risk characterization: the methods and their limitations

In ERA, risk characterization (i.e. integration of information on exposure and effects as well as estimation of uncertainties) forms a vital link between the scientific assessment of risks, and the subsequent management of these risks. ERICA definition of risk characterization is traditionally expressed as: “The synthesis of information obtained during risk assessment for use in management decisions. This should include an estimation of the probability (or incidence) and magnitude (or severity) of the adverse effects likely to occur in a population or environmental compartment, together with identification of uncertainties". Obviously risk characterization will neither be more accurate nor more precise than the data on which it is based. For example, lack of data and oversimplified assumptions may lead to inadequate results, as they would suffer from unacceptably large uncertainties [Williams and Paustenbach 2002].

Integration of exposure and effects into an estimate of risk can either be achieved *via* deterministic comparisons of point estimates of exposure and effects or *via* probabilistic methods. Deterministic methods are normally simple and easily communicated. Probabilistic methods are realistic and quantitative, but often complex and consequently hard to communicate. The use of these different methods is optimised among the various tiers of the risk assessment even though the optimum design is influenced by factors such as data availability, regulatory requirements and stakeholder opinions.

The most common approach to integrate exposure and effects data and characterize ecological risks of chemical contaminants is to calculate risk quotients (RQ) of estimated exposure and assumed safe benchmarks. The RQs can be calculated either based on concentrations or, in case stressors are radioactive substances, on doses or dose rates. The quotient method is well described in various guidelines on ecological risk assessment [Environment Canada, 1997; USEPA, 1998; EC, 2003]. RQ values lower than one are generally deemed to be acceptable and no further action is taken. Values greater than one either require reconsideration, such as further information and/or testing for refinement of exposure or effects analysis, or suggest the need for action, i.e. risk reduction. Typical exposure refinement options are based on use of real emissions instead of the conservative approach recommended in the TGD (European Technical Guidance Document; EC, 2003). Using the same idea, effect analysis can typically be refined by additional chronic or acute toxicity data or moving to higher tier assays such as mesocosms or field studies.

While deterministic point estimates simplify assessment and may be sufficient in a screening context, it is not possible to quantify the uncertainty related to the estimate, and worst-case assumptions in the assessment may be multiplied such that the final conclusion is overly conservative or unrealistic. Probabilistic risk assessment methods, in contrast, aim at ranges of plausible values, rather than single values or point estimates [Avila et al. 2004]. Several examples and recommendations of probabilistic risk assessment methods can be found in various guidelines on ecological risk assessment (e.g., [Environment Canada 1997; USEPA 1997]). At the moment though, as probabilistic approaches are dependent on more data and labour, they are typically only recommended at higher tier assessments to reduce the uncertainty in the conservative estimates of lower tiers.

2.6 Natural background and risk characterization

Screening against background is often motivated by the low (if any) ecological risk of background concentrations/doses [Jones and Gilek 2004] as well as the low probability of any risk management decision (e.g. remediation or restriction) ever being based on levels of exposure similar to background [Suter et al. 2000]. Following this line of reasoning ICRP [ICRP 2003] has proposed the development of derived consideration levels for reference flora and fauna, with explicit reference to background dose rates. The idea is to aid in the consideration of different management options by compiling information of ecological effects on various reference organisms relative to natural background levels. This information could then be classified into bands of concern recommending various management actions. For example, dose rates in the background range would generally imply low concern with no actions considered [ERICA 2005].

There are, however, several problems with using natural background as screening criteria. First of all, there is the problem of defining which value to use as representative of the natural background at the impacted site. This could be a substantial problem due to potential anomalies and inhomogeneous distributions [Suter et al. 2000]. It may be possible that there are differences in bioavailability or routes of exposure to resident organisms between natural and enhanced substances that could lead to an underestimation of risk. This comparison is motivated by the assumption that the natural background range is safe for the environment. However, even though the empirical evidence supports this assumption, the use of screening criteria based on derived safe doses of the specific radioactive substances being assessed is more scientifically justified.

2.7 Interpretation of a risk assessment: looking for other lines of evidence

Confidence in the conclusion of a risk assessment may be increased by using several lines of evidence. Rather than relying on a single approach, batteries of tests, modelling and/or field observations can be used to estimate risk. Obviously, there is a difference between prospective and retrospective assessments in the availability of data being used, and hence the lines of evidence available. In the retrospective assessment, monitoring and field data are often available and can be supplemented with additional sampling as the assessment moves through tiers. Further, it may for example be possible to perform toxicity testing on contaminated media or to measure biomarkers and other effects directly in exposed populations.

Another aspect that limits the lines of evidence is the availability of ecotoxicological data for radioactive substances. One of the major difficulties in the implementation of ecological risk assessments for radioactive substances is the lack of data from chronic studies at low levels of exposure. Within this context, tools for chronic testing constitute a key (i) to establish robust extrapolation rules necessary for the effect analysis in any ERA exercise and (ii) to improve our scientific knowledge about the effects of ionizing radiation on non-human biota. Further, expected safe levels of exposure are typically derived from dose-response relationships for effects that are generally assumed to be deterministic. However, stochastic effects may be important if protection of individual organisms is the aim. These topics remain a subject for future research. Bioassays are conducted according to a general scheme, in which organisms are exposed to a range of increasing concentrations of the contaminant, to obtain dose-effect relationships. The statistical treatment of these data allows determination of classical ecotoxicological values, such as the No Observed Effect Concentration (NOEC) corresponding to the maximal concentration that does not induce an effect. The principles, guidelines and statistical analysis applied when designing and carrying out controlled laboratory experiments to investigate biological effects of stressors in non-human organisms are summarized in an appendix to ERICA D5 [ERICA 2006]. These principles on how to study dose(rate)-effects relationships for chronic (long-term) exposure of organisms to low-level of radioactive substances are of major importance as a number of quality criteria must be applied to produce new data on effects. The higher their quality and robustness, the higher will be the confidence in their potential use into any methodology to derive benchmark values.

Biomonitoring field studies/programs can provide additional information on the toxic effects, such as indirect effects, bioavailability or biodegradation when relevant. These programs must clearly define the scope of the study, the cause and effects to be associated, the frequency of sampling, the nature of the measurements to be done, the geographic area to be monitored. The sampling strategies must be defined according to the temporal and spatial scales, to discriminate statistically significant differences in responses between sites and times. A particular care should be given to sampling strategies, including randomization, definition of reference sites, replication and criteria for target species (e.g. residency, sensitivity, size, uniformity, density and tolerance at affected sites). A difficulty in the context of ecological risk assessment and biological surveys for radionuclide discharges is that the parameters to be measured must be sensitive and respond adequately over a chronic exposure because concentrations released are managed according to the precautionary principle and consequently, they are low-level concentrations [ERICA 2005].

Many assessment approaches now incorporate this idea of multiple methods in assessing impact as a central theme using a “weight of evidence” approach. Ecological risk assessments should therefore incorporate both community and biological endpoints, especially as it has already been concluded that a field study which uses complimentary biomarker techniques combined with methods that relate to organism fitness and site chemistry, will provide the most profound data [Anderson et al. 1998].

2.8 Gaps in scientific knowledge and limitations to the conclusions of an ERA

The main gaps identified within the field of exposure analysis are mainly the lack of dynamic transfer models and, even for equilibrium models such as those today used, knowledge related to the associated transfer parameters. A number of extrapolations are then needed at present to fill in gaps of knowledge to quantify the transfer for a list of combinations (radionuclide, exposure pathway, reference organism). Actually, large information gaps exist to derive transfer factors for all combinations needed to describe properly any ecosystem model. Another asset of the ERICA approach is that it provides guidance on how to fill data gaps in transfer parameters so that a complete data set can be made available for use in the assessment. Where necessary, the use of the guidance approach to derive missing transfer parameters has been used in this current study.

Basic information on natural background in the OSPAR area is limited and gives rise to uncertainties. Brown et al. (2004) and MARINA II [EC 2003a] gave the range of typical dose rates of natural background exposure for different types of organisms in European and arctic ecosystems respectively. Brown et al. (2006) calculated weighted absorbed dose rates to selected marine organisms as an example of the background dose rate experienced by marine biota from the occurrence of natural radionuclides (Table 2.4).

Table 2.4: Calculated weighted dose rates (expressed in µGy/h) due to natural radionuclides measured in selected marine organisms (from Brown et al. 2006). Used RWF are as follows: 3 for low energy β doses, 10 for α.

Numbers in italics are dose rates calculated for external contribution from water and/or sediment only.

Radionuclide	Phytoplankton	Zooplankton	Macroalgae	Molluscs	Crustacea	Fish	Mammals
K-40	7.1E-03	4.9E-03	1.6E-02	3.8E-02	3.8E-02	3.8E-02	3.6E-02
Po-210	7.6E-02	7.6E-01	6.4E-02	1.1E+00	1.5E+00	6.1E-02	6.1E-01
Ra-226	4.6E-01	3.4E-02	5.1E-02	1.3E-01	1.3E-01	3.9E-02	*2.1E-03*
Th-228	1.8E-01	5.5E-02	7.4E-02	1.3E-01	1.1E-02	3.1E-03	*1.3E-03*
Th-230	2.7E-03	1.6E-03	2.2E-03	5.5E-02	3.6E-03	3.4E-04	*4.9E-05*
Th-232	2.3E-03	1.4E-03	4.4E-03	1.2E-02	1.4E-04	1.7E-05	*2.3E-07*
U-238	2.1E-02	1.0E-02	5.2E-02	5.2E-02	8.0E-03	4.8E-04	*1.6E-05*
Total	0.75	0.87	0.26	1.5	1.7	0.14	0.62
Range	0.31-6.0	0.36-2.6	0.16-0.95	0.88-5.2	0.27-27	0.08-0.71	0.49-3.2

Concerning the effects, particularly important data gaps for large and long-lived animals were identified in the FRED database [Réal et al. 2004]. Even within the FRED-ERICA database, the ERICA updated version of FRED, all wildlife groups are not represented.

Finally, it is possible to easily implement environmental impact and risk assessments for a list of radionuclides potentially released in the marine ecosystems. The method for the exposure analysis needs at least simple transfer factors to convert activity concentrations in the media (water, sediment) into whole-body concentrations in selected organisms. Then dose rates are obtained by using reference organism specific dose conversion coefficients. The latter can be weighted absorbed dose rates to account for the difference in damage caused by different radiation types. The problem of evaluating appropriate weighting factors is still unsolved but the impact of varying these values can be limited because all the main approaches to assessing doses to biota, including ERICA, allow the user to modify these weighting factors in the model. Anyway, the calculated total dose rates can be interpreted by comparison with a screening dose rate such as the one from ERICA (10 µGy/h for a generic ecosystem, the lowest of any recommended screening values). The calculated dose rates need therefore to be interpreted as an incremental dose rate above the natural background. It can also be directly compared to the natural background.

Chapter 3 – Methodology proposed

3.1 Objectives of the methodology

The aim of the proposed method is to demonstrate to which extent the progress the Contracting Parties to the OSPAR Convention are making in reducing anthropogenic inputs of radioactive substances to the North-East Atlantic, is propagated to doses or dose rates to biota living in the exposed marine ecosystems. Input data are measured concentrations in various compartments of the environment (medium compartments such as water and sediment) and biota compartments (such as algae, molluscs or fish).

To implement the demonstration, the proposed method is based on radioactive substances measured environmental activity concentrations, combined with modelling of the absorbed radiological dose rates delivered to living organisms representative of the marine ecosystems within the OSPAR area. In brief, exposure to ionizing radiation is estimated as the absorbed dose rate (i.e. the quantity of energy imparted by ionizing radiation to the tissue of a whole organism per unit time (µGy/h being used here)). To determine this, the activity concentrations in both media and biota are required together with the ability to convert these into estimates of external and internal exposure. Radionuclide activity concentration in media and/or biota may be known or they may need to be estimated by transport/transfer models from discharges.

To ensure consistency with the previous evaluations (RA-1 and RA-2), this demonstration is based on seawater and biota activity concentration data for defined regions (cf. Annex 1) as reported and set out in the Second Periodic Evaluation of Progress towards the Objective of the OSPAR Radioactive Substances Strategy. A number of limitations on the approach adopted to generate the seawater and biota concentration values and on the actual values themselves were identified in the Second Periodic Evaluation. These included:

a. The geographical representativeness of the data;

b. That calculated values are based on different sizes of data sets;

c. That monitoring results may contain data below detection limits;

d. That there maybe a time lag involved between changes in discharges and the transport of radionuclides thereafter;

e. That concentrations may also be influenced by, for example, global nuclear fall-out following atmospheric weapons tests, the Chernobyl accident; etc.

f. The limited number of data points, and/or differences between sampling and analytical methodologies between Contracting Parties;

g. That some of the data concentrations may be influenced by the remobilisation of radionuclides in sediments from discharges made in the past.

In basing this demonstration solely on data reported in the Second Periodic Evaluation a number of additional limitations must be considered in terms of investigating impacts on biota from anthropogenic sources (past and present) of radioactive substances:

a. The limited number of radionuclides considered - The Second Periodic Evaluation only contains environmental concentration data for the anthropogenic radionuclides ^{3}H, ^{99}Tc, ^{137}Cs and $^{239,240}Pu$ and for the naturally occurring radionuclides ^{210}Po, ^{226}Ra, ^{228}Ra and ^{210}Pb. Moreover, in many cases data does not even exist for all of these radionuclides in each region considered. Therefore, it is important to note that the dose calculated in this demonstration for each representative species does not represent the total dose both from anthropogenic and natural sources of radionuclides.

b. The limited time period considered – The Second Periodic Evaluation only contains environmental concentration data for anthropogenic radionuclides between the years 1995 to 2005, according to the methodological choice common to every periodic evaluation in OSPAR. This means that this demonstration excludes consideration of impacts on biota from anthropogenic sources of radionuclides from early time periods, for example as a result of global fall out from atmospheric nuclear weapon testing in the 1960's, peak authorised discharges from Sellafield and Cap la Hague in the 1970's and 1980's and the Chernobyl Accident in 1986.

For a radionuclide i and the zone r, seawater and biota activity concentrations are used directly to estimate the delivered dose rate to biota. Where activity concentrations in biota are not available, they are calculated on the basis of the equilibrium assumption with the water compartment, using appropriate concentration ratios.

The ERA methodology is today implemented in a number of approaches and/or tools, more or less achieved, complete and documented. Among those, the ERICA approach is the only European reference project that allows an Integrated Assessment of doses to biota. Moreover, this flexible approach may be adapted to the user needs, especially in terms of organisms and radionuclides. It was then selected as corresponding to the RA-3 requirements, as described hereafter. The justification of this choice is argued for each decisive criterion, on an inter-comparison basis. From the available similar complete approaches, two of the most recent ones have been selected in this objective, RESRAD-BIOTA (DOE, 2002) and the Environment Agency R&D 128 (Copplestone et al, 2001). It should be noted however that the RESRAD-BIOTA code is not designed for assessments in marine ecosystems and all the available transfer data are from freshwater aquatic ecosystems. These three models along with a further 12 models and approaches have been participating in the IAEA EMRAS Biota Working Group which has undertaken a series of intercomparison exercises to help establish how the models (i) perform against real data where it exists, (ii) compare to each other and (iii) where the models differ, to understand why they behave in differently. There have been comparisons of the models unweighted absorbed dose rates, predictions of biota activity concentrations, and the models have been applied to freshwater and terrestrial scenarios where the results were compared with real measured data and in one case against measured dose rates for small mammals. The results from this work are currently being drafted into an IAEA Techdoc report.

3.2 Outlines of the selected approach: ecosystem conceptual model, equations and parameters

At first, a conceptual representation of the marine ecosystem has been adopted. A set of representative biota species within the OSPAR area was selected consistently with Marina II [EC 2003a] for concentration calculation and dose rate assessment. This set is also consistent with the reference organisms selected for the ERICA Integrated Approach [ERICA, 2007]. These organisms have been defined and used for the derivation of geometric relationships between radiation source and radiation target (i.e. the organisms according to their habitat and mode of life), in order to limit dosimetric considerations both for external and internal exposure. They are listed in Table 3.1. For comparison, their equivalents in RESRAD-BIOTA and the Environment Agency R&D 128 are given in Table 3.2, with their full geometrical description. Only ERICA takes into account of the real shape and size of the reference organisms defined for the OSPAR region, by permitting the definition of new organisms added to the default list of the tool.

Within the conceptual model referring to all reference organisms, ecologically plausible pathways (both external and internal) and fluxes for radioactive substances are taken into account. Under equilibrium assumption which is acceptable regarding the time step of interest (i.e. the year), environmental concentration (C_i^{wat} for water in Bq/L and C_i^{sed} for sediment in Bq/kg) are measured for a given radioactive substance i. When only data for water concentration are available, distribution coefficients (Kds in L/kg) are used to relate equilibrium activity concentrations in sediments with those in water and is defined as $Kd_i = \frac{C_i^{sed}}{C_i^{wat}}$. On the basis of the medium concentrations, for a reference organism o, whole body activity concentrations of radionuclide i

($C_{i,o}$ in Bq/kg fresh weight) can be predicted from water activity concentrations using equilibrium concentration ratios (in L/kg fresh weight with $CR_{i,o} = \frac{C_{i,o}}{C_i^{wat}}$).

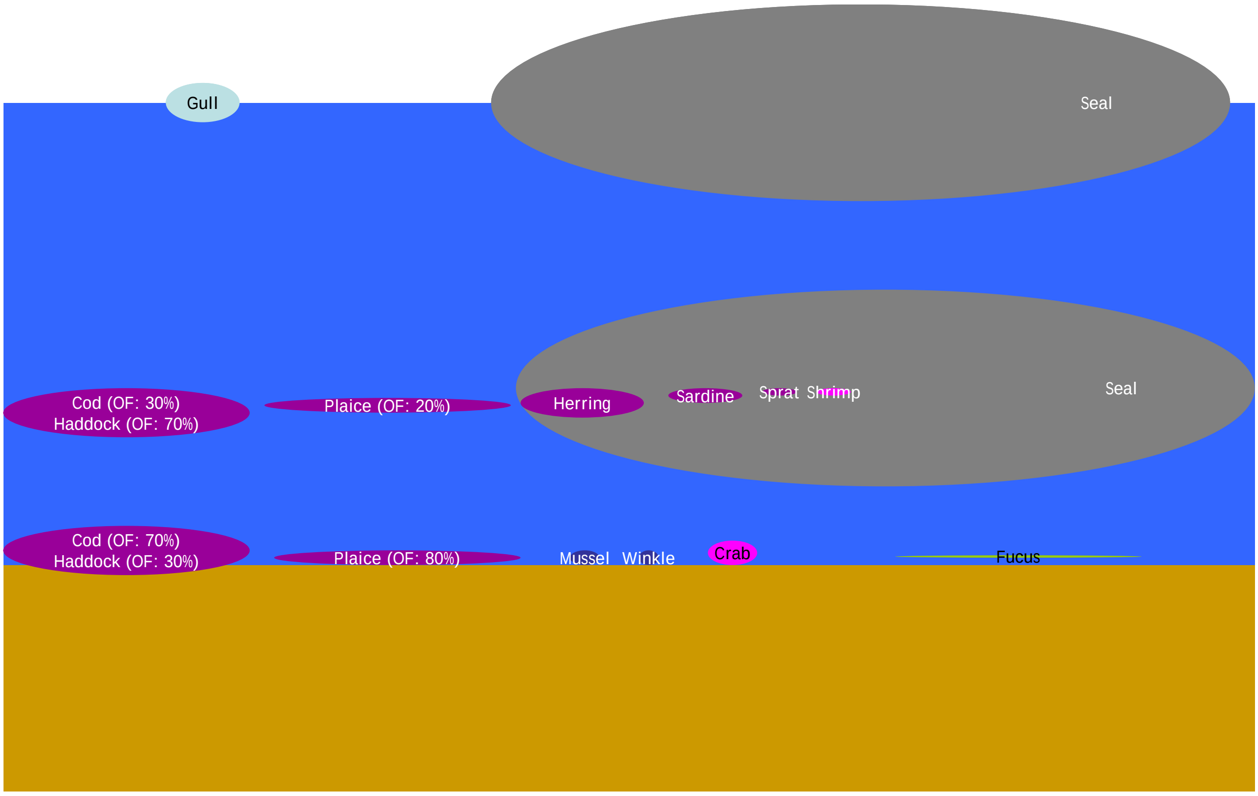

Figure 3.1: Schematic representation of the selected reference organisms and their location and geometries taken into account to calculate the concentration-to-dose rate coefficient for external and internal irradiation pathways.

Table 3.1: Selected reference organisms for the marine ecosystems within the OSPAR region. The reference indicates the origin of the choice and of the associated parameters (habitat and fraction of the time allocated to this habitat according to the species mode of life).

