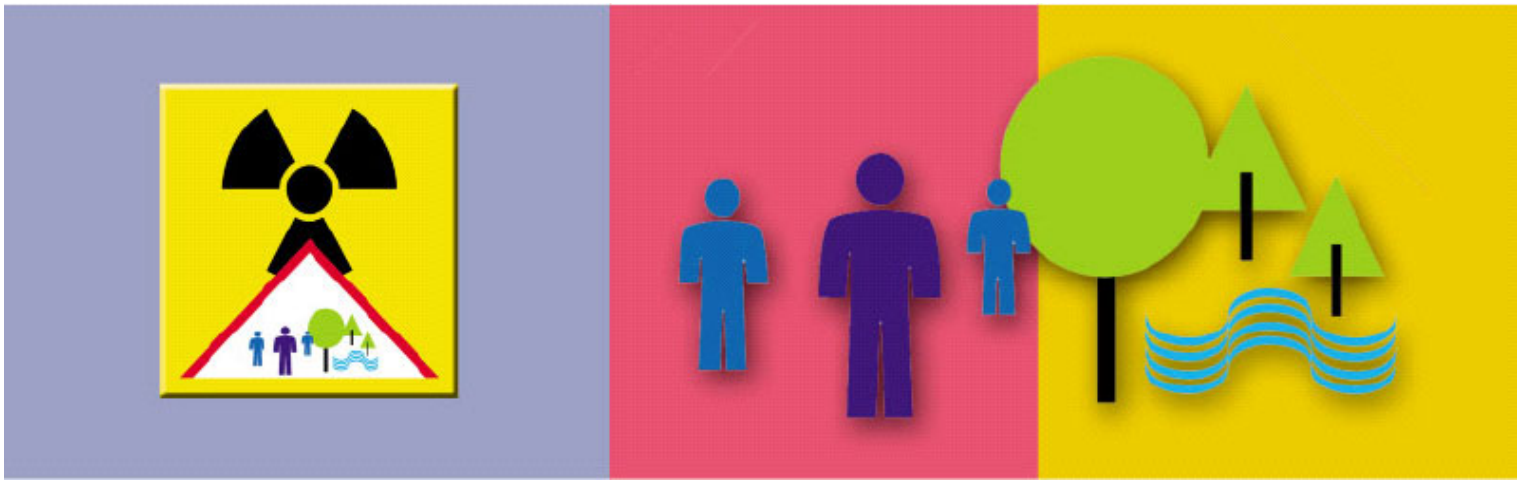
RADIATION PROTECTION



Effluent and dose control
from European Union NORM industries:

Assessment of current situation and proposal for a harmonised Community approach

Volume 1: Main Report

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Effluent and dose control from European Union NORM Industries Assessment of current situation and proposal for a harmonised Community approach

Volume 1: Main Report

Directorate-General for Energy and Transport
Directorate H – Nuclear Safety and Safeguards
Unit H.4 – Radiation Protection

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Effluent and Dose Control from European Union NORM Industries

Assessment of Current Situation and Proposal for a Harmonised Community Approach

Volume 1: Main Report

by

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Foreword

Provisions on Naturally Occurring Radioactive Materials (NORM) were introduced in the European Basic Safety Standards (BSS or Council Directive 96/29/EURATOM of 13 May 1996). The European Commission was interested in having an overview of how the Directive was implemented in order to pursue further harmonisation of the measures already taken in the Member States.

The Commission contracted the present study to a group of consultants lead by the National Nuclear Corporation (NNC), together with the Centre d'études sur l'Evaluation de la Protection dans le domaine Nucléaire (CEPN), the Nuclear Research and Consultancy Group (NRG) and the National Radiological Protection Board (NRPB). The study aimed to review the Member States' regulatory frameworks with regard to the implementation of Title VII of the Directive in respect of NORM industries including effluent discharges and the related disposal of waste. The final objective was to provide guidance on a suitable framework for the assessment of public exposure to naturally occurring radionuclides in effluent discharges from NORM industries, including the establishment of criteria allowing the rapid identification of effluent discharges of concern.

The extensive documentation was summarised into a number of tables and figures that should give the reader an overview of the way in which the various countries have started tackling the issue.

The report will be submitted to a working party of the Group of Experts established under the terms of Article 31 of the Euratom Treaty. The Experts will be invited to provide guidance on the basis of:

- examination of how Title VII has been implemented in the Member States,
- the proposed methodology for the assessment of doses to members of the public resulting from NORM industries,
- the screening levels derived for the rapid identification of effluent discharges potentially requiring regulatory control.

The views expressed in the current document are those of the contractor and the publication of this document does not imply endorsement by the Commission.

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Radiation Protection

Executive Summary

The present study has been undertaken for the Directorate-General for Environment of the European Commission, in order to provide information for Article 31 experts, and EU Member States, on effluent and dose control from European Union NORM Industries.

For this purpose NNC (UK) and its subcontractors, NRG (Netherlands), NRPB (UK) and CEPN (France), implemented the following tasks:

Task 1 Identification of industries giving rise to NORM discharges. Review of the quantities of NORM wastes discharged into the sea and into the rivers or disposed of in the EU.

Task 2 Review of the regime of prior authorisation and discharge authorisation in Member States (how it is implemented legally and in practice).

Task 3 Review of dose constraints and compliance with dose limits (as they relate to discharges from NORM industries).

Task 4 Provision of guidance for a realistic assessment methodology for the assessment of doses as a result of public exposure from the activities of NORM industries.

Task 5 Development of criteria for the quick identification of effluent discharges potentially requiring regulatory control.

In Task 1, an extensive literature review was conducted with a review of published reports and papers in the area of NORM industries, in particular their waste production processes and the radiological content of their raw materials and subsequent wastes. Information was also obtained from a number of industry trade associations.

NORM industries, which may be of radiological concern as a result of their discharges and wastes, are summarised in Table 1. Discharges and residue characteristics have been broadly characterised to provide an aid for the subsequent identification of the NORM industries that may require regulatory control.

Within Task 2 and 3, information was collected by means of a questionnaire to Member States in combination with a review of the relevant regulations.

It was found that most Member States in the EU have introduced new legislation to address the Directive within the past 2-3 years and so practical experience of implementing any new system is very limited.

It is clear that while all EU Member States have acknowledged the issue of ‘work activities’ within their regulatory structure, they appear to be at an early stage in the area of identification of work activities with significant exposures to the public as a result of wastes and discharges from NORM industries. It was found that at present there are no specific discharge controls, nor specific radiological impact/content assessment procedures or dose constraints with regards to the discharges from work activities in the majority of countries.

Guidance on approaches for assessing doses to members of the public from NORM discharges has been developed in completion of Task 4 of the study. The guidance covers all stages of an assessment of doses to members of the public, in terms of individual dose, due to discharges from NORM industries. The exposure pathways to be considered, the characteristics of the exposed groups and the methods for determining doses have been addressed for two types of discharge to the environment, those are: discharge to atmosphere and to water bodies. In general the guidance is very similar to that proposed for discharges from nuclear installations, however, the background levels of the radionuclides concerned, complicate the use of environmental monitoring data for determining doses from NORM discharges. Monitoring of emissions at source would provide a valuable input into dose assessments, and it is recommended that the need for environmental monitoring should be assessed on the basis of such data.

In Task 5 a proposal for the establishment of criteria allowing the quick identification of effluent discharges potentially requiring regulatory control, was developed using a risk based approach. Activity discharge screening levels were established such that provided these levels are not exceeded, it is very unlikely that members of the public would receive an effective dose above a defined dose criterion.

Norm discharge screening levels have been derived for the NORM release routes to atmosphere and to rivers. They are based on a dose criterion of 300 $\mu Sv\ y^{-1}$ effective dose. Proportionally lower discharge screening levels will result if a lower dose criterion is selected. Screening levels for atmospheric discharges are provided in Table 49 and those for river discharges are given in Tables 50 - 52. Such screening levels are calculated using deliberately cautious assumptions such that compliance with them would ensure virtual certainty of compliance with the dose constraint. Calculations were also undertaken for marine discharges however the resulting figures, given in Table 53, are only examples, rather than recommended screening levels due to the uncertainties inherent in the marine assumptions.

Synthèse de l'étude

La présente étude a été entreprise pour la Direction Générale pour l'Environnement de la Commission Européenne, afin de fournir aux experts de l'article 31 et des Etats Membres de l'Union Européenne (UE) des informations sur le contrôle des effluents et des doses des industries européennes impliquant la présence de Matières Contenant Naturellement des Radionucléides (MCNR)[1].

À cette fin, NNC (Royaume-Uni) et ses sous-traitants, NRG (Hollande), NRPB (Royaume-Uni) et CEPN (France), ont effectué les tâches suivantes :

Tâche 1	Identification des industries donnant lieu à des décharges de MCNR. Examen des quantités de déchets de MCNR rejetées en mer et dans les fleuves ou stockées dans l'UE.
Tâche 2	Examen des régimes d'autorisation préalable et d'autorisation de décharge dans les Etats Membres (aspects réglementaires et de mise en oeuvre pratique).
Tâche 3	Examen des contraintes de dose et de la conformité aux limites de dose (en ce qui concerne les rejets des industries de MCNR).
Tâche 4	Production de recommandations pour une méthodologie réaliste d'évaluation des doses associées à l'exposition des personnes du public résultant des activités des industries de MCNR.
Tâche 5	Développement de critères pour l'identification rapide des rejets d'effluents qui peuvent exiger un contrôle réglementaire.

Dans la tâche 1, une revue approfondie de littérature a été conduite, au travers de l'examen des rapports et articles publiés dans le secteur des industries de MCNR, et en particulier ceux concernant les modes de production des déchets et le contenu radiologique des matières premières et des déchets résultants. Des informations ont également été obtenues de la part d'un certain nombre d'associations commerciales d'industriels.

Les industries de MCNR qui peuvent être concernées du point de vue radiologique en raison de leurs rejets et déchets sont récapitulées dans le tableau 1. Les caractéristiques des rejets et des résidus ont été sommairement caractérisées afin de fournir une aide à l'identification des industries de MCNR qui peuvent exiger un contrôle réglementaire.

Dans les tâches 2 et 3, l'information a été rassemblée aux moyens d'un questionnaire adressé aux Etats Membres et de l'examen des réglementations pertinentes.

On a pu constater que la plupart des Etats Membres de l'UE n'ont adopté une nouvelle législation pour prendre en compte la Directive qu'au cours des 2 ou 3 dernières années et que, de ce fait, l'expérience pratique de mise en application d'un nouveau système est très limitée.

[1] Naturally Occurring Radioactive Materials (NORM)

Il est apparu que tous les Etats Membres de l'UE ont pris en compte dans leur structure réglementaire la question des 'activités professionnelles'[1]. Cependant, ils semblent n'être qu'au tout début de l'identification des activités professionnelles pouvant conduire à des expositions significatives des personnes du public résultant des déchets et des rejets des industries de MCNR. On a constaté qu'il n'y a pas actuellement, dans la majorité des pays, de contrôle spécifique des rejets, ni de procédure spécifique d'évaluation du contenu (/de l'impact) radiologique ou de contrainte de dose en ce qui concerne les déchets résultant de telles activités professionnelles.

Des recommandations concernant les approches d'évaluation des doses délivrées aux membres du public résultant des rejets de MCNR ont été développées au cours de la tâche 4 de l'étude. Ces recommandations couvrent toutes les étapes de l'évaluation, en termes de dose individuelle, des doses aux membres du public dues aux rejets des industries de MCNR. Les voies d'exposition à considérer, les caractéristiques des groupes exposés et les méthodes pour déterminer les doses ont été décrites pour deux types de rejets dans l'environnement : les rejets atmosphériques et les rejets liquides. De façon générale, les recommandations sont très proches de celles proposées pour les rejets des installations nucléaires. Cependant, les niveaux du bruit de fond naturel des radionucléides concernés rendent difficile l'utilisation des données de surveillance de l'environnement pour la détermination des doses résultant des rejets de MCNR. Néanmoins, la surveillance des émissions à la source peut fournir des données d'entrée utiles pour les évaluations de dose, et il est recommandé que les besoins en termes de surveillance de l'environnement soient évalués sur la base de telles données.

Dans la tâche 5, une proposition pour l'établissement de critères permettant l'identification rapide des rejets d'effluents qui peuvent exiger un contrôle réglementaire a été développée en utilisant une approche de type risque. Des niveaux de première identification[2] pour l'activité des rejets ont été établis de telle manière que si ces niveaux ne sont pas excédés, il est très peu probable que les membres du public reçoivent une dose efficace supérieure à un critère de dose défini.

Des niveaux de première identification des rejets de MCNR ont été dérivés pour les rejets vers l'atmosphère et vers les fleuves. Ils sont basés sur un critère de dose efficace de 300 $mSv.an^{-1}$. Une réduction proportionnelle des niveaux de première identification des rejets serait obtenue dans le cas du choix d'un critère de dose moins élevé. Les niveaux pour les rejets atmosphériques sont fournis dans le tableau 49 et ceux pour les rejets vers les fleuves sont présentés dans les tableaux 50 à 52. Ces niveaux de première identification ont été calculés en utilisant des hypothèses délibérément prudentes, de telle façon que la conformité à ces niveaux assure la quasi-certitude de la conformité au critère de dose correspondant. Des calculs ont été également entrepris pour les rejets marins. Cependant, les résultats de ces calculs, présentés dans le tableau 53, sont fournis seulement à titre d'exemple plutôt qu'en tant que niveaux de première identification recommandés, en raison des incertitudes inhérentes aux hypothèses nécessaires à de tels calculs.

[1] Activités professionnelles qui impliquent la présence de sources naturelles de rayonnement - où les radionucléides naturels ne sont pas traités, ou ne l'ont pas été, en raison de leurs propriétés radioactives, fissiles ou fertiles - et entraînent une augmentation notable de l'exposition des travailleurs ou du public, non négligeable du point de vue de la protection contre les rayonnements

[2] Screening levels

Glossary of terms and abbreviations

Glossary

Best Practical Environmental Option (BPEO): A BPEO is the outcome of a systematic consultative and decision-making procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefit or least damage to the environment as a whole, at acceptable cost, in the long term, as well in the short term (RCEP, 1988).

Clearance: Release of material from a regulated practice/work activity from the requirements of the Directive for disposal, reuse or recycling if the radioactivity content is below so-called 'clearance levels' (European Commission, 2000(a)). (See Title III, Article 5 of Council Directive 96/29/EURATOM).

The term 'clearance' is reserved for the release of material which does not require further regulatory control to ensure the actual destination of the material (European Commission, 2000(a)). This avoids regulatory resources being wasted in situations where there would be little or no benefit (European Commission, 2000(a)).

Clearance levels: Values established by the national competent authorities, and expressed in terms of activity concentrations and/or total activity, at or below which radioactive substances or materials containing radioactive substances, arising from any practice subject to the requirement of reporting or authorization may be released from the requirements of the Directive for disposal, reuse or recycling (European Commission, 1996; European Commission, 2000(a)).

The notion of 'specific clearance levels' has been introduced for specific conditions which can be verified prior to release while 'general clearance levels' are for any possible application. There are no restrictions on the origin or type of material to be cleared (European Commission, 2000(a)).

Dose constraint: A restriction on the prospective doses to individuals which may result from a defined source, for use at the planning stage in radiation protection whenever optimisation is involved (European Commission, 1996).

Dose criteria: Effective dose at which

(a) the radiological risks in individuals caused are sufficiently low as to be of no regulatory concern and

(b) the collective radiological impact is sufficiently low as to be of no regulatory concern under the prevailing circumstances.

It is used to derive levels e.g. clearance or exemption levels which are in the form of concentrations (Bq m^{-3}) etc.

Dose limit: Maximum references laid down in Title IV for the doses resulting from the exposure of workers, apprentices and students and members of the public to ionising

radiation covered by the Directive that apply to the sum of the relevant doses from external exposures in the specified period and the 50-year committed doses (up to age 70 for children) from intakes in the same period (European Commission, 1996).

Exemption: The Directive requires Member States to establish a procedure for regulatory control of practices by competent authorities. However, the concept of exemption allows for release from the requirement to report all practices, in specified circumstances (Article 3(2)). The Directive uses the concept of exemption only within the context of practices and indirectly the concept is applicable to waste generated by such practices (European Commission, 2000a). The mechanism of exemption is used to avoid unwarranted regulatory efforts (Clarke R., 2001).

Exemption Levels: Values given in Annex I of the Directive at or below which exemption applies. In exceptional situations EU Member States can vary levels from those given provided they satisfy the basic general criteria set out in Annex I (European Commission, 1996).

Note that values of activity corresponding to exemption from reporting do not imply exemption from prior authorisation in case of deliberate direct or indirect administration of radioactive substances to persons (Article 4.1 (b)(d)) (European Commission, 2000(a)).

Effective dose: The sum of the weighted equivalent doses in all the tissues and organs of the human body. The unit for effective dose is the sievert (European Commission, 1996).

Equivalent dose: The absorbed dose, in tissue or organ weighted for the type of radiation. The unit for equivalent dose is the sievert (European Commission, 1996).

Exclusion: Sources which are not intrinsically amenable to control and so excluded from regulation. These include K-40 in the body, cosmic radiation at ground level and unmodified concentrations of radionuclides in most raw materials (European Commission, 1996).

Exposure pathways: When radionuclides are released into the environment there are a number of different ways in which they can lead to radiation doses to individuals. The different ways are referred to as exposure pathways.

NORM: All naturally occurring radioactive materials where human activities have increased the potential for exposure in comparison to the unaltered situation. Activity concentrations may or may not be increased (Vandenhove et al, 2002). In this project the term NORM is preferred to other terms used in literature such as TENORM (Technically Enhanced NORM). (Note that Uranium mining is covered by this definition but does not fall within the scope of the study).

NORM discharge screening levels: These are defined as estimates of the amount of activity discharged to the environment from a NORM plant, which, if not exceeded, mean that it is very unlikely that members of the public would receive an effective dose above a defined dose criterion.

Practice: A human activity that can increase the exposure of individuals to radiation from an artificial source or from a natural radiation source where natural radionuclides are processed for their radioactive, fissile or fertile properties, except in the case of an emergency exposure (European Commission, 1996).

Reference groups: A group comprising individuals whose exposure to a source is reasonably uniform and representative of that of the individuals in the population who are the more highly exposed to that source (European Commission, 1996)

Work Activities: Within the scope of the Directive with regard to natural radiation sources a distinction based on the intended use of a radionuclide is made. Where the presence of natural radiation sources leads to *a significant increase* in the exposure of workers or members of the public (and the material is not used because of its radioactive, fissile and fertile properties) these are referred to as work activities; had the material been used because of its radioactive, fissile or fertile properties it would be a practice (European Commission, 2001).

Abbreviations

'BPEO' Best Practical Environmental Option.

'BSS' International Basic Safety Standards (IAEA, 1996).

'**the Directive'** Council Directive 96/29/EURATOM (European Commission, 1996).

'na' not applicable.

'NK' unknown.

'-' not given / not available to authors.

'0' < 0.5 or zero.

'+' or 'sec' nuclides carrying these suffixes represent parent nuclides in equilibrium with their correspondent daughter nuclides as listed in Table B of Annex I of the Directive.

1 Introduction

This report summarises the findings of a project initiated by Radiation Protection Unit of DG Environment of the European Commission[1].

The first objective of the project was to review the regulatory framework within Member States regarding the implementation of Title VII of Council Directive 96/29/Euratom (the Directive), (see Appendix A), with respect to effluent discharges and related disposal of wastes from NORM industries, and also to review the industries concerned.

The second objective was to provide guidance for:

- A suitable framework for the assessment of public exposure to naturally occurring radionuclides in effluent discharges and related disposal of wastes from the NORM industries.

- The establishment of criteria allowing the quick identification of effluent discharges potentially requiring regulatory control.

- The deliberations by the relevant working parties of the Article 31 Group of Experts on an appropriate regulatory framework which will be the basis for the guidance to Member States for implementation of Title VII of the Directive. This was to be consistent with existing guidance, European Commission documents and legal acts.

In order to fulfil the above objectives the study was divided into the following five tasks:

Task 1 Identification of industries giving rise to NORM discharges. Review of the quantities of NORM wastes discharged into the sea and into the rivers or disposed of in the EU.

Task 2 Review of the regime of prior authorisation and discharge authorisation in Member States (how it is implemented legally and in practice).

Task 3 Review of dose constraints and compliance with dose limits (as they relate to discharges from NORM industries).

Task 4 Provision of guidance for a realistic assessment methodology for the assessment of doses as a result of public exposure from the activities of NORM industries.

Task 5 Development of criteria for the quick identification of effluent discharges potentially requiring regulatory control.

[1] This unit has since been transferred and now is part of the Directorate-General for Energy and Transport.

In Task 1, an extensive literature review was conducted of published reports and papers in the area of NORM industries, in particular, their waste production processes and the radiological content of their raw materials and subsequent wastes. Information was also obtained from a number of industry trade associations.

Within Task 2 and 3, information was collected by means of a questionnaire to Member States, in combination with a review of the relevant regulations.

The report summarises the key findings of this study. It has been structured as follows:

Part I: Main Report

- Section 2: Review of NORM industries giving rise to discharges and/or residues
- Section 3: Review of the regulatory framework including dose criteria in EU Member States
- Section 4: Guidance on the methodology for a realistic dose assessment
- Section 5: Derivation of screening levels and their application.
- Section 6: Conclusions

Part II: Appendices

- Appendix A contains a copy of Title VII from the Directive.
- Appendix B includes copies of all the responses from Member States to the questionnaire.
- Appendix C gives an overview of the regulations in each Member State and also of the dose constraints and limits they apply, based on the information provided by the Member States in their answers to the questionnaire.
- Appendix D gives guidance on assessing doses resulting from atmospheric discharges.
- Appendix E gives guidance on assessing doses resulting from aquatic discharges.
- Appendix F contains illustrative calculations to determine the important exposure pathways for atmospheric releases.
- Appendix G discusses the significance of foetal doses in assessments of exposure from NORM discharges.
- Appendix H contains habit data for reference groups.

2 Identification of industries giving rise to NORM discharges

2.1 Introduction

NORM is an acronym for Naturally Occurring Radioactive Material. Nearly all materials contain trace amounts of ^{238}U, ^{235}U and ^{232}Th, however, when these materials are processed, concentration or enhancement of the levels of these radionuclides may occur. Enhancement is said to have occurred when a naturally occurring radioactive material has its composition, concentration, availability or proximity to people altered by human activity (HPS, 2002). NORM can be defined as all naturally occurring radioactive materials where human activities have increased the potential for exposure in comparison to the unaltered situation. Activity concentrations may or may not be increased (Vandenhove et al, 2002).

The focus of this study is the identification of industries with discharges or residues potentially significant in relation to exposure of the public as a result of NORM. Previous studies (see Figure 1), including that leading to RP 95 (European Commission, 1999), have focused on work activities involving potentially significant exposure of workers. Although these 'sets' of work activities overlap, they are not identical (See Table 1 and Table 2). See Figure 2 for a comparison of the output of RP 95 and this report.

In subsections 2.3 to 2.9 industries operating within the European Union, which process materials that contain naturally occurring radioactive material (NORM) and are considered to be of potential significance with regard to public exposure, are outlined. The industries covered include:

- Fossil fuel power stations;
- Oil and gas extraction;
- Metal processing - iron and steel production in particular and also tantalum and niobium;
- Phosphate industry;
- Titanium oxide pigment production;
- Zirconium and rare earth processes - refractory products and brick manufacture;
- Cement production.

Information was prepared largely on the basis of published reports and from contact with appropriate industry trade associations. Information on wastes and discharges, both in terms of volumes and radioactivity content, has been very limited and there appears to be many errors, inconsistencies, misinterpretations and gaps with regard to the information. It is particularly important to note the variability inherent in natural materials which constitute the raw materials for all the industries considered.

Emphasis is placed on the waste/discharges from the selected industries with a short explanation of the process. Where the information is available, the radionuclide content or the raw materials and the subsequent by-products have been given, along with estimates of the likely rate of production of the wastes and an indication of the scale of the industry within the EU.

The water industry, that is waterworks and water purification, has been cited in the past, as an industry with potentially significant NORM wastes and by a number of countries in Table 2. The recent report Hofmann et al, 2000 (a), focused in detail on the radiological impact due to wastes containing radionuclides from the use and treatment of water and so, those seeking more detailed information on this industry are directed to this report. The report concluded that wastes from surface water treatment are of no concern.

2.2 Overview

Discharges and residue characteristics have been broadly characterised to provide an aid for the subsequent identification of the NORM industries that may require regulatory control in the following subsections. However, characteristics of discharges and residues, even from the same type of industry and production process, have been found to differ widely because of the variation in raw material used, processing details and in particular, with respect to discharges, differences in treatment of liquid wastes and off-gas before discharge.

The potentially significant industries with regard to naturally occurring materials (NORM) have been summarised in Table 1. Those industries identified as potentially significant by Member States in the replies to the questionnaire are given in Table 2. It is important to note that Member States have often identified industries on the basis of significant exposure to workers; the emphasis in this study is the identification of industries that may cause significant exposure to members of the public, i.e. radiological impact of residues and effluents. These lists are likely to be similar but not necessarily identical.

It was found that there is a dearth of reliable monitoring data for these industries as a consequence of lack of previous regulation. *Data on historical discharges and residues are of very limited value because of changes in the processes and closing down of production facilities. However, estimates of total liquid and atmospheric discharges have been provided for selected industries (i.e. power generation from coal and gas, oil and gas extraction and phosphoric acid production) for which the available data was felt to be sufficiently reliable (See Figure 4 and Figure 5).* However it is important to note that these are total discharge figures and not indicative of individual doses.

Under the Article 15 (3) Council Directive 96/61/EC of 24 September 1996 [OJ L 257 1996 p. 26] concerning integrated pollution prevention and control (IPPC Directive), Member States are required to catalogue and supply data on principal emissions and responsible sources. *Though the data are gathered for environmental (non-radioactive) purposes, this information could be used to identify sites in relation to NORM as the database includes process data, location and emissions for the facilities.* The industries include energy industries (power stations, refineries etc),

metal production and processing, mineral product industries (glass, ceramic etc) and fertilizer producers. It is also possible that existing controls in place to prevent non-radioactive pollution may have the additional benefit of controlling the radioactive discharges from these NORM industries as a by-product of controlling discharges generally. However, it must be highlighted that restricting discharges may increase the amount of radioactive residues contained in solid wastes as that which may, in the past, have been dispersed in the gases from stacks or in effluents may now be retained in sludges and dusts.

2.3 Fossil fuel power stations

2.3.1 The process

Fossil fuels such as coal, lignite, oil and natural gas are used to produce energy by combustion. European consumption of these fossil fuels for electricity is given in Table 3. These fuels contain varying amounts of natural radioactivity often depending on the area from which they are mined or extracted; there is, for example, considerable variation between coals from different origin (UNSCEAR, 1982). Average specific activities in three types of fossil fuels are given in Table 4.

2.3.2 Waste production

When burnt the radioactivity is transferred largely to the ash (see Table 5), except in the case of natural gas which is ash free, with certain volatile radionuclides released to the atmosphere along with a certain proportion of the ash. ^{210}Po and ^{210}Pb are volatised in the boiler and condense on the fly ash, in particular on the smaller particles. Enrichment factors increase with decreasing particle size (UNSCEAR, 1982, Annex C). The type of coal used has a very significant effect upon the activity discharged into the environment, as does the plant design (Martin et al, 1997).

Ash content of coal is on average around 16% (Smith et al, 2001) and the enrichment of the activity concentration from coal to ash depends on the ash content of the coal and is in the order of a factor of seven for an average ash content of 15%. Lignite/brown coal has a lower ash content than coal which results in a higher enrichment factor, but also has considerably lower activity concentration (Puch, 1997). The ash content of fuel oil is in the order of just 0.1%. However, the activity concentration of ash in fuel oil is assumed to be of the same order as that from coal (UNSCEAR, 1988). The ash content of brown coal/lignite is approximately 9%; peat has a low ash content of between 2 to 6% and the ash content of natural gas is negligible.

(i) Solid Residue:

It should be noted that ash is not waste in that it is often reused (see Table 6). The application of coal ash in building materials is regarded as the most significant from the radiological point of view because it may affect indoor dose from external radiation and inhalation of radon decay products (UNSCEAR, 1993).

(ii) Liquid Discharges:

The desulphurisation of flue gases generates water along with the gypsum. Often the liquid waste is used to carry the ash away and then the slurry is stored in ponds. Alternatively, the water can be recycled to the plant as part of a closed loop (Martin et al, 1997). It is unlikely that there is a significant liquid discharge of NORM nuclides from fossil fuel power stations.

(iii) Atmospheric Discharges:

It has been estimated that 0.4% of the ash is discharged via the stack along with volatilised radionuclides such as ^{210}Po and ^{210}Pb from coal (Smith et al, 2001). However, fly ash emissions from the stack of coal-fired power stations depend on the efficiency of the flue gas cleaning by electrostatic precipitators, scrubbers and desulphurisation systems and so this figure will vary between plants. The annual emissions in GBq by a 'typical' 600 MW e coal fired power station and that of a gas-fired power station quoted in UNSCEAR 2000 are reproduced in Table 7.

It is unlikely that for modern plants there is a significant aerial discharge of NORM nuclides from fossil fuel power stations. This is consistent with the conclusion of investigations in the UK (Smith et al, 2001) and the Netherlands where coal fuelled power plants are not considered to have significant aerial discharges. These installations do, however, have efficient filter systems to prevent the aerial discharge of fly ash.

2.4 Oil and gas extraction

2.4.1 The process

As has been explained in Gerchikov et al, 2002, there are no such discharges as 'typical' for an oil or gas production plant. Discharges of natural radionuclides depend strongly on type of reservoir, specific production conditions and numbers of years of exploitation of a reservoir. Production of oil and gas is accompanied by water which is co-produced from the well and so is known as 'produced water'. The ratio between the rate of water production and oil production is variable, affected by the age of the well and production conditions. The variability is even greater for gas extraction. Produced water contains radionuclides which have been mobilised from the reservoir rocks and in addition to being present in the produced water, they also are deposited as scales on the pipes, valves and vessels. These pipes may be descaled offshore or at onshore descaling facilities (Gerchikov et al, 2002).

2.4.2 Waste production

In the main releases of NORM from offshore oil and gas production originate from the following:

- Produced water released offshore (^{228}Ra, ^{226}Ra, ^{210}Pb)
- Scale from offshore mechanical descaling released offshore (^{228}Th, ^{228}Ra, ^{226}Ra, ^{210}Pb)

- Scale from coastal descaling site discharged into the sea or disposed on land (^{228}Th, ^{228}Ra, ^{226}Ra, ^{210}Pb)

As shown in Table 8 six out of fifteen EU Member States have no oil production and five have zero to negligible gas production. Austria and Luxembourg have only onshore production. The other countries have onshore as well as offshore production facilities.

(i) Solid Waste:

There is very large variability in radionuclide concentrations in sludges and scales from different wells because of the differences in the nature of the reservoirs and other conditions (Weers et al, 1997). Activity concentrations in sludges and scales vary from virtually zero to up to several hundred Bq g^{-1}. The ranges in samples from Norway, The Netherlands, Germany and UK are given in Table 9. These reported specific activities provide useful examples. However, it must be emphasised that individual analytical results do not necessarily pertain to the same amount of sludge and samples sent for analysis are sent because they are active and so simple averaging to determine a 'typical' sludge or scale radionuclide concentration is not reasonable.

In addition, production rates of sludges and scales may vary considerably between installations and 'typical' production cannot be quantified more precisely than that the annual production rate may be in the order of a few m^3 y^{-1} for onshore and offshore gas production installations. We have no reliable data on amounts of sludge arising from a given amount of oil production. We expect that these arisings per installation are not significantly lower than for gas production.

(ii) Liquid Discharges:

A recent study into marine discharges (Gerchikov et al, 2002), including discharges from the offshore oil and gas industry, produced reference ratios for oil and gas production and produced water along with reference concentration values. However, concentrations of ^{228}Ra, ^{226}Ra and ^{210}Pb in produced water vary between production wells and over the production period, by several orders of magnitude. The concentrations encountered range from virtually zero to near 100 Bq l^{-1}.

Produced water containing the radionuclides mobilised from the reservoir can be assumed to be re-injected at onshore production installations and to be discharged at offshore facilities. An estimate of annual discharges averaged over the lifetime of an oil or a gas-producing platform based on normalised data from Gerchikov et al, 2002, is provided in Table 10.

Onshore production installations can be assumed to discharge produced water by re-injection into the reservoir, although some installations are known to discharge produced water into a public sewer after pre-treatment. Offshore installations presently normally discharge produced water overboard.

(iii) Atmospheric Discharges:

There is no information to suggest that atmospheric discharges from the oil and gas extraction are significant.

2.5 Metal processing

2.5.1 The process

The basic process by which metals and alloys are produced from metal rich ores is that of smelting. Some typical values for natural radioactivity in ores are given in Table 11. However, the specific activities of the raw materials vary depending on their area of origin and the industry is increasingly sourcing ores of low activity as far as possible. There currently are smelters for aluminium, copper, iron, steel, lead and zinc within the European Union (Kuo et al, 2002). However, tin ore appears to no longer be produced/processed within the EU. See Table 12 for the extent of primary metal processing in Europe.

The process of producing aluminium metal from its ore (bauxite) differs from the others. In the Bayer process bauxite is refined to produce alumina by dissolution in aqueous caustic soda at high temperature and pressure (European Commission, 1999). Red sludge containing the radionuclide content of the ore, is a by-product of the process. In order to obtain the final product i.e. the metal, the alumina is reduced by electrolysis by the Hall-Heroult electrolytic process (European Commission, 1999).

2.5.2 Waste production

Slags, dross, fly ash, furnace coal ash and scales may be produced as a result of the smelting process. There are also likely to be stack emissions of fly ash and gases; each metal processing involving high temperatures is a potential source of emissions of ^{210}Po and ^{210}Pb to air. The radioactivity of the feedstock or ore is largely transferred to the slag (see Table 13). Although figures are not available, zinc production from zinc ore results in cadmium, copper and cobalt-cake and the latter is understood to be enriched in uranium.

(i) Solid Waste:

Some approximate ratio factors of waste production based on production figures have been identified for steel and ferroniobium but not for the iron/steel slag, copper, zinc, lead or aluminium smelting, nor for alumina production. However, it is important to note that ratios will be heavily dependent upon the efficiency of the individual plant and the process.

- **Steel:** It is estimated that for every million tonnes of steel produced 2000 t of dust is produced. This is eventually sent to landfill. Only a very small fraction of the dust escapes to the atmosphere (Crockett et al, 2001).

- **Ferroniobium:** The production of slag is at about the same rate as the consumption of feedstock (Martin et al, 1997).

Information is not available on the amounts of residues produced by the industry in Europe. However, as in power generation, solid residues are not necessarily a waste, as residues from one process can be the input to another process.

Detailed information on metal processing is limited, with the exception of iron and steel production and, thus, it has been included in more depth in the following sub-section. Some limited information is also given on tantalum and niobium (columbium) processing.

2.5.3 Iron and steel production

The Process

The main sources for emissions and residues are the installations for production of sinters and pellets from iron ore and the production of iron in blast furnaces from these sinters and/or pellets (as at CORUS, IJmuiden).

The CORUS steel production plant at IJmuiden operates blast furnaces to produce primary iron. The ore is fed into the blast furnaces after being prepared into sinters or pellets. So the CORUS plant at IJmuiden comprises blast furnaces, sintering plant (Sifa) and pelletizing plant (Pefa). Steel is produced from primary iron and scrap in converters.

The former British Steel (now CORUS) plants with blast furnaces are operated at Teesside and Scunthorpe on the east coast and Llanwern and Port Talbot in south Wales and these blast furnaces are fed with sinters (Harvey DS, 1999 and Harvey DS, 1998). It is not known whether other primary iron production facilities feed their blast furnaces with sinters only or with sinters and pellets as at CORUS IJmuiden.

Sinter plants
Iron ore sinters are produced from mixtures of ore, dolomite, cokes and recycled dust. The activity concentrations for most of the radionuclides from the decay chains of ^{238}U and ^{232}Th in the feed mix are in the order of 15 Bq kg^{-1}. ^{210}Po and ^{210}Pb concentrations can be somewhat higher because of the recycling of enriched dust.

The sinters are fired with gas and temperatures reached in the combustion zone are in the order of 1400°C. As a consequence ^{210}Pb and ^{210}Po, whose boiling points are 1740 and 962°C respectively, are volatilised and condense on dust particles also carried by the off-gas. Dust from sintering is enriched in ^{210}Po relative to ^{210}Pb and strongly depleted in all other natural radionuclides from the raw materials. The off-gas is cleaned with electrostatic precipitators (as at CORUS UK plants) or high-pressure water scrubbers (as at CORUS IJmuiden). The small particles emitted after passing through the cleaning system are enriched in ^{210}Po and to a lesser extent in ^{210}Pb. Emissions to the air depend on the efficiency of the off-gas cleaning system and emissions to water depend on post-treatment of water from the scrubbers. High pressure water scrubbing (as at CORUS, IJmuiden) removes, in two steps, coarse and fine dust. Solids are collected and dewatered in the two steps and the water is further treated in a biological water treatment plant.

Pellet plant
Ore preparation for input into the blast furnace is also carried out in a pelletizing plant (e.g. CORUS, IJmuiden). Ore mixes are dried and ground, sieved, mixed with water and benthonite and formed into wet pellets. The pellets are fired into hard pellets and cooled with air. The hot air is fed into the firing zone and to the ore dryer and then fed through low-pressure water dust scrubbers. As in the sinter process ^{210}Po and ^{210}Pb are volatilised and condense on dust particles carried by the off-gas. Solids collected from the wash water are re-fed into the pelletizing process and the water is treated in the biological water treatment system.

