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Radiological Protection from Naturally Occurring Radioactive Material (NORM) in Industrial Processes

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Abstract– The purpose of this Publication is to provide guidance on radiological protection in industries involving NORM. Industries involving NORM give rise to multiple hazards and the radiological hazard is not necessarily dominant. Such industries are diverse and may involve exposure to people and the environment where protective actions need to be considered. NORM presents no real prospect of a radiological emergency leading to tissue reactions or immediate danger for life. However, the accidental release of large volumes of NORM may result in detrimental effects on the environment, including of radiological nature. NORM associated with industrial processes is an existing exposure situation, except when NORM is used for its radioactive properties which should be addressed on the basis of the principles of justification (of the actions taken) and optimisation of the protection above or below appropriate reference levels. Radon and thoron exposures should be managed as recommended in *Publication 126*.

An integrated approach to NORM processes is recommended, starting with characterisation of the situation and protection strategies already implemented to manage other workplace hazards, and then assessing the need for additional actions. The selection and implementation of protection strategies for workers should be a graded response to the magnitude of the hazards. According to the characteristics of the exposure situation, notably the actual and potential exposure pathways, the individual dose distribution and the prospect for optimisation, an appropriate reference level can be selected, either below a few mSv per year or above a few mSv if necessary, but very rarely exceeding 10 mSv per year. In the same line, control of the workplace and the conditions of work are used to reduce the risk, while the control of workers enters when adequate protection has not already been achieved with workplace controls.

A graded approach should be used in implementing requirements. Public exposure should be dealt with through the control of discharge, waste and residue, after characterisation of the situation. The reference level for the protection of the public should be selected below a few mSv per year. The protection of non-human species should be dealt with as part of an environmental assessment, taking into account all hazards and impacts. This should include identification of exposed organisms in the environment and using relevant derived consideration reference levels (DCRL), to ascertain the magnitude of the impacts and inform decisions on options for control of exposure.

CONTENTS

EDITORIAL

To be drafted

MAIN POINTS

- **Situations involving Naturally Occurring Radioactive Material (NORM) are existing exposure situations except when NORM is used for its radioactive properties.**
- **NORM industrial activities are controllable, and protection is achieved through optimisation using reference levels.**
- **Protective actions may need to be considered with regard to external exposure, intake of radioactive material, and radon or thoron inhalation. Radon and thoron exposures should be managed as recommended in *Publication 126*.**
- **NORM presents no real prospect of a radiological emergency leading to tissue reactions or immediate danger to life, but may pose an issue of environmental contamination.**
- **An integrated and graded approach to protection is recommended, starting with strategies already implemented to manage other workplace hazards.**

1. INTRODUCTION

1.1. Background

(1) All minerals and raw materials of a geological nature may contain radionuclides of natural origin. The main radionuclides of interest are ^{40}K and radionuclides from the ^{232}Th and ^{238}U decay series. Thorium-232 and ^{238}U decay through a series of radionuclides to stable isotopes ^{208}Pb and ^{206}Pb, respectively. These decaying radionuclides are known as daughter radionuclides or progeny. The other primordial radionuclides are of much lower abundance.

(2) For most human activities involving minerals and raw materials, the level of exposure due to primordial radionuclides decay series is not a concern for radiological protection. However, there are a number of circumstances in which materials containing natural radionuclides are recovered, processed, used, or moved such that enhanced radiation exposures may result. Material involved in processes giving rise to these enhanced exposures is considered to be Naturally Occurring Radioactive Material (NORM). For example, certain minerals (e.g. zirconium, monazite), including some that are commercially exploited, may contain potassium and/or thorium and/or uranium progeny at significant concentrations.

(3) Furthermore, during the extraction of minerals and their processing, the radionuclides may become unevenly distributed between the products, by-products, discharge, residue or waste arising from the process(es). The radionuclide activity concentrations may exceed those in the original mineral, sometimes by several orders of magnitude, which in turn can significantly increase the exposure of workers and/or members of the public as well as lead to the contamination of the environment.

(4) Only a few years after the discovery of radioactivity by A. H. Becquerel in 1896, radon – or "radium emanation" as it was called, was found in petroleum and in natural gas brought to the surface. In 1898 Marie Curie identified radium and polonium after processing several tons of pitchblende, an ore with high uranium content. Later, several investigations led to the first general review of the radioactivity associated with sedimentary rocks, petroleum, underground water and brines (Monicard, 1952). The discovery of radioactive scales from natural sources in British and American oil production facilities was first mentioned in the 1950's (Schmidt, 2000). However, the potential health, safety and environmental risks due to radiation exposure from NORM in the industry were only widely realised since the 1980's (Miller et al., 1991).

(5) In *Publication 26* (ICRP, 1977), ICRP recognised that some practices may "increase the level of exposure from the natural background of radiation" (Para. 235) and that there may be levels of natural radiation that might have to be controlled in much the same way as for artificial sources. The Commission did not give practical guidance on the principles for such control. In the same year, UNSCEAR introduced for the first time a chapter on 'technologically enhanced exposures to natural radiation' in its report to the General Assembly (UNSCEAR, 1977).

(6) In *Publication 39* (ICRP, 1984) and later in *Publication 60* (ICRP, 1991), the Commission proposed principles for limiting exposures of workers and the public to natural sources of radiation and notably primordial radionuclides and progeny. The Commission stated that there should be requirements to include some exposures to natural sources as part of occupational exposures when it comes to 'operations with and storage of materials not usually regarded as radioactive, but which contain significant traces of natural radionuclides' (ICRP, 1991 Para. 136).