Type of organism	**Mode of life/Habitat**	**Feeding habit**	**Representative species**	**Reference**
Large fish	Benthic (30%) Pelagic (70%)	Predatory Omnivorous	Cod *Gadus morhua*	Marina II
	Benthic (70%) Pelagic (30%)	Benthivorous	Haddock *Melanogrammus aeglefinus*	Marina II
Medium-size fish	Pelagic (100%)	Planktinovorous	Herring *Clupea harengus*	Marina II
	Benthic (80%) Pelagic (20%)	Benthivorous	Plaice *Pleuronectes platessa*	Marina II
Small fish	Pelagic (100%)	Planctonivorous	Pilchard/Sardine *Sardina pilchardus*	Marina II
Very small fish	Pelagic (100%)	Planctonivorous	Sprat *Sprattus sprattus*	Marina II
Mollusc bivalve	Benthic (100%)	-	Mussel *Mytilus edulis*	Marina II

Type of organism	Mode of life/Habitat	Feeding habit	Representative species	Reference
Mollusc gastropoda	Benthic (100%)	-	Winkle *Littorina litorea*	Marina II
Crustacean	Benthic (100%)	-	Crab *Cancer pagurus*	Marina II
Crustacean	Pelagic (100%)	-	Shrimp *Pnadalus borealis*	Marina II
Bird	Interface water-air (100%)	-	Gull *Larus sp.*	Marina II
Mammal	Pelagic (50%) Interface water-air (50%)	-	Seal *Phoca sp.*	Marina II
Macroalgae	Benthic (100%)	-	Macroalgae *Fucus sp.*	ERICA (ICRP)

Table 3.2: Comparison of the characteristics of the selected reference organisms for the three selected ERA approaches

ERICA (MARINA II)		RESRAD-BIOTA		Environment Agency R&D 128	
Organism	**Size (cm) weight (g)**	**Organism**	**Size (cm) weight (g)**	**Organism**	**Size (cm) weight (g)**
Cod	(50x10x6, 1500)	geometry 4	(45x8.7x4.9, 1000)	pelagic fish (cod)	(45x8.7x4.9, 1000)
Haddock	(50x10x6, 1500)	geometry 4	(45x8.7x4.9, 1000)	benthic fish (plaice)	(45x8.7x4.9, 1000)
Herring	(25x6x4, 300)	geometry 4	(45x8.7x4.9, 1000)	pelagic fish (cod)	(45x8.7x4.9, 1000)
Plaice	(25x20x3,800)	geometry 4	(45x8.7x4.9, 1000)	benthic fish (plaice)	(45x8.7x4.9, 1000)
Sardine	(15x3x1.5, 30)	geometry 3	(10x2x2, 10)	pelagic fish (cod)	(45x8.7x4.9, 1000)
Sprat	(7x1.5x0.9, 5)	geometry 3	(10x2x2, 10)	pelagic fish (cod)	(45x8.7x4.9, 1000)
Mussel	(6x3x2.5, 5)	geometry 3	(10x2x2, 10)	benthic mollusc (mussel)	(2.5x1.2x0.62, 1)
Winkle	(4x3x2, 3)	geometry 2	(2.5x1.2x0.62, 1)	benthic mollusc (mussel)	(2.5x1.2x0.62, 1)
Crab	(10x10x5, 40)	geometry 3	(10x2x2, 10)	large benthic crustacean (lobster)	(3.1x1.6x0.78, 2)
Shrimp	(7x1.5x1.5, 5)	geometry 3	(10x2x2, 10)	small benthic crustacean (shrimp)	(0.62x0.31x0.16, 0.016)
Gull	(15x11x8, 600)	geometry 3	(10x2x2, 10)	seabird	(15x11x7.6, 600)
Seal	(150x40x40, 120000)	geometry 6	(100x42x33, 100000)	seal	(180x35x19, 58000)
Macroalgae	(50x0.5x0.5, 6.5)	no aquatic plant		macrophyte	(10x0.2x0.2, 0.21)

The relationship between the activity concentration of an organism or a media and internal or external absorbed dose rates is described by the Dose Conversion Coefficient (DCCi,o; µGy/h per Bq/ kg fresh weight). The method used to derive the DCC values is the one selected in the ERICA Tool, previously described by Pröhl et al. (2003) [Pröhl et al. 2003]. Application of the dose conversion coefficients allows the estimation of unweighted absorbed dose rate from media and organism activity concentrations. However, radiation effects depend not only on unweighted absorbed dose, but also on the type of radiation. For example, for a given unweighted absorbed dose rate, α-radiation may result in a more significant effect than β or γ-radiation. Therefore, radiation weighting factors may be introduced to account for the relative biological effectiveness of the different types of radiation. A value of 3 has been selected as radiation weighted factor for β low energy particles and a value of 10 for α [ERICA 2007]. These values correspond to the lower bound of the 95% Confidence Interval for the 95th percentile of the statistical distributions (Table 2.1); their selection highlights a high degree of conservatism.

To calculate the unweighted absorbed dose rate due to the radionuclide i to which the organism o is exposed, the following equations are used:

-for internal dose rate: $DR_{i,o}^{\text{int}} = C_{i,o} DCC_{i,o}^{\text{int}} = C_{i,o}^{wat} CR_{i,o} DCC_{i,o}^{\text{int}}$

where: $DCC_{i,o}^{\text{int}}$ is the radionuclide-specific dose conversion coefficient for internal exposure defined as the ratio between the dose rate to the organism and the activity concentration of radionuclide i in the organism o (µGy/h per Bq kg^{-1} fresh weight)

-for external dose rate: $DR_{i,o}^{ext} = \sum_{medium} DR_{i,o}^{ext-medium} = \sum_{medium} OF_o^{medium} DCC_{i,o}^{ext-medium} C_i^{medium}$

where: - OF_o^{medium} is the occupancy factor, i.e. the fraction of the time that the organism o spends at a specified location in its habitat constituted by one or several of the medium of interest (water, sediment, air);

- $DCC_{i,o}^{ext-medium}$ is the dose conversion coefficient for external exposure defined as the ratio between the dose rate and the activity concentration of radionuclide i in the medium corresponding to the habitat of the organisms o (µGy/h per Bq unit medium). It is generally assumed to be zero for alpha radiation, in view of the small range of alpha particles in water and biological material. However, for very small geometries (e.g. fish eggs, phytoplankton), the external alpha irradiation may be considerable and methodologies exist to quantify it.

The calculated total absorbed dose rate is then: $DR_{i,o} = DR_{i,o}^{\text{int}} + DR_{i,o}^{ext}$

For weighted total dose rates (in µGy/h), weighting factors (wf, dimensionless) are applied to various components of radiation (low β, β + γ and α) in the final value of $\overline{DCC}_{i,o}^{ext-medium}$ and $\overline{DCC}_{i,o}^{\text{int}}$ as follows:

$\overline{DCC}_{i,o}^{ext-medium} = wf_{low\beta} DCC_{i,low\beta,o}^{ext-medium} + wf_{\beta,\gamma} DCC_{i,\beta,\gamma,o}^{ext-medium}$ and

$\overline{DCC}_{i,o}^{\text{int}} = wf_{low\beta} DCC_{i,low\beta,o}^{\text{int}} + wf_{\beta,\gamma} DCC_{i,\beta,\gamma,o}^{\text{int}} + wf_{\alpha} DCC_{i,\alpha,o}^{\text{int}}$.

For any reference organism o, the concentration-to-dose rate conversion coefficient (µGy/h per Bq/L) can be easily calculated for each radionuclide i:

$\overline{DCC}_{i,o} = (CR_{i,o} \overline{DCC}_{i,o}^{\text{int}} + OF_o^{wat} \overline{DCC}_{i,o}^{ext-wat} + OF_o^{sed} \overline{DCC}_{i,o}^{ext-sed} Kd_i)$, applying weighting factors for different radiation types. These aggregated weighted coefficients represent the incremental dose rate to the organism o per elementary incremental concentration in water for a given radionuclide i ($\overline{DCC}_{i,o}$ in µGy/h per Bq/L).

The combination of $\overline{DCC}_{i,o}$ with the annual measured activity concentrations per radionuclide i into zone r allows an assessment to be made of the delivered dose rates per reference organism and to analyze the development in time of the range of delivered incremental dose rates for any zone. Input data needed are the outcome from the analysis performed to assess the baseline elements for activity concentrations and their temporal pattern. Two types of calculations were performed to assess the biota dose rates: the first used only the water concentrations as input data and the second used both the water concentrations and the biota concentrations. Comparisons between the two methods were performed.

The selected tool for numerical applications was the ERICA tool where Tier 2 was used, allowing to define specific reference organisms with their corresponding concentration ratios, and to calculate corresponding $\overline{DCC}_{i,o}^{\text{int}}$, $\overline{DCC}_{i,o}^{ext-medium}$ and $\overline{DCC}_{i,o}$. This tool has adopted a number of simplifications for considering the external irradiation pathway by calculating a unique $\overline{DCC}_{i,o}^{ext}$ that aggregates all external sources of radiation. The basic equation becomes then: $\overline{DCC}_{i,o} = (CR_{i,o}\overline{DCC}_{i,o}^{\text{int}} + OF_o\overline{DCC}_{i,o}^{ext}(1 + Kd_i))$. All Kd and CR values when needed are those from the ERICA Tool. By default, the ERICA tool considers a dry weight value of 100% for the sediment. In its present application, in a more realistic way, the default value of 80% of water content in the sediment (i.e. 20% dry weight value) recommended by the EC (EC, 2003) was preferred.

The final aim of such ERA approaches is to assess potential effects on ecosystems through the comparison of the exposure dose rate to a reference benchmark value related to no potential effect occurrence for the target ecosystem. Depending on their determination method, several benchmark dose rates have been suggested (Table 3.3). The IAEA guideline dose rates are values below which significant population level effects are unlikely. The FASSET value was indicated as a threshold below which no statistically significant effects were seen. In ERICA, the screening value was determined by statistical interpretation of the FRED data and is based on a hazardous dose rate for 5% of the species in the target ecosystem.

Table 3.3: Main guidelines or recommended dose limits (µGy/h) to biota from the literature

<table>
<tr><th></th><th>NCRP, 1991</th><th>IAEA, 1992</th><th>Thompson, 1999</th><th>DOE, 2002</th><th>FASSET, 2003</th><th>ERICA, 2007</th></tr>
<tr><td colspan="7">Terrestrial organisms</td></tr>
<tr><td>Plants</td><td></td><td>400</td><td></td><td>400</td><td rowspan="5">100</td><td rowspan="5">10</td></tr>
<tr><td>Animals</td><td></td><td>40</td><td></td><td>40</td></tr>
<tr><td>Mammals</td><td></td><td></td><td>10</td><td></td></tr>
<tr><td>Birds</td><td></td><td></td><td>50</td><td></td></tr>
<tr><td>Amphibians/reptiles</td><td></td><td></td><td>10</td><td></td></tr>
<tr><td colspan="7">Aquatic organisms</td></tr>
<tr><td>Freshwater organisms</td><td>400</td><td>400</td><td></td><td>400</td><td rowspan="4">100</td><td rowspan="4">10</td></tr>
<tr><td>Benthic invertebrates</td><td></td><td></td><td>100</td><td></td></tr>
<tr><td>Fish</td><td></td><td></td><td>50</td><td></td></tr>
<tr><td>Deep ocean organisms</td><td></td><td>1000</td><td></td><td></td></tr>
</table>

The determination of the concentration-to-dose rate conversion coefficient for a larger list of potentially released radionuclides may allow their ranking on the basis of the associated radiological hazard for the environment. Such an approach may be used to identify high-risk radionuclides for the environment, which would require a special attention for any future ERA study.

Chapter 4 – Periodic assessment of biota dose rates calculated for the OSPAR regions

4.1 Selected radionuclides and available data on concentrations

Considering the knowledge related to discharges of radioactive substances, more especially in relation with the significance of the radionuclides in terms of radiological dose, a restricted list of radionuclides (Table 4.1) is taken into consideration in OSPAR, for each of the sectors and sub-sectors the most significant to observe for the purpose of evaluating progress towards the objective of the OSPAR Radioactive Substances Strategy. Tritium is also included in the selection representative of the nuclear sector even though its relative contribution to the radiological dose is very low.

Table 4.1: Radionuclides considered in OSPAR according to their origin sector.

Non-nuclear sector		Nuclear sector
Offshore oil and gas industry	Medical sector	
Naturally occurring radionuclides	Anthropogenic radionuclides	
^{210}Pb ^{210}Po ^{226}Ra / ^{228}Ra 228Th	^{99}Tc (decay product of ^{99m}Tc) ^{131}I	^{99}Tc ^{137}Cs ^{239,240}Pu ^{3}H

To apply the method to calculate biota dose rates, input data are measured concentrations in various compartments of the environment (medium compartments such as water and sediment) and biota compartments (such as algae, molluscs or fish). According to the work done for the previous periodic evaluations on concentrations (RSC 07/2/1-E, OSPAR Second Periodic Evaluation), the selected anthropogenic radionuclides were: ^{3}H, ^{131}I, ^{137}Cs, ^{99}Tc, ^{239,240}Pu. Table 4.2 gives the qualitative list of the available information per radionuclide, year and compartment. Some data on seawater concentrations for a limited number of naturally occurring radionuclides (^{226}Ra, ^{228}Ra, ^{210}Pb, and ^{210}Po) were also reported for the non nuclear sector in the Second Periodic Evaluation.

Table 4.2: Overview of the available data for the marine ecosystem compartments concerning radionuclide concentrations measured from 1995 to 2005. These data constitute the input data to assess the dose rates delivered to the biota representatives. Ticked boxes denote data coverage for at least 1 OSPAR region. Grey box means no data are available for the radionuclide and the compartment for any of the regions.

		Anthropogenic radionuclides				
Period	**Compartment**	**^{3}H**	**^{99}Tc**	**^{131}I**	**^{137}Cs**	**^{239,240}Pu**
1995-2001	Water	✓	✓		✓	✓
	Seaweed		✓		✓	
	Fish				✓	✓
	Mollusc				✓	✓
2002-2005	Water	✓	✓		✓	✓
	Seaweed		✓		✓	
	Fish				✓	✓
	Mollusc				✓	✓

Transfer parameters needed to calculate concentration-to-dose rate coefficients according to the equation are reported for Kds in Table 4.3. The Kd values may be highly variable, depending on the location and the associated physico-chemical properties of water and sediments, as illustrated for open ocean and ocean margin in the IAEA document (IAEA, 2004). Consequently, the Kd values may also vary between approaches, depending on the choice made. The ocean margin Kds taken from IAEA (2004) are used in the ERICA tool. These are similar to those applied in Environment Agency R&D 128. As mentioned previously, the Kds found in RESRAD-BIOTA, derived from freshwater ecosystems, are significantly lower than those in ERICA. As with Kds, concentration ratios (CRs) values may also vary depending on the origin of the data (species, location, water chemistry, etc). Their variability with regards to the method applied is illustrated for pelagic fish as an example by Table 4.4. Once again, ERICA provides data for each required parameter, although it should be noted that for some radionuclide/reference organism combinations the CRs were determined using guidance rather than measured data. The full set of comparative data for all available combinations (radionuclide, reference organism) is given in Annex 2. The human dose assessment conducted in the OSPAR RA-2 report required also concentration ratios for three biota (mollusc, crustacean and fish). The corresponding values differ from those applied in ERICA (cf. Annex 3). To keep the internal consistency of the ERICA tool concerning the derivation of parameter values, the biota dose assessment was realised using the ERICA parameters databases.

Table 4.3: Comparison of radionuclide-specific distribution coefficients (Kd, in L/Kg w.w.)

	IAEA, 2004			
	open ocean	ocean margin (ERICA)	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	1.00E+00	1.00E+00	1.00E-03	1.00E+00
^{99}Tc	1.00E+02	1.00E+02	5.00E+00	1.00E+02
^{137}Cs	2.00E+03	4.00E+03	5.00E+02	3.00E+03
^{239}Pu	1.00E+05	1.00E+05	2.00E+03	1.00E+05
^{240}Pu	1.00E+05	1.00E+05	n.d.	n.d.
^{210}Pb	1.00E+07	1.00E+05	n.d.	n.d.
^{210}Po	2.00E+07	2.00E+07	n.d.	2.00E+07
^{226}Ra	4.00E+03	2.00E+03	7.00E+01	n.d.
^{228}Ra	4.00E+03	2.00E+03	7.00E+01	n.d.

n.d. no data

Table 4.4: Comparison of radionuclide-specific concentration ratios (CRs) for pelagic fish

	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	1.00E+00	2.00E-01	1.00E-03
^{99}Tc	3.10E+01	7.80E+01	3.00E-02
^{137}Cs	8.60E+01	2.20E+04	1.00E-01
^{239}Pu	3.50E+03	1.00E+03	4.00E-02
^{240}Pu	3.50E+03	n.d.	n.d.
^{210}Pb	2.00E+02	n.d.	n.d.
^{210}Po	1.70E+04	n.d.	2.00E+00
^{226}Ra	2.80E+02	3.20E+03	n.d.
^{228}Ra	2.80E+02	3.20E+03	n.d.

n.d. no data

For some radionuclides, concentrations in seawater and biota are both available for the same sampling time at a given region. CR values may be then validated by comparison between measurements in biota and calculated concentrations obtained by multiplying the appropriate seawater concentration and the CR. This approach is possible for ^{99}Tc and ^{137}Cs in macroalgae and for ^{137}Cs and ^{239,240}Pu for fish and mollusc (Figure 4.1). The values of the ERICA concentration ratios lead to a good agreement between measurement and calculation, except for Cs in algae and Pu in fish, which are underestimated. Consequently, the dose rate calculated on these bases may be also underestimated.

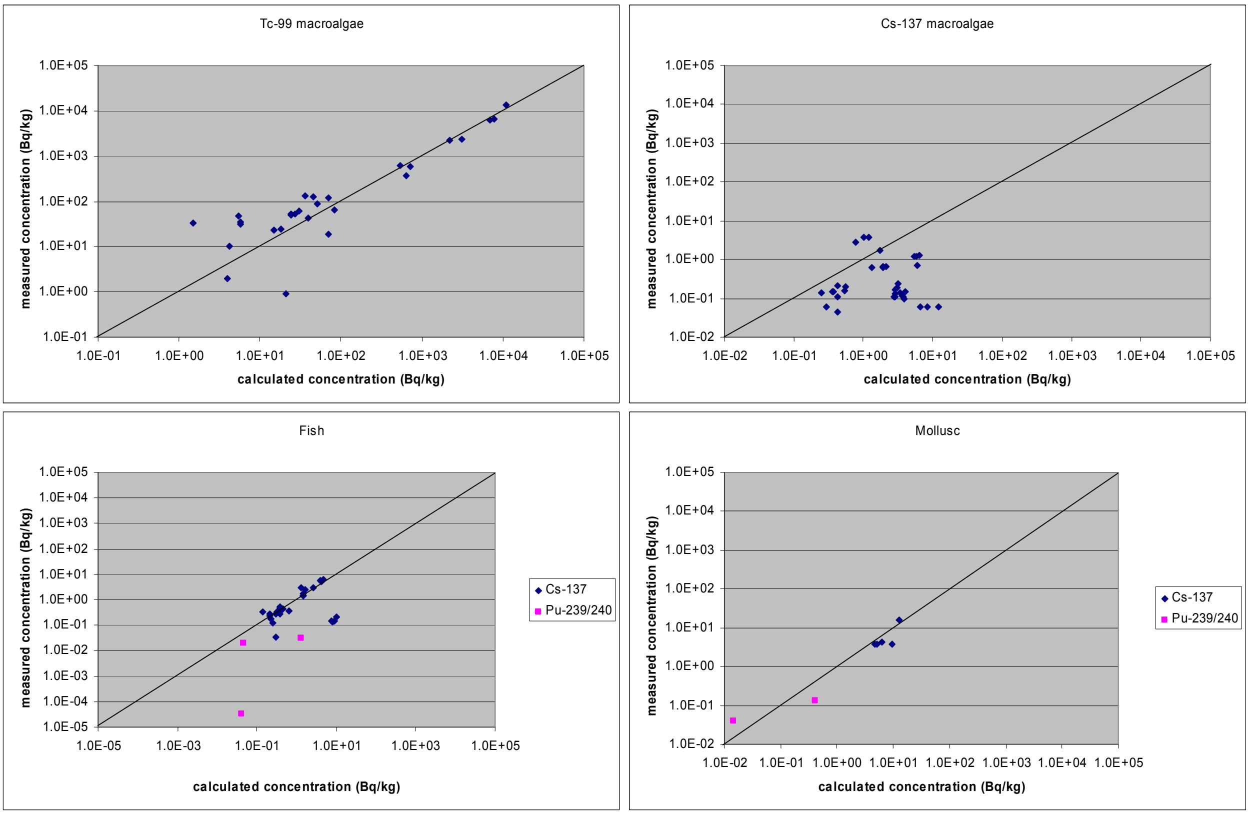

Figure 4.1: Comparison of biota concentrations calculated on the basis of seawater concentrations (X-axis) with concentrations measured (Y-axis).

The calculation of dose rate according to the equation requires a Dose Conversion Coefficient for each combination of radionuclide and reference organism and its associated geometry. Depending on the geometrical description of the organism and its location in the environment, calculation of the DCC may vary between modelling approaches. The variation in the range of DCCs is illustrated for one organism of each trophic level for external and internal exposure respectively (Table 4.5 and Table 4.6) within the ERICA, Environment Agency R&D 128 and RESRAD-BIOTA codes. Detailed results for each of reference organism are reported in Annex 4. All the reported DCCs are weighted according to the models default approaches (RWFs of 1, 3 and 10 for gamma and beta, low beta and alpha radiation respectively for ERICA and Environment Agency R&D 128; 1.1 and 10 for gamma, beta, and alpha radiation respectively for RESRAD-BIOTA). There is a lack of data for some radionuclide/reference organism combinations in both RESRAD-BIOTA and the Environment Agency R&D 128 codes, whereas ERICA allows the DCC calculation for every radionuclide.

For radionuclide/reference organism combinations with sufficient data available in each of the three approaches, the external DCCs are more or less similar for ERICA and the Environment Agency R&D 128, but are significantly different for RESRAD-BIOTA (two orders of magnitude higher for ^{99}Tc, about one order of magnitude lower for ^{239}Pu, a factor three lower for ^{226}Ra etc. However as noted previously this is likely to be due to the use of CRs and Kds derived from freshwater ecosystems in RESRAD-BIOTA). In contrast, there is generally a good agreement between the internal DCCs calculated with the three methods, except for ^{228}Ra, where RESRAD-BIOTA has values which are two orders of magnitude higher than ERICA. Where differences exist, they cannot be explained only by the slightly different weighting factors applied although possible reasons for the differences have been determined within the IAEA EMRAS Biota Working Group, the results of which will be published during 2008.