Blast furnace
Primary iron is produced from sinters (and pellets), coal and cokes in blast furnaces. They produce iron and slag, both fluid and blast furnace gas carrying dust. Because of the high temperature ^{210}Pb, and ^{210}Po still present in the feed materials, as well as zinc, are volatilised and condensate preferentially on the small particles carried by the gas. ^{210}Pb concentrations in this dust are higher than those of ^{210}Po because the latter radionuclide had, to a large extent, already been removed in the sintering or pellet process, due to its significantly lower boiling point.

Wet scrubbers are used to remove the solids from the gas in one or two steps and dewatered in filter presses. The coarse material is recycled into the sintering and/or pellet process. The finer fraction, zinc-rich filter cake, is stored for disposal. The cleaned gas is used as fuel elsewhere in the production process or sold as an energy source for electric power production.

Waste Production

(i) Solid Residues:

Dust from high pressure scrubbing of sinter plant off-gas:
This type of dust differs from the blast furnace dust as it is particularly enriched in ^{210}Po compared to ^{210}Pb. Implementation of advanced off-gas treatment by high pressure scrubbing at the sinter plants in IJmuiden, results in a more effective separation of fine dust, with higher activity concentrations, than the coarse fraction. Detailed information on these residues has been laid down in the Radiation Protection Annual Report 2001 of CORUS IJmuiden, published as confidential report in June 2002.

Blast furnace slag
Blast furnace slag contains 150 to 160 Bq kg^{-1} of most of the radionuclides of the decay chains of ^{238}U and ^{232}Th. ^{210}Po and ^{210}Pb are strongly depleted at about 1 and 10 Bq kg^{-1} respectively. About 1 Mt of the slag is produced per 5 Mt primary iron. Most of the slag is granulated and mixed with Portland clinker to produce cement.

Blast furnace dust
The finer fraction of the dust from scrubbing the blast furnace gas is strongly enriched in ^{210}Pb and to a lesser extent in ^{210}Po, compared to the blast furnace slag. It is depleted compared to the slag in the other natural radionuclides. Typical concentrations of ^{210}Pb in the zinc rich filter cake produced and stored at the IJmuiden CORUS plant are in the order of 15 – 25 Bq g^{-1}. ^{210}Po concentrations are a few Bq g^{-1}. The figure of 100 Bq g^{-1} quoted by Scholten, 1996 for the total activity in zinc-rich filter cake from the IJmuiden plant must be interpreted as three times a conservative estimate of 30 Bq g^{-1} ^{210}Pb. Under previous Dutch regulations, the total activity concentration had to be calculated by including all short-lived radionuclides. Because of the in-growth of ^{210}Bi and ^{210}Po from ^{210}Pb, the total activity concentration in this filter cake had to be calculated as three times the concentration of ^{210}Pb. The annual production of this waste material is about 2 kt dry weight per Mtonne primary iron produced.

The figure for the activity concentration of ^{210}Pb provided by Harvey, 1999, for blast furnace dust from UK plants is 8 Bq g^{-1}, about a factor of 2.5 lower than for the IJmuiden plant. The difference can probably be explained by differences in efficiency of the separation of coarse and fine dust fractions, the finer particles being more enriched in ^{210}Pb. The considerably lower concentration of ^{210}Po compared to ^{210}Pb is also characteristic for the blast furnace dust from the UK plants.

(ii) Liquid discharges:

Leenhouts et al, 1996 provides estimates for liquid discharges (see Table 14) based on the studies by ECN mentioned below.

Water treatment has since been improved and discharges have been considerably reduced compared to 1990 levels. No other information could be made available on discharges into water by other plants. For the time being, the CORUS IJmuiden discharges presented in Table 14 are regarded as typical for a plant producing about 5 Mtonnes of iron per year.

(iii) Atmospheric discharges:

Activity discharges from primary iron production are typical with respect to the radionuclides involved: ^{210}Po and ^{210}Pb. However, the annual discharges of an individual plant depend on the annual throughput of iron ore and on the efficiency of the off-gas cleaning systems and water treatment facilities. Estimates of discharges have been provided for the Dutch Hoogovens plant (now CORUS) by Leenhouts et al, 1996 (see Table 15). They are based on studies carried out by ECN (now NRG) in the late 1980s and 1990s.

Because of the implementation of improved off-gas and treatment systems, present discharges per unit of primary iron production may be lower, but will still not be very different from the figures given in Table 15.

Some additional information is available on the CORUS plants in the UK in Harvey, 1998. However, the figures are presented in terms of average ^{210}Po and ^{210}Pb activity per gram of stack gas emitted from five sinter plants. The figures are 2.8 10^{-3} and

1.0 10^{-3} Bq g^{-1} off-gas for ^{210}Po and ^{210}Pb respectively. A typical figure of 2 000 m^3 of gases is given by Harvey, 1998 as being discharged for each tonne of sinter produced.

Using the information from Harvey, 1998 and from the Dutch CORUS plant, the ratio between sinter used and primary iron produced, annual emissions of 58 and 21 GBq of ^{210}Po and ^{210}Pb respectively can be derived for an UK plant producing 5.2 Mt of primary iron. The corresponding values for the Dutch CORUS plant given in Table 15 are 84 and 54 GBq. However, the specific gravity of air was used in the calculation because no information was available on the specific gravity of the off-gas of the UK plants. If the normalised density of the off-gas is higher than that of dry air, which is likely to be the case, the mass of off-gas per tonne of sinter will be higher and the emission rate of ^{210}Pb and ^{210}Po will also be higher. Thus emissions estimates for the UK plant are likely to be underestimates.

On this basis it is concluded that the emission data for the CORUS plant in the Netherlands can be regarded as 'typical' for a primary iron production plant with a production of about 5 Mt y^{-1}.

2.5.4 Tantalum and niobium (columbium)

Tantalum (Ta) is a refractory metal that is highly corrosion resistant, a good conductor of heat and electricity and is used on a large scale in capacitors in all kinds of electronic equipment. Niobium (Nb) is used as an alloying element in steels and superalloys for aircraft turbine engines. The primary source of these elements are the tantalum and niobium bearing ores mined in Australia, Brazil, Canada, Thailand, China and Africa. Prospecting for tantalum is currently underway at sites in Ireland and Finland (Zogbi D, 2002).

The minerals in niobium bearing ores (pyrochlore and columbite) contain enhanced levels of the decay chains of ^{238}U and ^{232}Th. Tantalum occurs in combination with niobium and usually with tin, iron, manganese and rare earths. The processing of the ores into metal concentrates, carbides, oxides and metal powder starts with a wet process involving dissolution of the ore with strong acids and liquid-liquid extraction for removal of impurities. These production facilities are located outside the European Union.

A specific source of tantalum is the slag from tin production. This tin slag is processed for recovery of tantalum at the facilities of H.C. Starck at Goslar, Germany. The tin slag originates mainly from Thailand and contains enhanced levels of natural radionuclides. Typical concentrations encountered in tin slag from past tin production in the Netherlands and the UK were 4 Bq g^{-1} ^{238}U and 11 Bq g^{-1} ^{232}Th and daughters.

(i) Discharges:

No information could be made available on natural radionuclides in the tin slag processed in Goslar nor on the processing methods involved. Potentially the processing may involve discharges into the air of ^{210}Pb and ^{210}Po. However, the tin slag is most probably significantly depleted in ^{210}Pb and ^{210}Po because of the high temperatures in the tin smelting process. The solid waste from the tantalum

extraction probably contains virtually all of the other radionuclides of both decay chains.

2.6 Phosphate industry

2.6.1 The process

There are four main processes of producing phosphate fertilisers and phosphorus:

- The wet acid process using sulphuric acid (H_2SO_4)
- Hydrochloric acid (HCl) treatment
- Nitric acid (HNO_3) treatment
- Thermal processing

In the sulphuric acid, hydrochloric acid and nitric acid processes the chemical reaction is similar i.e. acidification of the ore. However, the waste products and by-products are markedly different with differing implications for NORM waste production. Across the European Union there have been significant changes in the industry, with a move away from the production of phosphoric acid from phosphate ore and its associated production of large amounts of phosphogypsum. Discharges of phosphogypsum by countries of the EU are in fact historical (see Table 16).

The thermal process uses high temperatures to reduce the phosphate to produce phosphorus, calcium silicate slag and calcinate. Elemental phosphorus plants are in operation in the Netherlands (Hofmann et al, 2000 (b)).

2.6.2 Waste production

In Europe 90% of the phosphate rock was treated by the sulphuric acid method (Vandenhove, 1999). However, changes in the industry has moved much of the phosphoric acid production, with its associated waste of phosphogypsum, to areas where the phosphate rock is mined i.e. Morocco and other North African countries. Phosphate fertiliser manufacturers may instead be using 'green' phosphoric acid (20-30% H_3PO_4) to produce the phosphate fertiliser. These changes are not highlighted in available production figures. See Table 17 for activity concentrations of the ore and waste products.

(i) Solid Waste Production:

From the sulphuric acid process
Discharges of phosphogypsum from European Union (EU) are historical. Therefore, where the industry remains, this material is being largely recycled or stored on land. Approximately 15% of phosphogypsum is being recycled into building material (Vandenhove, 1999). For estimation purposes a normalised figure of 4.5 t of phosphogypsum for every tonne of P_2O_5 has been assumed by Gerchikov et al, 2002, which is slightly lower than the 5.3 value observed in the French Grande Paroisse Grand-Quevilly site.

From the hydrochloric acid process
Available information suggests that the only company using the HCl process is Tessenderlo Chemie in Belgium.

The HCl process produces predominately CaF_2 sludge at a rate of 0.5 t for each tonne of processed P_2O_5. This sludge is stored on land, the combination of the radium sulphate precipitate and the calcium fluoride means the sludge contains 90% of the radium inventory resulting in radium levels of 8 to 10 Bq g^{-1} (Vandenhove, 2002).

From the thermal process
There is one phosphor plant within the European Union that uses this process: Thermphos International BV (TIBV) in Vlissingen, Netherlands.

The refined process in operation at TIBV results in no radionuclide enhancement of the silicate slag. However, the calcined dust contains 95% of the ^{210}Pb i.e. 1 000 Bq g^{-1} (Hofmann et al, 2000 (b)).

The following typical process data have been obtained for elemental phosphorus production by the thermal process at Thermphos in The Netherlands (W. Erkens, Proc. European ALARA Network Workshop, 1999):

- Annual throughput of phosphate ore, largely sedimentary: 600 000 t.
- Average activity concentration: 1 Bq g^{-1} ^{238}U decay chain.
- Annual slag production: 600 000 t (used in road construction).
- Average activity concentration in slag: as for ore except ^{210}Pb and ^{210}Po, which are depleted compared to ^{226}Ra and ^{238}U.
- In addition, the phosphorus furnaces produce smaller amounts of ferrophosphorus, which is recycled for recovery of iron.
- Annual production of calcined precipitator dust: 10 000 t (stored).
- Average activity concentration in calcined dust: 1 000 Bq g^{-1} ^{210}Pb.

(ii) Liquid Discharges:

From the sulphuric acid process
Past practice was to dispose of the phosphogypsum into rivers and the sea (see Table 18). However, phosphogypsum is now largely stored on land . As stated previously, discharges of phosphogypsum by countries of the EU are historical.

From the hydrochloric acid process
Calcium chloride is released as an effluent in the process. The specific activity is below 2 Bq l^{-1} ^{226}Ra.

From the thermal process

The new process used by TIBV appears not to have any significant release of effluent; any liquid is recycled into the mixing stage (Hofmann et al, 2000 (b)). Discharges up to 1997 are given in Table 19.

(iii) Atmospheric Discharges:

From the thermal process
In the course of the modern thermal process 95% of the ^{210}Po is emitted (Hofmann et al, 2000 (b)). The annual discharge of ^{210}Po is in fact even higher than the annual input with the ore because of the recycling of electrostatic precipitator dust that is highly enriched in ^{210}Po (1 000 Bq g^{-1}). As a consequence, this recycling ^{210}Po has a relatively long residence time in the production facilities and gives rise to 'additional'^{210}Po, which is then discharged largely in the sintering process. This ^{210}Po is additional in the sense that it is more than would be expected from a simple calculation of the ^{210}Po content of the phosphate used to produce the batch of phosphorus.

2.7 Titanium oxide pigment production

2.7.1 The process

Titanium oxide pigment is produced from the ores rutile (TiO_2) and ilmenite ($TiO_2 \cdot FeO$). In addition tin slag can be used as the raw material in either process (German Federal Environment Agency, 2001).

In the original sulphuric acid process ilmenite is dried and ground, mixed with concentrated sulphuric acid and heated until an exothermic reaction starts between the titanium raw material and sulphuric acid. A solid reaction cake is formed that is composed mainly of titanium and iron sulphates. The reaction cake is dissolved in a mixture of water and recovered process acid. Ferric iron in the solution is reduced to the ferrous form in separate reduction tanks with scrap iron as the reducing agent. The reduced solution is settled and filtered to remove un-reacted solids and much of the iron is removed by cooling and crystallisation into hydrated ferrous sulphate (copperas, $FeSO_4.7H_2O$). After removal of the copperas by centrifugation, the solution is concentrated by vacuum evaporation followed by preferential precipitation of TiO_2 from the iron and titanium basic sulphate ($TiOSO_4$) liquor as white titanium oxihydrate. The titanium oxihydrate is filtered from the dissolved sulphates and extensively washed to remove impurities. The pure white precipitate is calcined in a kiln at about 1000°C to form the TiO_2 crystals of the required size and shape (see Figure 5 for a process diagram including emissions). This traditional production process is being phased out in favour of the cleaner chloride process, but it is unlikely to be phased out completely as it is the only way to produce anastase.

In the chloride process rutile, cokes and chlorine react at about 1000°C to form a mixture of chlorides including the highly volatile $TiCl_4$. The other chlorides are separated from $TiCl_4$ in a series of condensation steps. After purification by distillation the $TiCl_4$ is oxidised to TiO_2 and finished into pigment. About 70% of the European production is from the chloride process (see Figure 6 for a process diagram including emissions). Therefore, typical discharges and residues discussed below focus on this process. From the report prepared for the OSPAR Commission on

Waste from the Titanium Dioxide Industry, 1979-1997, it appears that, although during the period covered sulphuric acid discharges into the marine waters of the OSPAR region have been reduced very considerably, plants in France, United Kingdom, Spain and Germany were still discharging sulphuric acid in 1997. See Table 20 for information on the extent of the industry in the EU. The Dutch plant introduced the chloride process at the end of the 1980s and has used the chloride process since 1990.

Annual throughput:

The scale of the process at a typical intermediate size plant is of the order of 90 000 t rutile or ilmenite being processed annually. On the basis of the uranium and thorium concentrations in 15 rutile samples given in Table 21, the average activity concentration in the rutile is set at 400 and 600 Bq kg^{-1} for the ^{238}U chain and ^{232}Th chain nuclides respectively. However, it is important to emphasis the potential variability of concentrations in such minerals. It is assumed that both chains are in secular equilibrium which is not necessarily the case for synthetic rutile produced from ilmenite in which the iron content of the ilmenite is strongly reduced. The process, involving reductive roasting with coal in a kiln, magnetic separation and acid leaching of the ilmenite (Becher process), not only removes non-radioactive impurities, but may also preferentially remove certain members of the ^{238}U and ^{232}Th decay chains either in the roasting or leaching step.

On the basis described above the annual activity throughput for a typical TiO_2 production plant is 40 GBq for each of the nuclides from the ^{238}U chain and 60 GBq for the members of the ^{232}Th chain.

2.7.2 Waste production

The highly purified TiO_2 pigment, virtually 100% of the rutile input, is practically completely free of the natural radionuclides contained in the ore. Emissions to the air, apart from the radon in the ore, are negligible. Consequently, all radioactivity from the ore appears in the liquid effluent and solid wastes. Solid wastes arise as blow-over of cokes and ore from the reactor and as precipitate from the treatment of acidic solutions of chlorides separated from $TiCl_4$ in the condensation steps. This acidic solution of chlorides contains virtually the entire radioactivity contained in the ore. The partitioning of the radionuclides between solid waste and discharged wastewater depends on the treatment of the acidic liquid waste stream. This treatment involves the precipitation of the cations as hydroxides by increasing the pH. Radionuclides of the elements radium and lead tend to remain in solution if the pH endpoint is not high enough.

(i) Solid residues:

Chloride process
Most of the radioactivity from the ore will appear in the solids from the treatment of the acidic chloride liquor. Part of radioactivity will be found in the ore residues and coke blow-over from the reactor. Concentration data cited in Leenhouts et al, 1996 from a confidential report from ECN indicates that the latter type of waste can be enriched in ^{210}Po. Because of the high titanium oxide content of rutile, the mass of

solids from the treatment of the acidic chloride liquor is only in the order of 5.5 % of the rutile throughput. If it is conservatively assumed that all activity from the rutile appears in this solid waste, the typical upper concentrations on the basis of dry weight can be derived estimated at 7 and 11 Bq g^{-1} for ^{238}Usec and ^{232}Thsec radionuclides respectively. The amount of this solid waste is about 5 000 t annually for a plant producing 90 000 t y^{-1} of TiO_2. Activity concentrations will be lower and amounts of waste higher when the neutralisation of the acidic chloride liquor is carried out at a higher pH endpoint. Significantly lower concentrations in this waste will result when the activity concentrations in the rutile are considerably below the concentrations of 0.4 Bq g^{-1} and 0.6 Bq g^{-1} assumed here for ^{238}Usec and ^{232}Thsec respectively.

The annual amounts of un-reacted ore residue, also containing the coke blow-over, will depend on ore characteristics and average process conditions. They may amount to about 20% of the annual rutile throughput. Activity concentrations in this type of waste can be expected to be of the same order of magnitude as in the rutile used.

Sulphuric process
No data are available on activity concentrations in the solid wastes or by-products from the sulphuric acid process. From the data for the Greatham UK sulphuric acid process plant in Calais given in Huntsman Tioxide, 2000, it seems that the annual amounts of un-reacted ore residue are of the same order of magnitude as in the chloride process. Activity concentrations may be of the same order as in the chloride process as most of the iron is probably leached from the ilmenite. In addition, the sulphate process produces radium scales in the pipes.

With the lack of specific information it can be assumed that without gypsum production from the acidic waste stream, the amounts and activity concentrations are similar to those of a chloride plant. When all the sulphate is converted to gypsum the total amount of solid waste is much higher. If all activity from the ilmenite is assumed to end up in the gypsum the activity concentrations of ^{238}Usec and ^{232}Thsec will be of the order of 60 and 100 Bq kg^{-1} respectively for activity throughputs of 40 and 60 GBq annually from the ilmenite ore.

(ii) Liquid discharges:

As explained above, activity discharges into water from a TiO_2 pigment production plant depend on the treatment of the waste chloride solution. Presently it is highly likely that liquid waste treatment has been implemented in all plants to limit discharges of acids and heavy metals such as cadmium, chromium, zinc and lead (OSPAR Commission, 1999). Total discharge of all activity from the ore into water is therefore rather unlikely. On the other hand complete removal of all dissolved radioactivity from the liquid waste is also not practically achievable if the effluent from the treatment process is still acidic as appears from the data provided in the OSPAR 1999 report.

Chloride process
Typical discharges for a titanium pigment plant of 50,000 t of rutile throughput annually have been presented in UNSCEAR 2000, Annex B, Table 28. The annual discharges of 2-3 MBq for radionuclides from the decay chains of ^{238}U and ^{232}Th were cited from Leenhouts et al. 1996. However, in the latter report the annual

discharge of ^{226}Ra, for instance, is quite wrongly calculated to be 2 MBq on the basis of 154 000 m^3 liquid effluent with 30 Bq l^{-1} ^{226}Ra. The correct figure for the annual discharge of ^{226}Ra on the basis of these data is 4.6 GBq instead of 0.002 GBq. The same error occurs in the estimates for the other radionuclides. The 30 Bq l^{-1} ^{226}Ra concentration data were taken from a confidential report by ECN (now NRG). In that report (Weers, 1992) it was concluded that the still slightly acidic effluent carried about 60% of the input of the radium isotopes, 8% of the ^{210}Po and 25% of the ^{210}Pb.

We can use these observations to derive typical activity discharges with acidic effluents for a 90 000 t annual TiO_2 production from rutile with 0.4 Bq g^{-1} ^{238}Usec and 0.6 Bq g^{-1} ^{232}Thsec. The results are given in Table 22.

If the neutralisation of the acidic effluent is taken to a higher pH endpoint, more iron will precipitate which increases the amount of solids from the effluent treatment and probably significantly reduces the residual activity concentrations in the effluent. Activity discharges will also be reduced when synthetic rutiles are used with considerably lower activity concentrations than assumed for Table 22.

Sulphuric acid process
No published data are available for activity discharges from a TiO_2 plant using the sulphuric acid process. It is assumed that if these plants are discharging acidic effluents, typical discharges will be of the same order of magnitude as for a plant of the same annual production using the chloride process. Plants that remove sulphuric acid from the liquid waste by converting the sulphate into gypsum, are likely to reduce their activity discharges quite considerably. The sulphates of radium and lead are rather insoluble and will be carried down with the bulky precipitate of gypsum, as will most of the un-dissolved solids.

2.8 Zirconium and rare earth processes

2.8.1 Zircon ($ZrSiO_4$)

Zircon is a zirconium ore used mainly for high temperature purposes in steel and iron foundries and in refractory materials and products and also in fine ceramics. Minor volumes are used as additives in special types of glass. Other uses for zircon and the associated minerals of zirconia and zirconium include abrasive materials, catalysts, paints, fuel cladding and structural materials in nuclear reactors (UNSCEAR 1993). Zircon is not mined in Europe and so approximately 350 000 tonnes per year are imported.

Milling which is a physical process involving crushing, grinding and sizing, is conducted at various sites including the Netherlands, England, Germany, Italy and Spain (see Table 23). The only waste problem associated with the process is that of dust which is kept to a minimum by good housekeeping. There is a loss of between 0.1% and 1% of the turnover by this route. An average figure for the radioactivity content of Zircon is given in Table 24. However, it must be emphasised again that there is a high potential for variability in concentrations in such minerals.

At zircon mills comparatively small amounts of waste are produced which usually are disposed of at landfill sites. It may consist of spilled zircon mixed with other

substances explaining why it cannot be recovered. Quantities of 200 t y^{-1} (1% of turnover) were reported for one site using dry milling (Scholten, 1996).

2.8.2 Zirconium smelting

In the UK one factory makes fused zirconium for high specification refraction products and dielectrics. Baddleyite (an ore, see Table 25) is heated in a furnace to extract the zirconium. Sources of waste from this process includes liquid effluent from floor washing, dust from the ventilation system and atmospheric discharges from the furnace.

Approximately 20 t y^{-1} of solid powder from the filters is produced from a production of 2000 t of refractory material which is approximately 1% of the feed ore. The waste from floor washing is thought to be minimal, assumed to be 20 kg y^{-1}, as is the dust emissions at approximately 5 kg y^{-1} (Martin et al, 1997).

Other processes with minimal waste production include rare earth glass polish and factories producing refractory bricks where the waste is likely to be floor washings and dust releases estimated at 20 kg y^{-1} and 5 kg y^{-1} respectively (Martin et al, 1997).

2.8.3 Ceramics (and brick factories in particular)

The largest plants produce bricks and roofing tiles. The firing temperature of the ovens is between 1000 and 1200°C. The clays usually have concentrations of the radionuclides from the decay chains ^{238}U and ^{232}Th in the order of 35 Bq kg^{-1}. Between 40 and 100% of the ^{210}Po is volatilised in the firing process. The fraction of the throughput of ^{210}Po emitted depends on the extent of the off-gas cooling and cleaning to abate dust and HF emissions.

Estimates provided in UNSCEAR 2000, Annex B, are based on Leenhouts et al, 1996. However, Table 28 of that Annex provides emission estimates for the ceramic industry that are incorrectly taken from Leenhouts data for the much smaller plants producing fine ceramics. The annual production figure (total for all plants in the Netherlands) of 3 200 kt annually is, in fact, the figure for brick production. The average total annual emissions as dust and gases for brick production plants provided by Leenhouts et al, 1996 are 0.23, 1.2 and 0.22 GBq for ^{210}Pb, ^{210}Po and ^{40}K respectively. They are significantly higher than the figures in the UNSCEAR report.

An upper estimate of the aerial discharge of ^{210}Po from a brick factory can be based on the following assumption: typical production 30 kt y^{-1}, average concentration in clay 35 Bq kg^{-1}, volatilisation 100%, trapping in off-gas 0%. The maximum annual emission for such a plant is 1 GBq.

Italian ceramics is probably the largest consumer of zircon in Europe. Italy imports about 170 000 tonnes per year of zircon sands of which 70% is used in the ceramic industry (Trotti, 2002). However, the zirconium is fixed in the glaze (see Table 26).

2.9 Cement production

2.9.1 The process

Production of cement involves the heating calcining and sintering of blended and ground raw materials, typically limestone and clay or shale and other materials to form clinker. This clinker burning takes place at a material temperature of 1450°C in kilns. The clinker is ground and mixed with small amounts of gypsum to give Portland cement. In addition, blended cements are produced from cement clinker with blast furnace slag and fly-ash. Large cement plants produce of the order of 4 000 t of cement per day (1.5 Mt y^{-1} (BCA, 2002)). Cement production in 1998 in EU Member States is given in Table 27.

From these figures it is clear that cement is produced in each of the EU Members States and that some countries have a large number of cement plants.

2.9.2 Typical discharges

Because of the very high temperature of the raw materials in the kilns volatilisation of ^{210}Po and ^{210}Pb is the main potential source of aerial discharge. Estimates on 'typical' discharges provided in UNSCEAR 2000, Annex B, are based on Leenhouts et al., 1996 (see Table 28). In the figures quoted, the fact that blast furnace slag which can be used in blended cements, as mentioned above, is considerably depleted in ^{210}Pb and ^{210}Po has been taken into account. No other source of activity emission data has been identified.

The discharge figure for ^{210}Po is based on the assumption that 50% of the polonium escapes from the thermal process in analogy with the assumption used for the production of bricks and roofing tiles.

3 Review of regulations

3.1 Introduction

A limited review of the regulatory framework in EU Member States in relation to the regulation of 'work activities' as defined in Title VII has been undertaken. The objective of the study was not a legal review of Member States' compliance with Title VII of the Directive.

The focus of research has been upon the regulation of the impact on the public of work activities and, specifically, on discharge control from such activities. Work by Member States in the area of worker exposure and radon in the workplace has been investigated to a large extent in previous studies (see Figure 1 for relevant European Commission technical documents) and so is not part of this study.

Information was based on a review of recent papers and publications and in particular on the responses by national regulators, where possible, or by other national advisory bodies, to a questionnaire. The full text of the national responses are presented in Appendix B. The questionnaire responses have been extensively summarised in Tables 30 and 31 with the answers further presented in Figures 6 to 13. Extensive summaries relating to each Member State in turn are contained in Appendix C.

3.1.1 Background

The European Union prepared and adopted the Council Directive 96/29/Euratom (the Directive) including, in Title VII, following the publication by the International Atomic Energy Agency (IAEA) of the International Basic Safety Standards for Protection against Ionising Radiation and the Safety of Radiation Sources (BSS) (IAEA, 1996). The BSS applies to practices involving exposure to natural sources specified by the Regulatory Authority as requiring control, as stated in paragraph 2.1. However, generally exposure to natural sources under the BSS was normally to be considered as a chronic exposure situation and, if necessary, subject to the requirements for intervention.

Within the Directive activities involving naturally occurring radionuclides, (not being used for their radioactive, fissile or fertile properties), likely to result in a significant increase in exposure of workers or the public, were defined separately as 'work activities' as opposed to simply being included within the definition of practices as in the BSS.

The primary scope of the Directive remains 'all practices which involve a risk from ionising radiation from an artificial source or from a natural radiation source in cases where natural radionuclides are or have been processed in view of their radioactive, fissile or fertile properties'. Nevertheless, paragraph 2 of Article 2 states that the Directive also applies to 'work activities which involve the presence of natural radiation sources and lead to a significant increase in the exposure of workers or members of the public which cannot be disregarded from the radiation protection point of view'.

The Directive thus brings exposures to natural radiation within the same general framework as other exposures, but retains a distinction between natural and artificial sources. However, the same procedures do not necessarily have to be applied and even when applied, not necessarily to the same extent as practices (European Commission, 1997).

The main provisions relating to 'work activities' are contained in Title VII which has been included as Appendix A in this report.

Under Article 40 these activities should be identified by the Member States. Once identified as of concern, Article 41 states that Member States shall require exposure to be monitored and corrective/protective measures implemented, as necessary, pursuant to part or all of the requirements set out in rest of the Directive in Title IX (intervention) and Titles III (reporting and authorisation), IV (justification and optimisation), V (estimation of effective dose), VI (fundamental principles of radiation protection for workers) and VIII (radiation protection for the public).

The areas highlighted for consideration included:

(a) work activities in workplaces such as spas, caves, mines, underground workplaces and aboveground workplaces in identified areas where there is radioactive exposure.

(b) work activities involving operations with, and storage of, materials containing naturally occurring radionuclides causing a significant increase in exposure.

(c) work activities leading to the production of residues containing naturally occurring radionuclides causing a significant increase in exposure

(d) aircraft operation.

The concept of 'exclusion' is introduced within the context of natural radiation in Article 2 (4) where it states that:

4. This Directive shall not apply to exposure to radon in dwellings or to the natural level of radiation i.e. to radionuclides contained in the human body, to cosmic radiation prevailing at ground level or to aboveground exposure to radionuclides present in the undisturbed earth's crust.

Should Member States under Article 41 decide to apply the provisions of Title III to 'work activities' the exemption values for work activities are not explicitly given. The exemption levels given in Annex I of the Directive do not apply to NORM (Weers et al, 1997). Individual annual exposures may be much higher than 10 μSv and collective doses can be very important. Therefore values for natural sources cannot proceed on the same trivial risk criteria established in Annex I (European Commission, 2001).

Following the publication of the Directive, the European Commission commissioned research to assist Member States in the area of NORM and subsequently published

related guidance, in particular RP 95 and RP 122 Part II. Such documents are not regulations, they are simply guidance, so there is no obligation upon Member States to adopt these recommendations (see Figure 1 for a list of relevant European Commission guidance and technical reports).

Radiation Protection 95 (European Commission, 1999) provides reference levels for identifying those industries for which workers exposure should require regulatory control. Radiation Protection 122 Part II (European Commission, 2001), relates to exemption and clearance and is also of most relevance to the workplace. No guidance has yet been developed in relation to discharges. The relationship between RP 95 and this report is given in Figure 2.

(i) Radiation Protection 122 Part II – Application of The Concepts of Exemption and Clearance to Natural Radiation Sources

Two major conclusions of this report were:

- that for NORM one simple set of levels covering both concepts, exemption and clearance, is appropriate (See Table 29).

- that rather than an individual dose criterion, a dose increment in addition to background exposure of the order of 0.3 mSv for workers as well as members of the public is appropriate.

Though one set of values is recommended it is also emphasised that, for exemption, the levels must be fixed allowing industries to decide whether reporting is necessary. However, for clearance some flexibility will be necessary to allow for the best option for waste management and for the specifics of particular industries. So, though the levels may be the same, the concepts remain different requiring separate approaches.

The Article 31 Working Party on Exemption and Clearance decided that a dose criterion for NORM should be in the range of the variability of the natural background dose within the Member States i.e. between 0.1 and 1 mSv y^{-1} (Timmermans et al, 2001).

The European Commission has not yet produced guidance on approaches for the assessment of doses to members of the public from NORM discharges (this issue was addressed in this study and is reported in Section 4). It has, however, produced guidance on the assessment of doses from discharges from nuclear facilities (European Commission, 2002a; Jones et al, 2002) which has been used as the basis for developing guidance relating to NORM discharges.

3.2 An overview of national regulation in EU Member States

National legislation that is relevant to the control of NORM and implementation of Title VII in particular is listed in Table 32. As stated previously, information was collected by means of a questionnaire, the answers to which have been summarised in Table 30.

- *All EU Member States have acknowledged the issue of 'work activities' within their regulatory structure* although it is uncertain that Title VII has been fully enacted in Portugal (Figure 7).

- Often Member States have concentrated in the first instance on the impact on workers thus a number have taken measures to identify those workplaces in which exposure to ionising radiation to the workers cannot be disregarded. However, Member States appear to be *at an early stage in the area of identification of significant exposure to the public from wastes and discharges.*

- Initial identification, be that just identification of general groups of industries that may be affected based on published reports, has been completed in eleven out of fifteen of the countries with a further four countries currently in the process of their initial identification process. Only Portugal has not started (Figure 8).

- A number of countries are beyond the initial identification stage and have *completed detailed studies into the industries within their countries establishing which processes do require regulation; such countries include Germany, the Netherlands, Finland, Sweden and the UK.* Denmark and Greece have completed detailed studies into some industries, but the identification process is still ongoing. In the other Member States where the initial identification process is complete, detailed investigations are either planned or are ongoing.

- Three quarters of those who answered and had regulations relating to NORM, have used the concept of exemption within their legislation. By restricting regulatory control to those industries, for example, where effective doses could exceed 1 mSv y^{-1}, regulatory resources can be concentrated on those industries of significance (Figure 9).

- Regulatory changes can be slow and difficult to achieve. Therefore, due to the possibility of technical changes and developments, it is important that there is scope within legislation for control of unforeseen new activities, which may be significant from a radiological protection viewpoint. Provision appears to have been made within the legislation in the majority of countries to allow the existing legal measures to encompass the aforementioned new and currently unforeseen activities should they arise (Figure 10). Detailed legal provision in Portugal in the area of work activities does not yet exist, while in Spain and Greece the detailed legal instruments are currently being development further and so it is difficult to definitively determine whether the provision exists to control new activities as they arise without requiring new primary or secondary legislation.

- *At present there are no specific discharge controls, specific assessment procedures or constraints for wastes from work activities in the majority of countries (Figure 11).* A number of countries including Spain, Ireland, Austria and Sweden indicated an intention to review their discharge controls with respect to NORM wastes in the near future (Figure 12).

- Less than half the Member States responded positively to the benchmark question relating to a hypothetical marine discharge from a non-nuclear installation. Four

of the *six countries* (Belgium, Italy, Luxembourg, the Netherlands, Finland and the UK), which *had controls in place to deal with NORM discharges,* suggested discharge limits were likely to be introduced. There would also be an added requirement that the operator to show that the best practical environmental option was being applied. Of the other two countries, one would require a radiological impact study before the likely required actions could be suggested and the other suggested the discharges could be exempt.

- *There appears to be little radiological control in the area of liquid and aerial discharges specific to the NORM industries.* This is clearly indicated in Figure 13 by the high number of cases where no answer was given to the benchmark. It should be noted that *environmental protection measures in place to control particulate emissions and heavy metal releases etc may have the additional benefit of also limiting radiological releases* and this was highlighted by Ireland who suggested that they may fall within the scope of their Environmental Protection Act 1992. *Solid waste controls are more common* for example in Greece an Order exists requiring authorisation of phosphogypsum disposal, and in Germany there are also detailed regulations on the disposal of solid material.

On the basis of the information provided, Member States could be divided into three categories as follows:

Category 1: Legislation relating to/encompassing NORM has been enacted and industries have been identified and some controls put in place.

Category 2: Legislation in draft form or industry identification incomplete or discharge controls at an early development stage.

Category 3: Legislation incomplete and identification of industries process not underway.

Category 1	Category 2	Category 3
Germany, Greece, Luxembourg, Netherlands, UK and Finland.	Belgium, Denmark, Spain, Ireland, Italy, Austria France and Sweden	Portugal

A more detailed summary of information by Member State is contained in Appendix C. Some practical examples of implementation from the Member States have been listed in Table 33.

3.2.1 Dose limits and constraints

According to Article 41 (b) of the Directive (see Appendix A) Member States shall apply radiation protection measures including Title IV, Dose limits, as necessary. It can, therefore, be concluded that these aforementioned dose limits could be applied to NORM. This subsection, therefore, concentrates upon a review of how the dose control mechanisms of 'dose constraints' and 'dose limits' have been applied to the area of work activities in Member States. The information relating to these matters from the questionnaire is summarised in Table 31. It should be noted that the emphasis of this report as a whole is upon discharge control and so questions were

tailored towards dose constraints in relation to effluents and to a limited extent, on dose limits to members of the public.

In RP 122 Part II it is suggested that a higher value than the 300 μSv recommended as a dose constraint for practices, up to 1 mSv, would probably be appropriate for work activities (European Commission, 2001). The value of 300 μSv is also mentioned as an annual effective dose increment by the Article 31 Experts, for the criteria for exemption-clearance of work activities, as outlined in 3.1.1 (i) and is said to be coherent with any dose constraint which may usually be considered for the control of effluents (European Commission, 2001). However, no advice is given in existing guidance as to what value should be used as the dose constraint for the control of effluents from work activities.

The application of these concepts in the case of Member States can be summarised as follows. Further detail on a state-by-state basis can be found in Appendix C.

- In relation to dose criterion for the disposal of solid wastes and NORM residues Greece and Denmark both include a value of 0.3 mSv y^{-1} increment, equal to the value recommended within RP 122 Part II. However, a number of countries, including Belgium, Germany, Luxembourg and the Netherlands, could not implement the guidance from the European Commission on the application of exemption and clearance to natural sources (RP 122, Part II), as one of the regulatory tools mentioned in Title VII, Article 41 of the Council Directive. The reason for the omission was that their *national regulations were implemented before the publication of RP 122, Part II.* The Netherlands does use 0.3 mSv y^{-1} effective dose. However, this is the dose criterion for exposure of the public from solid residues containing natural radionuclides; for workers the criterion is 0.1 mSv y^{-1} under normal conditions or 1 mSv y^{-1} under unfavourable but realistic conditions.

- Ireland, Austria and the UK in particular, incorporate the *concept of dose constraints within secondary legislation. However, values are not stated in the legislation and are likely to be determined by the relevant regulator as directed by government policy*.