Table 4.5: Comparison of radionuclide-specific DCCs for external exposure of some reference organisms

	Plant		Invertebrates (crab)			Vertebrates (plaice)		
	ERICA	Environment Agency R&D 128	ERICA	RESRAD-BIOTA	Environment Agency R&D 128	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	2.60E-11	1.29E-08	2.23E-12	4.92E-11	1.41E-09	7.22E-15	9.92E-13	5.40E-10
^{99}Tc	1.50E-06	6.00E-06	3.47E-07	2.58E-05	7.60E-07	1.38E-07	2.35E-05	1.60E-07
^{137}Cs	3.40E-04	3.70E-04	3.13E-04	1.17E-04	3.30E-04	2.97E-04	1.07E-04	2.90E-04
^{239}Pu	3.00E-07	4.05E-07	1.65E-07	4.88E-08	2.91E-07	1.03E-07	1.95E-08	2.10E-07
^{240}Pu	6.80E-07	n.d.	3.47E-07	n.d.	n.d.	1.94E-07	n.d.	n.d.
^{210}Pb	4.70E-05	n.d.	1.02E-05	n.d.	n.d.	5.40E-06	n.d.	n.d.
^{210}Po	4.90E-09	4.90E-09	4.68E-09	n.d.	4.80E-09	4.47E-09	n.d.	4.40E-09
^{226}Ra	1.10E-03	n.d.	1.01E-03	4.25E-04	n.d.	9.56E-04	3.84E-04	n.d.
^{228}Ra	6.00E-04	n.d.	5.45E-04	4.92E-04	n.d.	5.16E-04	4.46E-04	n.d.

n.d. no data

Table 4.6: Comparison of radionuclide specific DCCs for internal exposure for some organisms

	Plant		Invertebrates (crab)			Vertebrates (plaice)		
	ERICA	Environment Agency R&D 128	ERICA	RESRAD-BIOTA	Environment Agency R&D 128	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	8.27E-06	9.90E-06	8.22E-06	1.20E-06	9.90E-06	8.22E-06	1.20E-06	9.90E-06
^{99}Tc	5.70E-05	5.20E-05	5.84E-05	2.18E-05	5.80E-05	5.86E-05	2.40E-05	5.80E-05
137Cs	1.30E-04	9.47E-05	1.56E-04	5.42E-05	1.41E-04	1.73E-04	6.42E-05	1.71E-04
^{239}Pu	3.00E-02	3.00E-02	2.97E-02	1.10E-02	3.00E-02	2.97E-02	1.10E-02	3.00E-02
^{240}Pu	3.00E-02	n.d.	2.97E-02	n.d.	n.d.	2.97E-02	n.d.	n.d.
^{210}Pb	2.08E-04	n.d.	2.48E-04	n.d.	n.d.	2.53E-04	n.d.	n.d.
^{210}Po	3.10E-02	3.10E-02	3.06E-02	n.d.	3.10E-02	3.06E-02	n.d.	3.10E-02
^{226}Ra	1.36E-01	n.d.	1.39E-01	7.33E-02	n.d.	1.39E-01	7.33E-02	n.d.
^{228}Ra	2.59E-04	n.d.	3.18E-04	6.88E-02	n.d.	3.47E-04	6.88E-02	n.d.

n.d. no data

Results on $\overline{DCC}_{i,o}$, $\overline{DCC}_{i,o}^{\text{int}}$, $\overline{DCC}_{i,o}^{ext}$ are reported in tables 4.7a to 4.7c for the radionuclides of interest. Using these coefficients, for each radionuclide, organisms can be ranked with regard to their relative sensitivity to radioecological impact in terms of dose rates. The top list of organisms (i.e. those characterized by the highest values of coefficients whatever the radionuclide) may be used to support the selection of species with a certain mode of life for monitoring purpose within the OSPAR area and/or within each zone. Moreover, for a given organism (representing a typical mode of life), radionuclides can be ranked in terms of radiological impact, supporting the selection of specific radionuclides to monitor in the area and/or in the zone.

(i.e. those characterized by the highest values of coefficients whatever the radionuclide) may be used to support the selection of species with a certain mode of life for monitoring purpose within the OSPAR area and/or within each zone. Moreover, for a given organism (representing a typical mode of life), radionuclides can be ranked in terms of radiological impact, supporting the selection of specific radionuclides to monitor in the area and/or in the zone.

Table 4.7a: Total Weighted concentration-to-dose rate conversion coefficients ($\overline{DCC}_{i,o}$) expressed in µGy/h per Bq/L. Each value has been calculated with the ERICA tool and takes into account all irradiation pathways for each reference organism and radionuclides of interest. Reference organisms that are highlighted in grey are those considered to be the most radioecologically sensitive (i.e. with the highest DCC). One per trophic level was selected to run the dose rate calculation in the proposed method. Note that the selection of one representative per trophic level/or pseudo taxonomic group allows to take into account the difference in the radiosensitivity of each taxonomic group (vertebrates being more sensitive than invertebrates being more sensitive than algae).

Trophic Level	Algae	Invertebrates				Vertebrates							
		Molluscs		Crustaceans		Pelagic Fish			Mixed Fish	Benthic Fish		Mammals	Birds
Reference Organism	*macroalgae*	*mussel*	*winkle*	*shrimps*	*crab*	*herring*	*sardine*	*sprat*	*cod*	*haddock*	*plaice*	*seal*	*gull*
Radionuclides													
H-3	**8.25E-06**	8.23E-06	8.23E-06	8.23E-06	**8.23E-06**	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	**8.23E-06**	8.23E-06	8.23E-06
Tc-99	**1.71E+00**	5.17E-01	5.16E-01	1.28E+00	**1.28E+00**	1.82E-03	1.81E-03	1.80E-03	1.82E-03	1.82E-03	**1.82E-03**	1.41E-03	1.82E-03
Cs-137	**1.52E-01**	1.40E-01	1.40E-01	6.23E-03	**1.32E-01**	1.49E-02	1.33E-02	1.26E-02	5.03E-02	9.54E-02	**1.10E-01**	6.59E-02	8.40E-02
Pu-239	**1.23E+02**	3.27E+01	3.27E+01	4.75E+00	**4.75E+00**	1.04E+02	1.04E+02	1.04E+02	1.04E+02	1.04E+02	**1.04E+02**	8.32E+00	4.45E+00
Pu-240	**1.23E+02**	3.27E+01	3.27E+01	4.76E+00	**4.76E+00**	1.04E+02	1.04E+02	1.04E+02	1.04E+02	1.04E+02	**1.04E+02**	8.33E+00	4.46E+00
Pb-210	**6.78E-01**	5.95E-01	6.21E-01	2.38E+00	**2.58E+00**	5.04E-02	4.88E-02	4.72E-02	6.22E-02	7.74E-02	**9.37E-02**	4.88E+00	4.81E+00
Po-210	**3.10E+01**	1.07E+03	1.07E+03	1.83E+03	**1.83E+03**	5.19E+02	5.19E+02	5.19E+02	5.19E+02	5.19E+02	**5.19E+02**	3.06E+02	3.06E+02
Ra-228	**1.43E-01**	1.33E-01	1.34E-01	4.42E-02	**1.57E-01**	9.62E-02	8.63E-02	8.12E-02	1.34E-01	1.73E-01	**1.80E-01**	3.49E-02	1.02E-01
Ra-226	**1.23E+01**	9.23E+00	9.23E+00	2.08E+01	**2.10E+01**	3.89E+01	3.88E+01	3.88E+01	3.89E+01	3.90E+01	**3.90E+01**	8.35E+00	3.89E+01

Table 4.7b: Weighted concentration-to-dose rate conversion coefficients due to external irradiation pathway ($\overline{DCC}_{i,o}^{ext}$) expressed in µGy/h per Bq/L. Each value has been calculated with the ERICA tool.

Trophic Level	Algae	Invertebrates				Vertebrates							
		Molluscs		Crustaceans		Pelagic Fish			Mixed Fish	Benthic Fish		Mammals	Birds
Reference Organism	*macroalgae*	*mussel*	*winkle*	*shrimps*	*crab*	*herring*	*sardine*	*sprat*	*cod*	*haddock*	*plaice*	*seal*	*gull*
Radionuclides													
H-3*	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Tc-99	1.58E-05	6.91E-06	8.11E-06	6.62E-07	3.64E-06	1.85E-07	3.84E-07	6.75E-07	4.37E-07	8.69E-07	1.19E-06	2.06E-08	7.49E-08
Cs-137	1.36E-01	1.30E-01	1.31E-01	3.26E-04	1.25E-01	3.00E-04	3.19E-04	3.27E-04	3.42E-02	7.94E-02	9.52E-02	1.18E-04	1.44E-04
Pu-239	3.00E-03	2.34E-03	2.49E-03	2.43E-07	1.65E-03	1.15E-07	1.95E-07	2.50E-07	2.35E-04	5.48E-04	8.26E-04	1.81E-08	4.53E-08
Pu-240	6.80E-03	5.22E-03	5.61E-03	5.44E-07	3.47E-03	2.24E-07	4.22E-07	5.62E-07	4.03E-04	9.40E-04	1.55E-03	2.31E-08	8.23E-08
Pb-210	4.70E-01	1.89E-01	2.20E-01	2.02E-05	1.02E-01	6.07E-06	1.38E-05	2.20E-05	1.14E-02	2.66E-02	4.32E-02	7.49E-07	2.37E-06
Po-210	9.80E-03	9.61E-03	9.64E-03	4.81E-09	9.37E-03	4.52E-09	4.75E-09	4.82E-09	2.56E-03	5.98E-03	7.15E-03	1.83E-09	2.17E-09
Ra-228	1.20E-01	1.14E-01	1.15E-01	5.72E-04	1.09E-01	5.21E-04	5.56E-04	5.75E-04	2.99E-02	6.91E-02	8.28E-02	2.13E-04	2.50E-04
Ra-226	2.21E-01	2.14E-01	2.17E-01	1.07E-03	2.03E-01	9.64E-04	1.04E-03	1.08E-03	5.53E-02	1.28E-01	1.54E-01	4.04E-04	4.62E-04

* there is an international consensus that, due to its low beta radiation component, the external exposure to tritium can be considered as zero, even if a DCC calculation may be done, as is the case in the ERICA tool.

Table 4.7c: Weighted concentration-to-dose rate conversion coefficients due to internal irradiation pathway ($\overline{DCC}_{i,o}^{\text{int}}$) expressed in µGy/h per Bq/kg of tissue (w.w.). Each value has been calculated with the ERICA tool.

Trophic Level	Algae	Invertebrates				Vertebrates							
		Molluscs		Crustaceans		Pelagic Fish			Mixed Fish	Benthic Fish		Mammals	Birds
Reference Organism	*macroalgae*	*mussel*	*winkle*	*shrimps*	*crab*	*herring*	*sardine*	*sprat*	*cod*	*haddock*	*plaice*	*seal*	*gull*
Radionuclides													
H-3	8.25E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06
Tc-99	5.70E-05	5.81E-05	5.80E-05	5.81E-05	5.84E-05	5.86E-05	5.84E-05	5.81E-05	5.86E-05	5.86E-05	5.86E-05	5.87E-05	5.86E-05
Cs-137	1.30E-04	1.45E-04	1.43E-04	1.44E-04	1.56E-04	1.70E-04	1.51E-04	1.43E-04	1.87E-04	1.87E-04	1.73E-04	3.13E-04	1.82E-04
Pu-239	3.00E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02
Pu-240	3.00E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02	2.97E-02
Pb-210	2.08E-04	2.39E-04	2.36E-04	2.38E-04	2.48E-04	2.52E-04	2.44E-04	2.36E-04	2.54E-04	2.54E-04	2.53E-04	2.57E-04	2.53E-04
Po-210	3.10E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02	3.06E-02
Ra-228	2.59E-04	2.93E-04	2.87E-04	2.91E-04	3.18E-04	3.42E-04	3.06E-04	2.88E-04	3.71E-04	3.71E-04	3.47E-04	5.79E-04	3.63E-04
Ra-226	1.36E-01	1.39E-01	1.39E-01	1.39E-01	1.39E-01	1.39E-01	1.39E-01	1.39E-01	1.39E-01	1.39E-01	1.39E-01	1.39E-01	1.39E-01

4.2 Past dose rates in biota estimated from baseline seawater concentrations for naturally occurring radionuclides in the OSPAR regions

During the past period (1995-2001), concentration data concerning naturally occurring radionuclides are scarce and only dedicated to water and some isotopes (^{210}Pb, ^{210}Po, ^{226}Ra, and ^{228}Ra). Data series are heterogeneous from one region to another. No data is reported in RA-2 related to concentrations measured in biota from 1995 to 2001. Dose rates to biota were only calculated on the basis of the water concentrations as input data (the same is done for anthropogenic radionuclides).

Estimated dose rates are based on activity concentration measurements in the environment, that is to say that for naturally occurring radionuclides, the estimated dose rate for each biota is a total dose rate, for which the natural background was then included in the assessment.

The interpretation of the absorbed dose rates due on the basis of water concentrations to representatives of the marine biota is therefore narrowly limited. The total dose rate due to these radionuclides can not be estimated since values for other daughter isotopes are not available. However, radionuclide-specific maximum dose rates calculated for macroalgae (Table 4.8), invertebrates (Table 4.9) and vertebrates (Table 4.10) and whatever the region considered are consistent with the order of magnitude of values reported by Brown et al. (2006) (see Table 2.4). Only values calculated for ^{210}Po and ^{226}Ra in R8, R10 and to a lesser extent R13 (only one value is available for this region) appeared to be slightly higher than those reported by Brown et al. (2006).

Natural background estimated for biota in natural marine ecosystems reported in the literature compilation done by Sazykina and Kryshev for MARINA II project [EC 2003a] are consistent with those calculated by Brown et al. (2006) giving the following range: 0.8 to 3.3 µGy/h for molluscs, 0.5 to 14 µGy/h for crustaceans, 0.05 to 0.7 µGy/h for fish. No data is reported for macroalgae.

When summing dose rates for the four radionuclides and crustaceans, molluscs and fish, values obtained are slightly lower or within the order of magnitude of the total expected dose rates with minimum values obtained for R3 region (only ^{226}Ra and ^{228}Ra measured) and maximum values obtained for R13 (only ^{210}Po and ^{210}Pb). Comparison is reported in Table 4.11.

Table 4.8: Weighted dose rates in macroalgae expressed in µGy/h and calculated on the basis of the limited available seawater concentration data reported in RA-2 and associated standard deviation (smaller characters) of naturally occurring radionuclides in OSPAR regions. Boxes are empty when input data is not available. Standard deviation is not given when the number of input data is equal to one.

Region	Year	Pb-210 µGy/h		Po-210 µGy/h		Ra-226 µGy/h		Ra-228 µGy/h	
R1	1994					1.59E-02	4.44E-03	1.10E-04	6.45E-05
R2	1994					1.83E-02	2.47E-03	2.75E-04	9.89E-05
R3	1994					1.47E-02	3.21E-03	2.12E-04	5.16E-05
R4	1994					1.51E-02	2.96E-03	1.56E-04	7.31E-05
R5	1994					1.78E-02		3.04E-04	
R6	1994					2.27E-02	4.07E-03	5.13E-04	1.33E-04
R7									
R8	1985-86	5.42E-04		1.86E-02	4.34E-03	6.36E-02	2.59E-03		
R9									
R10	1976	6.03E-04	3.86E-04	2.39E-02	1.43E-02				
	1986-87					3.46E-02	8.64E-03	5.45E-04	2.15E-04
R11									
R12									
R13	1976	1.34E-03		4.62E-02					
R14									
R15									

Table 4.9: Maximum weighted dose rates in invertebrates (with crab as corresponding reference organism) expressed in µGy/h and calculated on the basis of the limited available seawater concentration data reported in RA-2 and associated standard deviation (smaller characters) of naturally occurring radionuclides in OSPAR regions. Boxes are empty when input data is not available. Standard deviation is not given when the number of input data is equal to one.

Region	Year	Pb-210 µGy/h		Po-210 µGy/h		Ra-226 µGy/h		Ra-228 µGy/h	
R1	1994					2.71E-02	7.57E-03	1.21E-04	7.06E-05
R2	1994					3.11E-02	4.20E-03	3.01E-04	1.08E-04
R3	1994					2.50E-02	5.46E-03	2.32E-04	5.65E-05
R4	1994					2.56E-02	5.04E-03	1.71E-04	8.00E-05
R5	1994					3.03E-02		3.33E-04	
R6	1994					3.87E-02	6.94E-03	5.62E-04	1.46E-04
R7									
R8	1985-86	2.06E-03		1.10E+00	2.57E-01	1.08E-01	4.41E-03		
R9									
R10	1976	2.29E-03	1.47E-03	1.41E+00	8.43E-01				
	1986-87					5.88E-02	1.47E-02	5.96E-04	2.35E-04
R11									
R12									
R13	1976	5.08E-03		2.73E+00					
R14									
R15									

Table 4.10: Maximum weighted dose rates in vertebrates (with plaice as corresponding reference organism) expressed in µGy/h and calculated on the basis of the limited available seawater concentration data reported in RA-2 and associated standard deviation (smaller characters) of naturally occurring radionuclides in OSPAR regions. Boxes are empty when input data is not available.

Region	Year	Pb-210 µGy/h		Po-210 µGy/h		Ra-226 µGy/h		Ra-228 µGy/h	
R1	**1994**					5.03E-02	1.40E-02	1.39E-04	8.10E-05
R2	**1994**					5.78E-02	7.80E-03	3.46E-04	1.24E-04
R3	**1994**					4.64E-02	1.01E-02	2.66E-04	6.48E-05
R4	**1994**					4.76E-02	9.36E-03	1.96E-04	9.18E-05
R5	**1994**					5.62E-02		3.82E-04	
R6	**1994**					7.18E-02	1.29E-02	6.44E-04	1.67E-04
R7									
R8	**1985-86**	7.50E-05		3.12E-01	7.27E-02	2.01E-01	8.19E-03		
R9									
R10	**1976**	8.34E-05	5.34E-05	4.00E-01	2.39E-01				
	1986-87					1.09E-01	2.73E-02	6.84E-04	2.70E-04
R11									
R12									
R13	**1976**	1.85E-04		7.74E-01					
R14									
R15									

Table 4.11: Minimum and maximum weighted dose rates expressed in µGy/h and calculated on the basis of available water concentrations of naturally occurring radionuclides in the OSPAR regions (see column "data from"). Comparison with ranges reported in the literature. Note that the calculated dose rates cannot be considered as total dose since only 4 radionuclides are measured.

Compartment	Macroalgae	Data from	Molluscs	Crustaceans	Fish	Data from
Minimum dose rates	1.49E-02	R3/(Ra-226, Ra-228)	1.12E-02	2.52E-03	4.67E-02	R3/(Ra-226, Ra-228)
Maximum Dose rates	8.27E-02	R8 (Po-210, Pb210, Ra-226)	1.59E+00	2.74E+00	7.74E-01	R13 (Po-210, Pb210)
Range from literature	0.16 to 0.95	Brown et al. 2006	0.79 to 3.3	0.5 to 14	0.05 to 0.7	Sazykina & Krishev 2002
.			0.88 to 5.2	0.27 to 27	0.08 to 0.7	Brown et al. 2006

4.3 Periodic assessment of dose rates in biota estimated from annual mean seawater concentrations for anthropogenic radionuclides in the OSPAR regions

Annual means of seawater concentrations from the second periodic report were used per region to calculate the corresponding dose rates to biota, for each of the reference organisms previously described. Radionuclide-specific dose rates were estimated for ^{3}H, ^{137}Cs, ^{99}Tc and ^{239,240}Pu. Among the whole set of results such obtained, the calculated dose rates reported hereafter are only those for the reference organisms giving the maximum value per taxonomic groups, i.e. macroalgae for algae or primary producers, crab for invertebrates and plaice for vertebrates (Table 4.7a). Dose rates are based on some concentration means calculated using all or some/most results below analytical detection limits. Where this occurs, such values are identified in the tables through use of different formats:

a. italics (all concentration measurements below detection limits);
b. bold italics (some/most concentration measurements below detection limits).

When a mean includes activity concentration value less than the limit of detection, the assumption made was that the value was equal to the limit of detection (RA-1).Values calculated using all or some/most results below detection limits are reported without any component for variability. When a standard deviation was reported in the second periodic report, the same calculation as for the concentration itself was processed, and the result, reported in smaller normal characters, is assumed to be the equivalent of a standard deviation of the dose rate. Grey boxes in tables related to dose rate correspond to a lack of concentrations in the RA-2.

The seawater mean concentrations are reported in the second periodic report (RA-2) for the period from 1995 to 2001, and then for each year between 2002 and 2005. The corresponding calculation in terms of dose rate are thus summarised under the name “past period” in association with the 7-year first period. For the years from 2002 to 2005, a value per year is reported in the result tables.

For all cases, a sum of incremental dose rate based on results obtained for each radionuclide among ^{3}H, ^{137}Cs, ^{99}Tc and $^{239,240}Pu$ was calculated. Dose rate estimates based on seawater concentration detection limit were taken into account to obtain a maximum value of these summed dose rate estimates for each region, compartment and year or period. Radionuclides were ranked according to their contribution to the incremental dose rates.

Calculated dose rates for macroalgae vary according to the region and the radionuclide. Globally the range is from 10^{-6} µGy/h to 10^{-1} µGy/h, the lowest value being mostly observed for ^{3}H (Table 4.12a) and the maximum for ^{99}Tc (Table 4.12c), close to ^{137}Cs (Table 4.12b). Values for $^{239,240}Pu$ (Table 4.12d) are too scarce to draw any conclusion about the contribution of these radionuclides to the dose rates with regard to the three others (^{3}H, ^{137}Cs, ^{99}Tc).

Table 4.12a: Periodic assessment of maximum weighted dose rates of tritium in OSPAR regions estimated for macroalgae and expressed in µGy/h.