- Austria and Denmark do not consider a lower boundary below which further optimisation is no longer required. In Greece dose constraints provided in their legislation were set within the process of optimisation and so there is no optimisation requirement below dose constraints.

- Finland has the provision within tertiary legislation for dose constraints for exposure from natural radiation in the range of 0.1 to 0.5 mSv y^{-1} which can be applied to effluents as well as solid disposal. However, despite these regulations being in place since 1992 no occasion has arisen, as yet, requiring the application of dose limitation to discharges. In Greece there are no discharge limits because, similarly, as yet no significant liquid or gaseous NORM waste have been found to be present at the identified work activities. In the Netherlands the dose constraint, within their explanatory notes, applying to exempted aerial and liquid NORM discharges is 10 μSv y^{-1} effective dose to members of the public, which is

the same as the Swedish dose constraint of members of the critical group from radiation sources.

- In Sweden and the UK existing *dose constraints are not NORM specific and were largely formulated for the purpose of controlling discharges from practices nevertheless can be used in relation to NORM.* However, Sweden is undertaking a review of their controls of natural radiation exposure in view of Title VII of the Directive. Spain and Ireland are also reviewing discharge controls; at present there are no specific discharge provisions.

- In conclusion *there are few NORM specific discharge controls in place at present and where these do exist, such as in Finland, there have been few occasions when the limits have been applied*, see Figure 14.

4 Guidance on the assessment of radiation doses to members of the public due to discharges from NORM industries

4.1 Introduction

This section addresses Task 4 of the study.

The main objective of Task 4 was to develop an approach for the realistic assessment of radiation exposures from discharges from NORM industries. The exposure pathways to be considered, the characteristics of the exposed groups and the methods for determining doses have been addressed. This has been achieved by reviewing current methodologies for the assessment of doses from discharges from the nuclear industry to assess their suitability for use in determining doses from NORM industries within the EU. In particular, the results of a recent European Commission study to provide guidance on the assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions (Jones et al, 2002) have provided a significant input. To judge the suitability of such methodologies for the assessment of doses from EU NORM industries, information on the characteristics and disposal routes of discharges from NORM industries, the location of NORM industries and the behaviour of radionuclides found in such releases have been used. This information has come from a number of sources including input from Task 1 of this study (see Section 2). On the basis of this review and analysis guidance is provided on the assessment of doses from the operation of NORM industries.

Guidance is given on approaches and methodologies for assessing doses to members of public, in terms of individual dose, due to discharges from NORM industries. Two types of discharge to the environment are considered here: discharge to atmosphere and to water bodies.

The main starting point in the development of the proposed guidance for assessing doses arising from discharges from NORM industries was the results of a study carried out for the European Commission to provide guidance on the assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions. A description of the study and its main conclusions are presented in RP 129 (European Commission, 2002a). More detailed information on the study is provided in Jones et al, 2002. These reports give guidance on all aspects of the assessment of doses to reference groups from the routine operations of nuclear installations. The work was developed in consultation with a working party on realistic assessment of the impact of nuclear installations on members of the public (RAIN) of the standing group of experts under Article 31 of the Euratom directive.

In this study the above guidance on dose assessments for discharges from nuclear facilities was examined, in parallel with information on discharges from NORM industries and other relevant information on dose assessment methodologies, to consider the extent to which the same guidance could be applied to NORM industries and to identify any significant differences. On this basis guidance for NORM industries is proposed.

4.1.1 Scope of guidance

The primary application of this guidance is for retrospective assessments of doses from the discharge of radioactive effluents from NORM industries. The emphasis of this guidance is on the realistic assessment of doses. The aim of a realistic assessment is to estimate doses as close as possible to those that would actually be received by members of the public. This is not straightforward and requires judgement, but the aim is to avoid significant over or under estimation. Retrospective assessments consider doses that are currently being received or that were received in the past. It is likely that information will be available on the location and behaviour of reference groups. Prospective assessments consider doses that may be received in the future say from planned discharges. In this case judgement is needed on what may happen in the future, for example regarding changes in land use and normally such assessments include an element of caution in the assumptions adopted. The guidance in this chapter is primarily related to retrospective assessments, but much of it is also relevant to prospective assessments.

The aim is to provide general guidance on all stages in the assessment of doses to reference groups, see Figure 15. It includes: the specification of the source term; what exposure pathways should be considered and their relative importance; methods for assessing doses from the important exposure pathways; issues to be considered in identifying reference groups; other factors involved in dose assessments such as the implications of short term releases, variability and uncertainty, the use of measurement data and the need to assess doses to different age groups. The guidance can necessarily only be general in nature and if an assessment is to be realistic it is essential that local conditions are considered. This guidance does not necessarily apply to methods and advice issued by Member States for regulatory purposes, for example connected with the authorisation of releases of radionuclides to the environment.

4.2 Source terms

The first stage in radiological assessments is to determine what radionuclides are being released and to which part of the environment they are being released. To undertake a realistic dose assessment it is essential to obtain as much information as possible for the site being assessed. Data will need to include:

- Type and amount of radionuclides being discharged e.g. 0.2 MBq of ^{210}Po;
- Type of release i.e., vapour, particles or liquid;
- Location of release e.g. atmospheric release from stack of height 80 m or vent from building, river or coastal area to which liquid releases are being discharged.

The naturally occurring radionuclides present in discharges from NORM industries are ^{238}U, ^{235}U and ^{232}Th, and members of their decay chains. Table 34 shows the radionuclides in the decay chains, together with their half-lives and branching fractions for those nuclides having two or more radioactive daughters.

The radionuclides ^{40}K and ^{14}C are also present in some NORM discharges but are not considered further in this section. This is because potassium in the body is under homeostatic control and thus small intakes of ^{40}K will have a negligible impact on the level in the body. In the upper atmosphere ^{14}C is continuously produced as a result of the reaction between cosmic rays and ^{14}N. The ^{14}C content of coal, however, is negligible and thus releases of carbon dioxide from plants that burn coal lead to a dilution of the isotopic content of this isotope in atmospheric carbon. This in turn leads to a reduction in the radiation dose from ^{14}C. However, this dose reduction is small and therefore releases of ^{14}C are not considered radiologically significant.

The decay chains in Table 34 each contain a number of radionuclides. Some of these nuclides are very short lived, with half-lives ranging from a few seconds to a few months. Thus, parts of the decay chain will quickly reach secular equilibrium within a few days to a few months, with the short-lived daughters having the same activity concentrations as their long-lived parent. This allows the full chain to be considered in terms of a number of chain segments which can be useful when performing assessments. These segments are listed in Table 35 in which the decay chains are simplified into a number of long-lived key nuclides and their chain segments. When performing assessments the chain segments are essentially treated as individual radionuclides with composite characteristics.

Naturally occurring radionuclides in ores and other raw materials are likely to be in secular equilibrium with the other members of their decay chain. However, processing of raw materials may concentrate naturally occurring radionuclides in particular waste streams and thus equilibrium will be lost. This enhancement can occur by means of mass separation, volatilisation or other physical and chemical reactions. For example, burning coal results in the release of ash to atmosphere that, due to the process of volatilisation, has enhanced concentrations of ^{210}Pb and ^{210}Po in comparison to other higher chain members. It is important, therefore, when characterising NORM source terms, to consider the implications of any enhancement mechanisms and design monitoring and measurements schemes to ensure the important radionuclides are identified.

Information on waste streams and discharges from EU NORM industries, including typical activity concentrations were collected as part of Task 1 of this study (see Section 2). It should be stressed that by the very nature of the industrial processes involving NORM, the discharges are likely to be continuous with a low probability of significant incidental or accidental releases.

From an analysis of this information on EU NORM industries it is clear that wastes are discharged to the atmosphere and aquatic bodies. Thus, in general terms, the discharge routes are similar to those from nuclear installations and other facilities producing radioactive waste, e.g. hospitals. There are, however, a number of specific differences.

1. It is possible for atmospheric releases from NORM industries (e.g. coal-fired power stations) to occur from significantly higher stacks than would be found in the nuclear industry or other radioactive waste producers.

2. Discharges to the marine environment from the nuclear industry occur to coastal areas (or estuaries) from pipelines onshore, whereas, the Oil and Gas industry discharges some waste directly into the open sea.

3. Some facilities discharge wastes to sewers, e.g. hospitals. This disposal route is not generally used for NORM wastes because of the large volumes involved and their chemical characteristics.

In some cases the chemical form of discharged radionuclides from the nuclear industry and other facilities producing radioactive waste can have a significant effect on radiation doses. This is also likely to be of significance for NORM industries. The physical form is also potentially important for particulate releases to atmosphere where the size of the particles can affect the subsequent doses from the discharges. ICRP recommend (ICRP, 1994) a default particle size of 1 μm for exposure of members of the public and 5 μm for workplaces. In general, the use of the default is considered reasonable for assessing doses from NORM industry atmospheric releases. However, where for example the release is from wind driven re-suspension of particles from large piles of raw materials, the particle size may be closer to the 5 μm values for workplaces. Some values for workplaces are given in Dorrian and Bailey (1994, 1995). More information in this area is expected to come from the European Commission SMOPIE (Strategies and Methods for Optimisation of Internal Exposures of Workers from Industrial Natural Sources) project.

Reference group doses are typically assessed on the assumption of annual discharges. This assumes that the activity is discharged continuously and uniformly throughout the year. In practice, not all discharges will be entirely uniformly continuous. For example, scale discharges from oil and gas platforms occur following routine cleaning operations that may occur at a number of intervals over the year. Given the other uncertainties in the assessment process, the results based on continuous release still remain valid for these normal operational daily variations in discharges.

However, if a significant proportion of the annual discharge was discharged in a short time period, this could lead to higher annual reference group doses than those assessed for a uniform release rate over the year depending on the conditions at the time of release. The assessment would need to take account of the month of year as dispersion, crop harvesting and outdoor occupancy varies over the year. The following factors could lead to higher doses:

a. Over the short time period that the release occurred, dispersion in the environment could be more localised than average dispersion over a year. This could lead to higher activity concentrations in some sectors of the environment, including the food chain. In the case of discharges to atmosphere, this might be due to occurrence of meteorological conditions leading to poor dispersion (e.g. inversion conditions at night or during anticyclones). For discharges to water, this could be a result of low flow conditions in rivers etc, such as can occur during summer months

b. For releases to atmosphere during rainfall this will lead to enhanced deposited activity.

c. Discharged solids such as scales or phosphogypsum may disperse quite differently in the aquatic environment than dissolved material.

d. Occupancy habits may change through the seasons. For example, fishing may be likely to occur more frequently in summer.

e. Food may be ready for harvesting shortly after the release leading to higher activity concentrations in the food than would have been assumed. Also, some foods (e.g. root vegetables and fruit) may be stored for consumption for many months after harvesting, giving prolonged exposure.

It should also be noted that, high activity short term releases could occur at times which would lead to lower doses (e.g. during winter when few crops are harvested).

Where it is assumed that foods are harvested (e.g. root vegetables, green vegetables), then peak activity concentrations (taking account of radioactive decay) should be used in the assessment. It is not realistic to assume that foods would be consumed containing these peak concentrations for a period of more than about two months, unless they can be stored, (e.g. root vegetables or fruit). In this case, storage beyond six months would not be normal. It should be noted that these assumptions remain cautious since it is unlikely that the whole of an individual's intake of a particular group of foods (e.g. green vegetables) is affected by a short-term release.

For animal products (e.g. milk, beef, lamb), the time-integrated activity concentrations over a period of one year following the short-term release, should ideally be used to assess the ingestion dose. This approach is appropriate for milk production which continues at a reasonably continuous rate throughout the year.

4.3 Exposure pathways

When radionuclides are released into the environment there are a number of different ways in which they can lead to radiation doses to individuals. The different ways are referred to as exposure pathways and radiation doses need to be assessed for each important exposure pathway. There are many different possible exposure pathways and it is not necessary to consider every possibility in a realistic assessment of doses. In Jones et al, 2002 recommendations on exposure pathways to consider in assessments of discharges from nuclear facilities were based on a series of illustrative calculations to investigate the relative importance of different exposure pathways following particular discharges to atmosphere and water bodies. A number of different discharges were considered. Discharge data for different nuclear installations were used, taken mainly from the EU discharge database (European Commission, 2000b) and generalised so as to be representative of a generic type of nuclear installation. Additional calculations were carried out to determine the relative importance of the different exposure pathways for discharges of individual radionuclides.

Given the difficulty in characterising typical releases from NORM industries a different approach has been considered herein to identify the most significant exposure pathways. In some cases, illustrative calculations of doses from various

exposure pathways have been undertaken for unit releases of the naturally occurring decay chain segments indicated in Table 35. The information obtained from these studies has been supplemented by consideration of the work carried out for nuclear installations (e.g. Jones et al, 2002) and information from other studies carried out to determine the radiological impact of various NORM industry releases.

The importance of the different exposure pathways for NORM discharges is discussed in Appendices D and E for atmospheric releases and liquid discharges respectively. Recommendations on which pathways should nearly always be considered in an assessment, those which may need to be considered and those which rarely need to be considered, are included.

For exposure pathways, as for other aspects considered in this guidance, it is important to take account of local and regional factors in determining which pathways to consider.

The dose to be compared with the applicable dose criterion will be the sum of the doses to the reference group from the relevant exposure pathways. For example, the total dose to a typical member of the reference group from atmospheric discharges will, in general, be the sum of the doses from external irradiation from radionuclides deposited on the ground, inhalation of radionuclides within the plume and resuspended following deposition, and ingestion of radionuclides in terrestrial foods, i.e.

Total dose from atmospheric discharges = Inhalation dose + External dose + Ingestion dose

It is possible in some cases that the reference group may receive doses from discharges to a number of media from a particular facility, e.g. from atmospheric releases and discharges to river. For example, a group of individuals may receive a dose from consumption of freshwater fish from a river into which a liquid discharge from a plant is made. The same individual may also receive a dose from ingestion of terrestrial foods grown in soil onto which radionuclides from an atmospheric discharge from the same plant have been deposited. Under these circumstances it is important to sum the doses from the different discharges, i.e.

Total dose from plant = Σ discharge Inhalation dose + Σ discharge External dose + Σ discharge Ingestion dose.

It is important, however, that the combinations of habits of the reference group are realistic, and care must be taken in this respect. It would, for example, not be realistic to assume that an individual consumes high rates of marine foods, high rates of freshwater fish and high rates of terrestrial foods. This issue is discussed further in Section 4.5.1.

4.4 Assessment methodology

Jones et al, 2002 advises that the most realistic method for assessing doses to members of the public from discharges from nuclear installations is extensive monitoring of the exposure pathways e.g. measuring activity concentrations in foods, air etc. and conducting surveys of habits of local people e.g. the amount of locally

grown food eaten, amount of time spent on beach etc. It is noted that this approach is costly both in monetary terms and time.

There are a number of reasons why this approach is not generally appropriate for assessing doses from NORM discharges:

- In general doses from NORM discharges will be low and so the costs involved in a very detailed site specific study are unlikely to be warranted;

- the practical problems of measuring activity concentrations of naturally occurring radionuclides from discharges above the normal background levels.

This latter problem is not encountered in monitoring for artificial radionuclides from nuclear installation discharges where the main issue is one of the ability to detect the generally low concentrations present.

It is expected, therefore, that in determining doses from NORM discharges, extensive use will have to be made of both environmental transport and dose assessment models.

A number of models are available and although no specific recommendations are made, (IAEA, 2001) and (Simmonds et al, 1995) are useful references (codes implementing the models in Simmonds et al, 1995, such as PC CREAM (Mayall et al, 1997) and BIOS (Martin et al, 1991), are available). However, it must be noted that the model given in (IAEA, 2001) is intended for screening purposes and uses conservative generic values. If a realistic assessment is intended these values would need to be replaced by more realistic and preferably site-specific values. It is necessary that any models used are robust and fit for purpose. Measures should have been taken to ensure that the models are valid. This means that the models should have been tested to ensure that they are behaving as intended, and where possible, should be compared with measurement data to ensure that they are an adequate representation of reality. For example an IAEA programme called VAMP (Validation of Environmental Model Predictions) (Koehler et al, 1991) tested the predictions of mathematical models against results of measurements made after the Chernobyl accident. It is important to emphasise that any realistic assessment of doses relies on the model parameter values and the habit data used being a realistic representation of the situation near the site. Detailed guidance on modelling for atmospheric and aquatic releases is given in Appendices D and E respectively.

For dose assessments, dose coefficients for ingestion and inhalation from the Directive (European Commission, 1996) should be used (see section 4.5.3 for more information). Dose coefficients from this source for each of the relevant naturally occurring radionuclides are listed in Table 36. The composite dose coefficients for chain segments are given in Table 37. The default chemical form from ICRP guidance has been assumed. If information is available on the chemical form and/or aerosol size then the appropriate dose coefficients should be used from the Directive (European Commission, 1996) or relevant ICRP Publications. (Note that the dose coefficients in Table 36 are identical to those in the relevant ICRP report, (ICRP Publication 72 (ICRP, 1996)).

4.4.1 Accumulation of radionuclides in the environment

When radionuclides are continuously discharged they can accumulate in the environment up to the point where equilibrium conditions are reached. Equilibrium conditions mean that the rate of discharge of a radionuclide equals the rate of transfer out of the environment being considered. The point at which equilibrium conditions are reached is dependent on the behaviour, chemical form and radioactive half-life of the nuclide. For assessments which are based on past discharges any models used need to take account of this build-up in the environment, for example, see Camplin et al, 1996.

The length of time needed to account for build-up will depend on the likely lifetime of the plant and whether a similar plant could be built at the same location. Plant lifetimes are likely to be in the range of 30 to 100 years, although it should be noted that the processes leading to the discharges are not likely to remain identical over such long time periods. Simmonds et al, 1995 assume continuous discharges for 50 years to represent the estimated lifetime of nuclear installations. This is also considered a reasonable general assumption for NORM industries. However, if site specific information indicates otherwise then this should be used.

Because the transfer rate is much higher compared with the accumulation rate in the aquatic environment in general, environment accumulation for aquatic releases is not considered except for sediments and irrigated soil. For atmospheric release only accumulation in the soil is taken into account, for the same reason.

4.4.2 Progeny ingrowth

A radionuclide may decay into progeny which are also radioactive and this may need to be taken into account in realistic dose assessments. In some cases, the decay products may have higher dose coefficients than the parent and so it is important to consider the ingrowth.

In other cases the situation is simpler in that, as mentioned in Section 4.2, the daughter has a short radioactive half-life and can be considered to be in equilibrium with the parent. In this case the two radionuclides are simply considered together. In some cases, for very long-lived radionuclides, the ingrowth of any progeny takes place on such a long timescale that it is not necessary to include this in assessments of routine discharges.

4.5 Reference groups

In specifying reference groups two broad approaches are possible. The first involves carrying out surveys of the local population to determine their habits, where they live etc. From these surveys the people who are receiving or who received the highest doses can be identified. The second approach involves using more generalised data to establish generic groups of people who are likely to receive the highest doses. The two approaches can be used separately or a combination of both used. For example local surveys of consumption of seafood used in conjunction with consumption rates of terrestrial food based on more generic data.

Reference groups can be identified for retrospective dose assessments through local knowledge and site-specific habit surveys supplemented as necessary by the use of generic studies of habits. Reference groups for prospective assessments can be identified in the same way, but consideration must be given as to whether the selected habits are likely to be sustained or new habits occur during the time period of interest.

This report provides information on habits in a generalised form (Appendix H) that can be used where limited or no local information is available or to establish generic reference groups. In general, it is better to use local or regional data for the purposes of defining reference groups. However, generalised data could be used where doses are considered low, for example in relation to limits or constraints and where regional variations are likely to be small. Generalised data may also be used when assessments extend over long time periods and relate to future rather than past exposures. It is important that any data used for reference groups are applicable over the time period being considered. It is also useful to compare the generalised data with the local habit data to enable the local data to be put into context.

Reference groups are intended to be representative of individuals likely to receive the highest doses. There are many different potential exposure pathways, but they vary markedly in importance. It is, therefore, not necessary or helpful to look at every possibility in order to make a realistic estimate of dose as long as the important pathways have been considered. For example, it is recommended that the marine pathways that should always be considered are consumption of fish, crustaceans and molluscs and exposure to contaminated beach sediments. Assessment of dose from these four pathways will typically ensure that the reference group dose is adequately estimated e.g. some individuals in the reference group may swim frequently but the dose from this pathway is negligible compared to the doses due to consumption of seafood. However, if a local survey indicates that no fish are locally caught then closer attention may have to be paid to the less important pathways to ensure that the reference group dose is fully represented.

Reference groups should be small enough to have relatively similar habits and will usually be up to a few tens of persons. It is not appropriate to use extreme habits. However, where the normal behaviour of one or two individuals results in them being significantly more highly exposed than any other individuals, then the reference group should be deemed to comprise only those individuals. Normal behaviour is taken to mean behaviour which is likely to occur on a continuing basis, e.g. exposure arising as a result of the location of a house or a form of employment and is not dependent on the presence of a particular individual. It is important that when occupancy or dietary habits are used they are appropriate for the entire year e.g. if the dietary survey is done in the summer, account must be taken that diets are likely to be different in the winter.

In Appendices D and E factors relevant to the identification of reference groups for the key routes of exposure, for releases to the atmospheric and aquatic environment, respectively, are discussed. The people who are the most exposed will depend on the radionuclides discharged and the particular environment. It may be necessary to consider more than one group of people to determine which is most exposed.

4.5.1 Combinations of habit

Reference groups will need to have combinations of habits, both high and average, based on local knowledge and plausible assumptions. These combinations of habits will need to be realistic and not lead to implausible situations, for example someone having an excessive intake of calories. Again a full range of exposure pathways should be considered for each of the potential reference groups. However, in most cases it is not realistic to assume that the same people are most exposed from all pathways and so a simple addition of doses attributed to different pathways is not necessarily appropriate. Instead, a combination of habits typical of average and most exposed people may be assumed i.e. both average habit data and higher than average habit data are required to assess doses. For example, members of the reference group who eat locally produced terrestrial foods at higher than average rates, could be assumed to eat a proportion of locally produced aquatic foods at average rates.

4.5.2 Age groups

ICRP Publication 72 (ICRP, 1996) gives dose coefficients for the ingestion and inhalation of radionuclides for six age groups, from three months to adult. Example calculations undertaken using releases from nuclear installations for all six age groups indicate that it is not necessary to consider all six age groups, as the limiting dose will be adequately represented by assessing doses to 1 y olds, 10 y olds and adults (Jones et al, 2002). This conclusion is also valid for naturally occurring radionuclides.

Typically, assessments estimate doses to infants consuming cow's milk rather than breast milk. An examination of data on doses to breastfed infants (Phipps et al, 2001) indicates that these are significantly lower than those to adults for all the naturally occurring radionuclides for which data is available. It is, therefore, clearly not necessary to consider such doses in assessments of NORM discharges. Foetal doses are not normally included in assessments of radiation doses for members of the public. However, the recent publication of foetal dose coefficients (ICRP, 2001) permits the assessment of foetal doses for some naturally occurring radionuclides. An analysis of these dose coefficients indicates that in general consideration of foetal doses will not be necessary for NORM discharges. See Appendix G for further details.

4.5.3 Dose coefficients

For dose assessments the dose coefficients published in the Directive should be used. Where data are provided for more than one chemical form of an element and the actual chemical form is not known, the defaults should be taken from (ICRP, 1996). Expert judgement should be used to determine the most appropriate chemical form for use in the assessment rather than assuming the chemical form that leads to the highest dose coefficient.

4.6 Issues in achieving realistic assessments

(i) Realism

The assessment must reflect the transfer of the radionuclides through the environment to man. There are many uncertainties and discrepancies that may occur at many stages, for example

- If modelling radionuclides in the environment is not a true representation.
- If measurements do not give an accurate representation of the environment, e.g. because of problems with the naturally high background levels.
- If significant exposure pathways are not included.
- If assumptions relating to the habit data for the reference group are not representative, e.g. it is assumed all fish consumed is locally caught whereas in reality only 10% is local.

These points emphasise the importance of having a good understanding of local conditions around the facility being assessed in order to make the assessment as realistic as possible. However, where the doses are expected to be low it is legitimate to make use of generic values for the region/country, as these will tend to result in a conservative assessment of dose. If such generic assessments indicate that doses are significant then additional more detailed site-specific surveys should then be considered.

(ii) Variability and uncertainty

Assessments of doses necessarily entail a series of assumptions about the behaviour of the reference group and about the transfer of radionuclides in the environment. The estimated mean dose to the reference group is, therefore, within a distribution of possible doses. There are two aspects to this distribution referred to as the uncertainty and variability. The uncertainty reflects the amount of knowledge about the system being investigated and relates to how accurately the dose can be estimated; for example how well are all of the parameter values in the calculations known. The variability refers to the actual differences that occur both in transfer in different environments and, most importantly, between individuals within a group (e.g. consumption rates and occupancies). This topic is discussed in detail in (IAEA, 1989) and a number of studies have been carried out to investigate uncertainty and variability (e.g. (Smith K R et al, 1998) and (Jones et al, 2000). In addition, this subject has been examined in France by the Nord-Contentin Radioecology Group (GRNC, 2002).

There are benefits in undertaking such analyses but they are time consuming and costly. It is only when ‘best estimate’ calculations indicate that the predicted dose may be a significant fraction of the applicable dose limit or constraint that it is generally worthwhile undertaking such studies for a particular site.

A workshop (Walsh et al, 2000) was held in the UK to consider the implications of distributions in critical group doses for the system of radiological protection. Participants included representatives from regulators and operators of nuclear establishments, the European Commission (DG Environment) and ICRP. It was concluded from the workshop that variability studies are useful when examining the composition of reference groups to ensure it is not composed only of individuals with extremes of behaviour and to ensure it adheres to ICRP homogeneity criteria (ICRP, 1985). It was concluded that an uncertainty/variability study need not be carried out for every assessment, but could be valuable to improve understanding of reference group dose assessments.

(iii) Use of measurement data

Use of measurement data to define source terms is clearly important for NORM industry assessments. For many NORM industries, however, as mentioned above, there are practical difficulties in measuring activity concentrations of naturally occurring radionuclides from discharges above the normal background levels in environmental materials, e.g. soils. Thus for many NORM industries, assessments of doses will not involve environmental measurement data except perhaps to indicate the limited impact on the local environment. There are a few NORM industries where statistically significant above background environmental concentrations can be found, e.g. some phosphate industry discharges. These can then be used directly in assessments.

4.7 Conclusions and recommendations

Guidance on approaches for assessing doses to members of the public from NORM discharges has been developed. This has been developed principally by considering recent guidance on assessing the impact of discharges from nuclear installations on the general public (European Commission, 2002a; Jones et al, 2002). This guidance was reviewed in the context of information on the characteristics of discharges from NORM facilities and information on assessments performed to determine the radiological significance of discharges from a number of NORM industries.

The guidance covers all stages of an assessment of doses to members of the public. In general the guidance is very similar to that proposed in (Jones et al, 2002) for discharges from nuclear installations. However, there are a number of significant differences:

- Release heights for large NORM facilities with significant discharges tend to be significantly higher than those for nuclear installations. This typically reduces the impact of such NORM discharges.

- The high background levels of the radionuclides concerned complicate the use of measurement data for determining doses from NORM discharges. Radionuclides originating from NORM discharges cannot be distinguished from those naturally present in the environment. There are a few NORM industries where statistically significant above background environmental concentrations can be found, e.g. some phosphate industry discharges, in these cases environmental monitoring can then be used directly in assessments. But

in the majority of situations, environmental monitoring information, which can play a significant role in assessing doses from nuclear installations, are unlikely to play a role in dose assessments for NORM discharges. Monitoring of emissions at the source provides a valuable input to dose assessments from NORM discharges. The need for environmental monitoring can be assessed on the basis of discharge data.

In general doses from NORM discharges will be low. The need to undertake very site-specific studies and uncertainty/variability analyses (as described in Jones et al, 2002) is thus not very likely.

(i) Summary of the recommendations made in Section 4

Specification of source term
The type and amount of radionuclides being discharged and the type and location of release must be determined. Unless a significant proportion of the annual discharge is discharged in a short time it can be assumed that the discharges are continuous, given the other uncertainties in the assessment process.

Determination of Exposure pathways
The report separates the exposure pathways into three types, those that should;

- almost always be considered e.g. consumption of food;
- be examined depending on local conditions e.g. consumption of milk from animal grazing on salt marshes
- not normally be considered e.g. inhalation of sea spray

The main focus of the assessment should be on the pathways contributing the highest doses to the reference group.

Methods for assessing doses
The most realistic method for assessing doses for discharges from nuclear installations would be by extensive monitoring of the main exposure pathways (environmental concentrations etc.). However, this is problematic for NORM discharges because of the ubiquitous nature of the radionuclides concerned and their significant spatial variation. Typically an assessment for NORM discharges will principally involve modelling with source monitoring data. Any models used should be robust and fit for purpose. Models need to take account of both accumulation in the environment and progeny in-growth.

Identification of reference groups
Reference groups are intended to be representative of individuals likely to receive the highest doses. The group should be small enough to have relatively similar habits and will usually be up to a few tens of individuals. It is not appropriate to use extreme habits.

The report provides generalised habit data for use where site-specific information is not available. There is a paucity of published site-specific data concerning

consumption and occupancy rates for EU countries. More information for the different age groups is needed on;

- Indoor/outdoor occupancies
- Occupancies over intertidal areas and riverbanks
- Consumption of terrestrial and aquatic foods for both average and high rate consumers for different age groups

Reference groups will need to have combinations of habits, both high and average, based on local knowledge and plausible assumptions. These combinations of habits will need to be realistic and not lead to implausible situations, for example someone having an excessive intake of calories.

For dose assessments the dose coefficients published in the Directive (European Commission, 1996) should be used. Where data are provided for more than one chemical form of an element and the actual chemical form is not known, the defaults should be taken from (ICRP, 1996). Expert judgement should be used to determine the most appropriate chemical form for use in the assessment rather than assuming the chemical form that leads to the highest dose coefficient.

It is recommended that it is sufficient to consider three age groups: 1 y old, 10 y old and adults. Foetal doses should be borne in mind if doses from ^{228}Th (important daughter ^{224}Ra) dominate and are a significant fraction of the applicable dose limit/constraint.

5 Derivation of criteria allowing quick identification of NORM discharges requiring regulatory control

5.1 Introduction

The discharges into air and water from NORM industries vary considerably with respect to the radionuclides discharged, the effective height of the stacks for aerial discharges and the characteristics of the receiving aquatic environment for liquid discharges. Radiation exposure of members of the public resulting from these discharges involves many exposure pathways and the level of exposure per unit discharge rate depends on quite a number of site-specific conditions. Consequently, no simple and general relationship exists between discharge rate and dose to members of the public. On the other hand, detailed site-specific analysis is not warranted when, on the basis of a generalised and conservative approach, it can be concluded that the discharges are of no radiological significance. NORM discharge screening levels are, therefore, defined as estimates of the amount of activity discharged to the environment from a NORM plant, which, if not exceeded, mean that it is very unlikely that members of the public would receive an effective dose above a defined dose criterion. NORM discharge screening levels can be determined for each NORM release route i.e. to atmosphere, rivers and the marine environment. Such screening levels are calculated using deliberately cautious assumptions such that compliance with them would ensure virtual certainty of compliance with the dose constraint. The aim of the present study is to derive discharge screening levels below which there is most likely no reason for a more detailed and site-specific radiological assessment of the discharge and above which levels such more detailed analysis is advised. The derivation of the discharge screening levels comprises the following steps:

- definition of reference discharge situations,
- choices on models, exposure pathways and parameter values,
- derived doses per unit discharge rate,
- dose criteria for screening levels,
- discharge screening levels.

It should be noted in advance that site-specific conditions can result in very large differences in the dose per unit discharge rate between sites. This seems particularly true for marine discharges where the receiving medium can be defined as a large volume box in the open sea as well as the estuary of a small river. The required conservatism in the choice of the receiving medium and the associated exposure assessment may be very difficult to prove. Therefore, the calculated doses per unit discharge rate for the reference discharge situations should be regarded as example calculations instead of a direct basis for deriving discharge screening levels.

The approach followed in this study in deriving screening levels for discharges is similar to the methodology described in the NCRP Reports No. 123, Vol. I and II,

published in 1996 (NCRP, 1996). The main features of the approach of the NCRP are:

- the derived screening levels serve to assess compliance with environmental standards (limiting values);
- doses estimated by screening are not intended to represent estimates of actual doses to individuals;
- simple models should always be applied first;
- models and parameters are chosen so as to produce conservative estimates of doses;
- sophisticated models are not needed if compliance with environmental standards can be demonstrated on the basis of the screening models;
- screening can be carried out for aerial discharges and for liquid discharges into fresh surface water and marine surface water;
- screening can be carried out at two or three different levels of conservatism in the approach. Level I being the simplest approach with the highest degree of conservatism, Level II the highest level for discharge into surface water and Level III the highest level for aerial discharges.

It should be noted that the modelling approach underlying the present study is more sophisticated than the Level II screening for discharges into surface water in the NCRP report with respect to removal of radionuclides to sediments, correction for radioactive decay and ingrowth of daughter radionuclides. Simple comparison of screening results is, therefore, not possible. The same conclusion still holds for the Level III screening for aerial discharges despite this approach being more similar to the modelling approach of the present study.

5.2 Reference discharge situations

5.2.1 Atmospheric releases

One of the important parameters in relation to determining doses from atmospheric releases is the release height. An analysis of the stack heights from NORM industries (see Section 2), indicates a large range. Stacks of coal-fired power stations are generally around 200 m with heat rise producing effective release heights of 300 m – 500 m. For other facilities stacks of 100 m are not uncommon and for others, including vents from warehouses etc., the release position may be much lower. For this reason four reference discharge situations have been assumed involving effective stack heights of 10 m, 50 m, 100 m and 200 m respectively.

5.2.2 Discharge to rivers

Discharges to the aquatic environment can result in markedly different doses for the same release rates depending on the receiving water body. For example, the doses received from discharges to a river are dependent on the volumetric flow of the river.

On the basis of information from Task 1 it is clear that discharges from NORM industries can occur to rivers of many different sizes. For this reason three reference river discharge situations have been assumed. These are intended to represent large, medium and small rivers in Europe to which NORM discharges may occur. These are assumed to have volumetric flow rates of, respectively, 500 m^3s^{-1}, 100 m^3s^{-1} and 2.5 m^3s^{-1}.

Clearly the size, sediment load and other factors can vary, the values chosen are considered reasonable for the purposes of developing screening levels. The characteristics of the small river, in particular the volumetric flow, have been chosen to represent the lower extreme for a river that receives discharges from a NORM industry. The detailed characteristics of the rivers in terms of volume, depth, sediment, suspended load, distribution coefficient, sediment moving velocity etc. are summarised in Table 38.

5.2.3 Releases to the marine environment

Discharges to the marine environment can result in markedly different doses for the same release rates depending on the receiving water body. For example, discharges to the marine environment would result in doses affected by the current in the area that determines dilution processes. It is clear from our review of the NORM industries (see Section 2), that releases can occur to the marine environment from two positions: off-shore from the oil and gas industry and on-shore from other NORM facilities. Because of the different characteristics of the area to which the discharge occurs and the different exposure pathways for these releases, they are considered separately.

(i) Off-shore releases

Releases off-shore occur from the oil and gas industry. In order to determine doses per unit releases assumptions have to be made about the area to which the release occurs. The characteristics of the 'marine box' (Box 59 ($5.9\ 10^{13}$ m^3), North Sea North, of the Marina II marine box model (Simmonds et al, 2002)) into which the discharge occurs, has been chosen to represent a relatively large area of moderate depths bordering on the coastline at a large distance from the centre of the box. Because of the large size of Box 59 and the even larger size of the adjacent Box 27 ($1.0\ 10^{15}$ m^3), Norwegian waters, from which the exposures originate, the input is extremely diluted within these boxes. Consequently the resulting exposures will be towards the minimum range of possible discharge situations. The model gives very low doses per unit rate of input as a consequence of the choice of a large input box in combination with a large adjacent box.

(ii) On-shore releases

Releases from land to the marine environment occur from a number of NORM industries. In order to determine doses per unit releases assumptions have to be made about the area to which the release occurs. For screening levels it is appropriate to consider conservative assumptions. The characteristics of the 'marine box' (Box 50 ($2.62\ 10^{11}$ m^3), Bay de la Seine, of the Marina II marine box model) into which the discharge occurs has, therefore, been chosen to represent a relatively small and shallow compartment, bordering on the coastline, at short distance from the centre of

the box. These characteristics tend to result in the highest concentrations in seafood and hence doses.

It should however be noted that the choice of this box for assessing exposures from on-shore discharges does not necessarily represent a conservative approach for several reasons. Actual site-specific conditions at a NORM discharge site may still differ considerably from those used for defining dispersion and exposure pathways from discharges in Box 50. The modelling of exposures from onshore and offshore discharges in Marina II aimed at assessing collective doses. Therefore, the emphasis was not on modelling processes close to the point of discharge, which are the processes likely to be the dominant ones for exposure of critical groups making extensive occupational or recreational use of the local environment.

5.3 Models, pathways and parameters

The models, exposure pathways and parameters to be used for the present purpose have been extensively discussed in Section 4 and its' associated appendices, in particular with respect to the choices made. Nevertheless, the relevant information on the derivation of discharge screening levels is provided in this section for each of types of discharge. Approaches common to all types of discharge are described below.

NORM discharge screening levels are for continuous discharges of radionuclides to the environment and are for annual discharges, which are assumed to continue for 50 years. The ingrowth of radioactive progeny is considered for this 50-year period. They are also calculated assuming that annual average conditions apply. They, therefore, do not apply to uncontrolled or controlled short-term releases or to releases that vary significantly over the year. The conditions of the operation of industrial facilities processing NORM can be expected to comply with these assumptions in most, if not all, cases.

The age group considered is adults only. It would be possible to carry out the calculations for younger age groups taking into account variations in the dose coefficients and dietary and other habits with age. However, the derived screening levels of discharge, based on younger ages as critical groups, would differ only by a factor of about 2 - 4 from those derived for adults as critical group. For aerial discharges for instance the ratio between the doses to the most exposed younger age group and to adults is limited to a range of 1 – 3 for all radionuclides considered in the present study. Other choices are to be made in deriving generic screening levels. For instance, with respect to the choice of the reference discharge situation, the parameters used in dispersion modelling, the dose coefficient for inhalation and habit data for adults, characterise the result as an order of magnitude estimate of the screening level. Inclusion of results for other age groups would suggest a level of accuracy and precision in the results that is not appropriate.

Natural radionuclides occur in decay chains from ^{232}Th, ^{238}U and ^{235}U as the primordial starting points of the chains. In unprocessed raw materials like ores, the nuclides of the decay chain of ^{235}U occur in concentrations a factor of 22 lower than those of the ^{238}U chain. Generally there is little reason to include the nuclides of the

^{235}U chain in the derivation of screening levels, irrespective of the industrial process involved. An exception might be the chemical processing of rare earth elements. Further reduction of the list of radionuclides to be considered can be obtained by including ^{234}U in the ^{238}U chain segment as ^{234}U naturally occurs in a fixed activity ratio of 1 with ^{238}U. Its direct progeny ^{230}Th has a sufficient long half-life to be of no relevance through ingrowth within a period of 50 years after discharge of ^{234}U.

The decay chains of the natural radionuclides are separated by long-lived radionuclides. These long-lived radionuclides with their short-lived progeny constitute decay chain segments for which it can be assumed that the short-lived progeny is in radioactive equilibrium with the long-lived mother. These decay chain segments are presented in Table 35.

For calculating the doses from intakes of radionuclides, the lifetime of an individual is taken to be 70 years. Although it is slightly shorter than the average lifetime of individual within the EU, its use is sufficiently cautious because intakes of radionuclides and the resulting risks decrease in old age. The dose coefficients for ingestion and inhalation shown in Table 39 are taken from the Directive (European Commission, 1996).

For site-specific assessments information on the chemical form of the radionuclides should be used, but for the derivation of screening levels it is recommended that default absorption types be used. The reader is referred to the discussion on dose coefficients for inhalation in the ICRP Publication 66 (ICRP, 1994), for understanding to what extent the dose coefficient depends on assumed particle characteristics with respect to particle size (AMAD), and absorption type (F, M, S).

5.3.1 Atmospheric releases

(i) Exposure pathways

The following exposure pathways are considered in the derivation of screening levels for atmospheric discharges:

- external exposure to the plume external
- exposure from activity deposited on to the soil
- internal exposure from inhalation of the plume
- internal exposure from inhalation of resuspended activity
- ingestion of foods produced on land contaminated by activity from the plume

(ii) Modelling

Atmospheric dispersion and deposition modelling:
For release heights up to 100 m (i.e. 10 m, 50 m and 100 m) activity concentrations of each radionuclide in the plume were calculated using a Gaussian plume atmospheric dispersion model PLUME (part of the PC Cream suite of models) assuming a uniform

wind rose. For the release height of 200 m the atmospheric dispersion model ADMS was used. Atmospheric conditions relevant to Northern Europe were assumed. Depletion from the plume by deposition was calculated on the basis of dry deposition velocities and washout coefficients. Doses from external irradiation from radionuclides deposited on the ground were determined assuming 100% occupancy at 500m from the release point. Doses from ingestion were determined assuming food was produced on land 500 m from the release point. The peak ground air concentration was used for inhalation doses, and doses from external exposure from immersion in the plume, unless the peak occurred at less than 500 m, in which case, the air concentration at 500 m was used.

Foodchain modelling:
Activity concentrations in foods resulting from 50 years of continuous atmospheric discharges were predicted using the dynamic foodchain model FARMLAND. It was assumed that activity in the plume was deposited directly on to soil, some activity was directly intercepted by the plants, and that a fraction of the intercepted activity was transferred into the plant. Build up in soil over 50 years, uptake of activity from soil into plants and the transfer of activity into animal products was modelled. The activity concentrations in food products in the 50^{th} year of discharge were derived from the food product activity concentration in the 50^{th} year per unit deposition rate (Bq kg^{-1} per Bq m^{-2} s^{-1}) and the deposition rate to ground of activity from the plume 500 m from the release point at unit release rate.

Soil, external dose and resuspension modelling:
The predicted activity concentrations in soil in the 50^{th} year of continuous deposition from a plume can be modelled using the soil model part of the FARMLAND model, allowing for migration down the soil profile. Effective dose rates from external exposure above soil 500 m from the release point were calculated from the external dose rate in the 50^{th} year per unit deposition rate and the deposition rate at unit release rate.

Resuspension of deposited activity was modelled using a time-dependent resuspension model. The ground-level air concentrations were calculated from the activity concentration from resuspension of activity per unit deposition rate in the 50^{th} year of discharge and the deposition rate at unit discharge rate at 500 m from the discharge point.

The ingrowth of the longer-lived progeny of ^{226}Ra (^{210}Pb) and from ^{210}Pb (^{210}Po) has been considered, but the contributions of this progeny to external exposure and to doses from resuspension were shown to be negligible.

Habit data:
It was assumed in general that the exposed group lived 500 m from the release point and that food was also grown at this distance. The only exception to this was the dose from direct inhalation of the plume. For this it was assumed that the individual was at the point of peak ground air concentration (or 500 m if this was further). It was assumed that the individuals consumed the two most important foods at high rates and those for the other foods at average rates. The consumption rates used were derived by averaging the national consumption rates (see Appendix H, Table H4). The rates

are given in Table 40. Consistent with calculations of exemption/clearance levels for NORM in RP 122 Part II (European Commission, 2001) it was conservatively assumed that 50% of the food consumed was grown locally (at 500 m).

For exposure to external radiation from deposited activity 50% occupancy was assumed for both indoors and outdoors.

5.3.2 River discharges

(i) Exposure pathways

The exposure pathways for river discharges are those considered in RP 127 (Van der Stricht and Janssens, 2001) for assessment of doses from discharges by nuclear installations using the PC-CREAM version 98 software package. They are:

- Internal exposure from the use of untreated river water for drinking water
- Internal exposure through consumption of fish
- External exposure to gamma radiation from the river bank sediment

External exposure to beta radiation on the riverbank was neglected because the contribution would be very small, in particular for the NORM nuclides to be considered.

Doses from consumption of food grown on irrigated land were not included. In Appendix E these three pathways are identified as the most important, but it is noted that if the river is used for irrigation, then consumption of food from irrigated land should also be considered when undertaking a site specific assessment. It seems reasonable to assume, especially for a small river, that it is unlikely that any individual would be exposed via all the pathways considered. Summing of doses from all three pathways therefore leads to conservative estimates of exposures.

(ii) Modelling

Activity concentrations of each radionuclide released into each of the three generic river types are calculated using a compartmental model PC-CREAM (version 98) software package. From the model's options the screening model with complete mixing was used. A single compartment of 1 km river is defined into which the activity is discharged. Four main processes are modelled:

- downstream transport of radionuclides in solution;
- downstream transport of radionuclides in association with suspended sediment;
- sedimentation of radionuclides to the river bed and
- downstream transport of radionuclides in river bed sediment.

The river compartments for the three generic rivers considered are defined using the parameters given in Table 38. The large river has a volumetric flow rate that is approximately 20% of that of the Rhine. The medium river has a volumetric flow rate that is approximately 4% of that of the Rhine. The small river has a flow rate of typical of small rivers in Europe. Clearly the size, sediment load and other factors can vary, the values chosen are considered reasonable for the purposes of developing screening levels.

The partitioning of radionuclides between the dissolved and solid phases and the concentration in freshwater fish are defined by the parameters K_d and concentration factor respectively. It was assumed that the activity concentrations in bed sediments attained equilibrium with the discharges by year 50.

Nuclide specific parameters
The PC-CREAM software package only provides the default nuclide specific parameters for the natural radionuclides ^{238}U, ^{234}U, ^{235}U and ^{226}Ra. For the other radionuclides to be considered in the present study the decay characteristics were taken from ICRP Publication 38 (ICRP, 1983). The K_d's and fresh water fish concentration factors used are shown in Table 41.

Habit data
The following habit data for critical group adults were used in the derivation of the screening levels:

- River bank occupancy: 500 h y^{-1} (average and critical group),
- Drinking water ingestion: 600 l y^{-1} (average and critical group),
- Fresh water fish consumption: 30 kg y^{-1}, reduced by a factor of 10 for average consumption.

Annual fish consumption by a critical group at a rate of 30 kg y^{-1} may be a rather extremely conservative assumption for a small river, although this is not simply proven. Therefore, for the small river, a consumption rate of 3 kg y^{-1} indicated as 'average' has also been considered as a probably more realistic, but still conservative assumption.

5.3.3 Releases into the marine environment

(i) Exposure pathways

The exposure pathways considered for the releases are:

- Consumption of fish,
- Consumption of crustaceans,
- Consumption of molluscs,
- External exposure to beach sediment.

(ii) Modelling

The radiological assessment of the marine discharges was carried out using the Poseidon software originally developed by CEPN to assess the radiological consequences of regular and accidental releases of radionuclides in coastal waters of Europe. While the first version of the software (Lepicard et al, 1999) adopted the box modelling approach developed for the European MARINA I project (European Commission, 1990), the latest version of the software (Lepicard, 2001) used for the present calculations, incorporates the further developments of box modelling made in the MARINA II project (European Commission, 2002b). Input into the two boxes, North Sea N (Box 59) and Bay the la Seine (Box 50), of the MARINA-72 box model have been chosen as the reference discharge situations. For detailed description of the characteristics of Box 50 and 59 the reader is referred to the Report of Working Group D of the MARINA II project (Simmonds et al, 2002). The boxes differ in volume by a factor of about 200. It should be noted that in the latter project the marine modelling was used to derive collective doses resulting from discharges while the present aim is to derive doses to critical groups.

Inherent to the box modelling is the assumption of complete homogeneity within the compartments of the box and within their volumes. The vertical compartments of each box are several water column compartments and sediment compartments.

The dispersion of radionuclides released into the box is described by water exchange with adjacent compartments, by exchange of radionuclides between dissolved and particular state via sorption processes and by remobilisation from the bottom sediments into the water layers due to bioturbation and diffusion. The model assumes a constant equilibrium between dissolved and particular equilibrium between dissolved and particulate radioactivity, described by a distribution coefficient often referred to as K_d.

The prediction of the radionuclide concentration in marine biota is based on the steady-state approach which assumes a constant equilibrium between the concentration of dissolved radioactivity in water and in marine organisms through the concentration factor CF. This seems appropriate for consequence assessment of 50 year discharge at a constant rate into the compartment.

To evaluate the radiological consequences of daughter radionuclides the entire decay chain segment is taken into account. The contributions of the progeny within a decay chain segment are included in the calculated results for the 'mother of the segment'.

Habit data

The habit data for adults used in the dose calculations are presented in Table 42. They are largely based on the data presented for EU countries presented in Jones et al 2002. The critical group data were used to derive the screening levels. The 'average' habit data are included to illustrate the large difference between average and critical group habit data.

5.4 Doses per unit discharge rate

5.4.1 Discharge to the atmosphere

The doses per unit discharge rate for releases into the atmosphere are presented in Table 43.

5.4.2 River discharges

The doses per unit discharge rate of 1 GBq y^{-1} for discharges into rivers are given in Table 44 for the small river, in Table 45 for the medium river and in Table 46 for the large river. For reasons explained previously, average consumption and occupancy habits are used for the small river to derive screening levels of discharge, which remain conservative. For the medium and large river the critical group habits are used to derive discharge screening levels.

5.4.3 Discharges into the marine environment

The results for discharges into the small marine box are presented in Table 47 and for the large box in Table 48. The results for critical group habits are used to provide example calculation results for discharges resulting in exposures equal to different dose constraints chosen.

5.5 Screening levels of discharge rate

5.5.1 Discussion on the dose criteria used to derive screening levels

The calculated radiation exposures per unit discharge rate of 1 GBq y^{-1} can only be translated into discharge screening levels on the basis of a level of annual dose above which the discharge is regarded as potentially of radiological significance and would require more detailed assessment. The choice of such a dose criterion is not straightforward.

Recommended levels for exemption of practices from radiological control in the Directive is based on a level of annual individual dose of the order of 10 μSv. As may become clear from the discussion below, this dose level does not necessarily also apply to the exemption of residues from work activities from regulatory control.

RP 112 deals specifically with radiological protection principles concerning natural radioactivity in building materials. In chapter 3 of RP 112 the following levels of dose are provided as guidance:

- A **dose criterion for controls** in the range of 0.3 – 1 mSv y^{-1}. This is the excess gamma dose to that received outdoors.

- An **exemption level** of 0.3 mSv y^{-1} effective gamma dose at the most for exemption of building materials from all restrictions concerning their radioactivity. This is the excess gamma dose to that received outdoors.

    - Note that the exemption level dose criterion is chosen because small exposures from building materials are ubiquitous and controls should be based on

exposure levels which are above typical levels of exposures and their normal variations.

In other words:

- one cannot live in a house without being exposed to the radioactivity in its building materials,
- in building a house one cannot avoid the use of building materials,
- building materials vary considerably in their levels of natural radioactivity and exposures vary accordingly.

Guidance report Radiation Protection 122 Part II deals with exemption and clearance applied to natural radiation sources.

- It considers only reuse or disposal of solids and not discharges into air and water.
- It adopts 300 μSv y^{-1} as an incremental dose criterion for exemption-clearance of work activities which is justified because it is comparable to or smaller than the variation in total effective dose from natural radiation background (external radiation only).
- The exposure pathways of the public resulting from reuse and disposal are comparable to those from 'normal' natural sources and originate from natural radioactivity in the ground and in construction materials for buildings.
- Exposure of the public to multiple sources is not considered. This seems reasonable because of the conservative nature of each of the exposure scenarios and seems consistent with the fact of life that one cannot occupy two different houses full-time nor can one stand on different areas of ground, full-time, at the same time.

In our opinion, these arguments to use 300 μSv y^{-1} for the purpose of deriving guidance concentration values for exemption-clearance of solid residues or wastes, are not necessary valid for deriving screening levels for discharges because:

- The variation in natural exposures from airborne activity (except Rn) and waterborne activity is much smaller than 300 μSv y^{-1},
- Discharges to air and water will very likely involve exposure to multiple sources.

In the UK, NRPB have produced GDCs (generalised derived constraints) for discharges[1]. These are based on a dose constraint of 300 μSv y^{-1}. The discharge GDCs are determined using conservative assumptions such that even if actual discharges are at the level of the GDC it is unlikely that the dose constraint is exceeded. However, it is noted that this is possible and, therefore, if the actual

[1] These do not include marine discharges.

discharge is above 30% of the GDC (i.e. dose implied of 100 μSv y^{-1}) then this is the level at which further investigation should be undertaken e.g. the situation should be examined in more detail, taking account of site specific factors.

In the present study the screening levels are intended ultimately to identify NORM discharges that definitely should not be regulated or, the other way around, to identify discharges that are of potential radiological significance and would require a more detailed and possibly site specific assessment. In this case it seems sensible to choose a dose criterion for the derivation of the screening levels that is below the dose constraint. This would tend to suggest somewhere between a trivial level and a fraction of the constraint e.g. a dose criterion in the range 10 - 100 μSv y^{-1} would seem reasonable.

5.5.2 Discharge screening levels

(i) Dose criteria applied in the screening level calculations

The data provided in Section 5.4 on doses per unit discharge rate can be used to calculate discharge screening levels for any dose criterion. The derived discharge screening levels presented in this section are based on a provisional screening level dose criterion of 300 μSv y^{-1}, but can easily be scaled down to correspond to a lower dose criterion. To illustrate this a comparison is included of the derived discharge screening levels based on three different dose criteria: 10, 100 and 300 μSv y^{-1}, with typical discharges by NORM industries. The results are used to highlight the practical aspects of derived discharge screening levels on the basis of different screening levels dose criteria.

(ii) Discharges into the atmosphere

The screening levels for rate of discharge into the atmosphere are presented in Table 49 for a provisional screening level dose criterion of 300 μSv y^{-1}. Not surprisingly very high screening levels of discharge are derived for a 200 m stack and a dose criterion of 300 μSv y^{-1}. The extreme on the low side of screening levels of discharge is derived for a stack of 10 m and a dose criterion of 10 μSv y^{-1}.

This is further illustrated by the comparison of typical annual aerial discharges of ^{210}Po with the derived discharge screening levels for different stack heights and different screening levels of dose shown in Figure 16 – 19. Figure 16 shows that for each of the screening level dose criteria, all typical discharges, except those from a coal fired power plant, are higher than the derived discharge screening levels for a 10 m stack.

When the stack height is taken at 50 m the typical discharges of the cement, primary steel and thermal phosphorus plant are higher than the derived discharge screening level based on 10 μSv y^{-1}, but lower than the level when 300 μSv y^{-1} is taken as the dose criterion for derivation of the screening levels. With a stack of 100 or 200 m the typical discharges of ^{210}Po by a number of industries still exceed the derived screening based on a 10 μSv y^{-1} dose criterion. It should be noted that using a dose coefficient for ^{210}Po based on lung absorption type S instead of M would not decrease the derived screening level of discharge by more than about 25%. However, if the

screening was applied to ^{210}Pb a change from absorption type M to S would result in a reduction of the derived discharge screening level by a factor of 5 because of the considerably higher inhalation dose coefficient for the latter absorption type.

(iii) River discharges

The derived screening levels for discharges into rivers are shown in Tables 50 - 52.

A comparison of typical discharges with the derived screening levels for small, medium and large rivers based on three different dose criteria is presented in Figures 19 – 21.

Figure 16 illustrates that the typical discharge of ^{226}Ra by a phosphoric acid production plant discharging phosphogypsum is considerably higher than the derived screening level into a small river for each of the dose criteria. The same applies to the typical discharge of ^{210}Pb by a thermal phosphorus plant. The typical discharge of ^{226}Ra by a titanium oxide plant exceeds only the derived screening level of discharge based on the 10 μSv y^{-1} dose criterion. Typical discharges of ^{210}Pb by a primary steel plant do not exceed the derived screening level of discharge for a small river irrespective of the dose criterion. The same comparison is presented for a medium river in Figure 21. The typical discharge of ^{210}Pb by a thermal phosphorus plant exceeds the derived discharge screening level based on 10 and 100 μSv y^{-1} and the typical discharge of ^{226}Ra by the phosphoric acid plant exceeds the derived screening level based on 10 μSv y^{-1}.

When the discharge is assumed to take place in a large river, the typical discharge of the phosphoric acid plant exceeds only the screening level of discharge based on 10 μSv y^{-1}. In all other situations illustrated, the screening levels of discharge are higher than the derived screening levels of discharge irrespective of the dose criterion being 10 μSv y^{-1} or 300 μSv y^{-1}.

(iv) Discharges into the marine environment

The results of example calculations for discharges into the small and large marine compartments are provided in Table 53.

With respect to the example levels for the large compartment it should be noted that potentially there are many discharge points, as is clear from the scale of offshore exploitation of oil and gas reserves. Therefore, the example levels principally apply to the total discharge from all installations within the large box. From the results of the MARINA II study it is clear that the total discharges from all oil and gas production facilities in the northern area of the North Sea are lower than the example levels derived for discharges in Box 59 on the basis of 300 μSv y^{-1} exposure of critical groups. This could also be stated otherwise: actual discharges from oil and gas production in the northern area of the North Sea will most likely result in exposures of critical groups far below 300 μSv y^{-1}. On the other hand, if critical group exposures would indeed reach a level of 300 μSv y^{-1}, the associated collective dose from discharges into Box 59 would be much higher than derived in MARINA II for estimated actual discharges.

The example levels for the small box, Box 50, are for the less conservative (more mobile) elements, considerably lower than for the large box, in particular when based on critical group habits. However, the example levels are still high compared with actual or potential inputs from near shore oil and gas production or onshore NORM industries. This is illustrated in Figure 23 which shows that typical discharges of the example NORM industries, when assumed to take place in the small marine box, would not result in a dose criterion of 10 $\mu Sv\ y^{-1}$ being exceeded. However, it is again to be stressed that the example calculations for the small marine box do not necessarily provide conservative estimates of the resulting exposures. On the contrary, actual site-specific conditions, in particular close to the point of discharge, may well result in much higher doses per unit discharge rate than derived with the Poseidon model applied to the Box 50, the Bay de la Seine.

5.6 Use of screening levels

The screening levels are intended for screening purposes and have been calculated using a set of generic assumptions such that the resultant doses are expected to be overestimated in most circumstances.

The screening levels should be used within the context of demonstrating compliance with the screening level of dose chosen. If the expected discharge is less then the screening level then, subject to adequate demonstration of Quality Assurance (QA) procedures, no regulatory controls on the discharge are necessary. If the discharge is above the screening level the first step is to check the relevance of the generic assumptions used to derive the screening levels. If the data are overly conservative or otherwise inapplicable to the particular site in question then, depending on the complexity of the issue, either a modified generic assessment should be undertaken to determine doses or arguments presented on the basis of the site-specific information demonstrating clearly that the actual doses received would be less than one tenth of the dose constraint that will likely be set at a significantly higher level of dose.

In practice, discharges of more than one radionuclide will occur. Account must be taken of exposures from all radionuclides discharged. If the sum of the ratios for each nuclide discharged divided by the appropriate screening level is less than or equal to one then the total discharge is below the screening level. For some sites it is possible that radionuclides will be discharged by more than one route, for example, discharges to atmosphere and to a local river may occur from the same location. In this case the critical group for the different discharge routes is unlikely to be the same and so summing fractions of the screening level is very cautious and not recommended. If a site-specific dose assessment is required then a more realistic approach could be adopted where account is taken of exposure from all routes using a combination of critical group and average habits.

In some cases aerial discharges involve the natural radionuclides in secular equilibrium because the industrial process involved does not result in the separation of chain segments or nuclides. This is likely to be the case when raw materials in secular equilibrium are only processed by physical treatments at low temperatures. For such cases the doses per unit discharge rate can be derived by summing the data for nuclides and chain fragments over the whole decay chain. The result in $Sv\ y^{-1}$ per

unit discharge rate can then be converted to a discharge screening on the basis of the selected dose criterion.

In industrialised areas several sources may discharge into the atmosphere or into the same river. The higher the screening level dose criterion that is chosen, the greater the chance that exposures of the same critical groups to the combined sources may approach or exceed the dose constraint or dose limit.

A discharge greater than the screening level does not, of course, necessarily imply that the dose criterion will be exceeded. Significantly different radiation doses will result from the discharges occurring under different circumstances than those assumed in the generic cases considered here, which have been chosen to give cautious estimates of the resulting doses. For releases to atmosphere, significantly lower concentrations of radionuclides in air or on the ground than those assumed here would arise for discharges from a greater height. In the case of discharges to a river, the characteristics of the river, particularly the volumetric flow rate, have a significant effect on the extent to which the radionuclide is diluted and hence on doses. In many cases the receiving river is likely to have a higher flow and dilution which is greater than assumed here, but it may also be possible for the dilution to be less. The assumed location of the critical group relative to the discharge point also has a significant effect on the estimated doses. For discharges to atmosphere, doses will generally be lower for groups living further from the discharge point and higher for those living closer. Similarly, for discharges to a river, the location of the drinking water abstraction point relative to the discharge location can have a significant effect on the resulting estimated activity concentration in water and, hence, on doses.

If a proposed or actual discharge is above the screening level and, therefore, worthy of further investigation, then the first factor to consider is the nature of the discharge and the location of the critical group.

6 Conclusions

6.1 Work activities and their wastes

- In Section 2 discharges and residue characteristics have been broadly characterised to provide an aid for the subsequent identification of the NORM industries that may require regulatory control. These *NORM industries, which may be of radiological concern as a result of their discharges and wastes, are summarised in Table 1.*

- However, *characteristics of discharges and residues, even from the same type of industry and production process, have been found to differ widely because of the variation in raw material used, processing details and in particular, with respect to discharges, differences in treatment of liquid wastes and off-gas before discharge* and therefore no summary table of total discharges for all industries could be constructed.

- The need for precision with regard to which radionuclides have been measured when reporting results became clear in the course of the review of existing literature. *It is recommended that authors are precise as to which radionuclides are present when measurements are reported such as in the case of* $^{238}U+$ *and* ^{238}U*sec for example.*

- There is a *dearth of reliable radiological emissions data for NORM industries*, possibly as a consequence of a lack of regulation in this area in the past. Data on historical discharges and residues are of very limited value because of changes in the processes and closing down of production facilities.

- Under the Article 15 (3) Council Directive 96/61/EC of 24 September 1996 [OJ L 257 1996 p. 26] concerning integrated pollution prevention and control (IPPC Directive) Member States are required to catalogue and supply data on principle emissions and responsible sources. *Though the data are gathered for environmental (non-radioactive) purposes, this information could be used to identify sites in relation to NORM as the database includes process data, location and emissions for the facilities.*

6.2 Discharge control in the Member States

- The focus of the study has been upon regulation of the impact on the public of work activities, and specifically on discharge control from such activities. Following the review of the legal framework in Member States in Section 3, it is clear that *all EU Member States have acknowledged the issue of 'work activities' within their regulatory structure* although it is uncertain that Title VII has been fully enacted in Portugal.

- With regard to the identification of work activities, it is clear that Member States have concentrated, in the first instance, on the impact on workers and thus a number have taken measures to identify those workplaces in which exposure to ionising radiation to the workers cannot be disregarded. However, *Member States*

appear to be at an early stage in the area of identification of significant exposure to the public from wastes and discharges.

- At present *there are no specific discharge controls, specific assessment procedures, constraints etc for wastes from work activities in the majority of countries*. Discharge controls exist in Belgium, Italy, Luxembourg, the Netherlands, Finland and the UK. A number of countries including Spain, Ireland, Austria and Sweden have indicated an intention to review their discharge controls with respect to NORM wastes in the near future.

- There *are few radiological controls in the area of liquid and aerial discharges specific to the NORM industries*; solid waste controls are more common. Where specific discharge controls do exist, such as in Finland, there have been few occasions when limits have been applied in practice.

6.3 Realistic dose assessment of NORM industries

- *Guidance on approaches for assessing doses to members of the public from NORM discharges has been developed in the study*. The guidance covers all stages of an assessment of doses to members of the public, in terms of individual dose, due to discharges from NORM industries. The exposure pathways to be considered, the characteristics of the exposed groups and the methods for determining doses have been addressed for two types of discharge to the environment, those are: discharge to atmosphere and to water bodies.

- The guidance in Section 4 includes: the specification of the source term; what exposure pathways should be considered and their relative importance; methods for assessing doses from the important exposure pathways and consideration on difficulties relating to assessment of doses resulting from NORM discharges; issues to be considered in identifying reference groups; other factors involved in dose assessments such as the implications of short term releases, variability and uncertainty, the use of measurement data and the need to assess doses to different age groups.

- *In assessing doses from nuclear installations environmental monitoring data plays a significant role, however, for NORM discharges they are unlikely to play a role,* as the background levels of the radionuclides concerned complicate the use of such environmental data. There are a few NORM industries where statistically significant above background environmental concentrations, can be found, such as in the case of some phosphate industry discharges, in these cases environmental monitoring can then be used directly in assessments.

- *Monitoring of emissions at the source provides a valuable input to dose assessments from NORM discharges.* It is recommended that the need for environmental monitoring can be assessed on the basis of such discharge data.

6.4 Screening levels

- *The study has derived screening levels*. For discharges below these screening levels there is unlikely to be a reason for a more detailed and site-specific

radiological assessment of the discharge, and above the levels such a detailed analysis is advised.

- The derived NORM discharge screening levels in GBq y^{-1} are estimates of the amount of activity discharged to the environment from a NORM plant, which, if not exceeded, mean that it is very unlikely that members of the public would receive an effective dose above a defined dose criterion. *It is recommended that a dose criterion is chosen for the screening levels that is below the dose constraint. This would tend to suggest somewhere between a trivial level and a fraction of the constraint i.e. a screening level of dose in the range 10 - 100 μSv y^{-1}.*

- *The screening levels of discharge provided in Tables 50 -52 for aerial and river discharges are based on a screening level dose criterion of 300 μSv y^{-1}.* Such screening levels are calculated using deliberately cautious assumptions such that compliance with them would ensure virtual certainty of compliance with the dose constraint. For marine discharges the figures given in Table 53 are only examples, rather than recommended screening levels.

- *Derived discharge screening levels are directly dependent on the selected dose criterion.* This is illustrated in Figures 16 - 22 by comparing typical discharges by a number of NORM industries with derived screening levels of discharge based on dose criteria of 10, 100 and 300 μSv y^{-1}.

- *If discharge screening levels are exceeded it is recommended that regulatory bodies:*
    - verify the actual level of discharges,
    - check discharge conditions:
        - stack height,
        - receiving waster body (river flow)
    - check the existence of assumed exposure pathways and
    - decide on the need for site-specific assessment.

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Table 1 Summary of potentially significant NORM industries

Industry or work activity	Potentially significant solid residues?	Potentially significant liquid discharges?	Potentially significant aerial discharge?	Is such a facility present in EU Member State?														
				B	DK	D	EL	E	F	IRL	I	L	NL	A	P	FIN	S	UK
Onshore oil/gas	Yes, sludges, scales	Yes, if discharged but no if liquids are re-injected.	No	-	Yes	Yes	-	-	Yes	-	Yes	No	Yes	Yes	-	-	No	Yes
Offshore oil/gas	Yes, sludges, scales	Yes, produced water, scales	No	-	Yes	Yes	Yes	Yes	No	Yes	Yes	No	Yes	-	No	-	No	Yes
Phosphoric acid	Yes, if phosphogypsum is stockpiled	Yes, if phosphogypsum is discharged	No	Yes	-	-	Yes	Yes	Yes	-	-	-	-	-	-	-	-	-
Phosphate fertiliser[1]	Yes/no, depending on process	Yes/no, depending on process	No	Yes	Yes	Yes	Yes	Yes	Yes	-	Yes	-	Yes	-	Yes	Yes	Yes	-
Thermal phosphorus	Yes, calcined dust and slag	Yes, ^{210}Po, ^{210}Pb	Yes, ^{210}Po, ^{210}Pb		-	-	-	-	-	-	-	-	Yes	-	-	-	-	-
TiO_2 pigment	Yes, solids from liquid waste treatment	Yes/no depending on process	No	-	-	Yes	-	Yes	Yes	-	Yes	-	Yes	-	-	Yes	-	Yes
Steel	Yes, blast furnace and sinter dust	Yes/no depending on waste water treatment	Yes, ^{210}Po, ^{210}Pb	Yes	Yes	Yes	Yes	Yes	Yes	-	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cement	No	No	Yes, ^{210}Po, ^{210}Pb	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Coal fuelled power plants	Bottom and fly ash	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Bricks and roofing tiles	No	No	Yes, ^{210}Po	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Tin smelters (closed down)	Slag, slag wool, historical	No	Yes, ^{210}Po, ^{210}Pb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Metal extraction from tin slag	Yes, slag	No	Yes, ^{210}Po, ^{210}Pb	-	-	Yes	-	-	-	-	-	-	-	-	-	-	-	-
Lead/Zinc smelter	Yes, cobalt-cake	No	Yes, ^{210}Po, ^{210}Pb	Yes	-	Yes	Yes	Yes	Yes	-	Yes	-	Yes	-	Yes	Yes	Yes	Yes
Copper smelter	NK	No	Yes, ^{210}Po, ^{210}Pb	Yes	-	Yes	-	Yes	Yes	-	-	-	-	-	-	Yes	Yes	-

[1] Include production with phosphoric acid produced elsewhere

Table 2 Industries named by Member States as of potential significance (Qu 16)

Belgium	Denmark	Germany	Greece	Spain
Radon accumulation in work places from the soil. Underground work places including mushroom nurseries and show caves. Production of phosphates Use of mineral sands Tin smelters Extraction of rare earths Production of thoriated welding rods.	Oil and gas industry Refractory industry Coal and bio-fuel –fired power stations	Utilisation and disposal of residues requiring surveillance as stated in Appendix XII Part A of the Ordinance: 1 Sludge and sediments from oil and natural gas production, 2 Impure phosphogypsum, sludges from the production as well as dust and slags from the processing of raw phosphate (phosphorite), 3 a) ore, sludge, sand, slag and dust from the extraction and preparation of bauxite, columbite, pyrochlore, microlite, euxenite, copper shale, tin, rare earths and uranium ores from the processing of concentrates and residues that arise during the extraction and preparation of these ores and minerals as well as b) minerals corresponding to the above specified ores that occur with the extraction and preparation of other raw materials. 4 Dust and sludges from the off-gas cleaning from blast furnaces in raw iron and non-ferrous metal processing Residues within the meaning of § 97 are also a) materials in accordance with the subparas. 1 ff., when the production of these materials is deliberate, b) Castings from the materials specified in subparas. 1 and following, as well as c) excavated or cleared soil and building rubble from the dismantling of buildings or other structures when these contain residues in accordance with the subparas. 1 and following. and are removed in accordance with § 101 after completion of the work activities or in accordance with § 118, para. (5) or from properties. No residues within the meaning of § 97 are materials in accordance with subparas. 1 to 4, a) if their specific activity is below 0.2 becquerel per gram (Bq/g) for each radionuclide of the nuclide chains U-238sec and Th-232sec, or b) if they are introduced into technological processes as raw materials.	(a) Mines and quarries, (b) Thermal spas, (c) Phosphate industry, (d) Cement industries, (e) Oil & gas industry and (f) Caves visited by tourists Fertilizer production industries Places where aero-engines constructed from Th-Mg alloy are repaired.	Industries not named in reply.

Table 2 (cont'd)

France	Ireland	Italy	Luxembourg	The Netherlands
Oil extraction industries Coal extraction industries Industrial installations for coal combustion Metal smelting industries involving tin and bauxite ores, rutile and colombite Metal smelting industries involving monazite sands Smelting industries for magnesium and thorium alloys manufacturing Transformation industries involving materials containing uranium, thorium and radium Zircon industries Phosphate extraction industries Installations for nitrogenous fertilizers manufacturing Colouring pigment industries, especially those using titanium oxide Industries processing rare earths, including monazite Optical glass industries using rare earths based materials, including cerium	Use of thoriated products (TIG welding, etc) Metal recycling Oil and gas extraction Power industry – peat combustion/ flyash Power industry – handling of coal flyash Bauxite processing The use of titanium dioxide in the pigment industry Cement production Bulk handling/ use of zircon sands Handling of fertiliser	Industry utilising phosphate ores, warehouses for bulk distribution of fertilisers; Processing of metal ores for tin extraction, ferro-niobium from pyrochlore and aluminium from bauxite; Processing of zircon sands and production of refractory materials; Processing of rare earths; Processing and use of Th compounds in welding electrodes; production of Th containing lenses and optical glass and Th gas mantles; Production of titanium dioxide pigment; Oil and gas extraction and refining, as far as NORM presence in, and removal from, piping and storage tanks of sludge and scales are concerned.	**Industries that might give significant exposure to radon and radon decay products:** 6 water supply industries each of them covering several waterworks 1 spa 2 show-mines 1 hydro-electricity producing company with pumping stations located in caverns **Industries that might give significant exposure to cosmic radiation:** 2 aviation companies **No other industries were actually identified giving rise to enhanced exposure.** .	The list not published will cover: Production of: • Zinc • Primary iron • TiO_2 • Fertiliser • Fluid cracking catalysts (RE) • Oil and gas • Thermal phosphorous Dismantling involving insulation wool (from tin slag) Electricity generation Preparation of mineral sands.

Table 2 (cont'd)

Austria	Portugal	Finland	Sweden	UK
Radon exhalation from soil and accumulation in houses and working places Radon exhalation from water and accumulation in water rocks Radon in mining and excavation Mining and milling of ores Phosphate and fertilizer industry Coal mining and burning Oil and natural gas industry Rare earth industry, Zirconium industry Radium industry Thorium industry Purification of water	No regulation however possible industries include: • Phosphate industry • spas • uranium mining • coal burning.	Practices falling under the Radiation Act, Section 11(2) are: • Radon in workplaces • Natural radioactivity in drinking water (excluding water taken from a private well of an individual • Natural radioactivity in building materials • Industries listed in ST12.1 (based on RP 88) However the only industry identified as potentially radiologically significant as a source of discharges and waste is: • Production of TiO_2 using ilmenite as a raw material.	Radon in mines, and other underground construction sites. Radon at work places including waterworks. Phosphoric acid production. Foundries using zircon sands. Use of thoriated welding rods. Papermills and waterworks where radium-rich scales are formed inside pipes.	Oil and gas extraction Descaling plant (i.e. removal of scales from piping used in the oil industry). China Clay extraction (Cornwall and Devon) Industries using refractory sands (i.e. zircon and monazite) e.g. foundries Industries using thoriated tungsten welding rods.