	H-3 µGy/h				
region	**Past period**	**2002**	**2003**	**2004**	**2005**
R1		4.21E-06 1.53E-05 ***2.23E-05***	1.16E-06 2.48E-07 ***2.15E-05***	1.24E-06 4.13E-07 ***2.06E-05***	1.24E-06 4.95E-07 ***2.23E-05***
R2	***1.15E-04***	1.73E-04 1.06E-04 ***1.14E-04***	1.18E-04 4.62E-05 ***9.16E-05***	1.67E-04 1.06E-04 ***1.13E-04***	1.04E-04 3.14E-05 ***8.91E-05***
R3	*8.23E-05*	***6.02E-05***	***6.19E-05***	***5.78E-05***	***1.78E-04***
R4					
R5					
R6	***1.15E-04***	***1.82E-04***	***1.07E-04***	***1.49E-04***	***9.90E-05***
R7	***1.40E-05***	*9.90E-06*	***9.08E-06***	*9.90E-06*	*8.25E-06*
R8	3.38E-05 5.76E-06	3.05E-05 9.08E-06	3.05E-05 7.43E-06	4.13E-05 9.08E-06	1.65E-05 1.16E-05
R9	2.41E-05 7.24E-06	***2.31E-05***	3.38E-05 6.60E-06	3.55E-05 1.24E-05	3.55E-05 9.08E-06
R10	***6.59E-06***	***1.57E-05***	***1.57E-05***	***1.24E-05***	***9.90E-06***
R11					
R12		*2.56E-05*	***1.90E-05***	***2.39E-05***	*1.90E-05*
R13					
R14					
R15					

Table 4.12b: Periodic assessment of maximum weighted dose rates of ^{137}Cs in OSPAR regions estimated for macroalgae and expressed in µGy/h.

	Cs-137 µGy/h									
region	**Past period**		**2002**		**2003**		**2004**		**2005**	
R1	*4.86E-03*		3.79E-04 ***8.36E-03***	6.07E-05	2.43E-04 ***1.05E-02***	7.59E-05	3.79E-04 ***1.14E-02***	1.06E-04	3.79E-04 ***1.54E-02***	1.52E-04
R2	***4.55E-03***		***4.34E-03***		***3.64E-03***		***3.52E-03***		***3.61E-03***	
R3	*5.16E-03*		*4.75E-03*		*3.64E-03*		*3.99E-03*		*3.87E-03*	
R4	4.25E-03	1.52E-03	2.43E-03	9.11E-04	1.67E-03	7.59E-04	2.43E-03	7.59E-04	2.73E-03	1.52E-03
R5	4.55E-03	1.52E-03	2.88E-03	9.11E-04	2.58E-03	4.55E-04	2.58E-03	7.59E-04	2.58E-03	9.11E-04
R6	2.88E-02	6.07E-03	1.47E-02	1.06E-02	1.11E-02	7.59E-03	2.23E-02	1.11E-02	1.18E-02	7.28E-03
R7	***7.59E-03***		6.98E-04 ***1.03E-02***	6.07E-05	*1.52E-02*		5.31E-04 ***1.03E-02***	1.97E-04	*1.52E-02*	
R8	6.56E-04	1.58E-04	4.55E-04 ***1.35E-02***	7.59E-05	*1.62E-02*		3.64E-04 ***1.43E-02***	1.06E-04	*1.78E-02*	
R9	6.56E-04	1.58E-04	5.16E-04	1.52E-04	5.62E-04	1.06E-04	4.40E-04	9.11E-05	3.95E-04	6.07E-05
R10	1.11E-03	5.01E-04	6.83E-04	2.58E-04	6.37E-04		6.83E-04	2.12E-04	6.37E-04	1.37E-04
R11	2.23E-03	1.27E-03			1.00E-03		1.52E-03	3.04E-04	1.31E-03	9.11E-05
R12	4.60E-03	1.61E-03	***9.12E-03***		8.15E-03	3.95E-03	6.83E-03	4.70E-03	7.30E-03	4.31E-03
R13	6.68E-04	6.07E-05	6.83E-04	2.73E-04	4.70E-04	9.11E-05	3.19E-04	1.06E-04	4.55E-04	3.04E-05
R14	5.31E-04	6.07E-05								
R15	6.91E-04	1.32E-04	6.07E-04	2.43E-04	5.31E-04	2.12E-04	5.16E-04	2.12E-04	3.64E-04	1.82E-04

Table 4.12c: Periodic assessment of maximum weighted dose rates of ^{99}Tc in OSPAR regions estimated for macroalgae and expressed in µGy/h.

	Tc-99 µGy/h									
region	**Past period**		**2002**		**2003**		**2004**		**2005**	
R1			*1.71E-04*		*1.71E-04*					
R2										
R3										
R4	4.10E-02	1.54E-02	3.59E-02	1.37E-02	3.08E-02	1.71E-02	2.91E-02	1.20E-02	2.05E-02	8.55E-03
R5										
R6	6.16E-01	5.99E-01	4.38E-01	2.98E-01	3.93E-01	2.33E-01	1.78E-01	9.23E-02	1.25E-01	5.13E-02
R7										
R8										
R9	2.86E-03	2.07E-03								
R10	4.79E-03	1.37E-03								
R11	3.93E-03	3.59E-03	2.91E-03	1.03E-03	2.57E-03	6.84E-04	3.93E-03	3.08E-03	2.05E-03	6.84E-04
R12	2.22E-03	8.55E-04	8.55E-04	5.13E-04	1.03E-03	3.42E-04	8.55E-04	1.71E-04	8.55E-04	3.42E-04
R13	1.88E-03	6.84E-04	1.71E-03	3.42E-04	1.37E-03	1.71E-04	1.37E-03	1.71E-04	1.54E-03	1.71E-04
R14	1.20E-03	6.84E-04	3.08E-04		8.55E-05		3.25E-04		3.25E-04	
R15			2.22E-04	1.37E-04	2.39E-04	1.03E-04	2.39E-04	8.55E-05	2.05E-04	1.03E-04

Table 4.12d: Periodic assessment of maximum weighted dose rates of ^{239,240}Pu in OSPAR regions estimated for macroalgae and expressed in µGy/h.

region	Pu-239,240 µGy/h baseline	2002	2003	2004	2005
R1					
R2					
R3					
R4					
R5					
R6					
R7					
R8	1.62E-03 3.54E-04				***4.59E-02***
R9	1.40E-03 5.82E-04	7.38E-04 3.20E-04	9.23E-04 1.85E-04	1.55E-03 4.55E-04	
R10					
R11					
R12					
R13					
R14					
R15					

Calculated dose rates for invertebrates (crab selected as representative species) vary according to the region and the radionuclide. Globally the range is from 10^{-6} µGy/h to 10^{-1} µGy/h, the lowest value being mostly observed for ^{3}H (Table 4.13a) and the maximum for ^{99}Tc (Table 4.13c), close to ^{137}Cs (Table 4.13b). Values for ^{239,240}Pu (Table 4.13d) are too scarce to draw any conclusion about the contribution of these radionuclides to the dose rates with regard to the three others (^{3}H, ^{137}Cs, ^{99}Tc).

Table 4.13a: Periodic assessment of maximum weighted dose rates of tritium in OSPAR regions estimated for invertebrates (crab) and expressed in µGy/h.

	H-3 µGy/h				
region	**Past period**	**2002**	**2003**	**2004**	**2005**
R1		4.20E-06 1.53E-05 ***2.22E-05***	1.15E-06 2.47E-07 ***2.14E-05***	1.23E-06 4.12E-07 ***2.06E-05***	1.23E-06 4.94E-07 ***2.22E-05***
R2	***1.15E-04***	1.73E-04 1.06E-04 ***1.14E-04***	1.18E-04 4.61E-05 ***9.14E-05***	1.67E-04 1.05E-04 ***1.13E-04***	1.04E-04 3.13E-05 ***8.89E-05***
R3	*8.23E-05*	***6.01E-05***	***6.17E-05***	***5.76E-05***	***1.78E-04***
R4					
R5					
R6	***1.15E-04***	***1.81E-04***	***1.07E-04***	***1.48E-04***	***9.88E-05***
R7	***1.40E-05***	*9.88E-06*	***9.06E-06***	*9.88E-06*	*8.23E-06*
R8	3.38E-05 5.76E-06	3.05E-05 9.06E-06	3.05E-05 7.41E-06	4.12E-05 9.06E-06	1.65E-05 1.15E-05
R9	2.41E-05 7.24E-06	***2.31E-05***	3.38E-05 6.59E-06	3.54E-05 1.23E-05	3.54E-05 9.06E-06
R10	***6.59E-06***	***1.56E-05***	***1.56E-05***	***1.23E-05***	***9.88E-06***
R11					
R12		*2.55E-05*	***1.89E-05***	***2.39E-05***	*1.89E-05*
R13					
R14					
R15					

Table 4.13b: Periodic assessment of maximum weighted dose rates of ^{137}Cs in OSPAR regions estimated for invertebrates (crab) and expressed in µGy/h.

	Cs-137 µGy/h									
region	**Past period**		**2002**		**2003**		**2004**		**2005**	
R1	*4.22E-03*		3.30E-04 ***7.27E-03***	5.28E-05	2.11E-04 ***9.10E-03***	6.60E-05	3.30E-04 ***9.92E-03***	9.23E-05	3.30E-04 ***1.34E-02***	1.32E-04
R2	***3.96E-03***		***3.77E-03***		***3.17E-03***		***3.06E-03***		***3.14E-03***	
R3	*4.48E-03*		*4.13E-03*		*3.17E-03*		*3.47E-03*		*3.36E-03*	
R4	3.69E-03	1.32E-03	2.11E-03	7.91E-04	1.45E-03	6.60E-04	2.11E-03	6.60E-04	2.37E-03	1.32E-03
R5	3.96E-03	1.32E-03	2.51E-03	7.91E-04	2.24E-03	3.96E-04	2.24E-03	6.60E-04	2.24E-03	7.91E-04
R6	2.51E-02	5.28E-03	1.28E-02	9.23E-03	9.63E-03	6.60E-03	1.94E-02	9.63E-03	1.03E-02	6.33E-03
R7	***6.60E-03***		6.07E-04 ***8.97E-03***	5.28E-05	*1.32E-02*		4.62E-04 ***8.97E-03***	1.71E-04	*1.32E-02*	
R8	5.70E-04	1.37E-04	3.96E-04 ***1.17E-02***	6.60E-05	*1.41E-02*		3.17E-04 ***1.24E-02***	9.23E-05	*1.54E-02*	
R9	7.10E-04	2.66E-04	4.48E-04	1.32E-04	4.88E-04	9.23E-05	3.83E-04	7.91E-05	3.43E-04	5.28E-05
R10	9.63E-04	4.35E-04	5.94E-04	2.24E-04	5.54E-04		5.94E-04	1.85E-04	5.54E-04	1.19E-04
R11	1.94E-03	1.11E-03			8.71E-04		1.32E-03	2.64E-04	1.13E-03	7.91E-05
R12	4.00E-03	1.40E-03	***7.93E-03***		7.08E-03	3.43E-03	5.94E-03	4.09E-03	6.34E-03	3.75E-03
R13	5.80E-04	5.28E-05	5.94E-04	2.37E-04	4.09E-04	7.91E-05	2.77E-04	9.23E-05	3.96E-04	2.64E-05
R14	4.62E-04	5.28E-05								
R15	6.00E-04	1.15E-04	5.28E-04	2.11E-04	4.62E-04	1.85E-04	4.48E-04	1.85E-04	3.17E-04	1.58E-04

Table 4.13c: Periodic assessment of maximum weighted dose rates of ^{99}Tc in OSPAR regions estimated for invertebrates (crab) and expressed in µGy/h.

	Tc-99 µGy/h									
region	**Past period**		**2002**		**2003**		**2004**		**2005**	
R1			*1.28E-04*		*1.28E-04*					
R2										
R3										
R4	3.08E-02	1.16E-02	2.70E-02	1.03E-02	2.31E-02	1.28E-02	2.18E-02	8.99E-03	1.54E-02	6.42E-03
R5										
R6	4.63E-01	4.50E-01	3.29E-01	2.24E-01	2.95E-01	1.75E-01	1.34E-01	6.94E-02	9.38E-02	3.85E-02
R7										
R8										
R9	2.15E-03	1.55E-03								
R10	3.60E-03	1.03E-03								
R11	2.95E-03	2.70E-03	2.18E-03	7.71E-04	1.93E-03	5.14E-04	2.95E-03	2.31E-03	1.54E-03	5.14E-04
R12	1.67E-03	6.42E-04	6.42E-04	3.85E-04	7.71E-04	2.57E-04	6.42E-04	1.28E-04	6.42E-04	2.57E-04
R13	1.41E-03	5.14E-04	1.28E-03	2.57E-04	1.03E-03	1.28E-04	1.03E-03	1.28E-04	1.16E-03	1.28E-04
R14	8.99E-04	5.14E-04	2.31E-04		6.42E-05		2.44E-04		2.44E-04	
R15			1.67E-04	1.03E-04	1.80E-04	7.71E-05	1.80E-04	6.42E-05	1.54E-04	7.71E-05

Table 4.13d: Periodic assessment of maximum weighted dose rates of <u>^{239,240}Pu</u> in OSPAR regions estimated for <u>invertebrates (crab)</u> and expressed in µGy/h.

	Pu-239,240 µGy/h				
region	**Past period**	**2002**	**2003**	**2004**	**2005**
R1					
R2					
R3					
R4					
R5					
R6					
R7					
R8	6.26E-05 1.37E-05				***1.78E-03***
R9	5.44E-05 2.25E-05	2.86E-05 1.24E-05	3.57E-05 7.15E-06	6.00E-05 1.76E-05	
R10					
R11					
R12					
R13					
R14					
R15					

Calculated dose rates for vertebrates (plaice selected as representative species) vary according to the region and the radionuclide. Globally the range is from 10^{-6} µGy/h to 10^{-2} µGy/h, the lowest value being mostly observed for ^{3}H (Table 4.14a) and the maximum for ^{137}Cs (Table 4.14b). Values for ^{99}Tc in plaice (Table 4.14c) are two orders of magnitude lower than those calculated for invertebrates or for macroalgae according to the difference existing in the CR values. Values for ^{239,240}Pu (Table 4.14d) are too scarce to draw any conclusion about the contribution of these radionuclides to the dose rates with regard to the three others (^{3}H, ^{137}Cs, ^{99}Tc).

Table 4.14a: Periodic assessment of maximum weighted dose rates of tritium in OSPAR regions estimated for vertebrates (plaice) and expressed in µGy/h.

	H-3 µGy/h									
region	Past period		2002		2003		2004		2005	
R1			4.20E-06 ***2.22E-05***	1.53E-05	1.15E-06 ***2.14E-05***	2.47E-07	1.23E-06 ***2.06E-05***	4.12E-07	1.23E-06 ***2.22E-05***	4.94E-07
R2	***1.15E-04***		1.73E-04 ***1.14E-04***	1.06E-04	1.18E-04 ***9.14E-05***	4.61E-05	1.67E-04 ***1.13E-04***	1.05E-04	1.04E-04 ***8.89E-05***	3.13E-05
R3	*8.23E-05*		***6.01E-05***		***6.17E-05***		***5.76E-05***		***1.78E-04***	
R4										
R5										
R6	***1.15E-04***		***1.81E-04***		***1.07E-04***		***1.48E-04***		***9.88E-05***	
R7	***1.40E-05***		*9.88E-06*		***9.06E-06***		*9.88E-06*		*8.23E-06*	
R8	3.38E-05	5.76E-06	3.05E-05	9.06E-06	3.05E-05	7.41E-06	4.12E-05	9.06E-06	1.65E-05	1.15E-05
R9	2.41E-05	7.24E-06	***2.31E-05***		3.38E-05	6.59E-06	3.54E-05	1.23E-05	3.54E-05	9.06E-06
R10	***6.59E-06***		***1.56E-05***		***1.56E-05***		***1.23E-05***		***9.88E-06***	
R11										
R12			*2.55E-05*		***1.89E-05***		***2.39E-05***		*1.89E-05*	
R13										
R14										
R15										

Table 4.14b: Periodic assessment of maximum weighted dose rates of ^{137}<u>Cs</u> in OSPAR regions estimated for <u>vertebrates (plaice)</u> and expressed in µGy/h.

	Cs-137 µGy/h									
region	**Past period**		**2002**		**2003**		**2004**		**2005**	
R1	*3.52E-03*		2.75E-04 ***6.06E-03***	4.40E-05	1.76E-04 ***7.59E-03***	5.50E-05	2.75E-04 ***8.27E-03***	7.70E-05	2.75E-04 ***1.12E-02***	1.10E-04
R2	***3.30E-03***		***3.15E-03***		***2.64E-03***		***2.55E-03***		***2.62E-03***	
R3	*3.74E-03*		*3.44E-03*		*2.64E-03*		*2.89E-03*		*2.81E-03*	
R4	3.08E-03	1.10E-03	1.76E-03	6.60E-04	1.21E-03	5.50E-04	1.76E-03	5.50E-04	1.98E-03	1.10E-03
R5	3.30E-03	1.10E-03	2.09E-03	6.60E-04	1.87E-03	3.30E-04	1.87E-03	5.50E-04	1.87E-03	6.60E-04
R6	2.09E-02	4.40E-03	1.07E-02	7.70E-03	8.03E-03	5.50E-03	1.62E-02	8.03E-03	8.58E-03	5.28E-03
R7	***5.50E-03***		5.06E-04 ***7.48E-03***	4.40E-05	*1.10E-02*		3.85E-04 ***7.48E-03***	1.43E-04	*1.10E-02*	
R8	4.75E-04	1.14E-04	3.30E-04 ***9.79E-03***	5.50E-05	*1.18E-02*		2.64E-04 ***1.03E-02***	7.70E-05	*1.29E-02*	
R9	4.75E-04	1.14E-04	3.74E-04	1.10E-04	4.07E-04	7.70E-05	3.19E-04	6.60E-05	2.86E-04	4.40E-05
R10	8.03E-04	3.63E-04	4.95E-04	1.87E-04	4.62E-04		4.95E-04	1.54E-04	4.62E-04	9.90E-05
R11	1.62E-03	9.24E-04			7.26E-04		1.10E-03	2.20E-04	9.46E-04	6.60E-05
R12	3.33E-03	1.17E-03	***6.61E-03***		5.91E-03	2.86E-03	4.95E-03	3.41E-03	5.29E-03	3.13E-03
R13	4.84E-04	4.40E-05	4.95E-04	1.98E-04	3.41E-04	6.60E-05	2.31E-04	7.70E-05	3.30E-04	2.20E-05
R14	3.85E-04	4.40E-05								
R15	5.01E-04	9.57E-05	4.40E-04	1.76E-04	3.85E-04	1.54E-04	3.74E-04	1.54E-04	2.64E-04	1.32E-04

Table 4.14c: Periodic assessment of maximum weighted dose rates of ^{99}Tc in OSPAR regions estimated for vertebrates (plaice) and expressed in µGy/h.

	Tc-99 µGy/h									
region	**Past period**		**2002**		**2003**		**2004**		**2005**	
R1			*1.82E-07*		*1.82E-07*					
R2										
R3										
R4	4.36E-05	1.64E-05	3.82E-05	1.45E-05	3.27E-05	1.82E-05	3.09E-05	1.27E-05	2.18E-05	9.09E-06
R5										
R6	6.54E-04	6.36E-04	4.65E-04	3.16E-04	4.18E-04	2.47E-04	1.89E-04	9.82E-05	1.33E-04	5.45E-05
R7										
R8										
R9	3.04E-06	2.20E-06								
R10	5.09E-06	1.45E-06								
R11	4.18E-06	3.82E-06	3.09E-06	1.09E-06	2.73E-06	7.27E-07	4.18E-06	3.27E-06	2.18E-06	7.27E-07
R12	2.36E-06	9.09E-07	9.09E-07	5.45E-07	1.09E-06	3.64E-07	9.09E-07	1.82E-07	9.09E-07	3.64E-07
R13	2.00E-06	7.27E-07	1.82E-06	3.64E-07	1.45E-06	1.82E-07	1.45E-06	1.82E-07	1.64E-06	1.82E-07
R14	1.27E-06	7.27E-07	3.27E-07		9.09E-08		3.45E-07		3.45E-07	
R15			2.36E-07	1.45E-07	2.55E-07	1.09E-07	2.55E-07	9.09E-08	2.18E-07	1.09E-07

Table 4.14d: Periodic assessment of maximum weighted dose rates of ^{239,240}Pu in OSPAR regions estimated for vertebrates (plaice) and expressed in µGy/h.

	Pu-239,240 µGy/h				
region	**Past period**	**2002**	**2003**	**2004**	**2005**
R1					
R2					
R3					
R4					
R5					
R6					
R7					
R8	1.37E-03 3.00E-04				***3.88E-02***
R9	1.19E-03 4.93E-04	6.25E-04 2.71E-04	7.81E-04 1.56E-04	1.31E-03 3.85E-04	
R10					
R11					
R12					
R13					
R14					
R15					

4.4 Dose rates in biota estimated from seawater concentrations and from biota concentrations for radionuclides in the OSPAR regions

Annual means of biota concentrations from the second periodic report were used per region to calculate the corresponding internal dose rates to biota, while the external ones were estimated on the basis of seawater concentrations as input data. Radionuclide-specific dose rates were estimated for ^{3}H, ^{137}Cs, ^{99}Tc and ^{239,240}Pu. Calculated dose rates are reported only for those reference organisms being measured per taxonomic groups, *i.e.* seaweed for algae or primary producers, mussel for invertebrates and plaice (as a fish model giving the maximum value among the different fish species) for vertebrates (Table 4.7a).

Since too few data were available concerning the radionuclide measurements in biota, these data sets were used to compare the dose rates calculated on the basis of seawater concentrations as input data on one hand with the dose rates calculated on the basis of seawater and biota concentrations on the other hand.

Comparison (Figure 4.2) underlines that dose rates are in the same order of magnitude whatever the type of input data used (i.e. only water concentrations or both water and biota concentrations) for those compartments with adequate datasets for this exercise, i.e. seaweed, mussel and plaice as fish for ^{137}Cs, and seaweed for ^{99}Tc. In this last case, few data, related to the year 2003 in general plus the region 15 the following years, are less in agreement. Concerning ^{239,240}Pu, data are scarce and at least for fish estimating dose rates on the basis of both water and biota concentrations gives values lower than those obtained on the basis of water concentrations only, in correlation with the observations made on the comparison of measured and calculated biota concentrations.

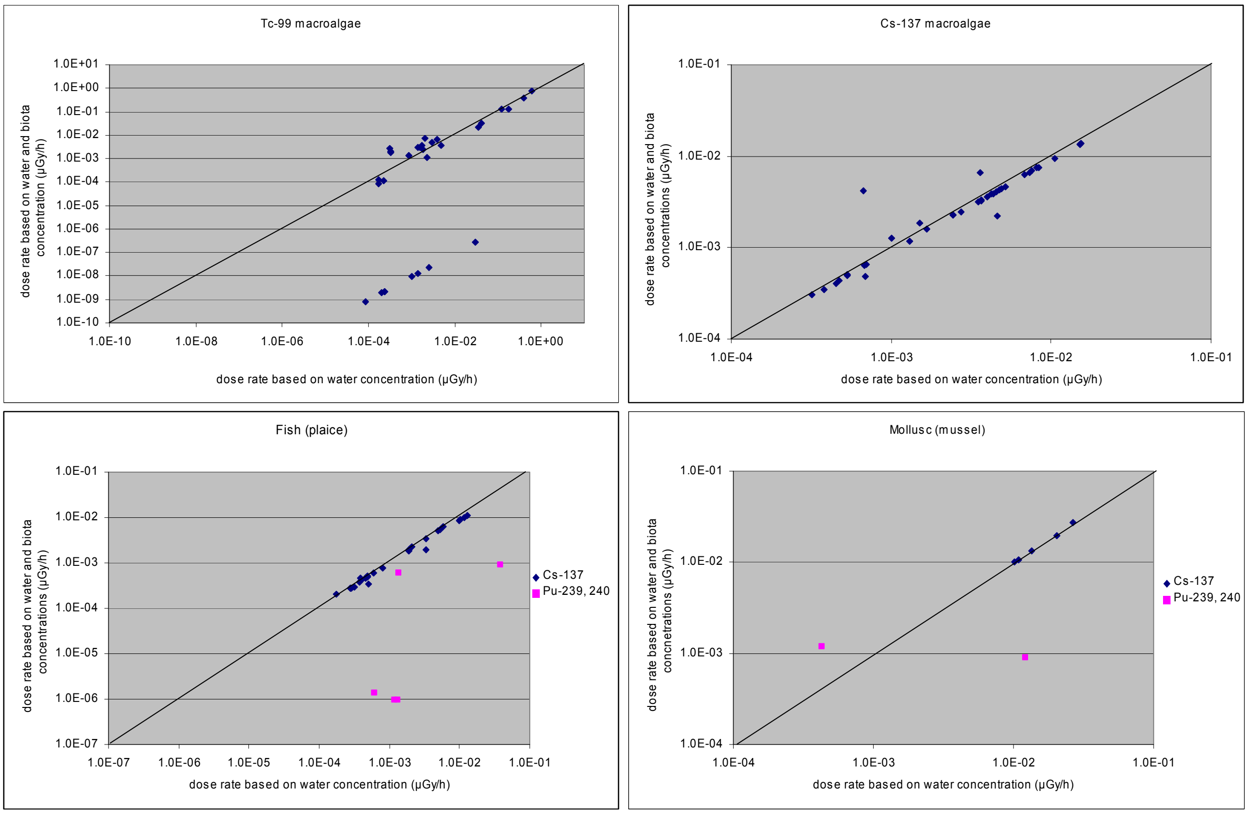

Figure 4.2: **Comparison of dose rates calculated on the basis of seawater concentrations as input data (X-axis) with dose rates calculated on the basis of seawater and biota concentrations (Y-axis).**

4.5 Ranking of potentially released radionuclides for future ERA

The concentration-to-dose rate conversion coefficients were determined for the full list of isotopes present in the ERICA tool, in order to rank them on the basis of the hazard they may represent for the ecosystem. A summary of this ranking is reported Table 4.15 and details are provided in Annex 5. For all organisms, the radionuclides that exhibit the lowest concentration-to-dose rate conversion coefficients are more or less the same and include ^{3}H, ^{36}Cl, ^{35}S, some iodine isotopes (^{125}I, ^{129}I, ^{131}I, ^{133}I) and for mammals and birds ^{89}Sr and ^{90}Sr. In contrast, the composition of the group of the most hazardous radionuclides depends on the organism, even if a certain common trend may be distinguished that concerns ^{210}Po and the isotopes 238, 239 and 240 of plutonium. Special attention should be paid to the future potential releases of these radionuclides in any future ERA.

Table 4.15: Categories of potentially released radionuclides ranked on the basis of their total weighted concentration-to-dose rate conversion coefficients (µGy/h for 1 Bq/l). In each cell, radionuclides are ranked from the lowest to the highest value of the coefficient.

	1.00E-06- 1.00E-03	1.00E-03 - 1.00E-02	1.00E-02 - 1.00E-01	1.00E-01 - 1.00E+00	1.00E+00 - 1.00E+01	1.00E+01 - 1.00E+02	1.00E+02 - 1.00E+03	> 1.00E+03
macroalgae	^{3}H, S-35, Cl36	Cs-135, Se-79, Ni-59, Ni-63	Sr-89, Sr-90, Pu-241, Sb-125, Se-75, Cd-109	I-125, ^{228}Ra, ^{137}Cs, I-129, C-14, Sb-124, Cs-134, I-131, P-33, Cs-136, Te-123m, ^{210}Pb, I-133, I-132	Ru-103, Np-237, Ag-110m, ^{99}Tc, Co-57, Ru-106, U-238, P-32, U-235, Te-132, U-234, Th-231, Te-129m	^{226}Ra, Ce-141, Co-58, Am-241, ^{210}Po, Nb-95, Co-60, Th-232, Th-234, Th-230, Nb-94, Zr-95, Th-227, Mn-54, Ce-144	^{239}Pu, ^{240}Pu, Pu-238, Eu-152, Eu-154, Cm-244, Cm-243, Cm242, Th-228	Ra-223, Eu-155
cod	^{3}H, Cl-36, S-35, I-125, I-129	I-131, Ni-59, ^{99}Tc, I-133, Ni-63, Cs-135, I-132, Sr-89	Sr-90, Np-237, Pu-241, Sb-125, ^{137}Cs, ^{210}Pb, Te-123m	Cd-109, Cs-134, ^{228}Ra, Sb-124, Cs-136, Ru-106, Ru-103, Se-79, U-238, C-14, U-235, U-234, Se-75, Te-129m, Te-132, Th-231, Co-57	Ag-110m, Eu-155, Am-241, Th-234, Ce-141, Cm-244, Cm-242, P-33, Co-58, Ce-144, Cm-243, Nb-95	Co-60, Th-232, Th-230, Nb-94, Zr-95, Th-227, Mn-54, Eu-152, Eu-154, R-32, ^{226}Ra, Ra-223	^{239}Pu, ^{240}Pu, Pu-238, Th-228, ^{210}Po	
haddock	^{3}H, Cl-36, S-35, I-125, I-129	I-131, Ni-59, ^{99}Tc, I-133, Ni-63, Cs-135, I-132, Sr-89	Sr-90, Np-237, Pu-241, Sb-125, ^{137}Cs, ^{210}Pb, Te-123m	Cd-109, Cs-134, ^{228}Ra, Sb-124, Cs-136, Ru-106, Ru-103, Se-79, U-238, C-14, U-235, U-234, Se-75, Te-129m, Te-132	Th-231, Co-57, Ag-110m, Eu-155, Am-241, Th-234, Ce-141, Cm-244, Cm-242, P-33	Co-58, Ce-144, Cm-243, Nb-95, Co-60, Th-232, Th-230, Nb-94, Zr-95, Th-227, Mn-54, Eu-152, Eu-154, R-32, ^{226}Ra, Ra-223	^{239}Pu, ^{240}Pu, Pu-238, Th-228, ^{210}Po	
plaice	^{3}H, Cl-36, S-35, I-125, I-129	I-131, Ni-59, ^{99}Tc, I-133, Ni-63, Cs-135, I-132, Sr-89	Sr-90, Np-237, Pu-241, Sb-125, ^{137}Cs, ^{210}Pb, Te-123m	Cd-109, Cs-134, ^{228}Ra, Sb-124, Cs-136, Ru-106, Ru-103, Se-79, U-238, C-14, U-235, U-234, Se-75, Te-129m, Te-132	Th-231, Co-57, Ag-110m, Eu-155, Am-241, Th-234, Ce-141, Cm-244, Cm-242, P-33	Co-58, Ce-144, Cm-243, Nb-95, Co-60, Th-232, Th-230, Nb-94, Zr-95, Th-227, Mn-54, Eu-152, Eu-154, R-32, ^{226}Ra, Ra-223	^{239}Pu, ^{240}Pu, Pu-238, Th-228, ^{210}Po	
mussel, winkle	^{3}H, Cl-36, S-35, I-125, I-129	Cs-135, I-131, I-133, Pu-241	I-132, Sr-89, Ni-59, Sr-90, Te-123m, Ni-63, Sb-125	^{228}Ra, ^{137}Cs, Se-79, Se-75, C-14, Sb-124, Cs-134, Cs-136, Te-132, ^{99}Tc, Te-129m, ^{210}Pb, U-238, U-235, U-234, P-33	Ru-103, Co-57, Ru-106, Th-231, Ag-110m, Cs-109, P-32, Eu-155, ^{226}Ra, Ra-223	Np-237, Th-232, Ce-141, Th-230, Co-58, Th-234, ^{239}Pu, ^{240}Pu, Nb-95, Pu-238, Th-227, Co-60, Ce-144, Nb-94, Zr-95, Mn-54	Eu-152, Eu-154, Am-241, Th-228	^{210}Po, Cm-244, Cm-243, Cm-242
crab	^{3}H, Cl-36, S-35, I-125, I-129	Pu-241, Cs-135, I-131, I-133, Sr-89, Ni-59, Ni-63, Sr-90	I-132, Te-123m	^{137}Cs, Sb-125, ^{228}Ra, Se-79, U-238, Se-75, U-235, U-234, C-14, Cs-134, Cs-136, Te-129m, Te-132, Sb-124	Ru-103, Ru-106, P-33, ^{99}Tc, Cd-109, Co-57, ^{210}Pb, Np-237, Ag-110m, ^{239}Pu, ^{240}Pu, Pu-238, Eu-155,	P-32, Ce-141, Co-58, Th-234, ^{226}Ra, Ra-223, Th-232, Th-230, Nb-95, Ce-144, Co-60, Cm-244, Am-241, Cm-242, Th-227, Cm-243, Nb-94, Zr-95, Mn-54	Eu-152, Eu-154, Th-228	^{210}Po

	1.00E-06- 1.00E-03	**1.00E-03 - 1.00E-02**	**1.00E-02 - 1.00E-01**	**1.00E-01 - 1.00E+00**	**1.00E+00 - 1.00E+01**	**1.00E+01 - 1.00E+02**	**1.00E+02 - 1.00E+03**	**> 1.00E+03**
herring, sardine, sprat	^{3}H, Cl-36, S-35, I-125, I-129, I-131	I-133, Ni-59, ^{99}Tc, Ni-63, Ru-103, I-132, Nb-95, Cs-135, Zr-95, Sr-89	Cs-136, Nb-94, Cs-134, Ce-141, Sr-90, ^{137}Cs, Mn-54, Ru-106, Sb-125, Eu-155, Np-237, Pu-241, ^{210}Pb, Sb-124, Te-123m, Ce-144, Th-231, Eu-154, Eu-152, ^{228}Ra, Cd-109	Co-57, Se-75, Ag-110m, Th-234, Se-79, U-238, Te-132, C-14, U-235, U-234, Co-60, Te-129m, Co-58	Am-241, Cm-244, Cm-243, Cm-242, P-33	Th-232, Th-230, Th-227, P-32, ^{226}Ra, Ra-223	^{239}Pu, ^{240}Pu, Pu-238, Th-228, ^{210}Po	
shrimps	^{3}H, Cl-36, S-35, I-125, I-129, I-131	I-133, Pu-241, Cs-135, I-132, Sr-89, Nb-95, Ni-59, Cs-134, Cs-136, ^{137}Cs, Ni-63, Sr-90	Nb-94, Zr-95, Ru-103, ^{228}Ra, Co-57, Te-123m, Sb-125	Mn-54, Th-231, Co-60, Se-75, Eu-155, Ru-106, Se-79, Co-58, U-238, U-235, U-234, C-14, Sb-124, Ce-141, Te-132, Th-234, Te-129m, Eu-154, Eu-152	P-33, ^{99}Tc, Ag-110m, Cd-109, Ce-144, ^{210}Pb, Np-237, ^{239}Pu, ^{240}Pu, Pu-238, P-32	^{226}Ra, Ra-223, Th-232, Th-230, Th-227, Am-241, Cm-244, Cm-243, Cm-242	Th-228	^{210}Po
seal	Cl-36, ^{3}H, I-125, I-129, S-35, I-131, I-133, Sr-89, Sr-90	I-132, ^{99}Tc, Ni-59, Ni-63, Pu-241, Ru-103, Cs-135, U-238	U-235, U-234, Np-237, Ce-141, Nb-95, Th-231, Ru-106, Zr-95, Eu-155, ^{228}Ra, Co-57, Sb-125, Nb-94, ^{137}Cs, Ce-144, Th-234	Te-123m, Cs-134, Cs-136, Sb-124, Co-58, Eu-152, Eu-154, Se-79, Cd-109, Co-60, C-14, Te-129m	Te-132, Mn-54, Se-75, Th-232, Th-230, ^{210}Pb, Th-227, ^{239}Pu, ^{240}Pu, ^{226}Ra, P-33, Pu-238, Am-241, Ra-223, Cm-244, Cm-243, Cm-242	Ag-110m, Th-228, P-32	^{210}Po	
gull	Cl-36, ^{3}H, I-125, I-129, S-35, I-131, I-133, Sr-89, I-132, Sr-90	Pu-241, Ni-59, ^{99}Tc, Ni-63, Ru-103, Th-231, Nb-95	Zr-95, Ce-141, Th-234, Nb-94, Cs-135, Co-57, Ru-106, Eu-155, Sb-125, Sb-124, Te-123m, ^{137}Cs, Ce-144, Cs-134, Co-58, U-238	^{228}Ra, U-235, Cs-136, Co-60, U-234, Np-237, Eu-154, Eu-152, Se-79, Mn-54,Cs-109, Se-75, C-14, Te-132, Te-129m, Th-232, Th-230	Th-227, P-33, ^{239}Pu, ^{240}Pu, Am-241, Pu-238, ^{210}Pb, Cm-244, Cm-243, Ag-110m, Cm-242, Th-228	P-32, ^{226}Ra, Ra-223	^{210}Po	

Chapter 5 – Conclusion

Until now, ecological impact devoted to radioactive substances released into ecosystems has been exclusively viewed implicitly through the human radioprotection. At the present time, although there is a considerable international effort to consider the issue of protection of the environment (IAEA, ICRP, UNSCEAR), it does not exist international standards. However, methodologies for the assessment of impact and/or risk on biota of radioactive substances have been recently developed.

In the present report, the Environmental Risk Assessment (ERA) methodology proposed by the European project ERICA is used to assess the impact on biota of radionuclides considered in the second periodic evaluation report (i.e. ^{3}H, ^{99}Tc, ^{137}Cs, ^{239,240}Pu, ^{210}Po, ^{226}Ra, ^{228}Ra, and ^{210}Pb). However, it should be noted that all these radionuclides were not measured in all regions.

For the past period (1995-2001) and each year of the assessment period, the radionuclide-specific dose rates were added per compartment (Table 5.1). These total dose rates are maximum values since all data from previous tables (Tables 4.11 to 4.13) were taken into account, included those calculated on the basis of detection limit values. Where several sums are possible, only the highest is reported. The last column gives a radionuclide ranking for 2005 on the basis of dose rates calculated from water concentration means excluding detection limits.

For radionuclides from the nuclear sector, highest dose rates were systematically estimated for R6 (including dose rate estimates for the past period) and to a lesser extent for R4, and R7 (except in 2004 for R7).

In 2005 and for radionuclides from the nuclear sector, the highest dose rates were obtained for R6 (*ca.* 0.1 µGy/h), then for R4 (*ca.* 0.01 µGy/h) both in macroalgae and invertebrates. These values are from one to three orders of magnitude higher than the dose rates summed for the same radionuclides (^{137}Cs and ^{99}Tc) for other regions (R11, R12, R13, R15). For regions R4, R6 and R13 and macroalgae and invertebrates, ^{99}Tc is the most important contributor to the “total” dose rates, delivering a dose rate one order of magnitude higher than the one delivered by ^{137}Cs. For fish, and the same region, ^{137}Cs delivers a dose rate higher than ^{99}Tc. The same kind of calculation gives a variation range for the highest sum of dose rate between 3.45 10^{-7} µGy/h (R14) and 1.15 10^{-2} µGy/h (R8) and between 2.68 10^{-7} µGy/h (R14) and 1.08 10^{-2} µGy/h (R8) for birds and mammals respectively.

In 2005, for regions where ^{3}H and ^{137}Cs data were adequate to perform the same contribution analysis, ^{137}Cs gives rise to a dose rate higher than ^{3}H does.

For radionuclides from the non-nuclear sector (^{210}Po, ^{226}Ra, ^{228}Ra, and ^{210}Pb), very few data were available and it was not possible to perform the assessment for each year. When considering the years where data were available, the highest dose rate was observed in 1976 in crustaceans with a value of 2,74 µGy/h, ^{210}Po being the most important contributor (99%).

Calculation of a dose rate on the basis of concentrations averaged on a large area may mask a local result significant in terms of effect for the population of interest. But such an impact assessment requires the full knowledge of the qualitative and quantitative radioactive contamination. Including only a few radionuclides in the assessment (as in this case) may lead to misinterpretation of the assessment in terms of the biological effect of radioactivity in the OSPAR region.

It is possible to compare the incremental dose rates summed for the selected radionuclides to the screening value of 10 µGy/h used at Tier 2 within the ERICA method to characterize the potential risk to the structure and function of the marine ecosystems in each OSPAR regions. This screening value, highly conservative, does not correspond to an agreed standard and is the lowest among guidelines values recommended by other studies, which range between 10 and 1000 µGy/h (see table 3.3). The conclusion of such comparison is robust only when input data on source term is exhaustive. Here, this constraint is not respected so any conclusion about the risk level in those OSPAR regions would be speculative. However, only as indication exemplified for 2005, it is possible to evaluate for each of the OSPAR regions the contribution of the maximum sum of dose rate to the screening value of 10µGy/h. This is illustrated on Figure 5.1 to Figure 5.6, depending on organisms and location. According to these results, the regions may be ranked as follows: less than 0.01% for R1, R2, R3, R7, R8, R9, 14, R15, between 0.01 and 0.1% fro R5, R10, R11, R12, R13, between 0.1 to 1% R4 and more than 1%, R6. For each region, radionuclides are ranked on dose rates, whether the water concentration means from which they are calculated included values at the limit of detection or not.

Finally, the partial calculated dose rates corresponding to the exposure of marine biota to radionuclides from the nuclear sector are low, and below the lowest levels at which any effects are likely to occur.

Table 5.1: Main results obtained from dose rates calculations in biota using seawater concentrations as input data for OSPAR regions and the selected radionuclides. For all compartments selected (macroalgae, invertebrates and vertebrates), the maximum sum of dose rates (in µGy/h) estimated for each radionuclide was calculated for the past period and for each year of the assessment period. The last column indicates the rank of the radionuclides by decreasing order of contribution to the total dose rate estimated for 2005. The number of symbol ">"indicates the difference in each dose rates in terms of order of magnitude (e.g., ^{137}Cs>>^{3}H means that the dose rate delivered by ^{137}Cs is two orders of magnitude higher than the dose rate delivered by ^{3}H).