Table 3 Fuel consumption for electricity for 2000

[Based on EURPROG, 2000 figures]

	Coal (Mt)	Brown Coal or Peat (Mt)	Oil (Mt)
Belgium	3.0	-	0.3
Denmark	6.1	0	1.3
Germany	44.9	98.5	0.8
Greece	-	25.0	2.1
Spain	20.0	10.4	4.1
France	-	0	0.7
Ireland	2.3	1.6	0.7
Italy	7.7	0	16.9
Luxembourg	0	0	0.01
Netherlands	7.6	-	0.02
Austria	1.0	0.7	0.5
Portugal	4.3	0	1.9
Finland	4.0	2.9	0.2
Sweden	0.4	0	0.4
UK	34.8	0	0.9
EU-15	137.4	139.0	30.7

Table 4 Typical values of natural radioactivity in fossil fuels

[Scholten, 1996 [1]; UNSCEAR, 2000 [2]; O'Dea and Dowdall, 1999 [3]]

	^{238}U series (Bq kg^{-1})	**^{232}Th series (Bq kg^{-1})**
Coal (global av.) [1]	20	22
Natural gas [2]	340 Bq m^{-3} (^{222}Rn)	
Peat (global av.) [3]	40	

Table 5 Arithmetic average of concentrations of radionuclides in certain ash (Bq kg^{-1})

[UNSCEAR, 1992, Annex C [1]; Leenhouts, 1996 [2]; Hedvall, 1997 [3]]

	^{238}U	^{232}Th	^{228}Th	^{228}Ra	^{226}Ra	^{210}Pb	^{210}Po	^{40}K
Escaping fly ash (coal) [1]	200	70	110	130	240	930	1700	265
Bottom ash/ fly ash (coal) [2]	240/200	240/200			240/200	151/220	138/220	653/670
Peat fly ash [3]	268-1048				<215			<1480

Table 6 Coal combustion products (CCP) production in EU 15 in 1999 (kt)

[ECOBA, 2002]

	Fly Ash	Bottom Ash	Boiler Slag	FBC Ashes	Other	SDA-Product	FGD-Gypsum	Total	Total %
CCP Production	37 144	5 622	2 417	985	240	520	7 574	54 502	na
Utilization	18 169	2 500	2 417	445	240	471	6 622	30 864	55.6
Landfill, Reclamation Restoration	15 425	2 070	0	393	0	37	424	18 349	33
Temporary Stockpile	717	31	0	0	0	0	445	1 193	2.1
Disposal	3 806	1 057	0	147	0	12	94	5 116	9.2

Table 7 Annual emissions (GBq) by 'typical' coal and gas-fired power stations

[UNSCEAR 2000 from Leenhouts, 1996]

	^{238}U	^{232}Th	^{226}Ra	^{222}Rn	^{210}Pb	^{210}Po
Coal-fired power plant (600 MW e)	0.16	0.08	0.11	34	0.4	0.8
Gas-fired power plant (400 MW e)	-	-	-	230	-	-

Table 8 Crude oil and natural gas production in EU Member States in 1998

[Based on United Nations Statistics Division, 1998 figures]

Country	Oil (kt)	Natural gas (10^3 toe)
Belgium	na	0.5
Denmark	11 432	6 613
Germany	2 934	16 863
Greece	293	44
Spain	529	114
France	1 698	2 043
Ireland	na	1 564
Italy	5 600	17 309
Luxembourg	na	na
Netherlands	1 714	63 950
Austria	959	1 438
Portugal	na	na
Finland	na	na
Sweden	0	na
United Kingdom	124 222	93 236
EU	149 381	203 175

NB One metric tonne of oil corresponds to 1165 m^3
One thousand tonne oil equivalent (toe) corresponds very roughly with 10^6 Standard m^3

Table 9 Range of reported specific activity from scales and sludge samples

[Weers et al, 1997]

	Specific Activity (Bq g^{-1}) (dry)			
	^{228}Th	^{228}Ra	^{226}Ra	^{210}Pb
Scale from Norwegian offshore gas or oil platforms	-	5 - 30	8 - 100	0 - 6[1]
Sludge from Dutch onshore and offshore oil and gas production installations	0 - 60[1]	0 – 500	1 - 800	0 - 300
Scale from Dutch onshore and offshore oil and gas production installations	0 - 200[1]	0 - 400	0 - 900	6 - 2500
Scale from German onshore oil and gas production installations	40 – 200	40 - 200	100 – 500	20 - 600
Scale from UK offshore oil or gas production platforms	-	20 - 300	20 – 400	-

[1] Not measured in all samples

Table 10 Order of magnitude estimates of discharges of natural radionuclides from offshore oil and gas production platforms

	Assumed annual oil production (10^3 m^3)	Annual water discharge (10^3 m^3)	^{228}Ra and ^{226}Ra (Bq l^{-1})	^{228}Ra and ^{226}Ra (GBq y^{-1})		
Oil	1 000	3 000	10	30		
	Assumed annual gas production (10^6 m^3)	**Annual water discharge (10^3 m^3)**	**^{226}Ra (Bq l^{-1})**	**^{226}Ra (GBq y^{-1})**	**^{228}Ra and ^{210}Pb (Bq l^{-1})**	**^{228}Ra and ^{210}Pb (GBq y^{-1})**
Gas	3 000	150	10	1.5	5	0.75

NB It should be noted that the actual annual discharges at a given platform in a particular year may be quite different from the figures derived from normalised data. Discharges of ^{210}Pb from oil producing platforms have not been estimated, as the radium isotopes are likely to be the dominant radionuclides in the discharges. However, ^{210}Pb cannot be assumed to be absent.

Table 11 Typical values of natural radioactivity in ores (Bq kg^{-1})

[Reichelt et al, 1994 [1]; Scholten, 1996 [2]; European Commission, 1999 [3]]

	^{238}Usec	^{232}Thsec
Bauxite (aluminium) [1]	37 - 530	41 - 527
Iron ore [2]	<50	<50
Pyrochlore (ferro-niobium) [3]	6 000 – 10 000	7 000 – 80 000
Tin ore [3]	1 000	300

Table 12 Production figures (kt) for selected European metal processing in 2000

[Kuo et al, 2002]

	Iron and Steel		Aluminium		Copper[1]	Lead[1]	Tin[1]	Titanium	Zinc[1]
	Pig iron[23] and direct-reduced iron	Crude steel[4]	Alumina	Primary Metal	Primary (refining)	Primary (refining)	Primary (smelting)	Metal Sponge	Primary (smelting)
	Metal Content	Gross Weight	Quantity	Quantity	Metal content	Quantity	Quantity		Quantity
Belgium	8 472	11 637	0	0	236	98	0	0	252
Denmark	0	783	0	0	0	0	0	0	0
Germany	30 846	46 376	600	644	335	210	0	0	325
Greece	0	1 056	600	163	0	0	0	0	0
Spain	4 059	15 844	1 200	366	265	0	0	0	391
France	13 661	21 002	400	441	0	100	0	0	348
Ireland	0	375	1 200	0	0	0	0	0	0
Italy	11 223	26 544	950	190	0	75	0	0	168
Luxembourg	0	2 571	0	0	0	0	0	0	0
Netherlands	4 969	5 667	0	302	0	0	0	0	215
Austria	4 318	5 725	0	0	2	0	0	0	0
Portugal	382	1 060	0	0	0	0	0	0	4
Finland	2 983	4 096	0	0	100	0	0	0	223
Sweden	3 146	5 227	0	100	105	38	0	0	0
UK	10 989	15 306	100	305	1	166	0	0	99
EU-15	95 048	163 269	5 050	2 511	1 044	687	0	0	2 025

[1] Primary production also includes undifferentiated (primary and secondary) production for those countries listed

[2] Pig iron is primary iron melted into a standard pyramidal mould or trapezoidal mould, ~ 4.5 and 6.5 kg respectively.

[3] Primary iron production (blast furnace iron) figures are those relevant to emissions and residues.

[4] Crude steel can be produced from primary iron and scrap in a basic oxygen furnace (converter) or from recycled steel in an electric arc furnace. Crude steel production figures are therefore higher than primary iron production figures as the latter are included in the former.

Table 13 Activity concentrations in process materials and residues

[Weers and Stokman-Godschalk [1]; Baxter et al, 1996 [2]; Crockett et al, 2002 [3]; Weers et al, 1991 [4]; Reichelt et al, 1994 [5]; Umweltradioaktivität, 1978 [6]; Schmitz et al, 1985 [7]]

Material	Activity Concentration (Bq kg^{-1})	Radionuclides
Tin smelting		
Slag wool[1] [1] (produced from tin slag)	4 000	^{238}Usec
	11 000	^{232}Thsec
Black slag [2]	5 000 – 6 200	^{238}U
	12 100 – 14 700	^{232}Th
Iron/steel production		
Sinter plant stack gas emissions [3]	1	^{210}Pb
	2.8	^{210}Po
Sinter dust [3]	11 300	^{210}Pb
	99 800	^{210}Po
Blast furnace slag [4]	150 to 160	^{238}U and ^{232}Th decay chain (^{210}Po, ^{210}Pb depleted see below)
	1	^{210}Po
	10	^{210}Pb
Blast furnace off-gas dusts [3]	8 000	^{210}Pb (dry weight)
	2 800	^{210}Po (dry weight)
Aluminium		
Red Sludge [5]	260 – 537	^{238}U
	250 – 496	^{232}Th
	122 – 335	^{226}Ra
Lead		
Furnace Slag [6]	36	^{232}Th
	265	^{226}Ra
Zinc		
Electrolysis waste [7]	<6	^{238}U
	8	^{230}Th
	8	^{226}Ra
	96	^{210}Pb
	-	^{210}Po
Slag [7]	33	^{238}U
	30	^{226}Ra
	44	^{210}Pb
	-	^{210}Po

[1] Slag wool will be depleted with regard to ^{210}Pb from the slag due to volatilisation.

Table 14 CORUS IJmuiden, discharges in 1990 into the water on the basis of a production of 5.2 Mt primary iron

[Leenhouts 1996]

Source	^{210}Po (GBq)	^{210}Pb (GBq)	^{210}Po (GBq Mt^{-1} primary iron)	^{210}Pb (GBq Mt^{-1} primary iron)
Blast furnace gas scrubbing	0.063	0.22	0.012	0.04
Dust scrubbers	8.0	0.26	1.5	0.05
Bio-cleaning	0.05	0.04	0.01	0.008
Total	8.1	0.52	1.6	0.31

Table 15 CORUS IJmuiden, discharges in 1990 into the air on the basis of a primary iron production of 5.2 Mt

[Leenhouts, 1996]

Plant Type	Nuclide		
	^{210}Pb	^{210}Po	
Sintering Plant	54	84	**GBq**
Pellet Plant	0.82	7.4	**GBq**
Total	**54.82**	**91.4**	**GBq**
Sintering Plant	10.4	16.1	**GBq Mt^{-1} primary iron**
Pellet Plant	0.16	1.42	**GBq Mt^{-1} primary iron**
Total	**10.5**	**17.5**	**GBq Mt^{-1} of primary iron**

NB Differences in ^{210}Pb/^{210}Pb ratio's and differences in emission rates between sinter plants and pellet plants are related to the higher temperature reached in sintering process and to the different scrubbing methods of the off-gas. 'Typical' discharges may therefore change when the off-gas scrubbing is modified.

Table 16 Estimate of P_2O_5 production in the European Union

[Hofmann et al, 2000 (b)]

Process	P_2O_5 Production		Phosphate Fertilizer Production		Comments
Country	kt y^{-1}	% of total EU	kt y^{-1}	% of total EU	
Belgium/ Luxembourg	270	14	340	14	Two phosphate plants in Belgium, one using H_2SO_4 (with phosphogypsum stockpiled on land (Ministry of Housing, 2001)) and the other using HCl (Vandenhove, 2002).
Germany	0	0	220	9	
Greece	200	11	120	5	Two integrated phosphoric acid/ phosphate fertilisers plants from the Phosphoric Fertilizers Industry group: one in Kavala and the other in Thessaloniki (2002), with phosphogypsum stockpiled on land (Ministry of Housing, 2001)
Spain	530	28	180	7	One Huelva phosphoric acid plant from Fertiberia group (1999), with phosphogypsum stockpiled on land (Ministry of Housing, 2001)
France	250	13	930	39	One phosphoric acid plant in France, (Elf-Atochem -Grande-Paroisse: Grand-Quevilly (76)) (2002), with phosphogypsum stockpiled on land (Ministry of Housing, 2001)
Italy	250	13	330	14	No phosphoric acid plant, no thermal process, no HCl process. No NORM discharges (Trotti et al, 2002).
Netherlands	120	6	290	12	TIBV producing elemental phosphorous (Hofmann et al, 2000 (b)), no other NORM producing phosphate industry.
Austria	55	3	-	-	
Finland	240	12	-	-	One integrated phosphoric acid plant at Siilinjärvi, from the Kemira group (2001), with phosphogypsum stockpiled on land (Ministry of Housing, 2001)
Total EU	1900	100	2410	100	

Table 17 Indicative activity concentration in ore and waste products of the phosphate industry

[Penfold, 1999 [1]; Vandenhove et al, 2002 [2]]

Material	Activity Concentration Bq kg^{-1}	Radionuclide
Ore[1] [1]	1 400	^{238}U+
	160	^{232}Th
	1 400	^{226}Ra+
	1 400	^{210}Pb+
SULPHURIC ACID PROCESS		
Phosphogypsum [1]	200	^{238}U+
	17	^{232}Th
	850	^{226}Ra+
	200	^{210}Pb+
HYDROCHLORIC ACID PROCESS		
Calcium Fluoride (solid) with radium sulphate precipitate (from $BaCl_2$ precipitate step) [2]	8 000 – 10 000	^{226}Ra
Calcium Chloride (effluent) [2]	2 Bq/l^{-1}	^{226}Ra
NITRIC ACID PROCESS		
Calcium carbonate (recycled)	NK	NK
THERMAL PROCESS		
Calcium Silicate Slag [1]	2 700	^{238}U+
	310	^{232}Th
	2 300	^{226}Ra+
	270	^{210}Pb+
Calcined dust [1]	1 600 000	^{210}Pb+

NB The above data are as cited in the source material and may be for the selected chain and radionuclide only.

[1] It is important to note that phosphate ore of igneous origin is lower in radioactivity than that of sedimentary origin and the range of ^{238}U+ measured in ores is quoted in Penfold et al, 1999 as between 40 – 5000 Bq kg^{-1}.

Table 18 Typical liquid discharge data based on Dutch HAR plant at Vlaardingen

Year	Phosphogypsum (kt)	^{226}Ra (GBq)	^{210}Pb (GBq)	^{210}Po (GBq)
1993	563	257	279	235
1994	649	377	328	363
1995	682	361	336	299
1996	671	315	314	288
1997	670	313	315	293
1998	660	283	242	284

NB (closed down in 2000) with a production capacity of 160 000 t P_2O_5 annually and reported by the Dutch Government to the OSPAR Commission, September 1999.

Table 19 Discharges to air and water from the Thermphos plant

Year	^{210}Po to air (GBq)	^{210}Pb to air (GBq)	^{210}Po to water (GBq)	^{210}Pb to water (GBq)
1987	538	50	73	69
1988	843	98	95	40
1989	634	50	99	34
1990	381	34	107	24
1991	687	32	91	21
1992	490	66	166	24
1993	616	52	96	24
1994	506	33	82	29
1995	503	48	76	23
1996	390	95	58	36
1997	306	106	29	21

Table 20 Titanium dioxide industry in the European Union for 2000/2001

Country	Site	Company	Process	Capacity (10^3 t y^{-1})
Belgium	Langerbrugge	KRONOS	chloride	69
	Antwerp	Kerr-McGee	sulphate	NK
Germany	Uerdingen	Kerr-McGee	sulphate	130
	Leverkusen	KRONOS	sulphate	30
	Leverkusen	KRONOS	chloride	100
	Nordenham	KRONOS	sulphate	62
	Duisburg	Sachtleben	sulphate	100
France	Le Havre	Millennium	sulphate	110
	Thann	Millennium	sulphate	28
	Calais	Huntsman Tioxide	sulphate	100
Italy	Scarlino	Huntsman Tioxide	sulphate	80
Netherlands	Rotterdam	Kerr-McGee	chloride	80
Finland	Pori	Kemira Pigments	sulphate	130
United Kingdom	Greatham	Huntsman Tioxide	chloride	80
	Grimsby	Huntsman Tioxide	sulphate	80
	Grimsby	Millennium	sulphate (?)	150

NB It should be noted that this information although drawn from recently published sources it is not necessarily up to date. Production facilities may have changed ownership, may have closed down or have increased production capacity or changed their wastewater treatment process.

Table 21 Uranium and thorium concentrations in rutile samples

Code	Uranium ppm (µg g^{-1})	Thorium ppm (µg kg^{-1})	Uranium-238 (Bq g^{-1})	Thorium-232 (Bq g^{-1})
9	90	160	1.1	0.8
11	80	120	1.0	0.6
14	7	78	0.1	0.4
15	59	7	0.7	0.0
16	22	53	0.3	0.3
20	20	^{210}	0.2	1.1
21	50	91	0.6	0.5
g	53	51	0.7	0.3
h	12	455	0.1	2.3
NR p15	50	5	0.6	0.03
NR p25	25	123	0.3	0.6
NR p23	52	59	0.6	0.3
SR p18	70	119	0.9	0.60
SR p22	5	36	0.1	0.2
Sr p27	11	176	0.1	0.9
mix	30	118	0.4	0.6

Table 22 Typical discharges of ^{228}Ra, ^{226}Ra, ^{210}Pb, and ^{210}Po in acidic liquid effluent from TiO_2 pigment plant with an annual production of 90 000 t using the chloride process.

Nuclide	GBq y^{-1}
^{228}Ra	38
^{226}Ra	22
^{210}Pb	9
^{210}Po	3

NB Average concentration in the rutile 0.4 and 0.6 Bq kg^{-1} for ^{238}U sec and ^{232}Th sec.

Table 23 Zirconium ore processing in Europe

[Roskill, 1995]

Country	Quantity (kt y^{-1})
Belgium/Luxembourg	3
Germany	45
Greece	
Spain	52
France	40
Italy	98
Netherlands	
Austria	
Finland	
EU-15	238

Table 24 Radioactivity content of zircon in Bq kg^{-1}

[Scholten, 1996]

	^{238}U	^{232}Th	^{226}Ra
Average	6 800	11 000	8 300

Table 25 Radioactivity content of baddleyite in Bq kg^{-1}

[Harvey et al, 1994]

	^{238}U	^{232}Th	^{228}Th	^{228}Ra
Baddleyite	7 000	300	200	6 000

Table 26 **^{232}Th and ^{40}K activity concentrations (Bq kg^{-1}) measured on raw materials, residues and finished products in tile working**

[Bruzzi et al, 1991]

Samples	^{238}U	^{232}Th	^{40}K
Raw materials	26-58	38-73	422-1 286
Zircon silicate (<5μm)	2 334	880	na
Zircon silicate (<45μm)	2 084	858	na
Sludges	68-354	30-119	266-427
White porcelain stoneware	118-247	40-89	528-1 000
Red porcelain stoneware	42	42	625
Black porcelain stoneware	39	41	768
Other tiles	27-88	42-69	544-977

Table 27 Cement production in EU Member States in 1998

[GCIS, 2002]

Country	Cement produced 10^3 t
Belgium	8 000
Denmark	2 528
Germany	36 610
Greece	15 000
Spain	27 943
France	19 500
Ireland	2 000
Italy	35 000
Luxembourg	650
Netherlands	3 200
Austria	3 850
Portugal	9 500
Finland	903
Sweden	2 105
United Kingdom	12 409
EU-15	**179 198**

Table 28 Annual aerial discharges for a 'typical' cement plant with a 2000 kt y^{-1} output of different types of cement

[Leenhouts et al, 1996]

Nuclides	GBq
^{238}U	0.2
^{228}Th	0.05
^{226}Ra	0.2
^{222}Rn	157
^{210}Pb	0.2
^{210}Po	78
^{40}K	0.4

Table 29 Rounded general clearance levels in Bq g^{-1}

[European Commission, 2001]

Nuclides	All Materials	Wet Sludge from oil and gas industry
U_{nat}	5	100
^{238}Usec	0.5	5
^{235}Usec	1	10
^{235}U+	5	50
^{232}Thsec	0.5	5
^{232}Th	5	100
^{231}Pa	5	50
^{230}Th	10	100
^{228}Th+	0.5	5
^{228}Ra+	1	10
^{226}Ra+	0.5	5
^{227}Ac+	1	10
^{210}Pb+	5	100
^{210}Po	5	100
^{40}K	5	100

Table 30 Summary of questionnaire responses (Qu 1 - 9 and benchmark)

Country	Has Title VII been enacted? (Qu 1)	Where has 'work activities' been defined? (Qu 2)	At what stage is the identification of NORM industries? (Qu 3)	Will new work activities identified in the future be covered by existing legislation? (Qu 4)	Have discharge controls been agreed for NORM wastes? (Qu 5)	Who is the regulator? (Qu 6)	When is authorisation required? (present situation) (Qu 7)	Is the concept of exemption applied?	Any prohibition of disposal routes? (Qu 8)	Methodology for setting discharge limits? (Qu 9)	Benchmark
Belgium (not confirmed)	Yes	Within the scope in Article 1 of ARBIS.	Work activities have been identified and named in Article 4 of ARBIS. A detailed study into the industries is envisaged.	Yes a reference level of 1 mSv y^{-1} included in Article 9 ensures new work activities are included.	Legal instruments exist however in practice wastes have not been regulated.	Federal Agency for Nuclear Control (FANC)	Not yet agreed	-	-	-	-
Denmark	Yes	Not defined in the legislation.	Detailed studies into particular industries are being conducted, further identification ongoing.	Yes regulation defined by radioactive content criteria.	Industry specific instructions under the Ordinance are being written, currently only one for the oil and gas industry exists.	National Institute of Radiation Hygiene (NIRH).	When exemption levels in Order 192 are exceeded.	Yes	Disposal to sewers is prohibited.	No fixed methodology.	Discharge limits imposed, required to report discharges and show best practical means have been applied.
Germany (not confirmed)	Yes	In the definitions, Para 3(2) of RPO.	Detailed studies completed identifying work activities and further investigating exposure of workers and the public from residues.	Yes, definition is inclusive by exposure rather than category.	Generic controls and requirements given in legislation for residues no mention is made of discharges.	Unclear in legislation assumed to be the 'Länder' (the Federal States).	Emphasis in regulations on solid material liquid and aerial discharges appear uncontrolled.	Yes (§§97 and Appendix XII of RPO)	-	-	-

Table 30 (cont'd)

Country	Has Title VII been enacted? (Qu 1)	Where has 'work activities' been defined? (Qu 2)	At what stage is the identification of NORM industries? (Qu 3)	Will new work activities identified in the future be covered by existing legislation? (Qu 4)	Have discharge controls been agreed for NORM wastes? (Qu 5)	Who is the regulator? (Qu 6)	When is authorisation required? (present situation) (Qu 7)	Is the concept of exemption applied?	Any prohibition of disposal routes? (Qu 8)	Methodology for setting discharge limits? (Qu 9)	Benchmark
Greece	Yes	In para 1.2.5 of the RPR (not in definitions).	Surveys of workplaces being conducted, further identification ongoing	Action level of 1 mSv y^{-1} included in legislation, GAEC have preliminary plans for naming categories of industries requiring a NORM report.	Industry specific Orders issued, currently only for phosphogypsum disposal.	Greek Atomic Energy Commission (GAEC)	For NORM disposal.	Yes, RP 122 Part II recommendations are in general applied.	No	No discharge limits set.	Situation not encountered
Spain	Yes	In Title VII of Royal Decree 783/2001.	An action plan recently approved by CSN but identification could be considered to be at an early stage.	Yes, see reg 62 application - activities covered if exposure significant however regulatory strategy for work activities still under development.	No, apart from those under non-radioactive pollution control regulations	Ministry of Economy, Ministry of Development or the Regional Authorities with Nuclear Security Council (CSN) guidance	Generally controlled under general regulations for control of environmental pollution - no NORM specific controls as yet.	No	No specific legal provisions as yet.	Not developed.	Disposal controls/procedures not yet established
France	Yes	In a description of obligations. L1333-17 of the 2001-270 Ordinance	Categories of relevant industries identified, detailed studies into radiological characteristics etc still to be conducted.	Draft version of Decree lists specific industries but includes the option 'other work activities' so flexibility is retained	Awaiting completion of detailed studies into the industries.	-	-	-	-	-	-

Table 30 (cont'd)

Country	Has Title VII been enacted? (Qu 1)	Where has 'work activities' been defined? (Qu 2)	At what stage is the identification of NORM industries? (Qu 3)	Will new work activities identified in the future be covered by existing legislation? (Qu 4)	Have discharge controls been agreed for NORM wastes? (Qu 5)	Who is the regulator? (Qu 6)	When is authorisation required? (present situation) (Qu 7)	Is the concept of exemption applied?	Any prohibition of disposal routes? (Qu 8)	Methodology for setting discharge limits? (Qu 9)	Benchmark
Ireland	Yes	In Art 3(2) the scope of the Order.	Overview complete, in-depth study of industries underway	Yes, reference level of 1 mSv y^{-1} included as defining factor and Article 7 requires that RPII is notified on commencement.	Under development/review but likely to fall under non-radioactive pollution control regulations	Radiological Protection Institute of Ireland (RPII)	Generally controlled under general regulations for control of environmental pollution - no NORM specific controls as yet.	Yes, not within the scope i.e. not regulated unless dose to the public or workers exceed 1mSv y^{-1}	No NORM waste specific regulations.	None.	Specific regulations relating to discharges from work activities not developed, may fall within scope of Environmental Protection Agency Act 1992
Italy	Yes	Defined as in European Directive in Art 10bis of Decree No 230.	List of activities worthy of concern given in legislation detailed surveys won't commence until after Sept 2003.	Yes, definition by exposure thus will cover new activities as they arise in addition National Technical Commission on Exposure to Natural Radiation assigned task to develop criteria for identifying relevant new activities and updating legislation.	Yes, Operators involved in a listed activity are required to assess exposures from their activity and issue a report and take intervention measures to reduce exposures below Action levels.	Regional Agencies for the Protection of the Environment; Local Health Bodies; Labour Inspectorates. A technical commission from the National Agency for Environment Protection (ANPA) may advise.	Where exposures cannot be maintained below the Action Levels rules for the protection of workers and the public as applied to practices are required to be applied.	No even below Action levels control is required for the listed work activities.	-	-	-

Table 30 (cont'd)

Country	Has Title VII been enacted? (Qu 1)	Where has 'work activities' been defined? (Qu 2)	At what stage is the identification of NORM industries? (Qu 3)	Will new work activities identified in the future be covered by existing legislation? (Qu 4)	Have discharge controls been agreed for NORM wastes? (Qu 5)	Who is the regulator? (Qu 6)	When is authorisation required? (present situation) (Qu 7)	Is the concept of exemption applied?	Any prohibition of disposal routes? (Qu 8)	Methodology for setting discharge limits? (Qu 9)	Benchmark
Luxembourg	Yes	Art 1.1(e) in the scope of Decree.	The likely relevant industries/ companies identified.	Yes, scope is inclusive. In addition all companies that may cause pollution must be licensed and if NORM is involved the Ministry of Health must be notified before a licence is issued.	No difference is made between practices and work activities concerning authorisations, and release of radioactive substances requires prior authorisation with conditions set by the competent authority on a case-by-case basis.	Ministry of Health	If the industry handles or processes natural radionuclides with an activity higher than 100 Bq g^{-1} prior authorisation is required, authorisation is required for release of any radioactive substances.	No.	In principle nothing is prohibited however discharges require authorisation and disposal to public landfill sites or to public sewers would not be encouraged.	-	Annual discharge limits would likely be imposed and a specific evaluation would be requested from the applicant on the impact of the discharges including BPEO.
Netherlands (not confirmed)	Yes	In the explanatory notes to the regulations.	Detailed studies have been completed and published. There is an intention to publish two lists of industries which are likely to require control.	Yes control defined by radioactive content, list is indicative only not exclusive.	Generic controls are enacted in the regulations giving exemption and clearance levels and stating the requirements for reporting etc.	Joint responsibility of a number of Ministers 'Our Ministers'.	When levels exceed exemption levels set out in the regulations (same as Annex 1 Table 2 of the Directive).	Yes	No	No discharge limits set.	Authorisation required, discharge limits applied and reporting of total annual activities of specific radionuclides required.

Table 30 (cont'd)

Country	Has Title VII been enacted? (Qu 1)	Where has 'work activities' been defined? (Qu2)	At what stage is the identification of NORM industries? (Qu3)	Will new work activities identified in the future be covered by existing legislation? (Qu 4)	Have discharge controls been agreed for NORM wastes? (Qu 5)	Who is the regulator? (Qu 6)	When is authorisation required? (present situation) (Qu 7)	Is the concept of exemption applied?	Any prohibition of disposal routes? (Qu 8)	Methodology for setting discharge limits? (Qu 9)	Benchmark
Austria	Yes	In definitions of the Law	Overview complete, detailed studies being planned	Yes as work activities defined as in Directive. In draft of Ordinance several industries defined as potentially affected leaving the possibility open more might be added to list.	Under development in new Ordinance	Federal Ministry of Agriculture, Forestry, Environment and Water Management (BMLFUW).	For the time being (as for discharge of any radionuclide) when levels exceed permitted levels as set out in the existing Radiation Protection Ordinance..	Yes, maximum discharge limits in existing Ordinance	No - controlled by prior authorisation otherwise same controls as for non-radioactive waste	No discharge limits set but will be on the basis of the dose to the population.	Not known - under development
Portugal (as of May 2002)	No	na	No identification undertaken as yet.	na	No	na	na	No	No	na	No legislation
Finland	Yes	Not separately defined. Radiation practices defined as inclusive of 'work activities'. See Section 11 of Radiation Protection Act (592/1991)	Activities regulated since 1992 therefore relevant industries identified and regulated.	Yes and there is an obligation on operators to assess whether their operations involve significant exposures to natural radiation (Art 45 of Act)	Yes, where found to be necessary (i.e. for some mining disposal sites) orders have been issued.	Ministry for Social Affairs and Health in practice the Radiation and Nuclear Safety Authority (STUK) as an Agency of the Ministry.	Authorisation not required. Operators are required to notify STUK and carry out an investigation after which STUK issues orders as appropriate to control exposure.	Yes	No though operators must demonstrate that exposure from discharges are small.	No discharge limits set, however would most likely be site-specific based on dose to critical group considering a dose of 0.1 mSv.	Operator would be required to investigate the radiological consequences. Any further actions would be based on the results thereof.

Table 30 (cont'd)

Country	Has Title VII been enacted? (Qu 1)	Where has 'work activities' been defined? (Qu 2)	At what stage is the identification of NORM industries? (Qu 3)	Will new work activities identified in the future be covered by existing legislation? (Qu 4)	Have discharge controls been agreed for NORM wastes? (Qu 5)	Who is the regulator? (Qu 6)	When is authorisation required? (present situation) (Qu 7)	Is the concept of exemption applied?	Any prohibition of disposal routes? (Qu 8)	Methodology for setting discharge limits? (Qu 9)	Benchmark
Sweden	Yes, pre-existing legislation	Not defined	Detailed studies completed, continuous long-term commitment.	Regulations generic so yes however SSI is reviewing policy on treatment of 'work activities' as defined by the Directive.	SSI FS 1983:7 could be applied though the issue will be reviewed in the next year or two.	Swedish Radiation Protection Authority (SSI)	Special permission would be required to make radioactive releases greater than levels given in SSI FS 1983:7.	Yes	No	Based on estimation of presumed doses to the critical group.	Annual release limits are likely to be set with a requirement for annual reporting; the Operator would have to show that the BPEO is being exercised.
United Kingdom	Yes	Yes within the scope, reg 3(1)(c) of IRR99	Detailed studies complete	Yes, defined by presence of radioactive substance and risk not industry specific.	Yes, where found to be necessary, e.g. Oil and gas extraction and steel plant emissions.	Environment Agency (EA) in England and Wales, the Scottish Environmental Protection Agency (SEPA) in Scotland and Industrial Pollution and Radiochemical Inspectorate (IRPI) in N.Ireland.	For disposal and accumulation of radioactive material	Yes, Exemption Orders.	No, controlled by authorisation	Based on radiological impact in conjunction with dose constraints.	May be exempt.

Table 31 Summary of questionnaire responses (Qu 10 - 15)

Country	What dose constraints are used? (Qu 10)	Is there an agreed methodology for assessment of doses? (Qu 11)	What form do discharge limits take? (Qu 12)	How is compliance with limits monitored? (Qu 13)	Is there a lower boundary below which optimisation is not required? (Qu 14)	Are there any planned changes to legislation? (Qu 16)
Belgium (not confirmed)	-	-	-	-	-	-
Denmark	0.3 mSv y^{-1} effective dose to members of the public (Annex 3 of Order 192). Can be regarded as dose constraint for a single discharge.	No, but doses to critical groups are calculated and estimates based largely on conservative assumptions.	Activity concentrations (Bq g^{-1}).	Records kept and results submitted on a yearly basis to NIRH.	No	Legislation only came into force in 1st May 2002.
Germany (not confirmed)	-	-	-	-	-	-
Greece	For phosphogypsum 0.01 mSv y^{-1} but propose to use 0.3 mSv y^{-1} increment for other NORM residues. 0.01 mSv y^{-1} for effluents from practices.	No, but critical group doses calculated.	As yet only concentration limits for a specified pathway.	Measurements required and the methodology for sampling and measurement is prescribed, regulator also takes measurements.	Yes no optimisation is required below dose constraints provided in RPR e.g. 0.01 mSv y^{-1} for effluents from practices.	Under the RPR GAEC has the authority to issue orders and to establish specific clearance levels for practices and work activities as required.
Spain	Not yet developed.	Not established	Not established	Not established	Not established	CSN is currently preparing a plan for the development of rules, regulations and safety guides on waste management including for NORM wastes and discharges.
France	-	-	-	-	-	-
Ireland	Not yet developed there is however the general requirement (dose limit) that dose not exceed 1 mSv y^{-1}.	Not established	Not established	Not established	Not established	Existing controls on discharges of NORM material will be reviewed following the completion of current investigations into extent of exposure and potential releases and discharges from identified industries.
Italy	Action levels exist requiring intervention if exposure is greater than 0.3 mSv y^{-1} for members of the public.	-	-	-	-	-

Table 31 (cont'd)

Country	What dose constraints are used? (Qu 10)	Is there an agreed methodology for assessment of doses? (Qu 11)	What form do discharge limits take? (Qu 12)	How is compliance with limits monitored? (Qu 13)	Is there a lower boundary below which optimisation is not required? (Qu 14)	Are there any planned changes to legislation? (Qu 16)
Luxembourg	No generic values, constraints are used for optimisation and agreed on a case-by-case basis between the operator and regulator.	No, assumptions etc made on a case-by-case basis taking into account international recommendations.	They are site specific and determined on a case-by-case basis.	Specified in the licence.	No	None
The Netherlands (not confirmed)	For NORM discharges: 0.01 mSv y^{-1} effective dose to members of the public. The dose constraints for solid residues are 0.3 mSv y^{-1} effective dose to members of the public or 1 mSv y^{-1} ambient dose.	Yes methodologies for deriving exposures for authorisations for practices are laid down in a Ministerial Regulation which came into force on 1st March 2002 however this does not apply to discharges from work activities.	Previously total annual activity however authorisations under new legislation have not yet been made.	Monitoring and reporting of discharges at specified frequency. Samples analysed by independent research institutes and reported to the inspectorate. (Under old regulations no experience yet under new legislation)	Yes for exemption of discharges from work activities a dose criterion of 0.01 mSv y^{-1} effective dose has been used and this level of exposure is not regarded as needing optimisation.	-
Austria	Concept in Radiation Protection Law but values will defined in the new Ordinance.	No, however potential doses calculated for the critical group and must be done by authorised experts and checked by the authorities. It is expected that recommendations in the 'Radiation Protection Series', from the European Commission, will be closely followed; assumptions are conservative.	Limits are installation specific however the example given consists of annual, weekly, and single discharge limits as well as limits on activity concentration.	Require the operator to to take samples and monitor discharges. Samples must be stored in addition to records being kept of results to allow random checking by inspectors. The authorities may also take their own sampling, the installation will also provide an exposure assessment.	No	Yes new Ordinance is currently going through Parliament and changes will result from the implementation of the new legislation particularly as NORM was not previously regulated.
Portugal	na	na	na	na	na	No
Finland	The population dose constraint for a specific radiation source may be within the range of 0.1 to 0.5 mSv y^{-1} and the actual value is set on a case specific basis.	Yes see report STUK-B-STO 32 however no authorisation is required and the methodologies do not cover discharges and only to a limited extent do they cover wastes.	No such limits on discharges have been issued.	No limits on effluent discharges exist so compliance monitoring not applicable.	Yes, if doses to the public are less than 0.1 mSv y^{-1} the practice is exempted from limitations measures.	No existing legislation i.e. the Act and the Decree and ST Guides under it provide a sound legal basis for dealing with work activities.

Table 31 (cont'd)

Country	What dose constraints are used? (Qu 10)	Is there an agreed methodology for assessment of doses? (Qu 11)	What form do discharge limits take? (Qu 12)	How is compliance with limits monitored? (Qu 13)	Is there a lower boundary below which optimisation is not required? (Qu 14)	Are there any planned changes to legislation? (Qu 16)
Sweden	0.01 mSv y^{-1} to a critical group (this is a standard procedure and not NORM specific).	Conservative site specific assumptions are used in estimation of annual dose to the critical group. If the result shows it to be greater than the dose constraint it will be repeated using more realistic set of assumptions before decisions are made on the authorisation.	Currently there are monthly release limits and a activity concentration (Bq ml^{-1}) however SSI FS 1983:7 in which these reside is up for review in 2003.	Present regulations do not stipulate monitoring or sample collection.	Current regulations do not stipulate anything in this area.	Yes, SSI FS 1983:7 is to be revised in 2003. The Swedish system of regulations of NORM and other sources of radioactive waste outside of the nuclear industry is also to be improved and further developed from 2003.
United Kingdom	0.3 mSv y^{-1} for doses to the public	UK Environment Agencies are have published interim guidance, (EA et al, Dec 2002), on the general principles for the assessment of public doses. Doses to the critical group are calculated using a staged approach i.e. initially using conservative assumptions and results compared to threshold dose and if results exceed this a more detailed specific assessment will be required.	Installation and discharge route specific limits are given in authorisations and can be annual, rolling annual or monthly limits on total discharge.	Monitoring and records made and retained by operator for inspection; duplicate samples may be taken by the inspectorate.	Doses to the critical group are pushed down by means of the requirement to use the best practical means[1] (BPM) and not by reliance on numerical limits alone.	No, however 'UK Strategy for Radioactive Discharges 2001 - 2020' was finalised in July 2002 (DEFRA, July 2002) which may ultimately result in changes to relevant legislation. Statutory guidance to the Environment Agencies on the regulation of radioactive discharges is currently under development.