		Dose rates					Radionuclides ranking* in 2005	
		Past period	2002	2003	2004	2005	excluding DL	including DL
R1	***macroalgae***	*4.86E-03*	5.55E-04	4.15E-04	3.81E-04	3.81E-04	^{137}Cs>>^{3}H	^{137}Cs>>^{3}H
	invertebrates (crab)	*4.22E-03*	4.62E-04	3.41E-04	3.31E-04	3.31E-04	^{137}Cs>>^{3}H	^{137}Cs>>>^{3}H
	vertebrates (plaice)	*3.52E-03*	2.79E-04	1.77E-04	2.76E-04	2.76E-04	^{137}Cs>>^{3}H	^{137}Cs>>>^{3}H
R2	***macroalgae***	**4.67E-03**	**4.51E-03**	**3.76E-03**	**3.69E-03**	**3.70E-03**	^{3}H	^{137}Cs>>^{3}H
	invertebrates (crab)	**4.07E-03**	**3.95E-03**	**3.28E-03**	**3.23E-03**	**3.33E-03**	^{3}H	^{137}Cs>>^{3}H
	vertebrates (plaice)	**3.42E-03**	**3.32E-03**	**2.76E-03**	**2.72E-03**	**2.81E-03**	^{3}H	^{137}Cs>>^{3}H
R3	***macroalgae***	*5.24E-03*	**3.70E-03**	**3.70E-03**	**4.05E-03**	**4.05E-03**		^{137}Cs>^{3}H
	invertebrates (crab)	*4.57E-03*	**3.23E-03**	**3.23E-03**	**3.53E-03**	**3.54E-03**		^{137}Cs>^{3}H
	vertebrates (plaice)	*3.82E-03*	**2.70E-03**	**2.70E-03**	**2.95E-03**	**2.98E-03**		^{137}Cs>^{3}H
R4	***macroalgae***	4.53E-02	3.83E-02	3.24E-02	3.15E-02	2.33E-02	^{99}Tc>^{137}Cs	^{99}Tc>^{137}Cs
	invertebrates (crab)	3.45E-02	2.91E-02	2.46E-02	2.40E-02	1.78E-02	^{99}Tc>^{137}Cs	^{99}Tc>^{137}Cs
	vertebrates (plaice)	3.12E-03	1.80E-03	1.24E-03	1.79E-03	2.00E-03	^{137}Cs>>^{99}Tc	^{137}Cs>>^{99}Tc
R5	***macroalgae***	4.55E-03	2.88E-03	2.58E-03	2.58E-03	2.58E-03	^{137}Cs	^{137}Cs
	invertebrates (crab)	3.96E-03	2.51E-03	2.24E-03	2.24E-03	2.24E-03	^{137}Cs	^{137}Cs
	vertebrates (plaice)	3.30E-03	2.09E-03	1.87E-03	1.87E-03	1.87E-03	^{137}Cs	^{137}Cs
R6	***macroalgae***	**6.45E-01**	4.38E-01	4.04E-01	2.00E-01	1.37E-01	^{99}Tc>^{137}Cs	^{99}Tc>^{137}Cs>>>^{3}H
	invertebrates (crab)	**4.88E-01**	3.29E-01	3.05E-01	1.53E-01	1.04E-01	^{99}Tc=^{137}Cs	^{99}Tc=^{137}Cs>>>^{3}H
	vertebrates (plaice)	**2.17E-02**	6.47E-04	8.56E-03	1.65E-02	8.81E-03	^{137}Cs>^{99}Tc	^{137}Cs>^{99}Tc>^{3}H
R7	***macroalgae***	**7.60E-03**	**4.52E-01**	**1.52E-02**	**5.41E-04**	*1.52E-02*		^{137}Cs>>>>^{3}H
	invertebrates (crab)	**6.61E-03**	**3.42E-01**	**1.32E-02**	**4.72E-04**	*1.32E-02*		^{137}Cs>>>>^{3}H
	vertebrates (plaice)	**5.52E-03**	**1.11E-02**	**1.10E-02**	**3.95E-04**	*1.10E-02*		^{137}Cs>>>>^{3}H
R8	***macroalgae***	2.31E-03	4.86E-04	1.63E-02	4.05E-04	**6.37E-02**	^{3}H	^{137}Cs=^{239,240}Pu>>>^{3}H
	invertebrates (crab)	6.66E-04	4.26E-04	1.41E-02	3.58E-04	**1.72E-02**	^{3}H	^{137}Cs>^{239,240}Pu>>^{3}H
	vertebrates (plaice)	1.88E-03	3.61E-04	1.18E-02	3.05E-04	**5.17E-02**	^{3}H	^{137}Cs=^{239,240}Pu>>>^{3}H
R9	***macroalgae***	4.94E-03	2.91E-03	1.52E-03	2.03E-03	4.30E-04	^{137}Cs>^{3}H	^{137}Cs>^{3}H
	invertebrates (crab)	2.93E-03	2.53E-03	5.58E-04	4.78E-04	3.78E-04	^{137}Cs>^{3}H	^{137}Cs>^{3}H
	vertebrates (plaice)	1.69E-03	2.11E-03	1.22E-03	1.67E-03	3.22E-04	^{137}Cs>^{3}H	^{137}Cs>^{3}H
R10	***macroalgae***	**5.90E-03**	6.99E-04	6.53E-04	6.95E-04	6.47E-04	^{137}Cs	^{137}Cs>>^{3}H
	invertebrates (crab)	**4.57E-03**	6.09E-04	5.70E-04	6.06E-04	5.64E-04	^{137}Cs	^{137}Cs>>^{3}H
	vertebrates (plaice)	**8.15E-04**	5.11E-04	4.78E-04	5.08E-04	4.72E-04	^{137}Cs	^{137}Cs>>^{3}H
R11	***macroalgae***	6.16E-03	2.91E-03	3.57E-03	5.45E-03	3.36E-03	^{99}Tc=^{137}Cs	^{99}Tc=^{137}Cs
	invertebrates (crab)	4.89E-03	2.18E-03	2.80E-03	4.27E-03	2.68E-03	^{99}Tc=^{137}Cs	^{99}Tc=^{137}Cs
	vertebrates (plaice)	1.62E-03	3.09E-06	7.29E-04	1.10E-03	9.49E-04	^{137}Cs>>^{99}Tc	^{137}Cs>>^{99}Tc
R12	***macroalgae***	6.82E-03	**1.00E-02**	9.20E-03	7.71E-03	8.17E-03	^{137}Cs>^{99}Tc	^{137}Cs>^{99}Tc>^{3}H
	invertebrates (crab)	5.67E-03	**8.60E-03**	7.87E-03	6.60E-03	7.01E-03	^{137}Cs>^{99}Tc	^{137}Cs>^{99}TC>^{3}H
	vertebrates (plaice)	3.34E-03	**6.64E-03**	5.93E-03	4.98E-03	5.31E-03	^{137}Cs>>>>^{99}Tc	^{137}Cs>>^{3}H>>^{99}Tc
R13	***macroalgae***	2.55E-03	2.39E-03	1.84E-03	1.69E-03	1.99E-03	^{99}Tc>^{137}Cs	^{99}Tc>^{137}Cs
	invertebrates (crab)	1.99E-03	1.88E-03	1.44E-03	1.30E-03	1.55E-03	^{99}Tc>^{137}Cs	^{99}Tc>^{137}Cs
	vertebrates (plaice)	4.86E-04	4.97E-04	3.43E-04	2.33E-04	3.32E-04	^{137}Cs>>^{99}Tc	^{137}Cs>>^{99}Tc
R14	***macroalgae***	1.73E-03	3.08E-04	8.55E-05	3.25E-04	3.25E-04	^{99}Tc	^{99}Tc
	invertebrates (crab)	1.36E-03	2.31E-04	6.42E-05	2.44E-04	2.44E-04	^{99}Tc	^{99}Tc
	vertebrates (plaice)	3.86E-04	3.27E-07	9.09E-08	3.45E-07	3.45E-07	^{99}Tc	^{99}Tc
R15	***macroalgae***	6.91E-04	8.29E-04	7.71E-04	7.55E-04	5.69E-04	^{137}Cs=^{99}Tc	^{137}Cs=^{99}Tc
	invertebrates (crab)	6.00E-04	6.95E-04	6.42E-04	6.28E-04	4.71E-04	^{137}Cs=^{99}Tc	^{137}Cs=^{99}Tc
	vertebrates (plaice)	5.01E-04	4.40E-04	3.85E-04	3.74E-04	2.64E-04	^{137}Cs>>>^{99}Tc	^{137}Cs>>>^{99}Tc

* ranking based on dose rates calculated either on water concentrations excluding detection limits (excluding DL) or on all available data (including DL)

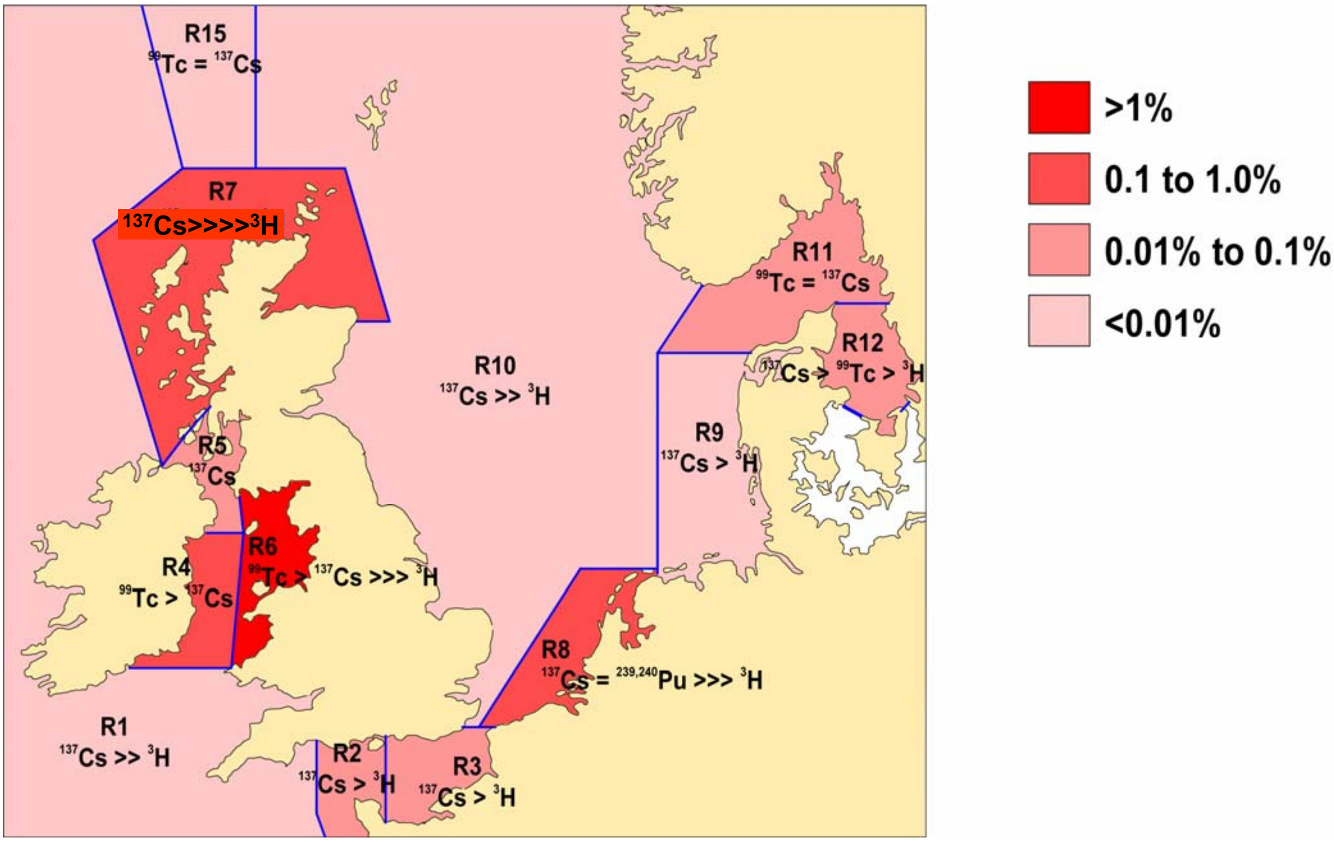

Figure 5.1: Graphical representation (colour code) of the percentage contribution of the maximum total dose rates (sum on detected radionuclides) to the screening value of 10µGy/h for macroalgae in the North Sea and surrounding waters in 2005. Rank of radionuclides by decreasing order of contribution to the total dose rate is also stated for each region. The use of the symbol ">"indicates the difference in dose rates, in terms of order of magnitude, between radionuclides for a particular region. For example $^{137}Cs >> ^{3}H$ means that the dose rate delivered by ^{137}Cs is two orders of magnitude higher than the dose rate delivered by ^{3}H. The use of the symbol "=" indicates that dose rates from radionuclides are of a similar order of magnitude. Where two doses are stated in associated tables (4.11 to 4.13), use of the value based only on real data (excluding data at the detection limit).

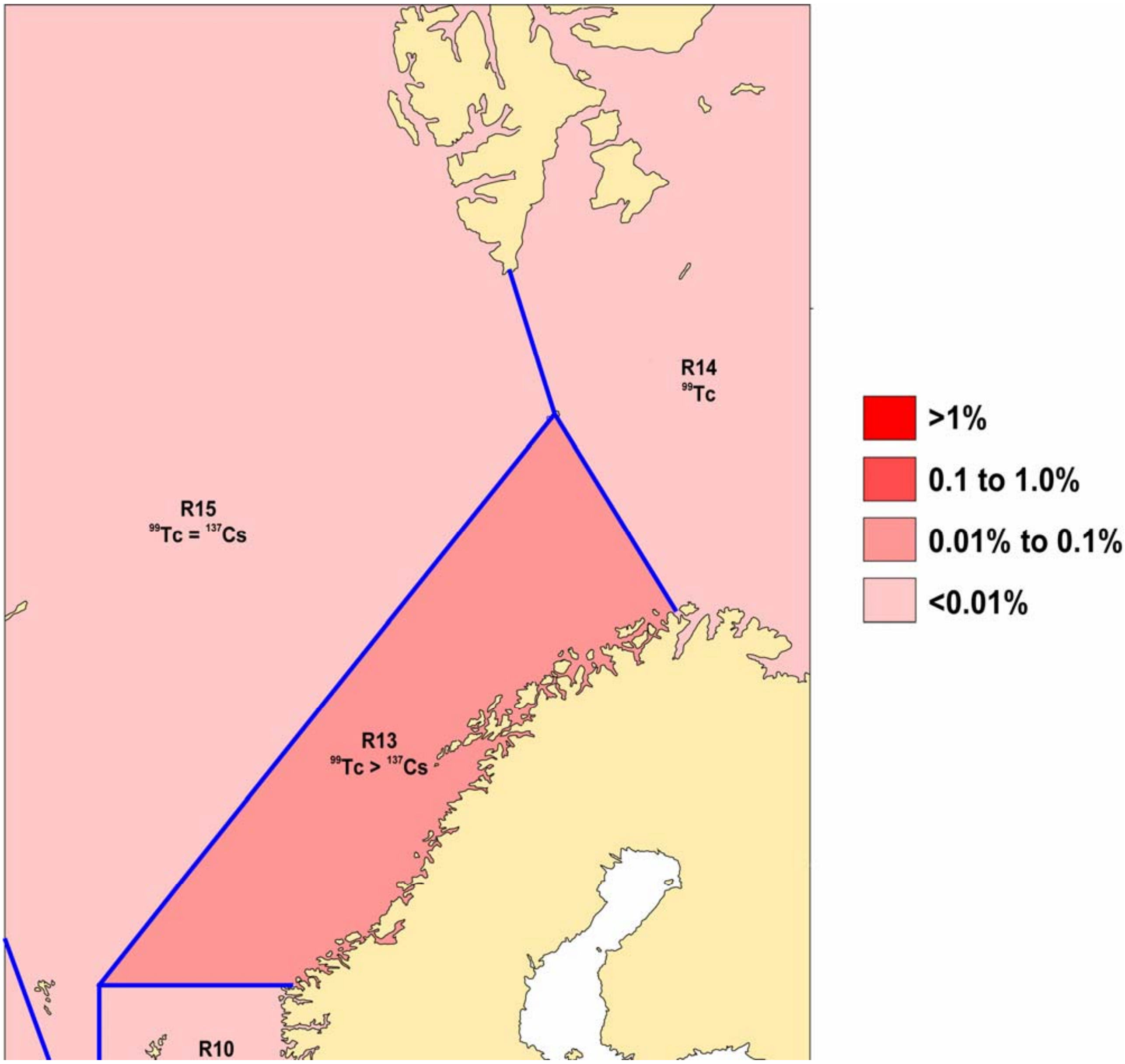

Figure 5.2: Graphical representation (colour code) of the percentage contribution of the maximum total dose rates (sum on detected radionuclides) to the screening value of 10µGy/h for macroalgae in the Norwegian Sea and surrounding waters. Rank of radionuclides by decreasing order of contribution to the total dose rate is also stated for each region. The use of the symbol ">"indicates the difference in dose rates, in terms of order of magnitude, between radionuclides for a particular region. For example ^{137}Cs >> ^{3}H means that the dose rate delivered by ^{137}Cs is two orders of magnitude higher than the dose rate delivered by ^{3}H. The use of the symbol "=" indicates that dose rates from radionuclides are of a similar order of magnitude. Where two doses are stated in associated tables (4.11 to 4.13), use of the value based only on real data (excluding data at the detection limit).

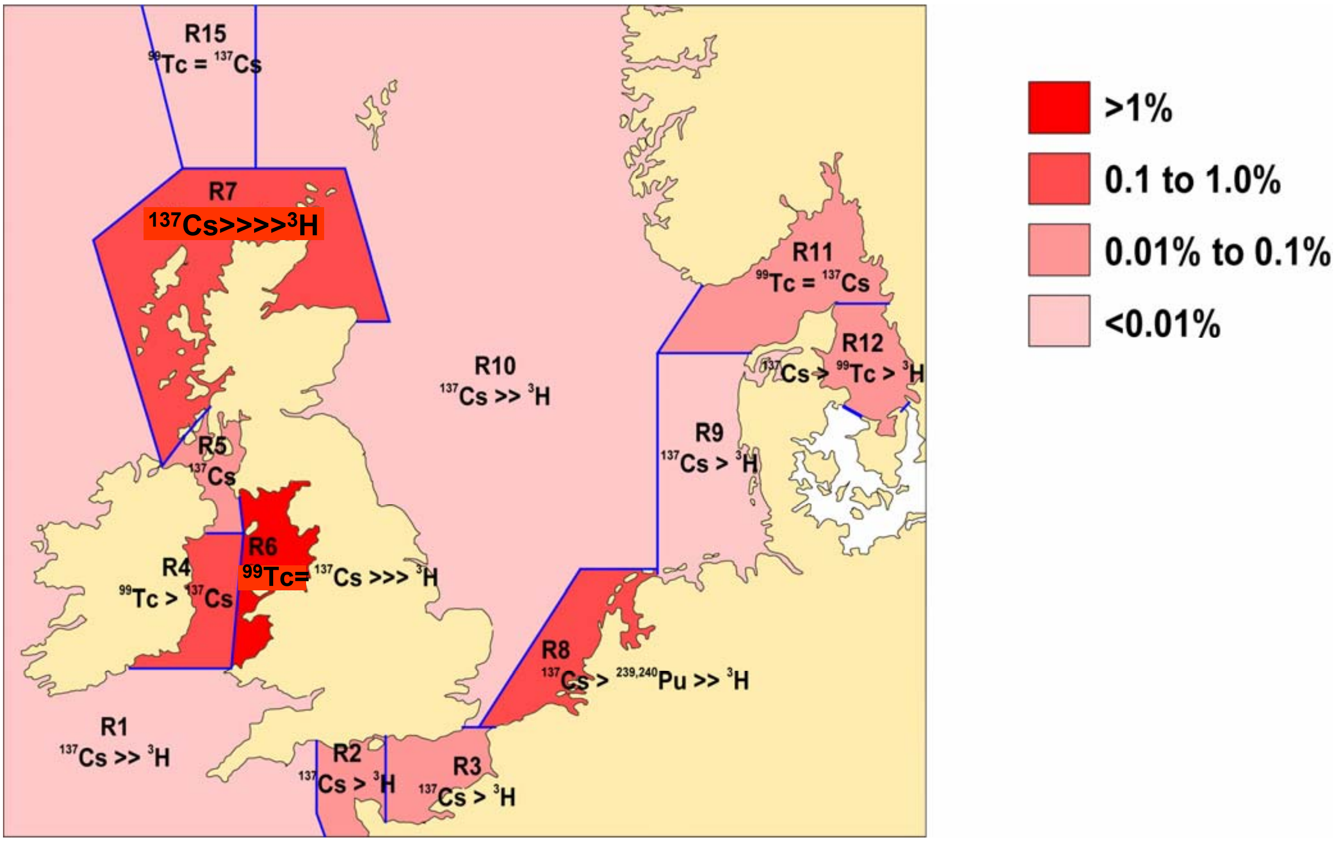

Figure 5.3: Graphical representation (colour code) of the percentage contribution of the maximum total dose rates (sum on detected radionuclides) to the screening value of 10µGy/h for invertebrates (crab) in the North Sea and surrounding waters. Rank of radionuclides by decreasing order of contribution to the total dose rate is also stated for each region. The use of the symbol ">"indicates the difference in dose rates, in terms of order of magnitude, between radionuclides for a particular region. For example ^{137}Cs >> ^{3}H means that the dose rate delivered by ^{137}Cs is two orders of magnitude higher than the dose rate delivered by ^{3}H. The use of the symbol "=" indicates that dose rates from radionuclides are of a similar order of magnitude. Where two doses are stated in associated tables (4.11 to 4.13), use of the value based only on real data (excluding data at the detection limit).

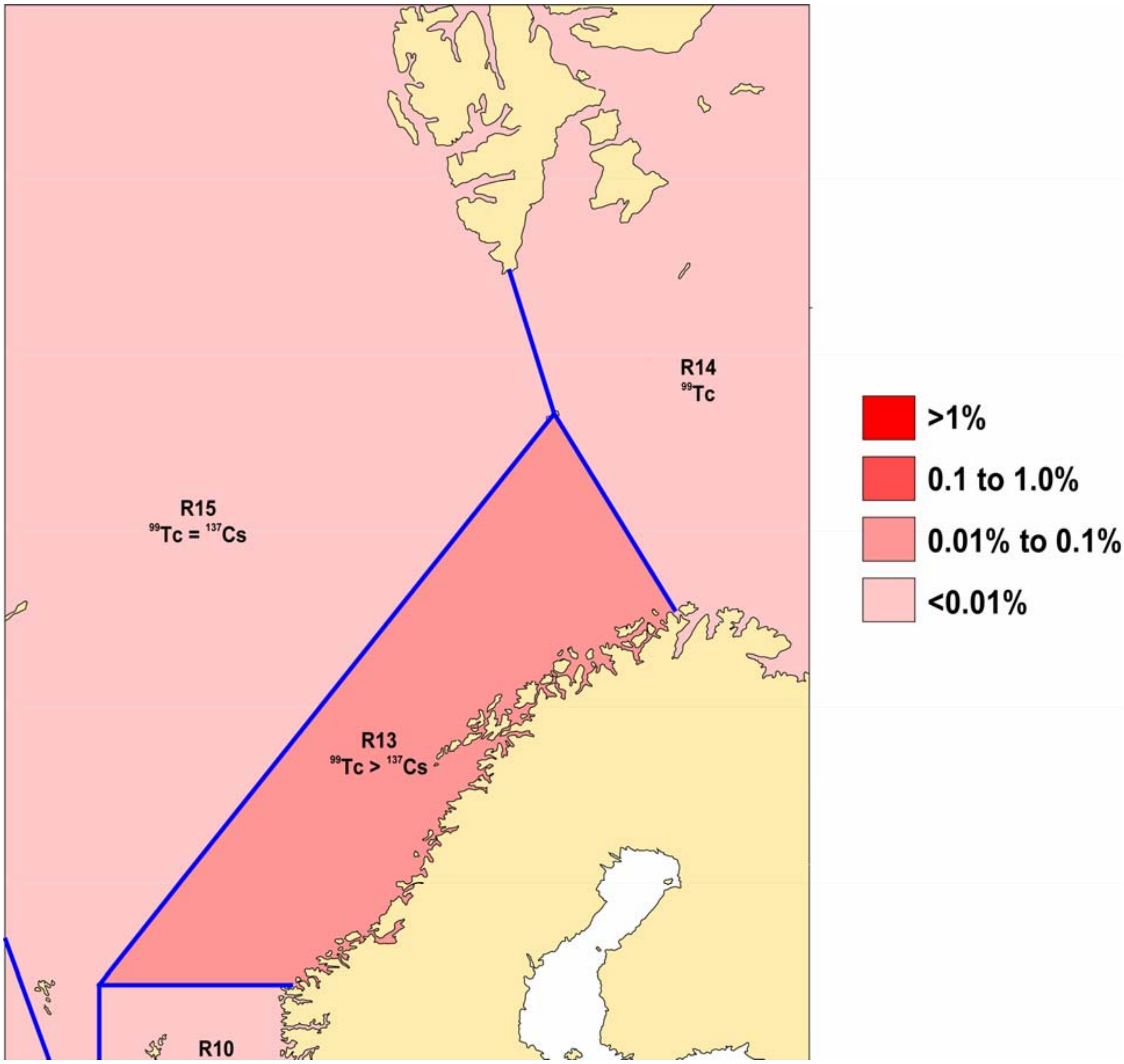

Figure 5.4: Graphical representation (colour code) of the percentage contribution of the maximum total dose rates (sum on detected radionuclides) to the screening value of 10µGy/h for invertebrates (crab) in the Norwegian Sea and surrounding waters. Rank of radionuclides by decreasing order of contribution to the total dose rate is also stated for each region. The use of the symbol ">"indicates the difference in dose rates, in terms of order of magnitude, between radionuclides for a particular region. For example ^{137}Cs >> ^{3}H means that the dose rate delivered by ^{137}Cs is two orders of magnitude higher than the dose rate delivered by ^{3}H. The use of the symbol "=" indicates that dose rates from radionuclides are of a similar order of magnitude. Where two doses are stated in associated tables (4.11 to 4.13), use of the value based only on real data.