[1] **Best Practical Means (BPM):** The BPM is that level of management and engineering control that minimises, as far as practicable, the release of radioactivity to the environment whilst taking account of a wider range of factors, including cost effectiveness, technological status, operational safety, and social and environmental factors. In determining whether a particular aspect of the proposal represents the BPM, the Inspectorates will not require the applicant to incur expenditure, whether in money, time or trouble, which is disproportionate to the benefits likely to be derived (HMSO, 1995).

Table 32 National legislation and *associated guidance*[1] relevant to NORM

Country	Document
Belgium	Royal Decision of 20th July 2001 (ARBIS)
Denmark	Radiation Law, Law No 94 31st March 1953 as modified by Law No 369 6th June 1991.
	Ministry of the Interior and Health Order No 192 of 2nd April 2002 on exemption from law on the use of radioactive substances.
Germany	Radiation Protection Ordinance (Strahlenschutzverordnung) 20th July 2001 (RPO)
	Nuclear Law (Atomgesetz) 3rd May 2000
Greece	Radiation Protection Regulations Joint Ministerial Order No 1014 (ΦΟΡ) 94, Official Gazette No 216B, 06/03/01 (RPR).
Spain	Royal Decree 783/2001 on the Health Protection against Ionising Radiation.
France	Ordinance No 2001-270 of the 28th March 2001 (FR 2001)
	Decree No 2002-460 of the 4th April 2002 (FR 2002)
Ireland	Radiological Protection Act, 1991.
	Radiological Protection Act, 1991 (Ionising Radiation) Order 2000 (S.I. No 125 of 2000)
Italy	Legislative Decree nr 230 of 17th March 1995
	Legislative Decree nr 241 of 26th May 2000 (modifying Decree nr. 230)
	Legislative Decree nr 257 of 9th May 2001 (modifying Decree nr 241)
Luxembourg	Regulations of the Grand Duchy, 14 December 2000.
Netherlands	Royal Decision of 16th July 2001 (BS).
Austria	Radiation Protection Act (146 Strahlenschutz-EU-Anpassungsgesetz 2002) 20th August 2002
	Radiation Protection Ordinance (draft)
Portugal	Decree No 165/2002 of 17th July
Finland	Radiation Act (592/1991) as amended by 1142/1998
	Radiation Decree (1512/1991) as amended 1142/1998
	ST 12.1 Radiation Safety in Practices Causing Exposure to Natural Radiation
	ST 12.2 Radiation of Construction Materials, Fuel Peat and Peat Ash
	ST 12.3 Radioactivity of Household Water
Sweden	Radiation Protection Act (1988/220)
	Radiation Protection Ordinance (1988/293) as amended 1st Sept 2001
UK	The Management of Health & Safety at Work Regulations 1999 SI 1999 No 3244
	Ionising Radiation Regulations 1999 SI 1999 No 3232
	Approved Code of Practice for IRR99 L121
	Radioactive Substances Act 1993 (c12)
	Exemption Orders (18 of) (See Appendix B for details)
	Radioactive Substances (Basic Safety Standards) (England and Wales) Direction 2000, 9th May 2000
	Radioactive Substances (Basic Safety Standards) (Scotland) Regulations 2000 SI 2000 No 100
	Radioactive Substances (Clocks and Watches) (England and Wales) Regulations 2001 SI 2001 No 4005
	Radioactive Substances (Basic Safety Standards) (Northern Ireland) Regulations 2003 SR 2003 No 208

[1] Guidance given in italics in the table.

Table 33 Examples from the EU Member States of practical implementation of NORM controls

Identification of Work Activities:
An Action Plan has been prepared and presented to the Government on in order to target/identify those work places which would be required to initiate studies envisaged under Reg 62 of Title VII of the Royal Decree 783/2001 i.e. those operating work activities involving natural sources of radiation (but not covered within the definition of a practice) to carry out studies to determine if a significant increase of the exposure of the workers or the members of the public exists which cannot be disregarded from the point of view of the radiological safety. (Spain).
A target time limit has been set (2 years) for the identification of relevant work activities and completion of investigative studies into them. (Italy, France).
The different ways used to locate the industries and companies that potentially could be affected by Title VII include through the Chamber of Commerce register, information possessed by other organisations of Administration or Regional Authorities and the Internet. (Spain).
Companies actively involved were identified using a variety of sources including Integrated Pollution Control licences and commercial databases such as Kompass. (Ireland).
Guidance given on how dose assessments are to be conducted. (Germany, UK).
NORM regulation:
Regulation of NORM waste (solid) is based on RP122 Part II guidance. (Greece).
Regulatory discharge levels at which authorisation will be required have been set. (Netherlands).
Exemption and Clearance levels provided in regulations for naturally occurring radionuclides based on RP 122 Part II levels. (Denmark).
A holistic approach to regulation taken (or likely to be taken) i.e. encompassing radioactive discharge controls (at least for NORM) within non-radioactive environmental protection pollution controls i.e. a separate discharge licence is unlikely to be required for radioactivity of the discharges in addition to the licence for the discharges due to their chemical or 'non-radioactive' pollution effects, all characteristics will be covered within the one licence. (Ireland).
A key role for a National Technical Commission on Exposure to Natural Radiation Sources, intended to deal with the scientific and technical problems specific to natural radioactivity has been set up under the regulation. The Commission is to be made up of 21 experts, coming from relevant ministries, national scientific institutions, agencies and regional authorities. (Italy).
Action levels have been defined, if exposures exceed either Action Level, the operator must submit a report to the Authorities and adopt remediation measures within a three year time limit, with a view to keeping exposures below Action Levels, taking into account the optimisation principle. (Italy).
Companies are required to keep records of all radioactive analysis and these must always be available for inspection by the Regulator who will also perform regular measurements to determine regulatory aspects and dose assessments. (Denmark).

NB See Part II: Appendix C for more detail.

Table 34 The decay chains of ^{238}U, ^{235}U and ^{232}Th

^{238}U series		^{235}U series		^{232}Th series	
Nuclide	Half-life	Nuclide	Half-life	Nuclide	Half-life
^{238}U	$4.5\ 10^{9}$ y	^{235}U	$7.1\ 10^{8}$ y	^{232}Th	$1.41\ 10^{10}$ y
^{234Th}	24.1 d	^{231}Th	25.6 h	^{228}Ra	5.76 y
^{234m}Pa (99.9%)	1.17 min	^{231}Pa	$3.4\ 10^{4}$ y	^{228}Ac	6.13 h
^{234}U	$2.47\ 10^{4}$ y	^{227}Ac	21.6 y	^{228}Th	1.913 y
^{230}Th	$8.0\ 10^{4}$ y	^{227}Th (98.8%)	18.6 d	^{224}Ra	3.66 d
^{226}Ra	1602 y	^{223}Ra	11.7 d	^{220}Rn	55.6 s
^{222}Rn	3.82 d	^{219}Rn	3.9 s	^{216}Po	0.15 s
^{218}Po	3.05 min	^{215}Po	$1.78\ 10^{-3}$ s	^{212}Pb (100%)	10.64 h
^{214}Pb (99.96%)	26.8 min	^{211}Pb	36.1 min	^{216}At (0.01%)	$0.3\ 10^{-3}$ s
^{214}Bi	19.7 min	^{211}Bi	2.2 min	^{212}Bi	60.6 min
^{214}Po	$0.16\ 10^{-3}$ s	^{211}Pb (0.3%)	0.516 s	^{212}Pb (66.3%)	$30\ 10^{-6}$ s
^{210}Pb	22.3 y	^{207}Tl (99.7%)	4.77 min	^{208}Tl (33.7%)	3.05 m
^{210}Bi	5.01 d	^{207}Pb	Stable	^{208}Pb	Stable
^{210}Po	138.4 d				
^{206}Pb	Stable				

NB Numbers in the bracket are branch ratios

Table 35 Summary of naturally-occurring radionuclide decay chain segments

Chain segment	Nuclides considered in secular equilibrium
U+238	U-238, Th-234, Pa-234m (99.8%), Pa-234 (0.2%)
U-234	U-234
Th-230	Th-230
Ra+226	Ra-226, Rn-222, Po-218, At-218 (0.04%), Pb-214 (99.96%), Bi-214, Po-214
Pb+210	Pb-210, Bi-210
Po-210	Po-210
Th-232	Th-232
Ra+228	Ra-228, Ac-228
Th+228	Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212 (64.1%), Tl-208 (35.9%)
U+235	U-235, Th-231
Pa-231	Pa-231
Ac+227	Ac-227, Th-227 (98.6%), Fr-223 (1.38%), Ra-223, Rn-219, Po-215, Pb-211, Bi-211, Po-211 (0.28%), Tl-207 (99.72%)
Entire chain	**Chain segments considered with the parent in the modelling**
U-238[c]	U+238, U-234, Th-230, Ra+226, Pb+210, Po-210
Th-232[c]	Th-232, Ra+228, Th+228
U-235[c]	U+235, Pa-231, Ac+227

NB 1. Numbers in brackets are equilibrium fractions. A single radionuclide is described by the element symbol (in upper case) and the mass number separated by a hyphen, e.g. U-238. Symbol '+' after a nuclide denotes a segment chain headed by that nuclide e.g. Ra+226. A superscript 'c' denotes the whole chain, such as U-238[c], which will include those chain segments as given in the table above.

2. The decay chain segment definitions are the same as those given in Table B of Annex I of the Directive, with the following exceptions:

a) U-235[c] and Ac+227 are not included in Table B of Annex I of the Directive. These radionuclides are found in fixed ratio to ^{238}U and are seldom of radiological significance. They have been included in the above table for completeness.

b) Ra+226 in the above table is not the same as Ra-226+ in Table B of Annex I of the Directive. Ra-226+ in Table B of Annex I of the Directive includes the full decay chain. Ra+226 in the table above only includes part of the decay chain. This is because processes within NORM industries (e.g. steel plants and coal-fired power stations) can lead to waste streams with concentrations of ^{210}Pb and ^{210}Po that are enhanced in relation to those of ^{226}Ra (i.e. not secular equilibrium). Under these circumstances it is necessary to consider ^{210}Pb and ^{210}Po separately from the higher members of the decay chain, defined as Ra+226 in the above table.

Table 36 Dose coefficients for intake by ingestion and inhalation

[European Commission, 1996]

Nuclide	Branching	Lung class	Half-life year	Committed effective dose per unit intake (Sv Bq^{-1}) Inhalation			Ingestion		
				Infant - 1 y	Child - 10 y	Adult	Infant - 1 y	Child - 10 y	Adult
U-238	1	M	4.47 E+09	9.40 E-06	4.00 E-06	2.90 E-06	1.20 E-07	6.80 E-08	4.50 E-08
Th-234	1	S	6.60 E-02	3.10 E-08	1.10 E-08	7.70 E-09	2.50 E-08	7.40 E-09	3.40 E-09
Pa-234m	0.998	*	2.23 E-06	0	0	0	0	0	0
Pa-234	0.002	*	7.65 E-04	2.00 E-09	6.80 E-10	4.00 E-10	3.20 E-09	1.00 E-09	5.10 E-10
U-234	1	M	2.45 E+05	1.10 E-05	4.80 E-06	3.50 E-06	1.30 E-07	7.40 E-08	4.90 E-08
Th-230	1	S	7.70 E+04	3.50 E-05	1.60 E-05	1.40 E-05	4.10 E-07	2.40 E-07	2.10 E-07
Ra-226	1	M	1.60 E+03	1.10 E-05	4.90 E-06	3.50 E-06	9.60 E-07	8.00 E-07	2.80 E-07
Rn-222	1	*	1.05 E-02	0	0	0	0	0	0
Po-218	1	M	5.80 E-06	0	0	0	0	0	0
Pb-214	0.9998	M	5.10 E-05	4.60 E-08	1.90 E-08	1.40 E-08	1.00 E-09	3.10 E-10	1.40 E-10
At-218	0.0002	*	6.34 E-08	0	0	0	0	0	0
Bi-214	1	*	3.79 E-05	6.10 E-08	2.20 E-08	1.40 E-08	7.40 E-10	2.10 E-10	1.10 E-10
Po-214	1	M	5.21 E-12	0	0	0	0	0	0
Pb-210	1	M	2.23 E+01	3.70 E-06	1.50 E-06	1.10 E-06	3.60 E-06	1.90 E-06	6.90 E-07
Bi-210	1	*	1.37 E-03	3.00 E-07	1.30 E-07	9.30 E-08	9.70 E-09	2.90 E-09	1.30 E-09
Po-210	1	M	3.79 E-01	1.10 E-05	4.60 E-06	3.30 E-06	8.80 E-06	2.60 E-06	1.20 E-06
Th-232	1	S	1.41 E+10	5.00 E-05	2.60 E-05	2.50 E-05	4.50 E-07	2.90 E-07	2.30 E-07
Ra-228	1	M	5.75 E+00	1.00 E-05	4.60 E-06	2.60 E-06	5.70 E-06	3.90 E-06	6.90 E-07
Ac-228	1	*	7.00 E-04	1.60 E-07	5.70 E-08	2.50 E-08	2.80 E-09	8.70 E-10	4.30 E-10
Th-228	1	S	1.91 E+00	1.30 E-04	5.50 E-05	4.00 E-05	3.70 E-07	1.50 E-07	7.20 E-08
Ra-224	1	M	1.00 E-02	8.20 E-06	3.90 E-06	3.00 E-06	6.60 E-07	2.60 E-07	6.50 E-08
Rn-220	1	*	1.76 E-06	0	0	0	0	0	0
Po-216	1	M	4.76 E-09	0	0	0	0	0	0
Pb-212	1	M	1.22 E-03	4.60 E-07	2.20 E-07	1.70 E-07	6.30 E-08	2.00 E-08	6.00 E-09
Bi-212	1	*	1.15 E-04	1.10 E-07	4.40 E-08	3.10 E-08	1.80 E-09	5.00 E-10	2.60 E-10
Po-212	0.641	M	9.67 E-15	0	0	0	0	0	0
Tl-208	0.359	*	5.84 E-06	0	0	0	0	0	0

Table 35 (cont'd)

Nuclide	Branching	Lung class	Half-life year	Committed effective dose per unit intake (Sv Bq^{-1}) Inhalation Infant - 1 y	Child - 10 y	Adult	Ingestion Infant - 1 y	Child - 10 y	Adult
U-235	1	M	7.04 E+08	1.00 E-05	4.30 E-06	3.10 E-06	1.30 E-07	7.10 E-08	4.70 E-08
Th-231	1	S	2.91 E-03	1.70 E-09	5.20 E-10	3.30 E-10	2.50 E-09	7.40 E-10	3.40 E-10
Pa-231	1	*	3.28 E+04	2.30 E-04	1.50 E-04	1.40 E-04	1.30 E-06	9.20 E-07	7.10 E-07
Ac-227	1	*	2.18 E+01	1.60 E-03	7.20 E-04	5.50 E-04	3.10 E-06	1.50 E-06	1.10 E-06
Th-227	0.9862	S	5.13 E-02	3.00 E-05	1.40 E-05	1.00 E-05	7.00 E-08	2.30 E-08	8.80 E-09
Fr-223	0.0138	*	4.15 E-05	7.30 E-09	1.90 E-09	8.90 E-10	1.70 E-08	5.00 E-09	2.40 E-09
Ra-223	1	M	3.13 E-02	2.10 E-05	9.90 E-06	7.40 E-06	1.10 E-06	4.50 E-07	1.00 E-07
Rn-219	1	*	1.26 E-07	0	0	0	0	0	0
Po-215	1	M	5.65 E-11	0	0	0	0	0	0
Pb-211	1	M	6.87 E-05	4.50 E-08	1.90 E-08	1.10 E-08	1.40 E-09	4.10 E-10	1.80 E-10
Bi-211	1	*	4.10 E-06	0	0	0	0	0	0
Tl-207	0.9972	*	9.07 E-06	0	0	0	0	0	0
Po-211	0.0028	M	1.64 E-08	0	0	0	0	0	0

Table 37 Composite dose coefficients for chain segment in secular equilibrium

	Committed effective dose per unit intake (Sv Bq^{-1})					
	Inhalation			Ingestion		
Chain segment	Infant- 1 years	Child- 10 years	Adult	Infant- 1 years	Child- 10 years	Adult
^{238}U+	9.43 E-06	4.01 E-06	2.91 E-06	1.45 E-07	7.54 E-08	4.84 E-08
^{235}U	1.00 E-05	4.30 E-06	3.10 E-06	1.33 E-07	7.17 E-08	4.73 E-08
^{234}U	1.10 E-05	4.80 E-06	3.50 E-06	1.30 E-07	7.40 E-08	4.90 E-08
^{232}Th	5.00 E-05	2.60 E-05	2.50 E-05	4.50 E-07	2.90 E-07	2.30 E-07
^{230}Th	3.50 E-05	1.60 E-05	1.40 E-05	4.10 E-07	2.40 E-07	2.10 E-07
^{228}Th+	1.39 E-04	5.92 E-05	4.32 E-05	1.09 E-06	4.31 E-07	1.43 E-07
^{231}Pa+	2.30 E-04	1.50 E-04	1.40 E-04	1.30 E-06	9.20 E-07	7.10 E-07
^{228}Ra+	1.02 E-05	4.66 E-06	2.63 E-06	5.70 E-06	3.90 E-06	6.90 E-07
^{226}Ra+	1.11 E-05	4.94 E-06	3.53 E-06	9.62 E-07	8.01 E-07	2.80 E-07
^{227}Ac+	1.65 E-03	7.44 E-04	5.67 E-04	4.27 E-06	1.97 E-06	1.21 E-06
^{210}Pb+	4.00 E-06	1.63 E-06	1.19 E-06	3.61 E-06	1.90 E-06	6.91 E-07
^{210}Po	1.10 E-05	4.60 E-06	3.30 E-06	8.80 E-06	2.60 E-06	1.20 E-06

Table 38 Assumed river characteristics

River characteristic	River 1 – large	River 2 – medium	River 3 - small
River section			
Length m	1 000	1 000	1 000
Width m	200	50	5
Water depth m	3	3	1
Water volume m^3	600 000	150 000	5 000
Bed sediment depth m	1	1	0.3
Dry sediment density kg m^{-3}	1 500	1 500	1 500
River suspended sediment load kg m^{-3}	0.04	0.04	0.04
River water flows			
Velocity m s^{-1}	0.83	0.67	0.5
Volumetric flow m^3 s^{-1}	500	100	2.5
Bed sediment flow			
Velocity m s^{-1}	0.0001	0.0001	0.000 0317
Volumetric flow m^3 s^{-1}	0.02	0.005	0.000 0476

Table 39 Dose Coefficients for intake by ingestion and inhalation by adults

[Based on Tables A, B, D and E of Annex III of European Commission, 1996]

Chain segment	Default absorption type	Inhalation Sv Bq^{-1}	Ingestion Sv Bq^{-1}
$^{238}U+$	M	$2.91\ 10^{-6}$	$4.84\ 10^{-8}$
^{234}U	M	$3.50\ 10^{-6}$	$4.90\ 10^{-8}$
^{230}Th	S	$1.40\ 10^{-5}$	$2.10\ 10^{-7}$
$^{226}Ra+$	M	$3.53\ 10^{-6}$	$2.80\ 10^{-7}$
$^{210}Pb+$	M	$1.19\ 10^{-6}$	$6.91\ 10^{-7}$
^{210}Po	M	$3.30\ 10^{-6}$	$1.20\ 10^{-6}$
^{232}Th	S	$2.50\ 10^{-5}$	$2.30\ 10^{-7}$
$^{228}Ra+$	M	$2.63\ 10^{-6}$	$6.90\ 10^{-7}$
$^{228}Th+$	S	$4.32\ 10^{-5}$	$1.43\ 10^{-7}$
$^{235}U+$	M	$3.10\ 10^{-6}$	$4.73\ 10^{-8}$
$^{231}Pa+$	M	$1.40\ 10^{-4}$	$7.10\ 10^{-7}$
$^{227}Ac+$	F	$5.50\ 10^{-4}$	$1.21\ 10^{-6}$

NB M = Medium, S = Small, F = Fast
The dose coefficients for children are given in Table 37.

Table 40 Average and critical group food ingestion rates and inhalation rate for adults

[Based on FOASTAT, 2000, 1996 Food Balance Sheets]

Food intake rates (kg y^{-1})	Average	Critical
Green and domestic vegetables	19	57
Potatoes and root vegetables	44	96
Domestic fruit	50	94
Cow meat	18	
Cow offal	2	
Milk*	105	265
Sheep meat	2	
Sheep offal	2	
Inhalation rates (m^3 y^{-1})		8100

NB See Part II: Appendix H for more detail.

Table 41 Sediment adsorption coefficients and fresh water fish concentration factors used for the river discharges

[Simmonds et al, 1995]

Element	K_d m^3 t^{-1}	Concentration factor m^3 t^{-1}
Uranium (U)	5.0E+01	1.0E+01
Thorium (Th)	5.0E+06	3.0E+01
Radium (Ra)	5.0E+02	5.0E+01
Lead (Pb)	1.0E+04	3.0E+02
Polonium (Po)	1.0E+04	5.0E+01
Protactinium (Pa)	5.0E+03	1.0E+01
Actinium (Ac)	1.0E+04	3.0E+01

Table 42 Habit data for the marine exposure pathways (adults)

[Based on data from Jones et al, 2002]

Exposure pathway	Average	Critical group
Beach occupancy, h y^{-1}	30	2 000
Fish consumption, kg y^{-1}	14	133
Crustacea consumption, kg y^{-1}	1.5	33
Molluscs consumption	2.6	11

Table 43 Doses per unit discharge rate of 1 GBq y^{-1} of atmospheric release at different effective stack heights

Stack height	10 m stack		50 m		100 m		200 m	
Radionuclide or chain segment	Sv y^{-1}	Critical pathway	Sv y^{-1}	Critical pathway	Sv y^{-1}	Critical pathway	Sv y^{-1}	Critical pathway
^{238}U+	2.2E-06	I (97%)	1.3E-07	I (95%)	2.5E-08	I (83%)	1.3E-08	I (92%)
^{235}U+	2.4E-06	I (95%)	1.4E-07	I (89%)	3.2E-08	I (71%)	1.5E-08	I (83%)
^{234}U	2.6E-06	I (98%)	1.5E-07	I (96%)	2.9E-08	I (88%)	1.5E-08	I (96%)
^{232}Th	2.1E-05	I (88%)	1.4E-06	I (73%)	4.1E-07	E (54%)	1.6E-07	I (65%)
^{230}Th	1.1E-05	I (99%)	5.9E-07	I (97%)	1.1E-07	I (91%)	6.0E-08	I (95%)
^{228}Th+	3.2E-05	I (100%)	1.8E-06	I (99%)	3.2E-07	I (99%)	1.8E-07	I (98%)
^{231}Pa+	1.1E-04	I (97%)	6.3E-06	I (91%)	1.3E-06	I (76%)	6.6E-07	I (86%)
^{228}Ra+	2.6E-06	I (76%)	2.0E-07	I (55%)	7.3E-08	C (48%)	2.4E-08	I (45%)
^{226}Ra+	4.6E-06	I (58%)	4.1E-07	I (35%)	1.9E-07	E (45%)	5.5E-08	E (39%)
^{227}Ac+	4.2E-04	I (100%)	2.3E-05	I (100%)	4.1E-06	I (99%)	2.3E-06	I (99%)
^{222}Rn	2.0E-09	I (100%)	1.1E-10	I (100%)	1.9E-11	I (100%)	1.1E-11	I (100%)
^{220}Rn	1.5E-07	I (100%)	8.2E-09	I (100%)	1.4E-09	I (100%)	8.2E-10	I (100%)
^{210}Pb+	1.9E-06	C (53%)	1.9E-07	C (74%)	9.6E-08	C (91%)	2.7E-08	C (81%)
^{210}Po	4.3E-06	I (58%)	3.8E-07	C (65%)	1.8E-07	C (86%)	5.2E-08	C (74%)

NB I = Plume inhalation, C = Consumption of food, E = External radiation.

Table 44 Doses in Sv y^{-1} per unit discharge rate of 1 GBq y^{-1} for discharges into a small river.

Nuclide or segment of decay chain	Small river			
	Average consumption and occupancy	Critical Pathway	High consumption and occupancy	Critical Pathway
^{238}U+	**3.6E-07**	W (94%)	5.2E-07	W (66%)
^{235}U+	3.9E-07	W (92%)	5.5E-07	W (65%)
^{234}U	**3.9E-07**	W (95%)	5.6E-07	W (66%)
^{232}Th	**6.3E-08**	E (84%)	7.4E-08	E (71%)
^{230}Th	**7.0E-08**	E (87%)	8.1E-08	E (75%)
^{228}Th+	**6.1E-05**	E (100%)	6.1E-05	E (100%)
^{231}Pa+	5.1E-06	W (89%)	7.1E-06	W (64%)
^{228}Ra+	**7.2E-06**	W (72%)	1.9E-05	F (69%)
^{226}Ra+	**4.0E-06**	W (52%)	8.7E-06	F (60%)
^{227}Ac+	1.1E-05	W (53%)	2.0E-05	F (46%)
^{210}Pb+	**9.5E-06**	F (60%)	6.0E-05	F (93%)
^{210}Po	**8.1E-06**	W (80%)	2.3E-05	F (72%)

NB Results in bold used for derivation of screening levels of discharge. W = Water ingestion; F = Consumption of fish; E = External radiation

Table 45 Doses in Sv y^{-1} per unit discharge rate of 1 GBq y^{-1} for discharges into a medium river.

Nuclide or segment of decay chain	Medium river			
	Average consumption and occupancy	Critical Pathway	High consumption and occupancy	Critical Pathway
^{238}U+	9.0E-09	W (94%)	**1.3E-08**	W (66%)
^{235}U+	9.7E-09	W (92%)	**1.4E-08**	W 65%)
^{234}U	9.8E-09	W (95%)	**1.4E-08**	W (67%)
^{232}Th	1.6E-09	E (84%)	**1.9E-09**	E (71%)
^{230}Th	1.8E-09	E (87%)	**2.0E-09**	E (75%)
^{228}Th+	1.5E-06	E (100%)	**1.5E-06**	E (100%)
^{231}Pa+	1.3E-07	W (89%)	**1.8E-07**	W (64%)
^{228}Ra+	1.8E-07	W (72%)	**4.7E-07**	F (69%)
^{226}Ra+	1.0E-07	W (52%)	**2.2E-07**	F (60%)
^{227}Ac+	2.9E-07	W (53%)	**4.9E-07**	F (46%)
^{210}Pb+	2.4E-07	F (60%)	**1.5E-06**	F (94%)
^{210}Po	2.0E-07	W (80%)	**5.7E-07**	F (72%)

NB Results in bold used for derivation of screening levels of discharge. W = Water ingestion; F = Consumption of fish; E = External radiation.

Table 46 Doses in Sv y^{-1} per unit discharge rate of 1 GBq y^{-1} for discharges into a large river.

Nuclide or segment of decay chain	Large river			
	Average consumption and occupancy	Critical pathway	High Consumption / occupancy	Critical Pathway
^{238}U+	1.8E-09	W (95%)	**2.6E-09**	W (66%)
^{235}U+	1.9E-09	W (92%)	**2.8E-09**	W (65%)
^{234}U	1.9E-09	W (95%)	**2.8E-09**	W (67%)
^{232}Th	3.1E-10	E (84%)	**3.7E-10**	E (71%)
^{230}Th	3.5E-10	E (87%)	**4.1E-10**	E (75%)
^{228}Th+	3.1E-07	E (100%)	**3.1E-07**	E (100%)
^{231}Pa+	2.5E-08	W (89%)	**3.5E-08**	W (64%)
^{228}Ra+	3.6E-08	W (72%)	**9.4E-08**	F (69%)
^{226}Ra+	2.0E-08	W (52%)	**4.3E-08**	F (60%)
^{227}Ac+	5.7E-08	W (53%)	**9.7E-08**	F (46%)
^{210}Pb+	4.7E-08	F (60%)	**3.0E-07**	F (94%)
^{210}Po	4.0E-08	W (80%)	**1.1E-07**	F (72%)

NB Results in bold used for derivation of screening levels of discharge. W = Water ingestion; F = Consumption of fish; E = External radiation

Table 47 Doses in Sv y^{-1} per unit discharge rate of 1 GBq y^{-1} for discharges into a small marine box.

Radionuclide or chain segment	Small box (Marina Box 50)			
	Average consumption and occupancy	Critical pathway	High consumption and occupancy	Critical pathway
^{238}U+	3.6E-12	M (55%)	**3.3E-11**	C (32%)
^{234}U	2.6E-12	M (73%)	**1.9E-11**	C (42%)
^{232}Th	3.6E-09	F (63%)	**5.6E-08**	E (52%)
^{230}Th	9.8E-11	F (64%)	**1.2E-09**	F (49%)
^{228}Th+	1.4E-10	F (52%)	**3.2E-09**	E (72%)
^{228}Ra+	3.0E-09	F (71%)	**2.6E-08**	F (80%)
^{226}Ra+	1.3E-09	F (69%)	**1.3E-08**	F (67%)
^{210}Pb+	9.0E-10	F (37%)	**9.9E-09**	C (54%)
^{210}Po	2.2E-10	C (59%)	**3.4E-09**	C (82%)

NB Results in bold used for example calculations with different dose constraints on discharges. M = molluscs consumption; F = Fish consumption; C = Crustacea consumption; E = External radiation.

Table 48 Doses in Sv y^{-1} per unit discharge rate of 1 GBq y^{-1} for discharges into a large marine box.

Radionuclide or chain segment	Large box (release in marina box 59 and exposure in box 27)			
	Average consumption and occupancy	Critical pathway	High consumption and occupancy	Critical pathway
^{238}U+	3.9E-13	F (58%)	**3.7E-12**	F (59%)
^{234}U	6.6E-14	M (73%)	**4.9E-13**	C (42%)
^{232}Th	1.7E-11	F (47%)	**4.6E-10**	F (79%)
^{230}Th	1.4E-12	F (63%)	**1.8E-11**	F (47%)
^{228}Th+	6.1E-13	F (51%)	**1.5E-11**	E (72%)
^{228}Ra+	2.7E-11	F (70%)	**2.6E-10**	F (70%)
^{226}Ra+	2.9E-11	F (69%)	**3.0E-10**	F (66%)
^{210}Pb+	1.3E-11	C (58%)	**2.0E-10**	C (81%)
^{210}Po	4.1E-12	C (59%)	**6.3E-11**	C (82%)

NB Results in bold used for example calculations with different dose constraints on discharges. M = Molluscs consumption; F = Fish consumption; C = Crustacea consumption; E = External radiation.

Table 49 Screening levels in GBq y^{-1} for discharges into the atmosphere based on a screening level dose criterion of 300 µSv y^{-1} to critical groups.

Nuclide or chain segment	Stack 10 m	Critical pathway	Stack 50 m	Critical pathway	Stack 100 m	Critical pathway	Stack 200 m	Critical pathway
^{238}U+	1.4E+02	I	2.3E+03	I	1.2E+04	I	2.3E+04	I
^{235}U+	1.2E+02	I	2.2E+03	I	9.3E+03	I	2.0E+04	I
^{234}U	1.1E+02	I	2.0E+03	I	1.0E+04	I	2.0E+04	I
^{232}Th	1.4E+01	I	2.1E+02	I	7.3E+02	E	1.9E+03	I
^{230}Th	2.8E+01	I	5.1E+02	I	2.7E+03	I	5.0E+03	I
^{228}Th+	9.3E+00	I	1.7E+02	I	9.4E+02	I	1.7E+03	I
^{231}Pa+	2.8E+00	I	4.8E+01	I	2.2E+02	I	4.6E+02	I
^{228}Ra+	1.2E+02	I	1.5E+03	C	4.1E+03	C	1.2E+04	C
^{226}Ra+	6.6E+01	I	7.3E+02	C	1.6E+03	E	5.4E+03	E
^{227}Ac+	7.1E-01	I	1.3E+01	I	7.3E+01	I	1.3E+02	I
^{222}Rn	1.5E+05	I	2.7E+06	I	1.6E+07	I	2.8E+07	I
^{220}Rn	2.0E+03	I	3.7E+04	I	2.1E+05	I	3.7E+05	I
^{210}Pb+	1.6E+02	C	1.6E+03	C	3.1E+03	C	1.1E+04	C
^{210}Po	7.0E+01	I	8.0E+02	C	1.7E+03	C	5.8E+03	C

NB I = Plume inhalation, C = Consumption of food and E = External radiation.

Table 50 Screening levels in GBq y^{-1} for discharges into a small river based on a screening level dose criterion of 300 µSv y^{-1}.

Radionuclide or chain segment	Small river			
	Average consumption/ occupancy	Critical pathway	High consumption/ occupancy	Critical pathway
^{238}U	**8.3E+02**	W	5.8E+02	W
^{235}U	7.7E+02	W	5.4E+02	W
^{234}U	**7.7E+02**	W	5.4E+02	W
^{232}Th	**4.8E+03**	E	4.0E+03	E
^{230}Th	**4.3E+03**	E	3.7E+03	E
^{228}Th	**4.9E+00**	E	4.9E+00	E
^{231}Pa	5.9E+01	W	4.2E+01	W
^{228}Ra	**4.2E+01**	W	1.6E+01	F
^{226}Ra	**7.5E+01**	W	3.4E+01	F
^{227}Ac	2.6E+01	W	1.5E+01	F
^{210}Pb	**3.2E+01**	F	5.0E+00	F
^{210}Po	**3.7E+01**	W	1.3E+01	F

NB Results in bold used for comparison with doses from typical discharges. W = water ingestion, F = Fish ingestion and E = External radiation.

Table 51 Screening levels in GBq y^{-1} for discharges into a medium river based on a screening level dose criterion of 300 µSv y^{-1}

Radionuclide or chain segment	Medium river			
	Average consumption/occupancy	Critical pathway	High consumption/occupancy	Critical pathway
^{238}U	3.3E+04	W	**2.3E+04**	W
^{235}U	3.1E+04	W	2.2E+04	W
^{234}U	3.1E+04	W	**2.1E+04**	W
^{232}Th	1.9E+05	E	**1.6E+05**	E
^{230}Th	1.7E+05	E	**1.5E+05**	E
^{228}Th	2.0E+02	E	**2.0E+02**	E
^{231}Pa	2.4E+03	W	1.7E+03	W
^{228}Ra	1.7E+03	W	**6.4E+02**	F
^{226}Ra	3.0E+03	W	**1.4E+03**	F
^{227}Ac	1.1E+03	W	6.2E+02	F
^{210}Pb	1.3E+03	F	**2.0E+02**	F
^{210}Po	1.5E+03	W	**5.3E+02**	F

NB Results in bold used for comparison with doses from typical discharges. W = water ingestion, F = Fish ingestion and E = External radiation.

Table 52 Screening levels in GBq y^{-1} for discharges into a large river based on a screening level dose criterion of 300 µSv y^{-1}

Radionuclide	Large river			
	Average Consumption and occupancy	**Critical pathway**	**High Consumption and occupancy**	**Critical pathway**
^{238}U	1.6E+05	W	**1.2E+05**	W
^{235}U	1.55E+05	W	1.1E+05	W
^{234}U	1.54E+05	W	**1.1E+05**	W
^{232}Th	9.61E+05	E	**8.1E+05**	E
^{230}Th	8.53E+05	E	**7.4E+05**	E
^{228}Th	9.80E+02	E	**9.8E+02**	E
^{231}Pa	1.19E+04	W	8.5E+03	W
^{228}Ra	8.39E+03	W	**3.2E+03**	F
^{226}Ra	1.51E+04	W	**6.9E+03**	F
^{227}Ac	5.30E+03	W	3.1E+03	F
^{210}Pb	6.35E+03	F	**1.0E+03**	F
^{210}Po	7.42E+03	W	**2.6E+03**	F

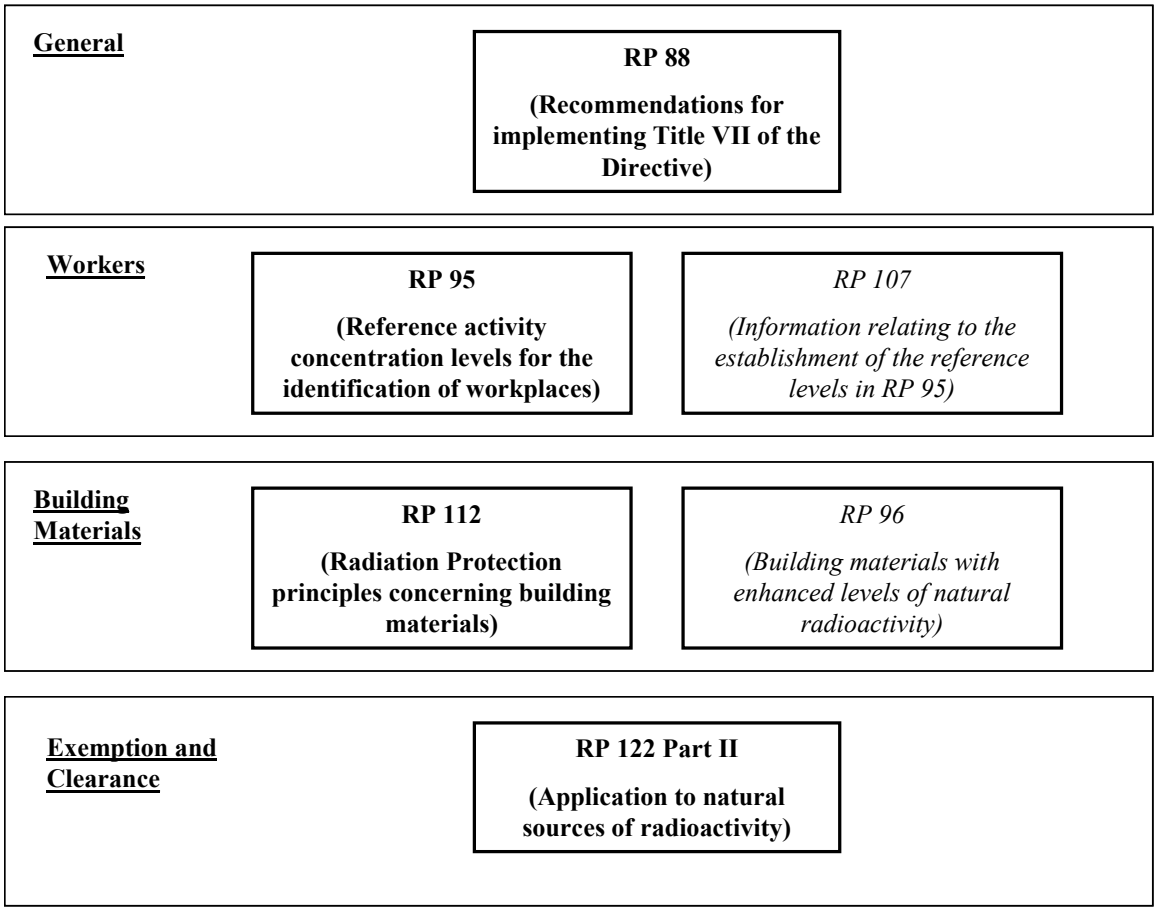
NB Results in bold used for comparison with doses from typical discharges. W = water ingestion, F = Fish ingestion and E = External radiation.

Table 53 Example calculations showing annual discharges into the sea in GBq y^{-1} that would result in a calculated dose of 300 µSv y^{-1} to critical groups.

Nuclide or chain segment	Small compartment (50)				Large compartment (59)			
	Average Consumption and occupancy	Critical pathway	High Consumption and occupancy	Critical pathway	Average Consumption and occupancy	Critical pathway	High Consumption and occupancy	Critical pathway
$^{238}U+$	8.3E+07	M	9.2E+06	C	7.8E+08	F	8.1E+07	F
^{234}U	1.1E+08	M	1.6E+07	C	4.5E+09	M	6.2E+08	C
^{232}Th	8.3E+04	F	5.4E+03	E	1.8E+07	F	6.6E+05	F
^{230}Th	3.0E+06	F	2.4E+05	F	2.1E+08	F	1.6E+07	F
$^{228}Th+$	2.2E+06	F	9.3E+04	E	4.9E+08	F	2.0E+07	E
$^{228}Ra+$	1.0E+05	F	1.2E+04	F	1.1E+07	F	1.1E+06	F
$^{226}Ra+$	2.2E+05	F	2.2E+04	F	1.0E+07	F	1.0E+06	F
$^{210}Pb+$	3.3E+05	F	3.0E+04	C	2.3E+07	C	1.5E+06	C
^{210}Po	1.4E+06	C	8.9E+04	C	7.4E+07	C	4.8E+06	C

NB M = Molluscs consumption; F = Fish consumption; C = Crustacea consumption; E = external radiation.

Figure 1 Summary of European Commission guidance[1] and *technical reports*[2] relating to NORM



Notes:

RP 88 Recommendations for the Implementation of Title VII of the European Basic Safety Standards Directive (BSS) Concerning Significant Increase in Exposure due to Natural Radiation Sources – Luxembourg, 1997

RP 95 Reference levels for workplaces processing materials with enhanced levels of naturally occurring radionuclides – A guide to assist implementation of Title VII of the European Basic Safety Standards Directive (BSS) concerning natural radiation sources – Luxembourg, 1999

RP 96 *Enhanced radioactivity of building materials – Luxembourg, 1999*

RP 107 *Establishment of reference levels for regulatory control of workplaces where materials are processed which contain enhanced levels of naturally-occurring radionuclides – Luxembourg, 1999*

RP 112 Radiological protection principles concerning the natural radioactivity of building materials – Luxembourg, 1999

RP 122 Part II Practical use of the concepts of clearance and exemption - Application of the concepts of exemption and clearance to natural radiation sources - Luxembourg, 2001.

[1] Highlighted in bold.
[2] These were the basis for the guidance established by the Article 31 Experts and are shown in italics.

Figure 2 Identification of 'Work Activities' in RP 95 and this study

RP 95 provides screening levels for the identification of significant NORM industries according to activity concentration of the input material in the process and the related potential to lead to **worker exposure** above predetermined 'marker points'.

This study provides screening levels for the identification of significant NORM industries according to activity concentration of the discharges from the process and the related potential to lead to **public exposure** above predetermined dose criteria for screening.

Workers

RP 95

Screening levels (and more detailed Reference levels) (Bq g^{-1}) are provided for input materials in the process.

The marker points are (under normal assumption scenarios):

- 1 mSv y^{-1} effective dose (the line between no regulations being necessary and a need for lower level of regulation)
- 6 mSv y^{-1} effective dose (the line between a need for a lower level of regulation and a higher level of regulation).
- 20 mSv y^{-1} effective dose (the line between a higher level of regulation and the process not being permitted)

The public (discharges)

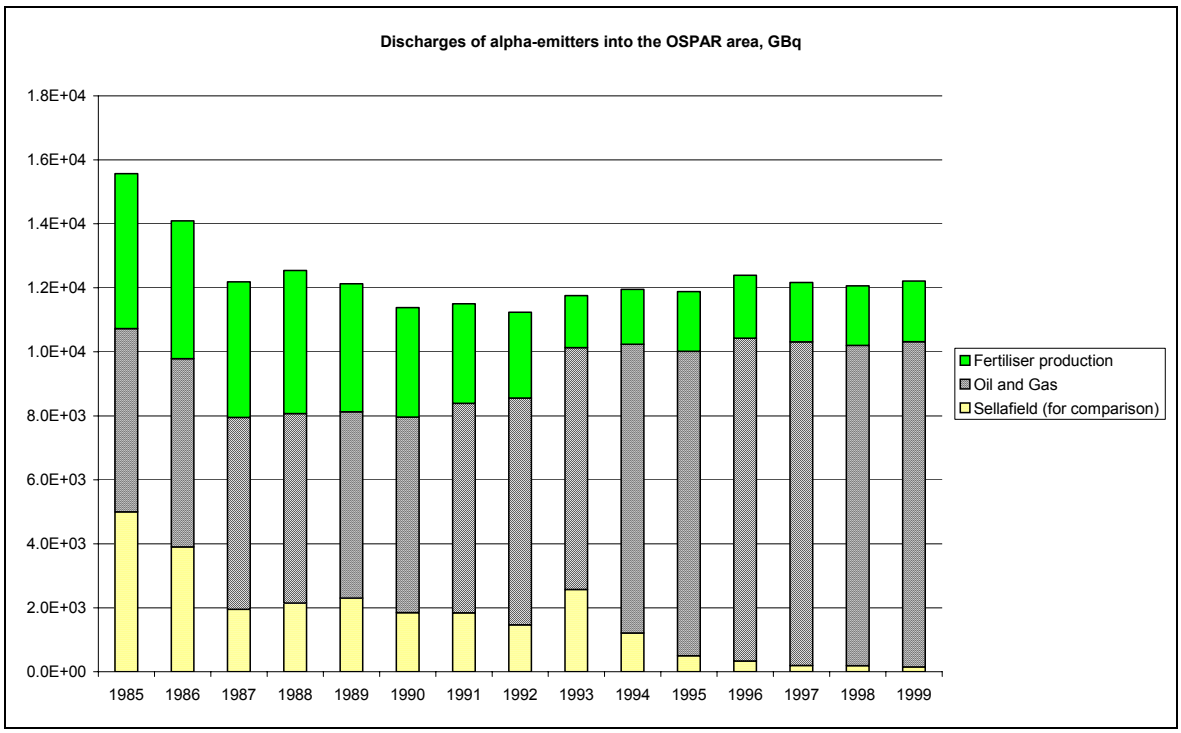
This study

Screening levels (GBq y^{-1}) for discharges to the atmosphere and to small, medium and large rivers. Screening levels have been calculated on the basis of three possible dose criteria i.e. 10 μSv y^{-1}, 100 μSv y^{-1}, 300 μSv y^{-1}. Sample calculations are also included for marine discharges.

Screening level defines the line between when no regulation of the discharge is necessary (with respect to public exposure) and further detailed assessment is necessary to determine if regulation is required.

Figure 3 Liquid discharges from selected industries into the OSPAR Region

[Gerchikov et al, 2002]



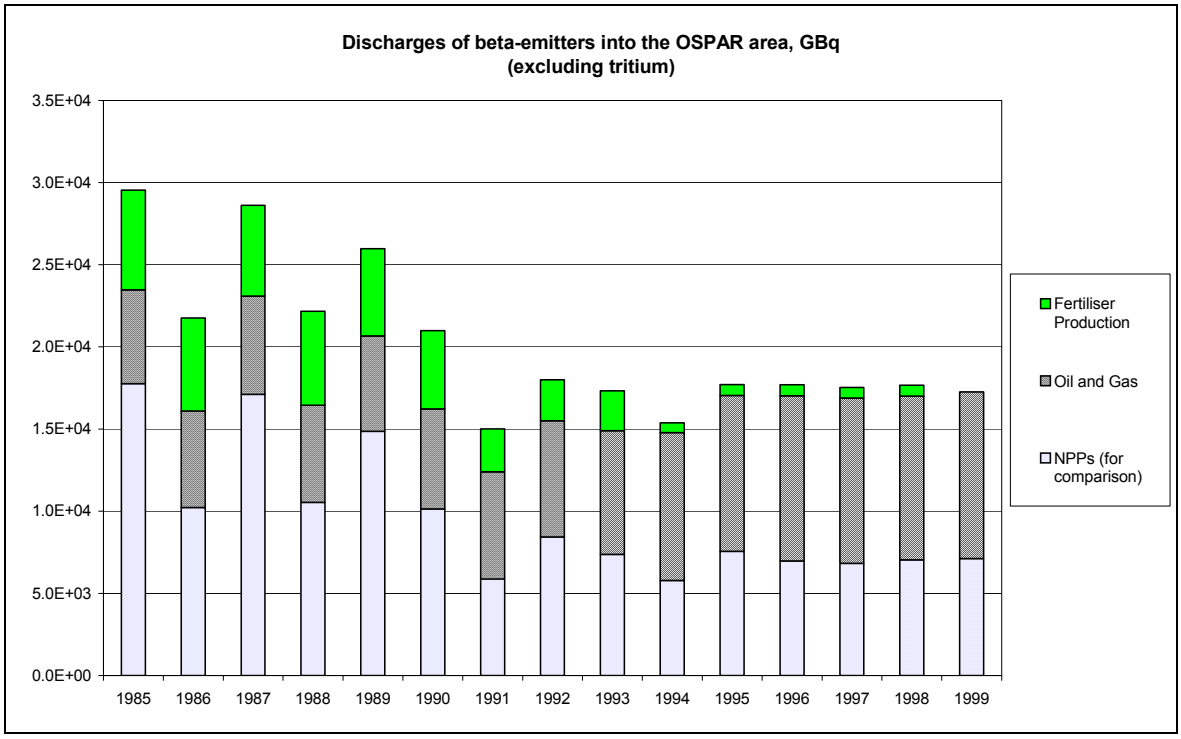
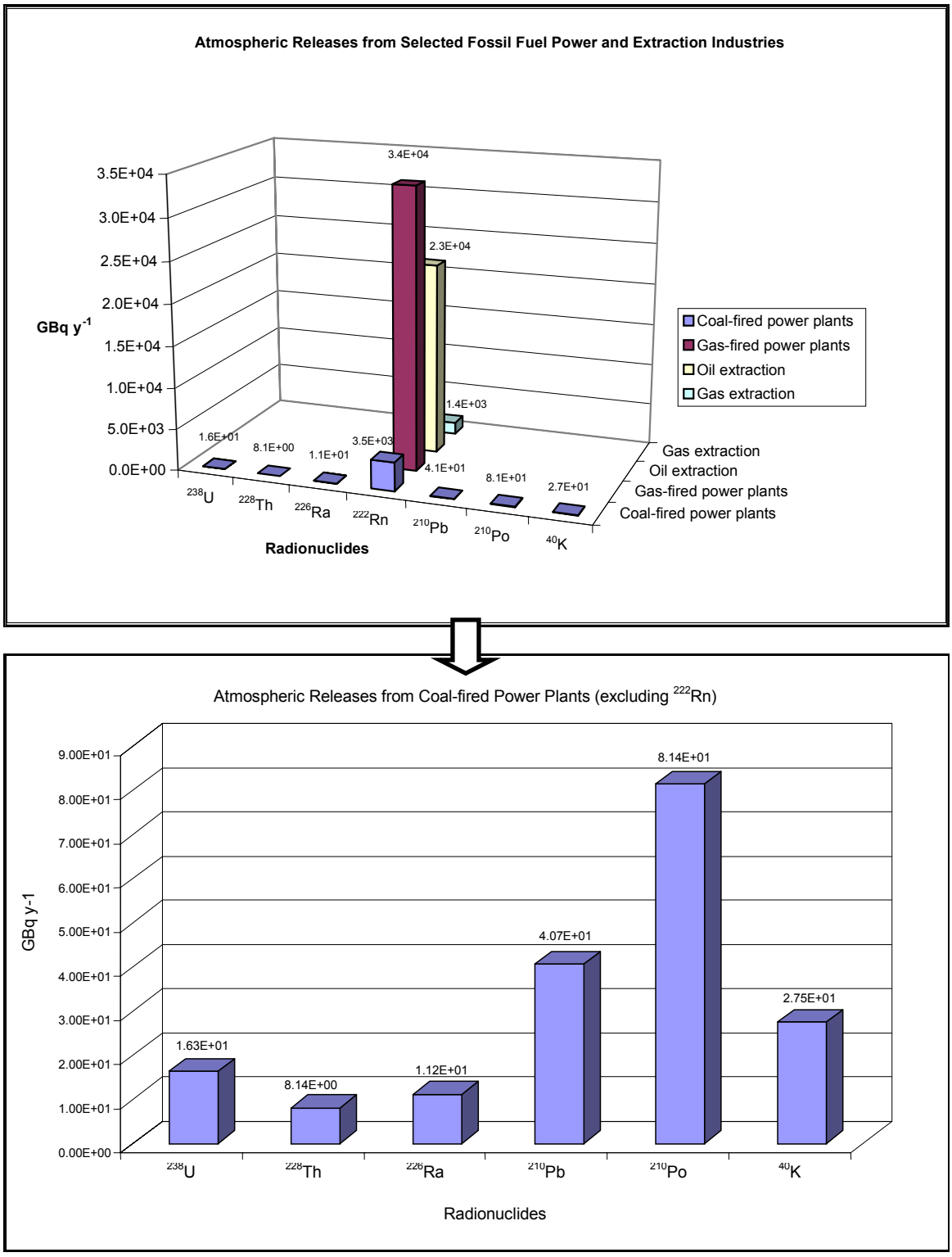


Figure 4 Atmospheric discharges from selected industries in the European Union

[Based on data from UNSCEAR 2000, EURPROG 2000 pp. 180 –184 and United Nations Statistics Division, 1998]



NB These are total discharge figures and not indicative of individual doses.

Figure 5 Process diagram (including emissions) for titanium dioxide production using the sulphate process

[German Federal Environment Agency, 2001]

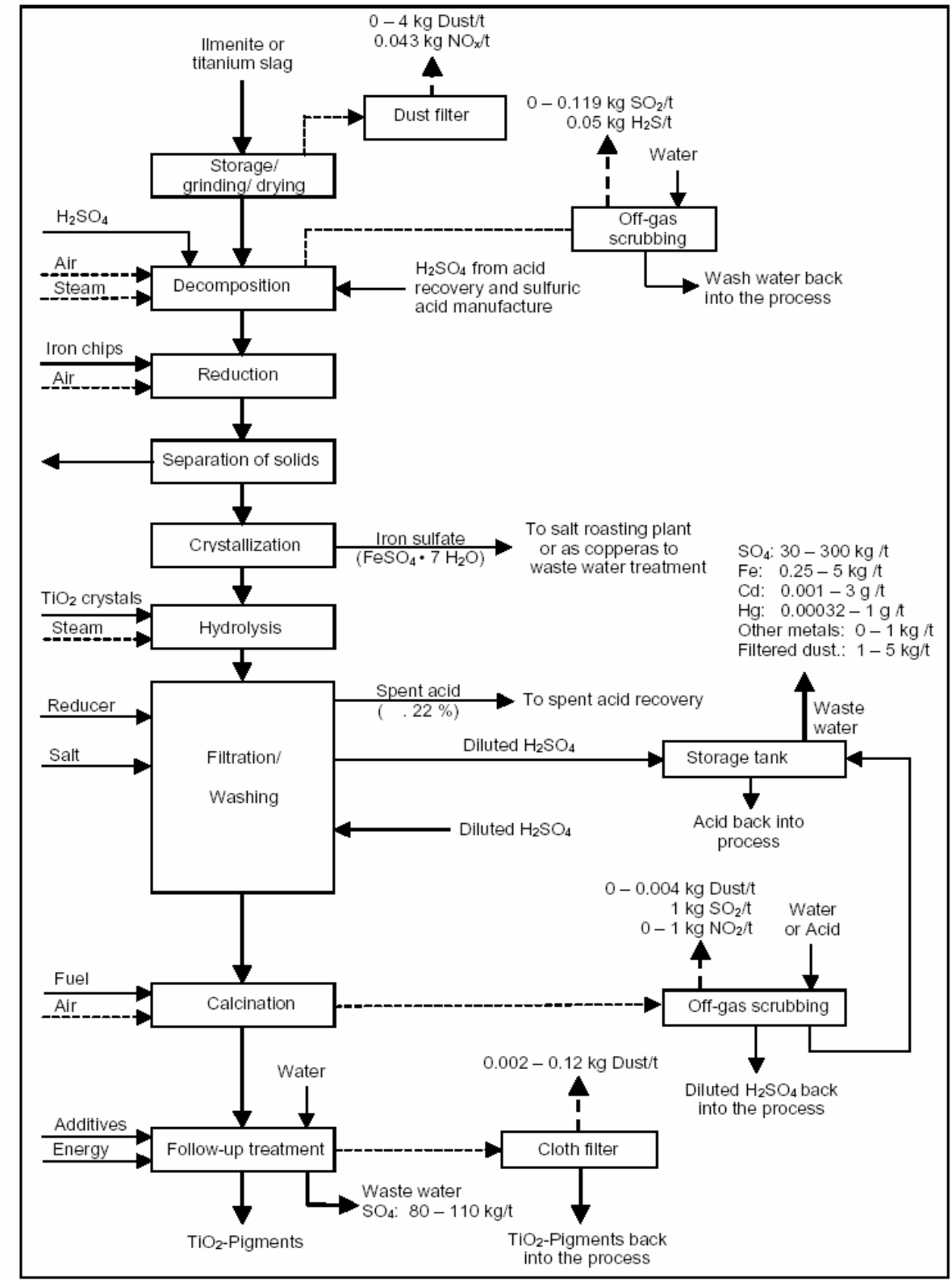


Figure 6 Process diagram (including emissions) for titanium dioxide production using the chloride process

[German Federal Environment Agency, 2001]

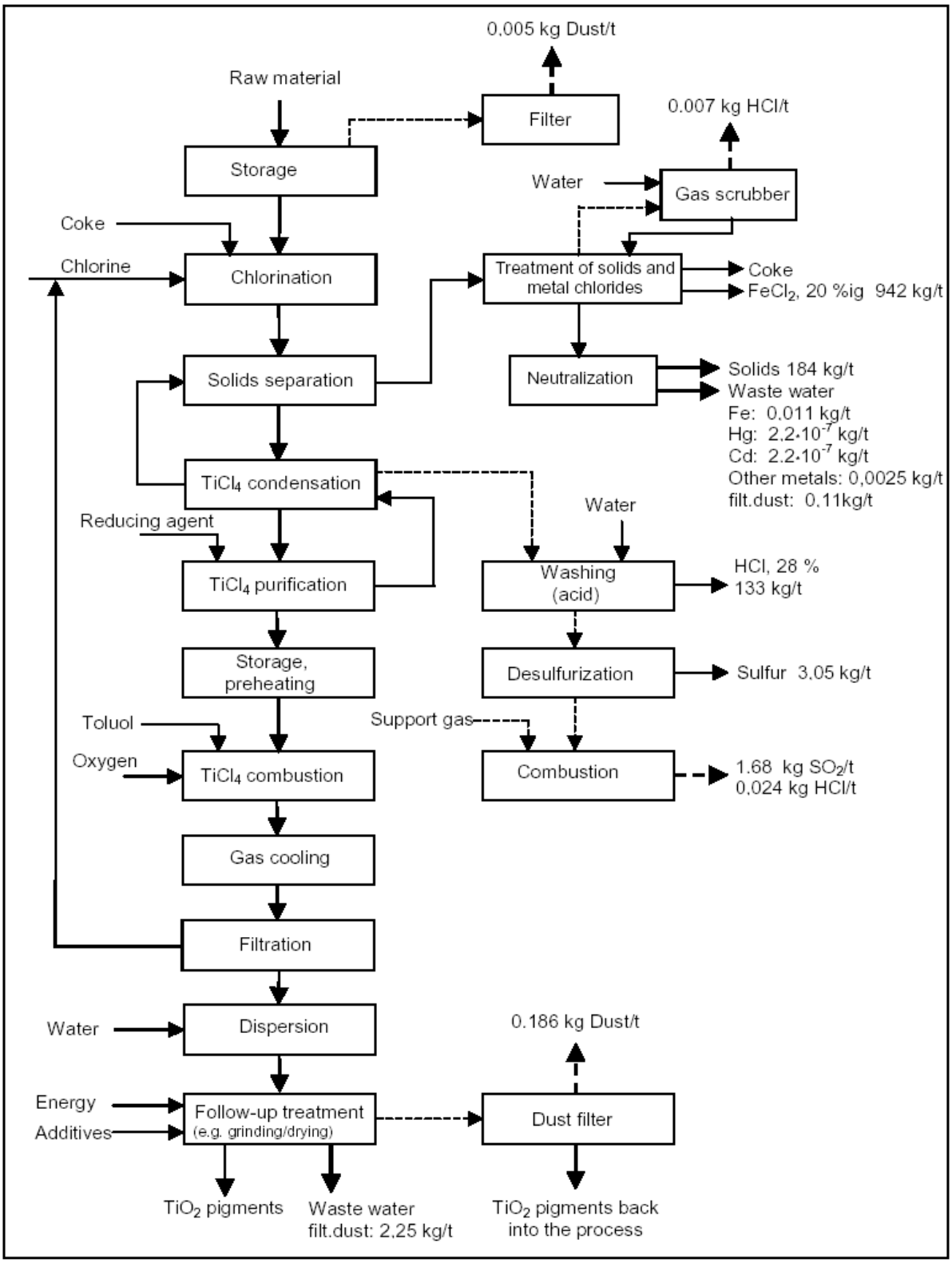


Figure 7 Summary of the enactment of Title VII in Member States (Qu 1)

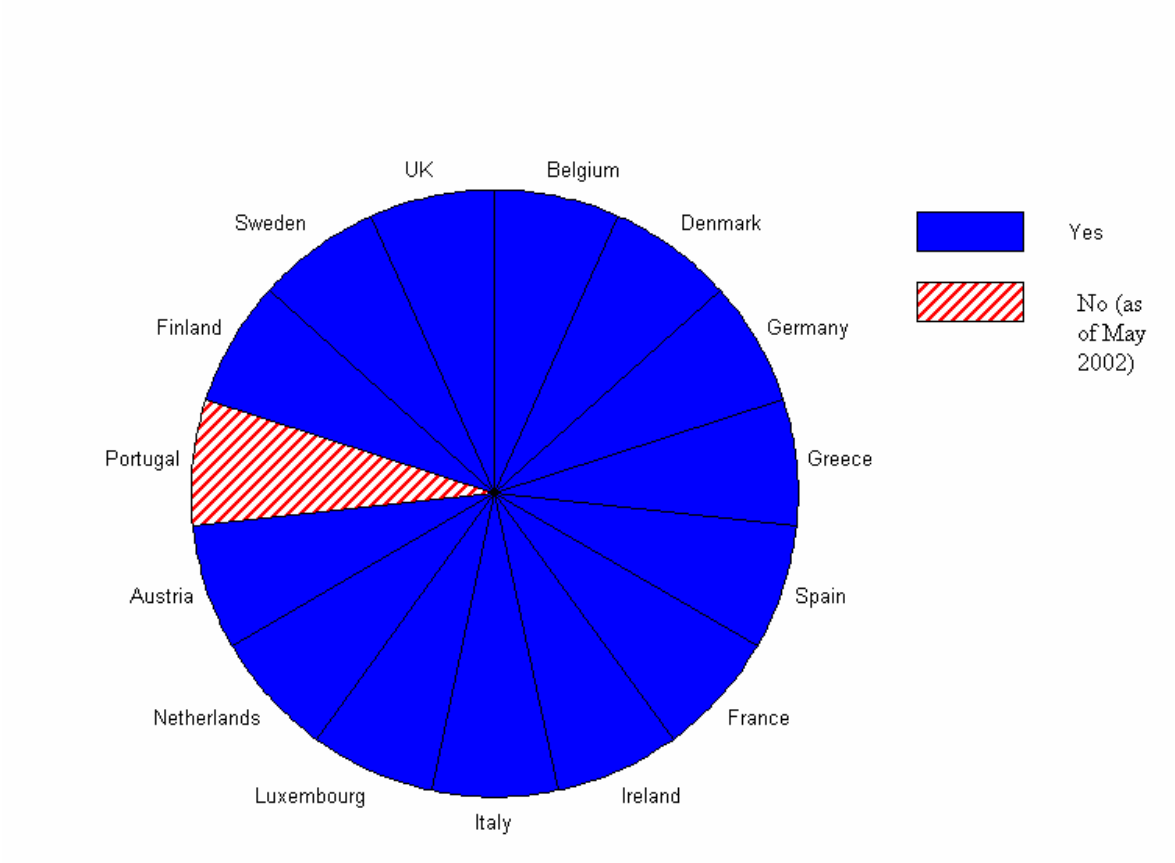


Figure 8 Progress in the identification of work activities in Member States (Qu 3)

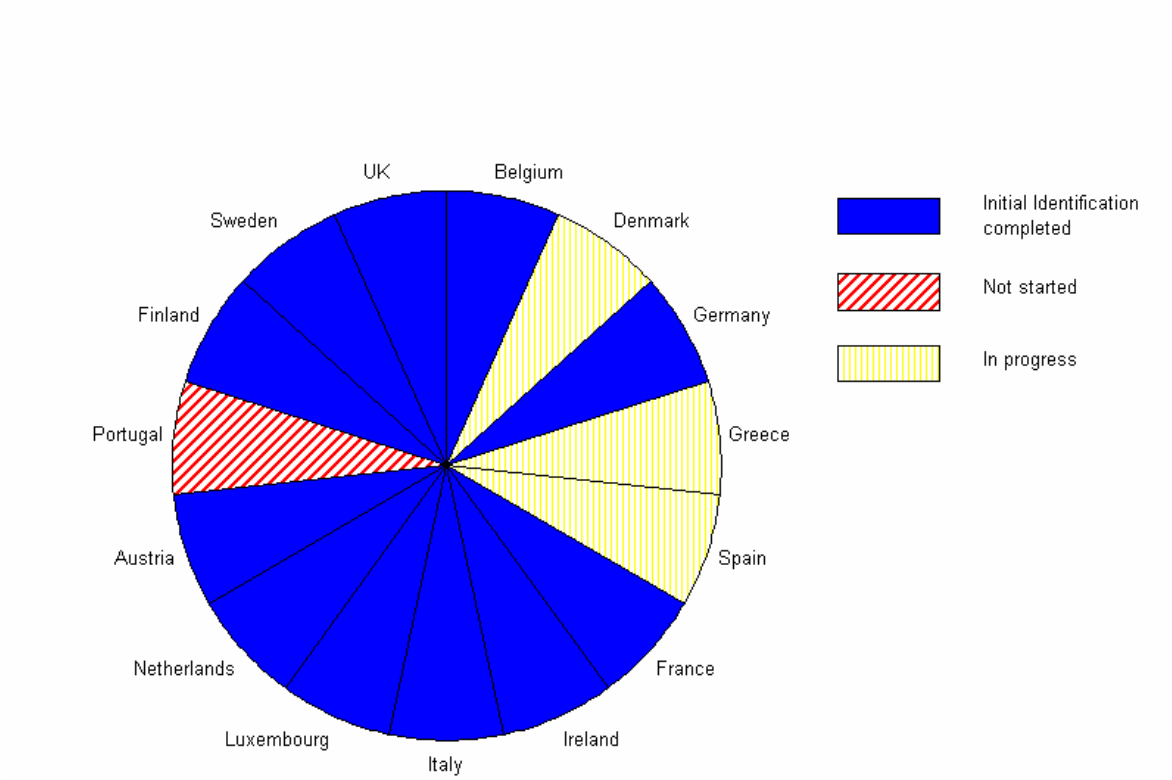


Figure 9 Application of the concept of exemption to NORM within Member States

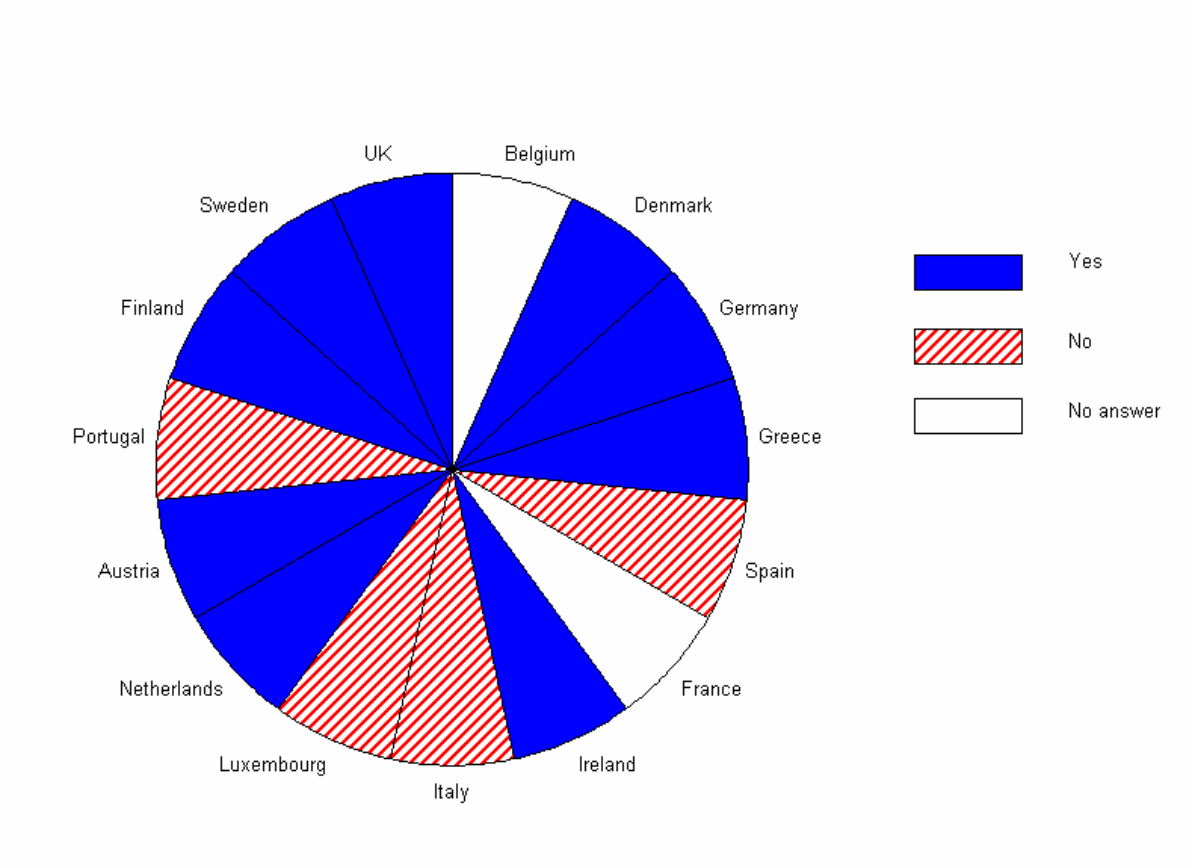


Figure 10 Provision within legislation for new work activities when and if identified, i.e. be within the scope of existing legislation (Qu 4)

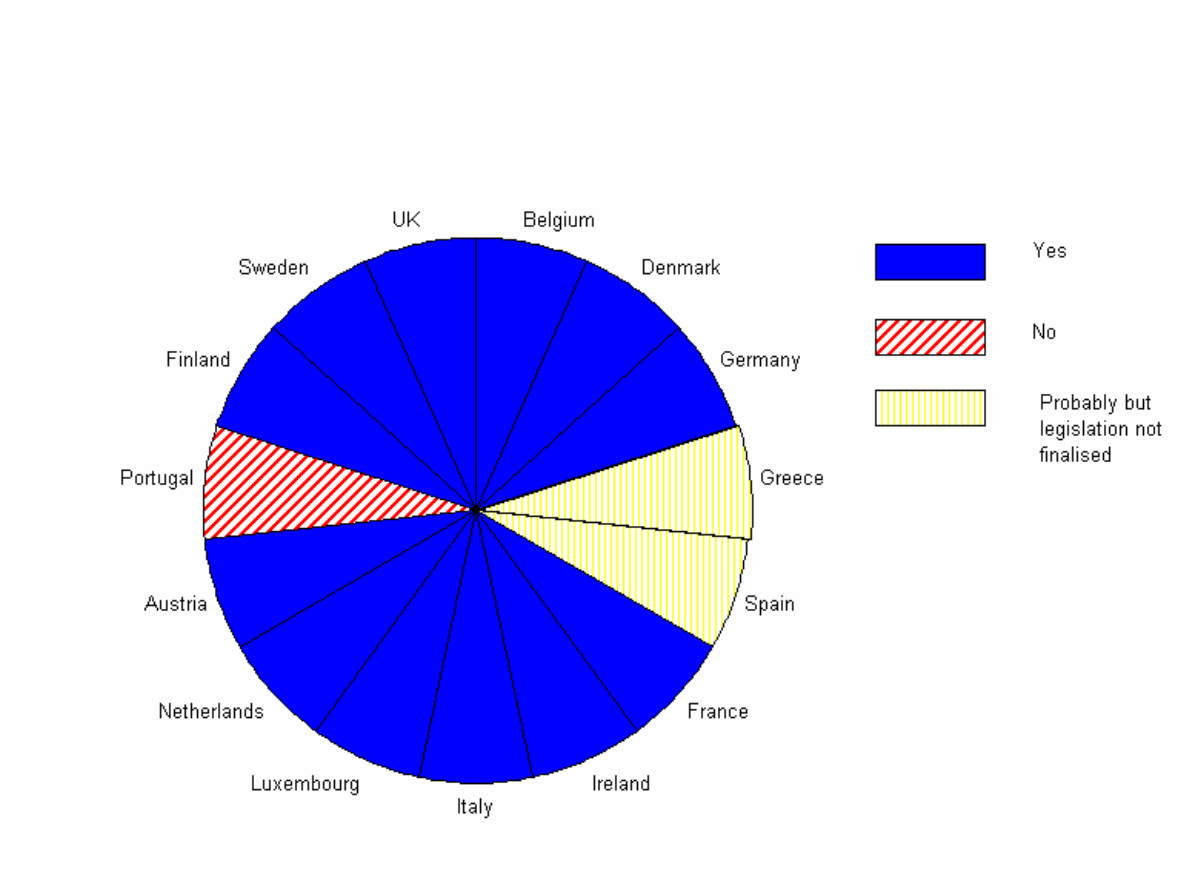


Figure 11 Existence of discharge controls for NORM within Member States (Qu 5)

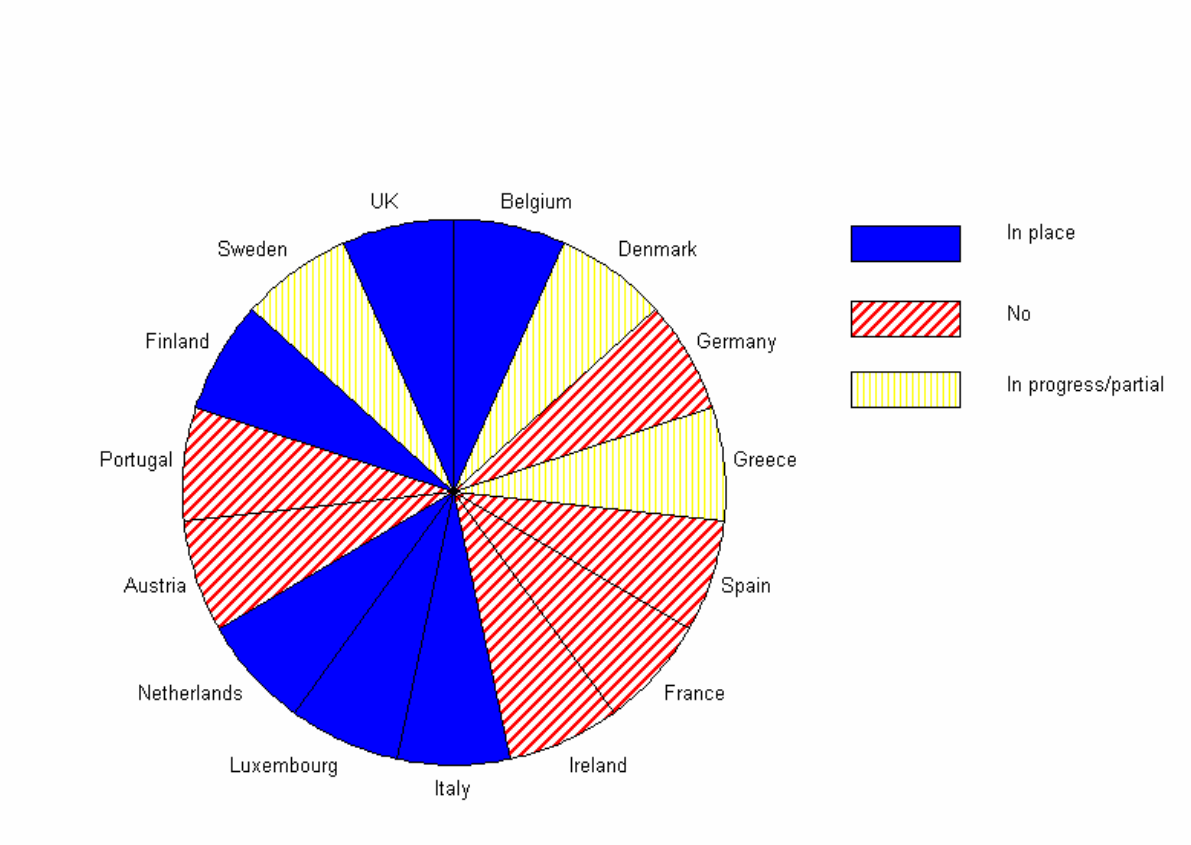


Figure 12 Overview of planned changes to national legislation (Qu 15)