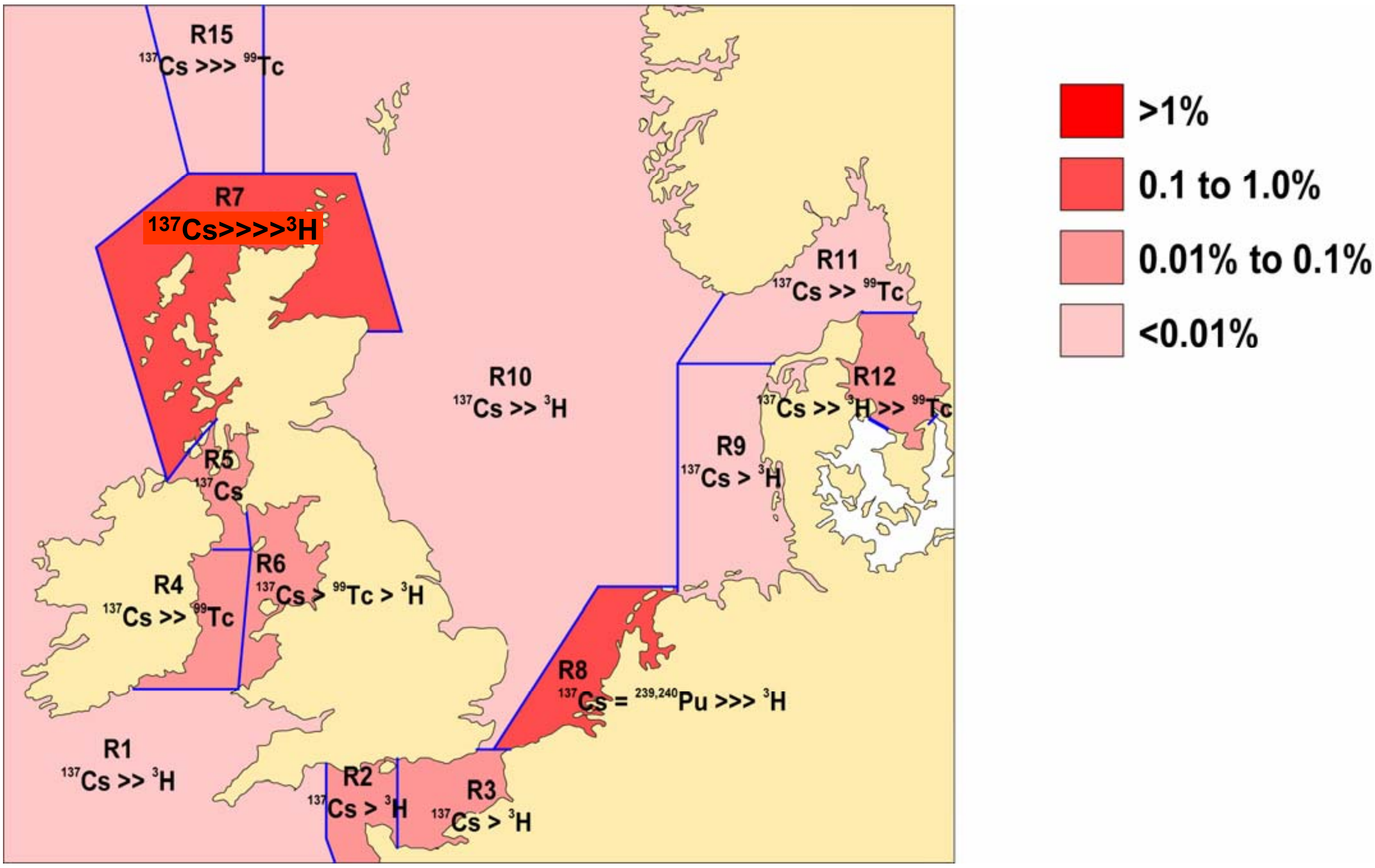

Figure 5.5: Graphical representation (colour code) of the percentage contribution of the maximum total dose rates (sum on detected radionuclides) to the screening value of 10µGy/h for vertebrates (plaice) in the North Sea and surrounding waters. Rank of radionuclides by decreasing order of contribution to the total dose rate is also stated for each region. The use of the symbol ">"indicates the difference in dose rates, in terms of order of magnitude, between radionuclides for a particular region. For example ^{137}Cs >> ^{3}H means that the dose rate delivered by ^{137}Cs is two orders of magnitude higher than the dose rate delivered by ^{3}H. The use of the symbol "=" indicates that dose rates from radionuclides are of a similar order of magnitude. Where two doses are stated in associated tables (4.11 to 4.13), use of the value based only on real data (excluding data at the detection limit).

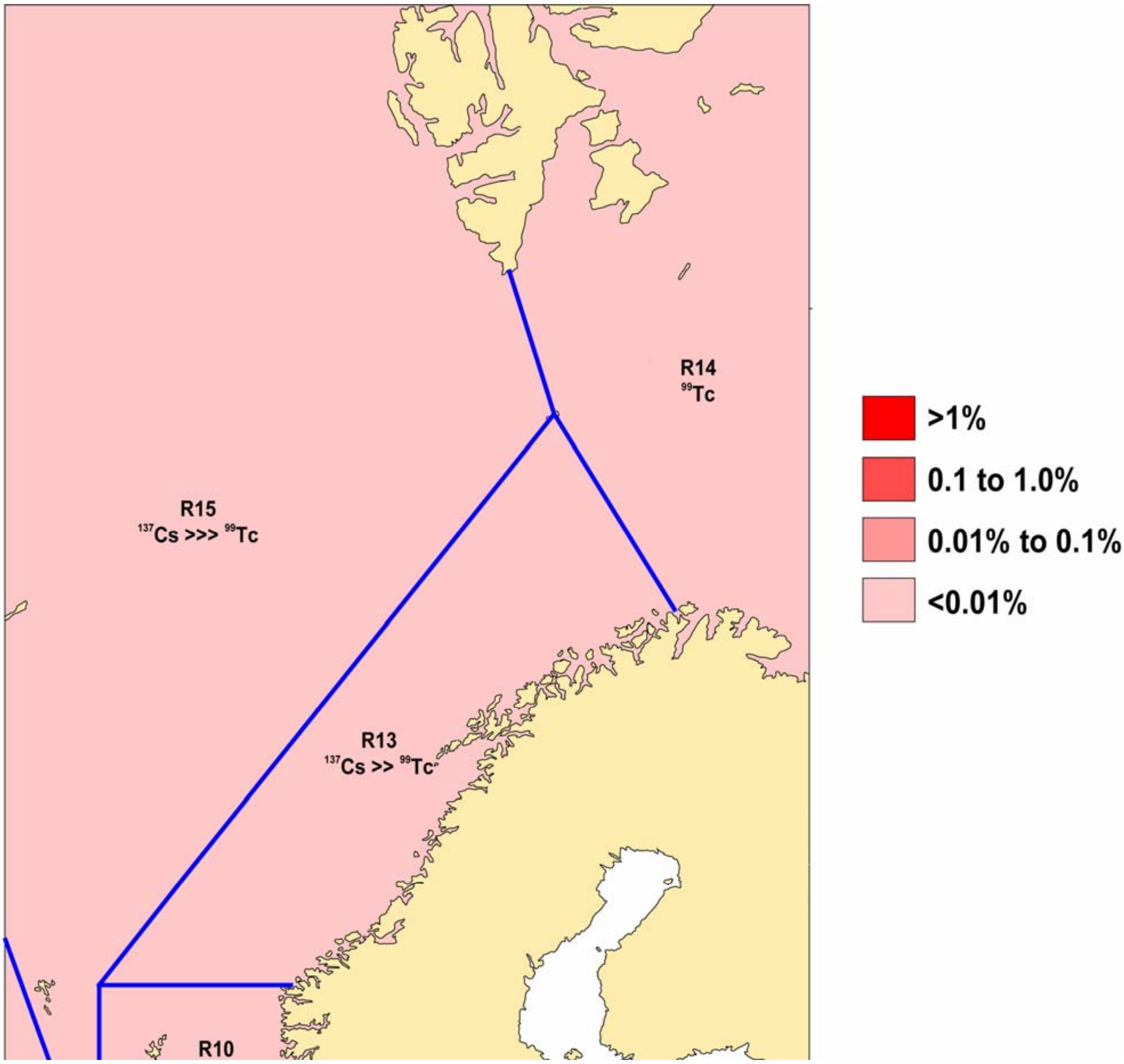

Figure 5.6: Graphical representation (colour code) of the percentage contribution of the maximum total dose rates (sum on detected radionuclides) to the screening value of 10µGy/h for vertebrates (plaice) in the Norwegian Sea and surrounding waters. Rank of radionuclides by decreasing order of contribution to the total dose rate is also stated for each region. The use of the symbol ">"indicates the difference in dose rates, in terms of order of magnitude, between radionuclides for a particular region. For example ^{137}Cs >> ^{3}H means that the dose rate delivered by ^{137}Cs is two orders of magnitude higher than the dose rate delivered by ^{3}H. The use of the symbol "=" indicates that dose rates from radionuclides are of a similar order of magnitude. Where two doses are stated in associated tables (4.11 to 4.13), use of the value based only on real data (excluding data at the detection limit).

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Annex 1 - Regions identified for the establishment of baselines on concentrations of radioactive substances

1. Wider Atlantic, Iberian Coast and Biscay and Channel West
2. Channel (Cap de la Hague)
3. Channel East
4. Irish Sea (Rep. of Ireland)
5. Irish Sea (Northern Ireland)
6. Irish Sea (Sellafield)
7. Scottish waters (Dounreay)
8. North Sea South (Belgian and Dutch Coast)
9. German Bight
10. North Sea (Northwest, Southeast and Central)
11. North Sea (Skagerrak)
12. Kattegat
13. Norwegian Coastal Current
14. Barents Sea
15. Norwegian, Greenland Seas and Icelandic Waters

Annex 2 – Radionuclide-specific concentration ratios for the reference organisms as selected in correspondence for ERICA, RESRAD-BIOTA and Environment Agency R&D 128.

Large taxa categories used for concentration ratio determination and corresponding OSPAR reference organisms:

Pelagic fish:	Cod Herring
	Sardine
	Sprat
Benthic fish:	Haddock
	Plaice
Molluscs:	Mussel
	Winkle
Large benthic crustaceans:	Crab
Small benthic crustaceans:	Shrimp
Seabird:	Gull
Mammal:	Seal
Macrophyte:	Macroalgae

In RESRAD-BIOTA, there is no reference to marine ecosystem. Values reported hereafter are then related to freshwater ecosystem.

The concentration ratios related to the pelagic fish are given in the text (Table 4.4).

Table A2-1: Radionuclide-specific concentration ratios for benthic fish

	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	1.00E+00	2.00E-01	1.00E-03
^{99}Tc	3.10E+01	7.80E+01	3.00E-02
^{137}Cs	8.60E+01	2.20E+04	1.00E-01
^{239}Pu	3.50E+03	1.00E+03	4.00E-02
^{240}Pu	3.50E+03	n.d.	n.d.
^{210}Pb	2.00E+02	n.d.	n.d.
^{210}Po	1.70E+04	n.d.	2.00E+00
^{226}Ra	2.80E+02	3.20E+03	n.d.
^{228}Ra	2.80E+02	3.20E+03	n.d.

n.d.: no data

Table A2-2: Radionuclide-specific concentration ratios for molluscs

	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	1.00E+00	2.00E-01	1.00E-03
^{99}Tc	8.90E+03	7.80E+01	1.00E+00
^{137}Cs	6.60E+01	2.20E+04	3.00E-02
^{239}Pu	1.10E+03	1.00E+03	3.00E+00
^{240}Pu	1.10E+03	n.d.	n.d.
^{210}Pb	1.70E+03	n.d.	n.d.
^{210}Po	3.50E+04	n.d.	1.00E+01
^{226}Ra	6.50E+01	3.20E+03	n.d.
^{228}Ra	6.50E+01	3.20E+03	n.d.

n.d.: no data

Table A2-3: Radionuclide-specific concentration ratios for large benthic crustacean

	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	1.00E+00	2.00E-01	1.00E-03
^{99}Tc	2.20E+04	7.80E+01	8.00E+00
^{137}Cs	4.10E+01	2.20E+04	3.00E-02
^{239}Pu	1.60E+02	1.00E+03	3.00E-01
^{240}Pu	1.60E+02	n.d.	n.d.
^{210}Pb	1.00E+04	n.d.	n.d.
^{210}Po	6.00E+04	n.d.	5.00E+01
^{226}Ra	1.50E+02	3.20E+03	n.d.
^{228}Ra	1.50E+02	3.20E+03	n.d.

n.d.: no data

Table A2-4: Radionuclide-specific concentration ratios for small benthic crustacean

	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	1.00E+00	2.00E-01	1.00E-03
^{99}Tc	2.20E+04	7.80E+01	1.00E+00
^{137}Cs	4.10E+01	2.20E+04	3.00E-02
^{239}Pu	1.60E+02	1.00E+03	3.00E-01
^{240}Pu	1.60E+02	n.d.	n.d.
^{210}Pb	1.00E+04	n.d.	n.d.
^{210}Po	6.00E+04	n.d.	5.00E+01
^{226}Ra	1.50E+02	3.20E+03	n.d.
^{228}Ra	1.50E+02	3.20E+03	n.d.

n.d.: no data

Table A2-5: Radionuclide-specific concentration ratios for seabird

	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	1.00E+00	2.00E-01	1.00E-03
^{99}Tc	3.10E+01	7.80E+01	8.00E+00
^{137}Cs	4.60E+02	2.20E+04	3.00E+00
^{239}Pu	1.50E+02	1.00E+03	1.00E+02
^{240}Pu	1.50E+02	n.d.	n.d.
^{210}Pb	1.90E+04	n.d.	n.d.
^{210}Po	1.00E+04	n.d.	2.00E+04
^{226}Ra	2.80E+02	3.20E+03	n.d.
^{228}Ra	2.80E+02	3.20E+03	n.d.

n.d.: no data

Table A2-6: Radionuclide-specific concentration ratios for seal

	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	1.00E+00	2.00E-01	1.00E-03
^{99}Tc	2.40E+01	7.80E+01	8.00E+00
^{137}Cs	2.10E+02	2.20E+04	4.90E-01
^{239}Pu	2.80E+02	1.00E+03	1.00E+02
^{240}Pu	2.80E+02	n.d.	n.d.
^{210}Pb	1.90E+04	n.d.	n.d.
^{210}Po	1.00E+04	n.d.	2.00E+04
^{226}Ra	6.00E+01	3.20E+03	n.d.
^{228}Ra	6.00E+01	3.20E+03	n.d.

n.d.: no data

Table A2-7: Radionuclide-specific concentration ratios for macroalgae

	ERICA	RESRAD-BIOTA	Environment Agency R&D 128
^{3}H	1.00E+00	n.d.	1.00E-03
^{99}Tc	3.00E+04	n.d.	1.00E+00
^{137}Cs	1.20E+02	n.d.	5.00E-02
^{239}Pu	4.10E+03	n.d.	2.00E+00
^{240}Pu	4.10E+03	n.d.	n.d.
^{210}Pb	1.00E+03	n.d.	n.d.
^{210}Po	1.00E+03	n.d.	1.00E+00
^{226}Ra	8.90E+01	n.d.	n.d.
^{228}Ra	8.90E+01	n.d.	n.d.

n.d.: no data

Annex 3 – Comparison of values of common parameters (CR or concentration ratios) between this assessment and the human dose calculations done in the OSPAR RA-2 report.

Table A3.1: Radionuclide-specific Concentration Ratios for each type of organisms common between the human (see RA-2 – Annex 3 Table A3.1) and the biota dose assessments.

Trophic level	CR invertebrates				CR vertebrates	
	molluscs		crustaceans		fish	
Dose assessment	human	biota	human	biota	human	biota
Radionuclides						
^{3}H	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00	1.00E+00
^{99}Tc	1.00E+03	8.90E+03	1.00E+03	2.20E+04	3.00E+01	3.10E+01
^{137}Cs	3.00E+01	6.60E+01	3.00E+01	4.10E+01	1.00E+02	8.60E+01
^{239}Pu	3.00E+03	1.10E+03	2.00E+02	1.60E+02	1.00E+02	3.50E+03
^{240}Pu	3.00E+03	1.10E+03	2.00E+02	1.60E+02	1.00E+02	3.50E+03
^{210}Pb	1.00E+03	1.70E+03	1.00E+03	1.00E+04	2.00E+02	2.00E+02
^{210}Po	1.00E+04	3.50E+04	5.00E+04	6.00E+04	2.00E+04	1.70E+04
^{228}Ra	1.00E+03	6.50E+01	1.00E+02	1.50E+02	5.00E+02	2.80E+02
^{226}Ra	1.00E+03	6.50E+01	1.00E+02	1.50E+02	5.00E+02	2.80E+02

Annex 4 – Comparison of DCC values for the reference organisms as selected in correspondence for ERICA, RESRAD-BIOTA and Environment Agency R&D 128.

Table A4.1: Weighted DCC (µGy/h) calculated with RESRAD-BIOTA for the geometries associated with the OSPAR reference organisms, applying a weight of 10 to alpha radiation and 1 to beta and gamma radiation.

RESRAD-BIOTA	Geometry 2		Geometry 3		Geometry 4		Geometry 6	
OSPAR	Winkle		Sardine, sprat, mussel, crab, shrimp, gull		Cod, haddock, herring, plaice		Seal	
exposure	external	internal	external	internal	external	internal	external	internal
^{3}H	1.03E-10	1.20E-06	4.92E-11	1.20E-06	9.92E-13	1.20E-06	0.00E+00	1.20E-06
^{99}Tc	2.65E-05	2.11E-05	2.58E-05	2.18E-05	2.35E-05	2.40E-05	1.27E-05	3.48E-05
^{137}Cs	1.21E-04	4.92E-05	1.17E-04	5.42E-05	1.07E-04	6.42E-05	6.54E-05	1.05E-04
^{239}Pu	8.46E-08	1.10E-02	4.88E-08	1.10E-02	1.95E-08	1.10E-02	4.14E-09	1.10E-02
^{240}Pu	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^{210}Pb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^{210}Po	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^{226}Ra	4.63E-04	7.33E-02	4.25E-04	7.33E-02	3.84E-04	7.33E-02	2.42E-04	7.38E-02
^{228}Ra	5.25E-04	6.88E-02	4.92E-04	6.88E-02	4.46E-04	6.88E-02	2.92E-04	6.88E-02

n.d.: no data

Table A4.2: Weighted DCC (µGy/h) calculated with Environment Agency R&D 128 for the non vertebrate taxa associated with the OSPAR reference organisms, applying a weight of 10 to alpha radiation, 3 to low beta radiation and 1 to beta and gamma radiation.

Environment Agency R&D 128	Macrophyte		Molluscs		Small benthic crustaceans		Large benthic crustaceans	
OSPAR	macroalgae		Mussel, winkle		Shrimp		Crab	
exposure	external	internal	external	internal	external	internal	external	internal
^{3}H	1.29E-08	9.90E-06	1.38E-09	9.90E-06	1.14E-08	9.90E-06	1.41E-09	9.90E-06
^{99}Tc	6.00E-06	5.20E-05	8.90E-07	5.80E-05	5.30E-06	5.30E-05	7.60E-07	5.80E-05
^{137}Cs	3.70E-04	9.47E-05	3.40E-04	1.31E-04	3.70E-04	9.87E-05	3.30E-04	1.41E-04
^{239}Pu	4.05E-07	3.00E-02	3.01E-07	3.00E-02	4.25E-07	3.00E-02	2.91E-07	3.00E-02
^{240}Pu	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^{210}Pb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^{210}Po	4.90E-09	3.10E-02	4.90E-09	3.10E-02	4.90E-09	3.10E-02	4.80E-09	3.10E-02
^{226}Ra	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^{228}Ra	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d.: no data

Table A4.3: Weighted DCC (µGy/h) calculated with Environment Agency R&D 128 for the vertebrate taxa associated with the OSPAR reference organisms, applying a weight of 10 to alpha radiation, 3 to low beta radiation and 1 to beta and gamma radiation.

Environment Agency R&D 128	Fish		Seabird		Seal	
OSPAR	Cod, haddock, herring, sardine, sprat, plaice		Gull		Seal	
exposure	external	internal	external	internal	external	internal
^{3}H	5.40E-10	9.90E-06	2.01E-10	9.90E-06	1.68E-11	9.90E-06
^{99}Tc	1.60E-07	5.80E-05	9.30E-08	6.30E-04	1.70E-08	6.40E-04
^{137}Cs	2.90E-04	1.71E-04	2.90E-04	1.81E-04	2.20E-04	2.51E-04
^{239}Pu	2.10E-07	3.00E-02	1.10E-07	3.00E-02	1.20E-07	3.00E-02
^{240}Pu	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^{210}Pb	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^{210}Po	4.40E-09	3.10E-02	4.30E-09	3.10E-02	3.30E-09	3.10E-02
^{226}Ra	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
^{228}Ra	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d.: no data

Table A4.4: Weighted DCC (µGy/h) calculated with ERICA for the OSPAR reference bird and mammal, applying a weight of 10 to alpha radiation, 3 to low beta radiation and 1 to beta and gamma radiation.

OSPAR	Gull		Seal	
exposure	external	internal	external	internal
^{3}H	8.11E-15	8.22E-06	3.55E-14	8.22E-06
^{99}Tc	1.50E-07	5.86E-05	2.75E-08	5.87E-05
^{137}Cs	2.88E-04	1.82E-04	1.57E-04	3.13E-04
^{239}Pu	9.06E-08	2.97E-02	2.41E-08	2.97E-02
^{240}Pu	1.65E-07	2.97E-02	3.09E-08	2.97E-02
^{210}Pb	4.74E-06	2.53E-04	9.98E-07	2.57E-04
^{210}Po	4.34E-09	3.06E-02	2.44E-09	3.06E-02
^{226}Ra	9.24E-04	1.39E-01	5.39E-04	1.39E-01
^{228}Ra	4.99E-04	3.63E-04	2.84E-04	5.79E-04

Table A4.5: Weighted DCC (µGy/h) calculated with ERICA for the OSPAR reference plant and invertebrates, applying a weight of 10 to alpha radiation, 3 to low beta radiation and 1 to beta and gamma radiation.

OSPAR	Macroalgae		Mussel		Winkle		Crab		Shrimp	
exposure	external	internal	external	internal	external	internal	external	internal	external	internal
^{3}H	2.60E-11	8.27E-06	4.27E-14	8.22E-06	5.03E-14	8.22E-06	2.23E-12	8.22E-06	4.27E-14	8.22E-06
^{99}Tc	1.50E-06	5.70E-05	6.58E-07	5.81E-05	7.72E-07	5.80E-05	3.47E-07	5.84E-05	6.62E-07	5.81E-05
^{137}Cs	3.40E-04	1.30E-04	3.25E-04	1.45E-04	3.27E-04	1.43E-04	3.13E-04	1.56E-04	3.26E-04	1.44E-04
^{239}Pu	3.00E-07	3.00E-02	2.34E-07	2.97E-02	2.49E-07	2.97E-02	1.65E-07	2.97E-02	2.43E-07	2.97E-02
^{240}Pu	6.80E-07	3.00E-02	5.22E-07	2.97E-02	5.61E-07	2.97E-02	3.47E-07	2.97E-02	5.44E-07	2.97E-02
^{210}Pb	4.70E-05	2.08E-04	1.89E-05	2.39E-04	2.20E-05	2.36E-04	1.02E-05	2.48E-04	2.02E-05	2.38E-04
^{210}Po	4.90E-09	3.10E-02	4.80E-09	3.06E-02	4.82E-09	3.06E-02	4.68E-09	3.06E-02	4.81E-09	3.06E-02
^{226}Ra	1.10E-03	1.36E-01	1.07E-03	1.39E-01	1.08E-03	1.39E-01	1.01E-03	1.39E-01	1.07E-03	1.39E-01
^{228}Ra	6.00E-04	2.59E-04	5.69E-04	2.93E-04	5.75E-04	2.87E-04	5.45E-04	3.18E-04	5.72E-04	2.91E-04

Table A4.6: Weighted DCC (µGy/h) calculated with ERICA for the OSPAR reference fish, applying a weight of 10 to alpha radiation, 3 to low beta radiation and 1 to beta and gamma radiation.

	Cod		Haddock		Herring		Plaice		Sardine		Sprat	
exposure	external	internal	external	internal	external	internal	external	internal	external	internal	external	internal
^{3}H	3.68E-13	8.22E-06	3.68E-13	8.22E-06	1.07E-14	8.22E-06	7.22E-15	8.22E-06	2.53E-12	8.22E-06	4.27E-14	8.22E-06
^{99}Tc	1.14E-07	5.86E-05	1.14E-07	5.86E-05	1.85E-07	5.86E-05	1.38E-07	5.86E-05	3.84E-07	5.84E-05	6.75E-07	5.81E-05
^{137}Cs	2.83E-04	1.87E-04	2.83E-04	1.87E-04	3.00E-04	1.70E-04	2.97E-04	1.73E-04	3.19E-04	1.51E-04	3.27E-04	1.43E-04
^{239}Pu	7.83E-08	2.97E-02	7.83E-08	2.97E-02	1.15E-07	2.97E-02	1.03E-07	2.97E-02	1.95E-07	2.97E-02	2.50E-07	2.97E-02
^{240}Pu	1.34E-07	2.97E-02	1.34E-07	2.97E-02	2.24E-07	2.97E-02	1.94E-07	2.97E-02	4.22E-07	2.97E-02	5.62E-07	2.97E-02
^{210}Pb	3.80E-06	2.54E-04	3.80E-06	2.54E-04	6.07E-06	2.52E-04	5.40E-06	2.53E-04	1.38E-05	2.44E-04	2.20E-05	2.36E-04
^{210}Po	4.27E-09	3.06E-02	4.27E-09	3.06E-02	4.52E-09	3.06E-02	4.47E-09	3.06E-02	4.75E-09	3.06E-02	4.82E-09	3.06E-02
^{226}Ra	9.09E-04	1.39E-01	9.09E-04	1.39E-01	9.64E-04	1.39E-01	9.56E-04	1.39E-01	1.04E-03	1.39E-01	1.08E-03	1.39E-01
^{228}Ra	4.91E-04	3.71E-04	4.91E-04	3.71E-04	5.21E-04	3.42E-04	5.16E-04	3.47E-04	5.56E-04	3.06E-04	5.75E-04	2.88E-04

Annex 5 – Concentration-to-dose rate conversion coefficients for the full list of radionuclides present in the ERICA tool.

Table A5.1: concentration-to-dose-rate conversion coefficients per OSPAR reference organism calculated for the full list of radionuclides present in the ERICA tool.

µGy/h per Bq/l	Cod	Crab	Gull	Haddock	Herring	Macro-algae	Mussel	Plaice	Sardine	Seal	Shrimp	Sprat	Winkle
Ag-110m	1.15E+00	3.47E+00	5.10E+00	1.70E+00	5.10E-01	1.68E+00	4.22E+00	1.71E+00	2.96E-01	1.83E+01	1.28E+00	2.27E-01	4.04E+00
Am-241	2.48E+00	4.40E+01	4.75E+00	3.34E+00	1.84E+00	2.97E+01	2.59E+02	3.76E+00	1.84E+00	8.86E+00	4.11E+01	1.84E+00	2.60E+02
C-14	3.51E-01	2.92E-01	4.97E-01	3.51E-01	3.51E-01	2.28E-01	2.92E-01	3.51E-01	3.51E-01	4.98E-01	2.92E-01	3.50E-01	2.92E-01
Cd-109	1.01E-01	1.59E+00	3.00E-01	1.08E-01	9.34E-02	8.89E-02	5.22E+00	1.11E-01	8.81E-02	3.21E-01	1.49E+00	8.58E-02	5.19E+00
Ce-141	3.34E+00	1.31E+01	1.27E-02	7.78E+00	1.25E-02	1.49E+01	1.36E+01	9.46E+00	1.21E-02	1.53E-02	3.37E-01	1.19E-02	1.38E+01
Ce-144	5.76E+00	3.92E+01	8.66E-02	1.33E+01	8.46E-02	9.70E+01	6.43E+01	2.19E+01	7.65E-02	9.19E-02	1.93E+00	6.72E-02	7.30E+01
Cl-36	1.00E-05	1.07E-05	5.62E-06	9.75E-06	1.10E-05	1.29E-04	1.09E-05	9.90E-06	1.39E-05	5.56E-06	1.65E-05	1.73E-05	1.15E-05
Cm-242	3.53E+00	4.58E+01	5.28E+00	3.54E+00	3.52E+00	4.20E+02	1.13E+03	3.56E+00	3.52E+00	9.86E+00	4.58E+01	3.52E+00	1.13E+03
Cm-243	7.09E+00	5.78E+01	5.03E+00	1.21E+01	3.35E+00	4.16E+02	1.09E+03	1.39E+01	3.35E+00	9.40E+00	4.36E+01	3.35E+00	1.09E+03
Cm-244	3.35E+00	4.35E+01	5.01E+00	3.36E+00	3.34E+00	3.96E+02	1.07E+03	3.38E+00	3.34E+00	9.36E+00	4.35E+01	3.34E+00	1.07E+03
Co-57	7.52E-01	2.05E+00	1.87E-02	1.46E+00	1.93E-01	2.13E+00	2.20E+00	1.70E+00	1.72E-01	3.59E-02	5.33E-02	1.65E-01	2.21E+00
Co-58	5.50E+00	1.64E+01	9.48E-02	1.14E+01	9.44E-01	1.71E+01	1.72E+01	1.33E+01	7.90E-01	2.04E-01	2.39E-01	7.36E-01	1.73E+01
Co-60	1.27E+01	4.18E+01	1.04E-01	2.81E+01	8.97E-01	4.21E+01	4.30E+01	3.29E+01	5.50E-01	3.61E-01	1.46E-01	4.40E-01	4.31E+01
Cs-134	1.12E-01	3.49E-01	9.27E-02	2.37E-01	1.52E-02	3.72E-01	3.60E-01	2.77E-01	1.15E-02	1.17E-01	5.40E-03	1.02E-02	3.61E-01
Cs-135	3.40E-03	1.67E-03	1.81E-02	3.41E-03	3.39E-03	4.82E-03	2.69E-03	3.41E-03	3.39E-03	8.29E-03	1.61E-03	3.38E-03	2.70E-03
Cs-136	1.52E-01	4.84E-01	1.04E-01	3.27E-01	1.67E-02	4.92E-01	4.97E-01	3.82E-01	1.17E-02	1.48E-01	5.54E-03	1.01E-02	4.99E-01
^{137}Cs	5.03E-02	1.32E-01	8.40E-02	9.54E-02	1.49E-02	1.52E-01	1.40E-01	1.10E-01	1.33E-02	6.59E-02	6.23E-03	1.26E-02	1.40E-01
Eu-152	3.50E+01	1.29E+02	1.11E-01	8.14E+01	1.01E-01	1.36E+02	1.33E+02	9.74E+01	8.56E-02	2.23E-01	7.27E-01	7.98E-02	1.34E+02
Eu-154	3.78E+01	1.39E+02	1.10E-01	8.81E+01	9.93E-02	1.46E+02	1.44E+02	1.05E+02	8.31E-02	2.30E-01	6.98E-01	7.66E-02	1.44E+02
Eu-155	1.72E+00	6.75E+00	2.09E-02	3.99E+00	2.02E-02	1.01E+14	7.09E+00	4.89E+00	1.92E-02	2.88E-02	1.72E-01	1.89E-02	7.12E+00
^{3}H	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.25E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06	8.23E-06
I-125	1.64E-04	2.42E-04	3.02E-05	1.92E-04	1.33E-04	1.04E-01	5.30E-04	2.07E-04	1.20E-04	3.25E-05	1.16E-04	1.16E-04	5.27E-04
I-129	2.14E-04	2.63E-04	4.00E-05	2.34E-04	1.95E-04	1.96E-01	7.70E-04	2.43E-04	1.88E-04	4.15E-05	1.86E-04	1.86E-04	7.68E-04
I-131	1.07E-03	2.02E-03	1.91E-04	1.56E-03	6.68E-04	4.12E-01	3.22E-03	1.71E-03	6.36E-04	2.32E-04	6.24E-04	6.23E-04	3.21E-03
I-132	5.02E-03	1.07E-02	8.78E-04	8.01E-03	2.59E-03	9.54E-01	1.38E-02	8.91E-03	2.40E-03	1.14E-03	2.32E-03	2.31E-03	1.38E-02

µGy/h per Bq/l	Cod	Crab	Gull	Haddock	Herring	Macro-algae	Mussel	Plaice	Sardine	Seal	Shrimp	Sprat	Winkle
I-133	1.92E-03	3.46E-03	3.43E-04	2.71E-03	1.27E-03	7.82E-01	5.87E-03	2.96E-03	1.20E-03	4.11E-04	1.17E-03	1.16E-03	5.84E-03
Mn-54	2.52E+01	9.21E+01	2.92E-01	5.88E+01	3.46E-02	9.61E+01	9.44E+01	7.03E+01	1.80E-02	1.14E+00	1.03E-01	1.29E-02	9.47E+01
Nb-94	1.90E+01	6.94E+01	1.72E-02	4.43E+01	1.49E-02	7.21E+01	7.13E+01	5.30E+01	1.13E-02	4.63E-02	1.22E-02	1.02E-02	7.16E+01
Nb-95	9.23E+00	3.37E+01	6.71E-03	2.15E+01	5.58E-03	3.52E+01	3.46E+01	2.57E+01	3.87E-03	2.09E-02	3.99E-03	3.34E-03	3.47E+01
Ni-59	1.59E-03	5.21E-03	1.57E-03	1.60E-03	1.57E-03	7.60E-03	5.86E-02	1.62E-03	1.56E-03	1.57E-03	5.01E-03	1.55E-03	5.85E-02
Ni-63	2.09E-03	6.77E-03	2.09E-03	2.09E-03	2.09E-03	9.71E-03	7.87E-02	2.09E-03	2.09E-03	2.09E-03	6.77E-03	2.09E-03	7.87E-02
Np-237	2.79E-02	2.76E+00	1.10E-01	2.84E-02	2.76E-02	1.46E+00	1.16E+01	2.86E-02	2.76E-02	1.10E-02	2.76E+00	2.76E-02	1.16E+01
P-32	3.87E+01	1.01E+01	3.73E+01	3.87E+01	3.80E+01	2.93E+00	6.88E+00	3.80E+01	3.58E+01	7.57E+01	9.24E+00	3.34E+01	6.70E+00
P-33	4.42E+00	1.20E+00	4.29E+00	4.42E+00	4.42E+00	4.40E-01	8.79E-01	4.42E+00	4.41E+00	8.50E+00	1.20E+00	4.40E+00	8.78E-01
^{210}Pb	6.22E-02	2.58E+00	4.81E+00	7.74E-02	5.04E-02	6.78E-01	5.95E-01	9.37E-02	4.88E-02	4.88E+00	2.38E+00	4.72E-02	6.21E-01
^{210}Po	5.19E+02	1.83E+03	3.06E+02	5.19E+02	5.19E+02	3.10E+01	1.07E+03	5.19E+02	5.19E+02	3.06E+02	1.83E+03	5.19E+02	1.07E+03
Pu-238	1.11E+02	5.07E+00	4.75E+00	1.11E+02	1.11E+02	1.31E+02	3.48E+01	1.11E+02	1.11E+02	8.86E+00	5.06E+00	1.11E+02	3.48E+01
^{239}Pu	1.04E+02	4.75E+00	4.45E+00	1.04E+02	1.04E+02	1.23E+02	3.27E+01	1.04E+02	1.04E+02	8.32E+00	4.75E+00	1.04E+02	3.27E+01
^{240}Pu	1.04E+02	4.76E+00	4.46E+00	1.04E+02	1.04E+02	1.23E+02	3.27E+01	1.04E+02	1.04E+02	8.33E+00	4.76E+00	1.04E+02	3.27E+01
Pu-241	2.84E-02	1.31E-03	1.22E-03	2.84E-02	2.84E-02	3.31E-02	8.92E-03	2.84E-02	2.84E-02	2.27E-03	1.30E-03	2.84E-02	8.92E-03
Ra-223	4.28E+01	2.30E+01	4.28E+01	4.29E+01	4.28E+01	2.53E+11	9.98E+00	4.29E+01	4.28E+01	9.18E+00	2.29E+01	4.28E+01	9.98E+00
^{226}Ra	3.89E+01	2.10E+01	3.89E+01	3.90E+01	3.89E+01	1.23E+01	9.23E+00	3.90E+01	3.88E+01	8.35E+00	2.08E+01	3.88E+01	9.23E+00
^{228}Ra	1.34E-01	1.57E-01	1.02E-01	1.73E-01	9.62E-02	1.43E-01	1.33E-01	1.80E-01	8.63E-02	3.49E-02	4.42E-02	8.12E-02	1.34E-01
Ru-103	2.83E-01	1.06E+00	2.79E-03	6.56E-01	2.65E-03	1.17E+00	1.18E+00	7.87E-01	2.30E-03	5.69E-03	2.40E-02	2.19E-03	1.18E+00
Ru-106	2.05E-01	1.19E+00	2.05E-02	4.50E-01	1.99E-02	2.50E+00	2.38E+00	6.36E-01	1.75E-02	2.28E-02	1.83E-01	1.49E-02	2.47E+00
S-35	2.72E-05	3.45E-05	4.36E-05	2.72E-05	2.72E-05	9.04E-05	9.24E-05	2.72E-05	2.72E-05	4.36E-05	3.46E-05	2.72E-05	9.23E-05
Sb-124	1.35E-01	5.56E-01	7.59E-02	2.09E-01	6.79E-02	2.49E-01	3.26E-01	2.25E-01	5.49E-02	1.64E-01	2.96E-01	4.88E-02	3.23E-01
Sb-125	3.61E-02	1.55E-01	2.25E-02	5.29E-02	2.02E-02	6.03E-02	8.55E-02	5.64E-02	1.70E-02	4.61E-02	9.66E-02	1.59E-02	8.51E-02
Se-75	4.77E-01	2.59E-01	3.75E-01	5.00E-01	3.36E-01	7.02E-02	1.74E-01	4.11E-01	2.27E-01	1.23E+00	1.49E-01	1.92E-01	1.69E-01
Se-79	3.05E-01	2.33E-01	2.72E-01	3.05E-01	3.05E-01	7.24E-03	1.63E-01	3.05E-01	3.05E-01	2.72E-01	2.32E-01	3.04E-01	1.63E-01
Sr-89	7.58E-03	4.13E-03	4.76E-04	7.58E-03	7.46E-03	1.06E-02	3.55E-02	7.47E-03	7.10E-03	4.83E-04	3.86E-03	6.71E-03	3.47E-02
Sr-90	1.45E-02	7.80E-03	9.16E-04	1.45E-02	1.42E-02	1.92E-02	6.51E-02	1.42E-02	1.33E-02	9.35E-04	7.07E-03	1.23E-02	6.29E-02
^{99}Tc	1.82E-03	1.28E+00	1.82E-03	1.82E-03	1.82E-03	1.71E+00	5.17E-01	1.82E-03	1.81E-03	1.41E-03	1.28E+00	1.80E-03	5.16E-01
Te-123m	8.01E-02	7.58E-02	7.60E-02	8.28E-02	7.20E-02	6.42E-01	7.32E-02	7.93E-02	6.64E-02	1.16E-01	6.47E-02	6.45E-02	7.27E-02
Te-129m	5.73E-01	5.53E-01	5.68E-01	5.75E-01	5.61E-01	4.40E+00	5.24E-01	5.66E-01	5.32E-01	5.96E-01	5.09E-01	5.04E-01	5.14E-01
Te-132	5.91E-01	5.56E-01	5.30E-01	6.43E-01	4.73E-01	3.21E+00	5.08E-01	5.96E-01	3.87E-01	1.12E+00	3.55E-01	3.50E-01	4.98E-01
Th-227	2.50E+01	5.14E+01	1.12E+00	3.12E+01	2.04E+01	8.60E+01	3.54E+01	3.34E+01	2.04E+01	6.12E+00	3.40E+01	2.04E+01	3.55E+01
Th-228	1.85E+02	4.61E+02	6.13E+00	2.84E+02	1.11E+02	7.00E+02	3.87E+02	3.19E+02	1.11E+02	3.35E+01	1.86E+02	1.11E+02	3.93E+02

µGy/h per Bq/l	Cod	Crab	Gull	Haddock	Herring	Macro-algae	Mussel	Plaice	Sardine	Seal	Shrimp	Sprat	Winkle
Th-230	1.62E+01	2.71E+01	8.89E-01	1.62E+01	1.62E+01	5.42E+01	1.39E+01	1.62E+01	1.62E+01	4.85E+00	2.70E+01	1.62E+01	1.39E+01
Th-231	6.79E-01	2.99E+00	4.00E-03	1.49E+00	7.20E-02	4.13E+00	3.47E+00	1.92E+00	7.05E-02	2.26E-02	1.16E-01	6.97E-02	3.59E+00
Th-232	1.38E+01	2.31E+01	7.61E-01	1.39E+01	1.38E+01	4.62E+01	1.19E+01	1.39E+01	1.38E+01	4.15E+00	2.31E+01	1.38E+01	1.19E+01
Th-234	2.95E+00	1.80E+01	1.64E-02	6.47E+00	2.93E-01	5.17E+01	3.00E+01	1.05E+01	2.73E-01	9.33E-02	4.25E-01	2.51E-01	3.43E+01
U-234	3.84E-01	2.75E-01	1.10E-01	3.84E-01	3.84E-01	3.36E+00	8.79E-01	3.84E-01	3.84E-01	1.10E-02	2.75E-01	3.84E-01	8.79E-01
U-235	3.60E-01	2.65E-01	1.02E-01	3.63E-01	3.57E-01	3.10E+00	8.26E-01	3.64E-01	3.57E-01	1.03E-02	2.55E-01	3.57E-01	8.26E-01
U-238	3.38E-01	2.42E-01	9.66E-02	3.38E-01	3.38E-01	2.88E+00	7.73E-01	3.38E-01	3.38E-01	9.66E-03	2.42E-01	3.38E-01	7.73E-01
Zr-95	2.23E+01	8.14E+01	1.00E-02	5.19E+01	8.92E-03	8.41E+01	8.39E+01	6.21E+01	7.23E-03	2.38E-02	1.72E-02	6.68E-03	8.43E+01

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