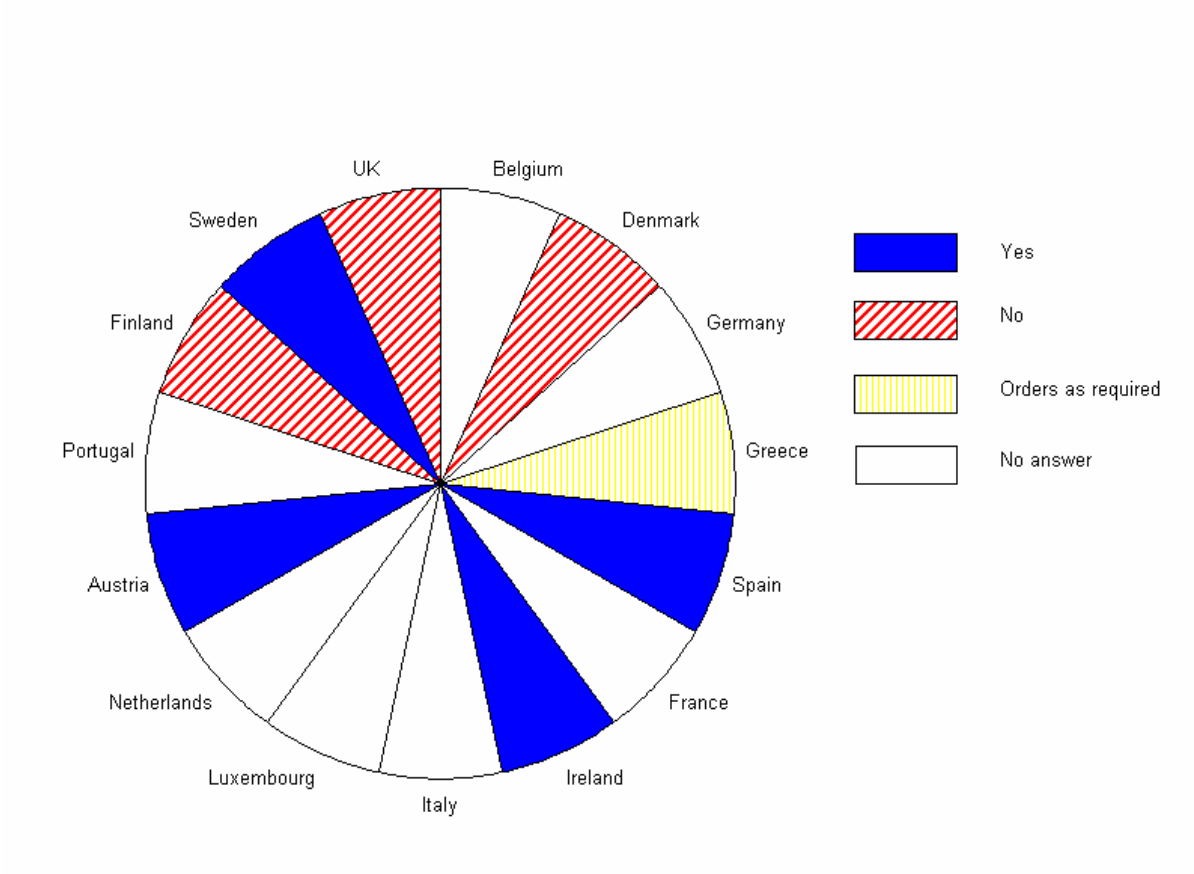


Figure 13 Summary of the responses to the benchmark

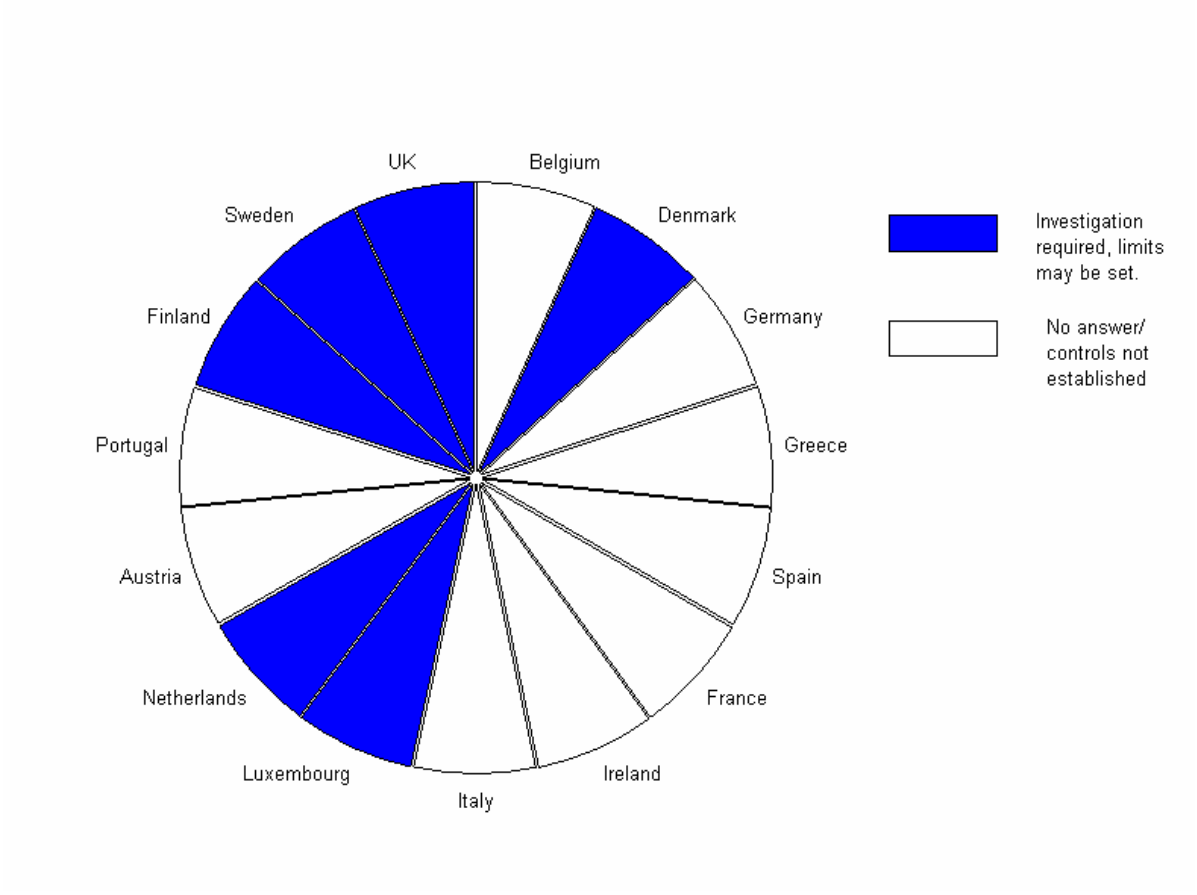


Figure 14 Summary of the application of dose constraints to NORM discharges (Qu 10)

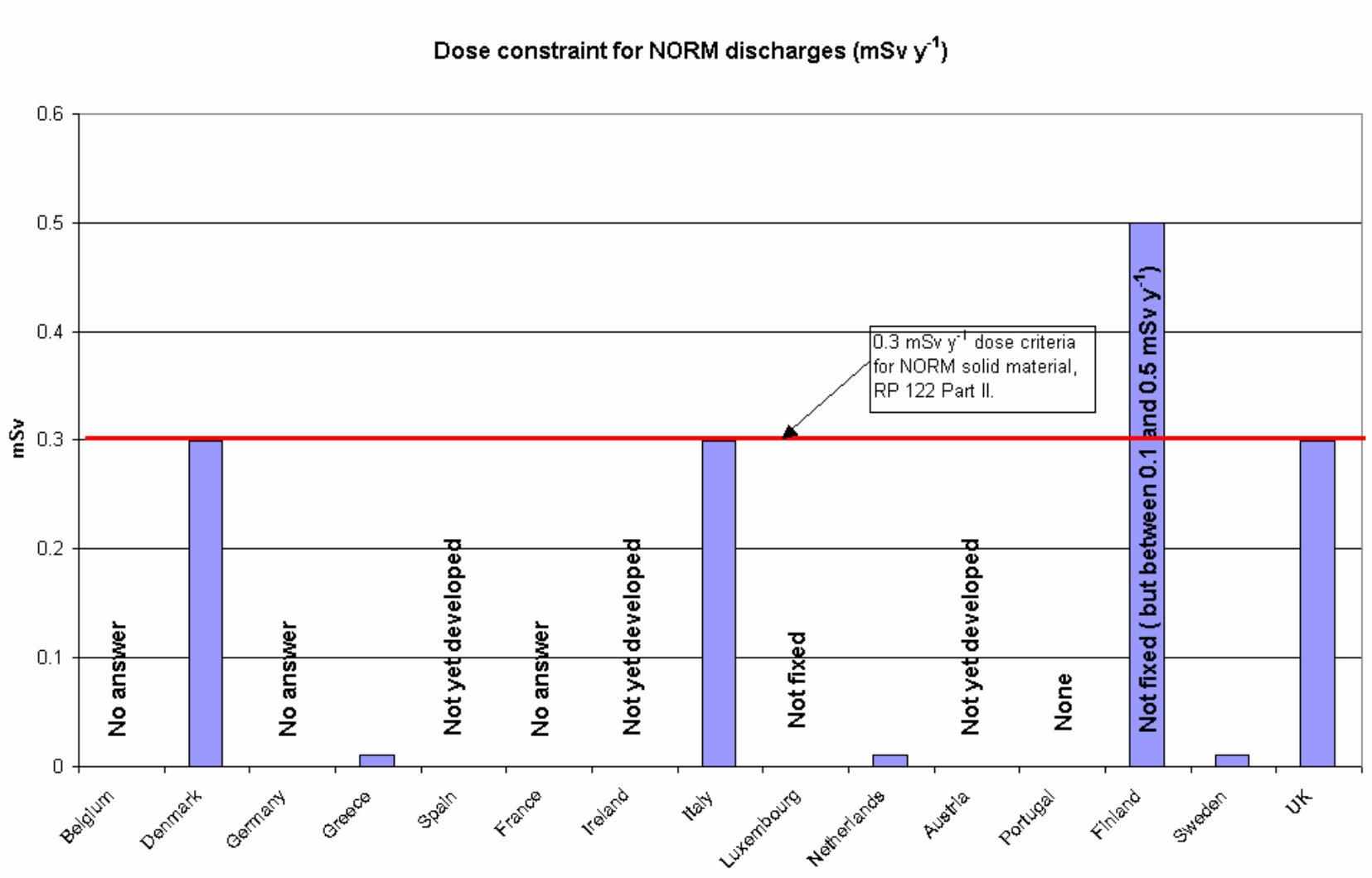


Figure 15 The dose assessment process

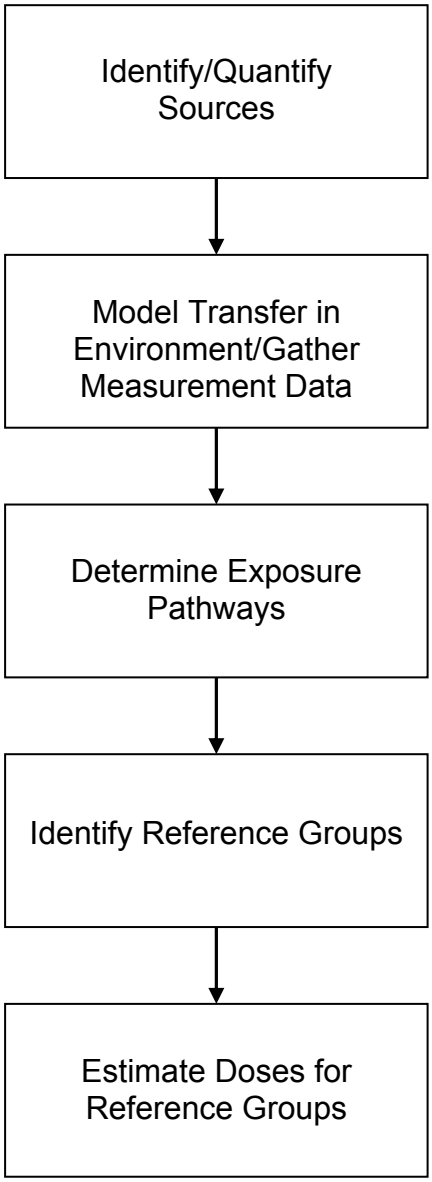


Figure 16 Comparison of typical aerial discharges of ^{210}Po with derived screening levels for a 10 m stack height using three different dose criteria

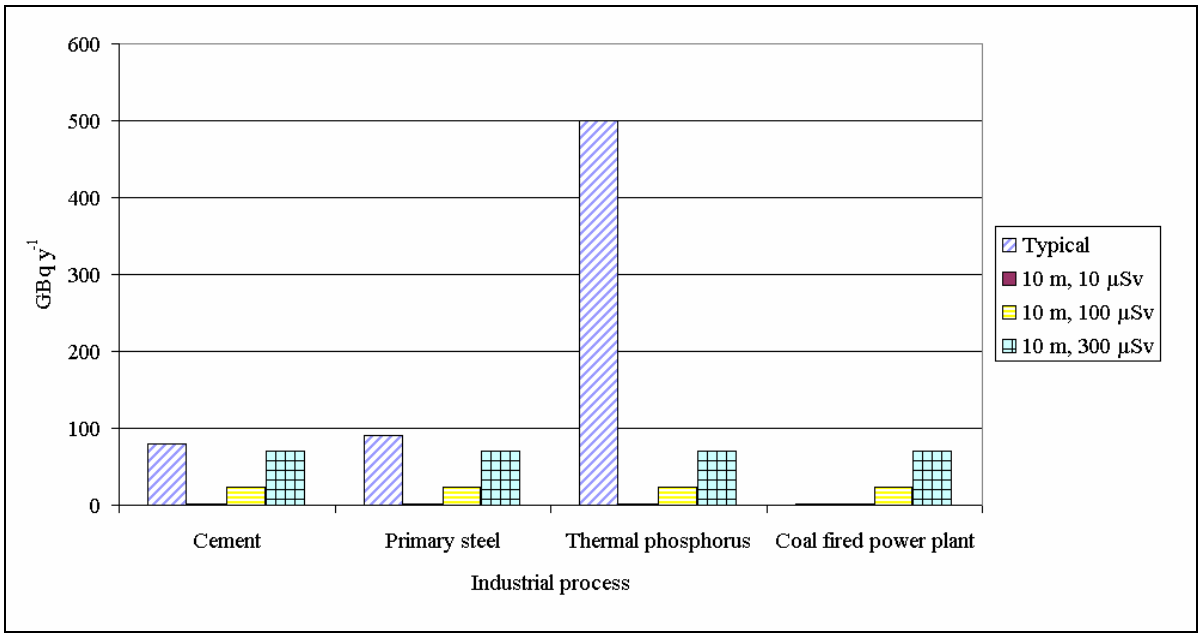


Figure 17 Comparison of typical aerial discharges of ^{210}Po with derived screening levels for a 50 m stack height using three different dose criteria

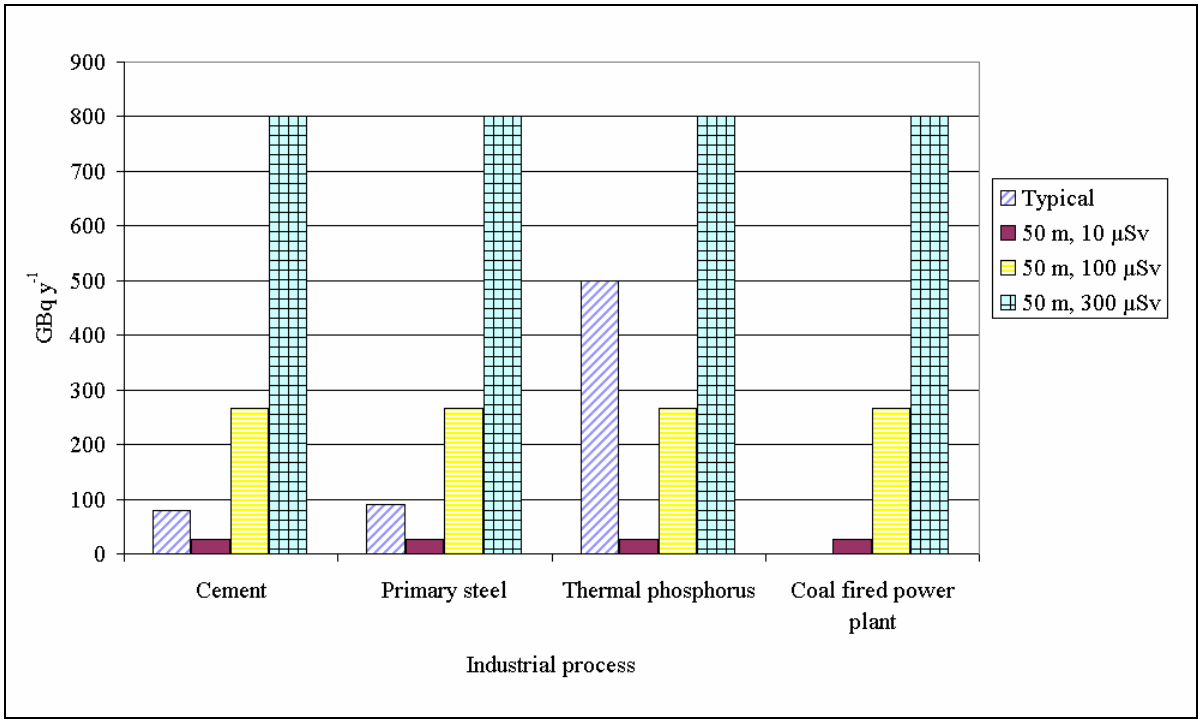


Figure 18 Comparison of typical aerial discharges of ^{210}Po with derived screening levels for 100 m stack height using three different dose criteria

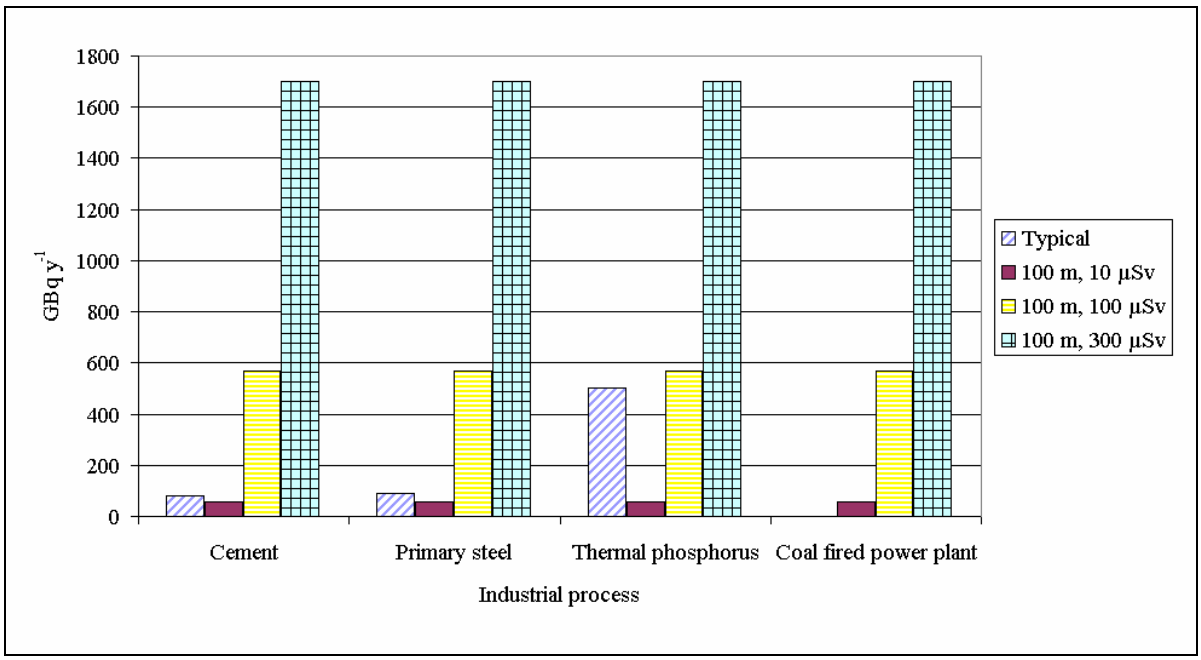


Figure 19 Comparison of typical aerial discharges of ^{210}Po with derived screening levels for 200 m stack height using three different dose criteria

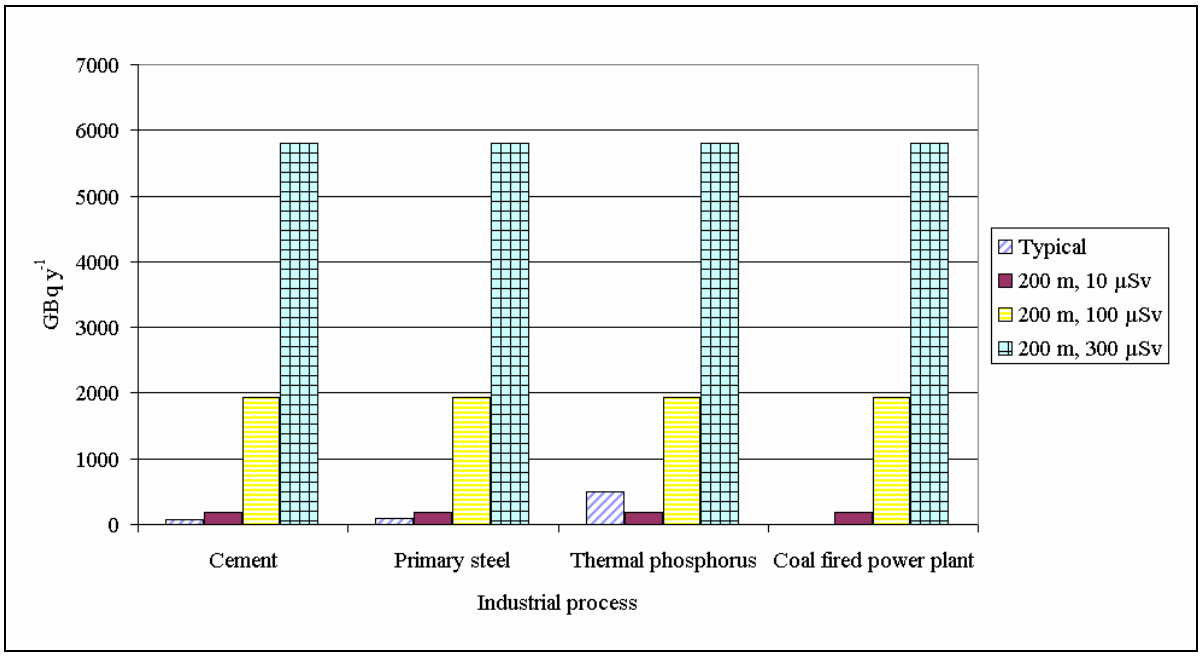


Figure 20 Comparison of typical discharges with derived screening levels for a small river using three different dose criteria

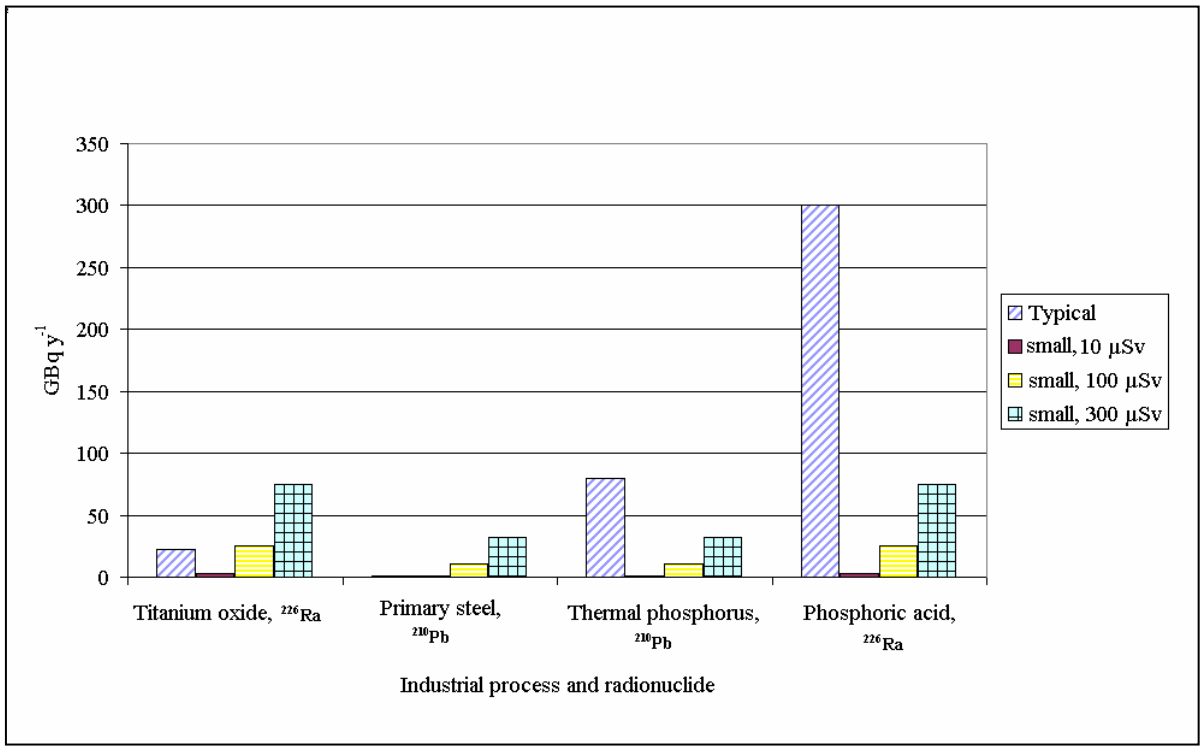


Figure 21 Comparison of typical discharges with derived screening levels for a medium river using three different dose criteria

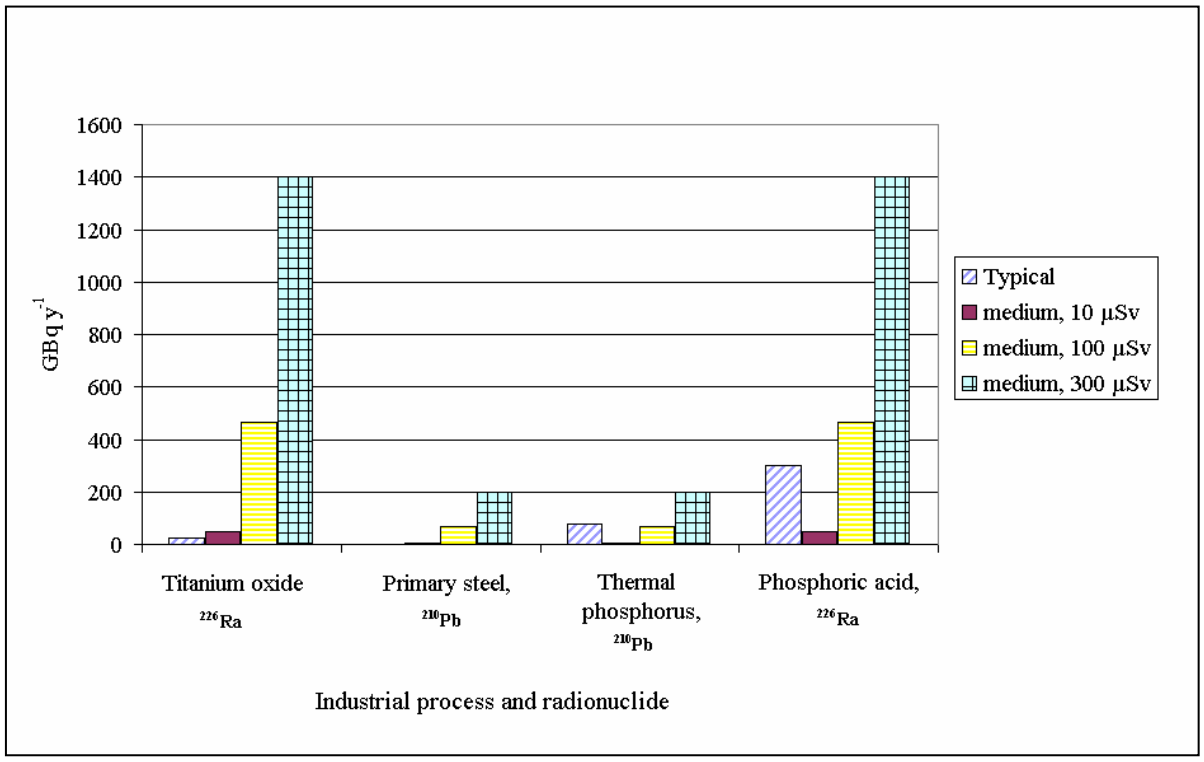


Figure 22 Comparison of typical discharges with derived screening levels for a large river using three different dose criteria

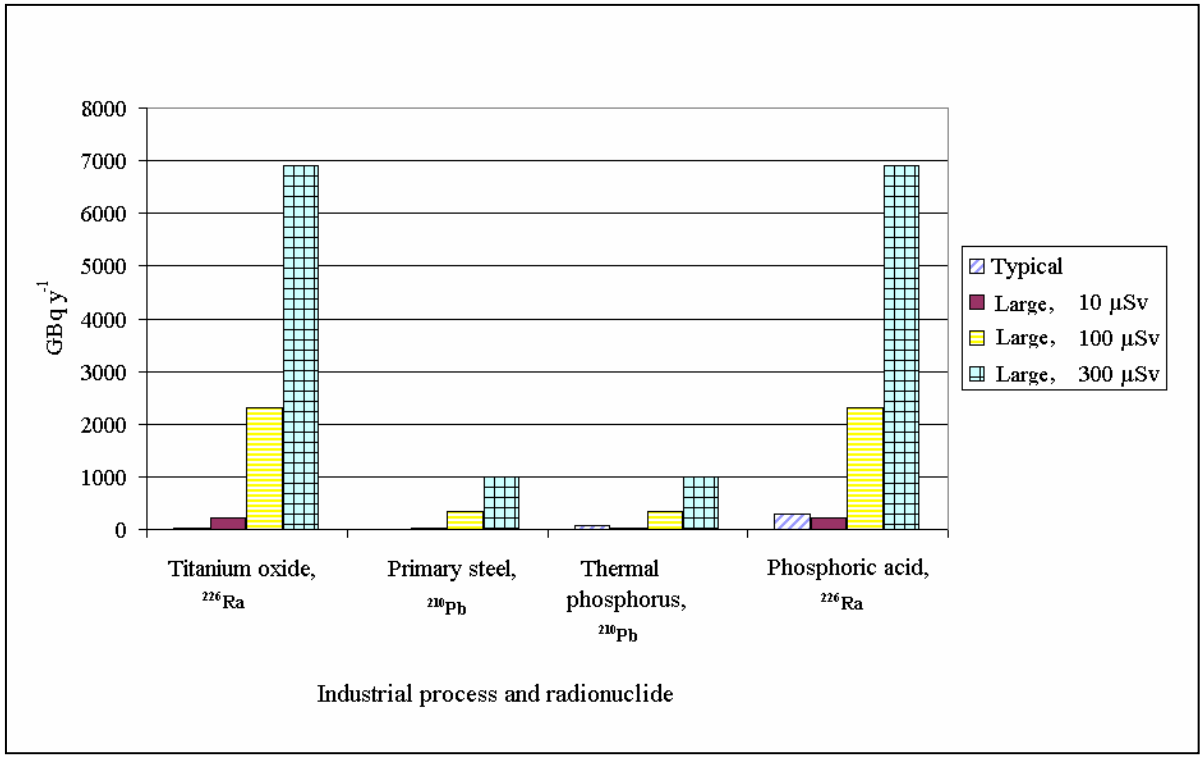
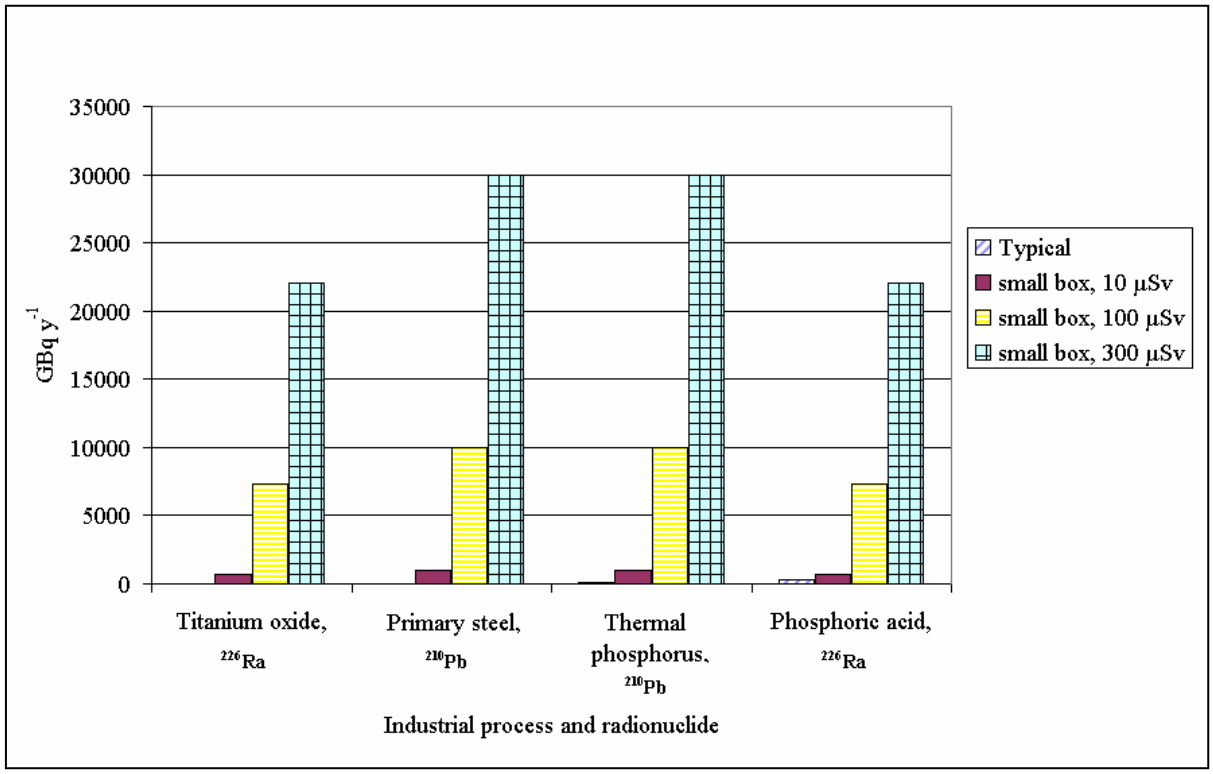


Figure 23 Comparison of typical discharges with the calculated discharges in a small marine box resulting in three levels of dose being reached



Abstract

In Title VII, the Council Directive 96/29/Euratom addresses the issue of exposure to natural radiation sources in an industrial context, referred to as "work activities". To assist Member States with the implementation of Title VII, the Commission has published a number of guidance documents dealing with general implementation issues (Radiation Protection 88), the establishment of reference levels for workplaces processing NORM (Radiation Protection 95) and the application of the concept of exemption and clearance to natural radiation sources (Radiation Protection 122 part II). No guidance has yet been developed in relation to discharges.

A review of the current regulatory framework within Member States regarding the implementation of Title VII of the Directive with respect to effluent discharges and the related disposal of wastes from NORM industries is presented. To date, all EU Member States have addressed the issue of 'work activities' within their regulatory structure. Most Member States are, however, at an early stage in the identification of work activities giving rise to significant exposures to the public as a result of wastes and discharges from NORM industries. At present there are no specific discharge controls in the majority of Member States.

Guidance on approaches for assessing the individual dose to members of the public from NORM discharges requiring regulatory control has been developed. In general the guidance is very similar to that proposed for discharges from nuclear installations (see Radiation Protection 129). However, the background levels of the radionuclides present in NORM complicate the use of environmental monitoring. Therefore monitoring of emissions at the source would be the most suitable approach to obtain input for dose assessment.

To allow a rapid identification of the effluent discharges potentially requiring regulatory control, screening levels for relevant natural radionuclides were derived for atmospheric and liquid discharges.

Available on: Europa, http://europa.eu.int/comm/energy in the Publications of the Radiation Protection section.

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