(7) In *Publication 82* (ICRP, 1999) devoted to the protection of the public against prolonged exposures, the Commission first acknowledged the term 'NORM' by noting: "industrial development has further increased the 'natural' exposure of people by technologically enhancing the concentrations of radionuclides in naturally occurring radioactive materials (NORMs)" (Para. 6). The Publication then focused on the application of the system described in *Publication 60* for radiological protection to practices resulting in prolonged exposure. Optimisation was expected to be applied to ensure that doses were 'as low as reasonably achievable' taking into account economic and social factors. The Commission later provided detailed guidance on the application of the optimisation principle in 'The Optimisation of Radiological Protection: Broadening the Process' (ICRP, 2006, Part 2). This publication recommended that dose constraints and dose limits for practices may be appropriate to NORM exposure, but should be applied with 'care and flexibility'.

(8) In *Publication 103* (ICRP, 2007a), the Commission revised the system for radiological protection of *Publication 60*. The approach is now based on the characteristics of the radiation exposure situation rather than the process-based approach previously employed. The system applies to all exposures to ionising radiation, from any source, regardless of size or origin, but apply in their entirety only to situations in which either the source of the exposure or the pathways leading to doses received by individuals can be controlled by some reasonable means.

(9) A major implication of this is that all exposures, including those from naturally occurring radiation sources, are now within the scope of the system and that the principles of justification and optimisation always apply. Exposures from natural sources are considered to be existing exposure situations.

(10) *Publication 104* (ICRP, 2007b) recognised that there is a need for international consensus on NORM exposure management and that industries involving NORM have been regulated variably with regard to radiological protection, because the radiological protection system has been introduced after the start of operation, and existing industrial hygiene controls already limit the potential for radiation exposure (e.g. control of airborne dust). Exclusion and exemption of industries involving NORM and activities using numerical criteria may be useful but lack the quantitative judgement that is also often necessary. Hence, *Publication 104* advocated a graded approach in the management of NORM exposure, taking into account the prevailing circumstances and the risk to people, with the global aim of promoting the protection of workers and public health (Para. 137).

(11) The Commission has recently engaged in a set of Publications dedicated to applying the system of radiological protection to existing exposure situations. *Publication 126* (ICRP, 2014b) updated the recommendations for the protection against exposure to radon. *Publication 132* (ICRP, 2016) is devoted to Radiological Protection from Cosmic Radiation in Aviation. *Publications 109* and *111* on Emergency Exposure Situations and Living in Long-term Contaminated Areas following a Radiological Emergency are currently being updated. A Publication is also in preparation dedicated to exposures resulting from contaminated sites from past industrial, military and nuclear activities.

1.2. Scope

(12) This publication elaborates on management of existing exposure situations with regard to NORM. The Commissions approach to NORM builds on *Publication 103* (the 2007 Recommendations), *Publication 124* (environment) and *Publication 126* (radon and thoron). For the purpose of management of NORM as an existing exposure situation, previous advice

may be considered superseded. The focus is upon industrial processes such as mining and mineral extraction, or other industrial activities that may lead to exposures to NORM of geological origin, which have been identified as requiring consideration of radiological protection. The term 'industrial' also includes small-size business activities. In many cases, the input to the process does not have elevated levels of NORM (e.g. fossil fuels); however, the subsequent industrial processes generate higher concentration of radionuclides in the products, by-products, discharge, residue or waste. The industrial processes may also increase the exposure of workers and/or members of the public and/or lead to discharges of radioactive substances to the environment. More details about activities that may involve NORM exposure are given in chapter 2 and Appendix 1.

(13) Some mining facilities, however, have been established for the expressed purpose of extracting materials such as uranium and thorium from ore to be used for their radioactive, fissile or fertile properties. These industries are considered as planned exposure situations under the current system of radiological protection as outlined by the Commission in ICRP, 2007 and are not the subject of this publication.

(14) One contributor to NORM exposures is usually radon (^{222}Rn) gas (from the decay of ^{238}U) and, to a lesser extent, thoron (^{220}Rn) gas (from the decay of ^{232}Th). ICRP recently provided information on lung cancer risk from radon and thoron by reviewing epidemiological studies (ICRP, 2010), formulated recommendations for the protection of workers and public against them (ICRP, 2014b) and provided new dose coefficients for radon (ICRP 2017). In *Publication 126* (ICRP, 2014b), the Commission recommends an integrated approach for controlling radon exposure, relying as far as possible on the management of buildings or locations in which radon exposure occurs, whatever the use of the building. This approach is valid for radon and thoron arising from different sources in the workplace (e.g. from the ground, building materials and from minerals containing NORM). Thus, radon and thoron exposures in industries involving NORM should be managed in accordance with the approach of *Publication 126* and will not be considered explicitly in this publication.

(15) Due to the long-standing history of many industries involving NORM, sites have been identified as contaminated by NORM residues and wastes from past activities (legacy sites). In 2014, ICRP established a Task Group to develop a report on how to apply the Commission's recommendations to exposures resulting from contaminated sites from past industrial activities, so this topic will not be fully addressed here.

(16) The 2007 Recommendations (ICRP, 2007a) extended the system of radiological protection to address protection of the environment, including flora and fauna, more explicitly. Later, in *Publication 124* (ICRP, 2014a), the Commission describes its framework for protection of the environment, through the introduction of Reference Animals and Plants and how it should be applied within the system of radiological protection. Consistent with the approach established by the 2007 Recommendations (ICRP, 2007a), this Publication will specifically address the protection of the environment against NORM exposure.

(17) The ethical underpinnings of the system of radiological protection rely on four core ethical values as described in the *Publication 138* (ICRP, 2018): beneficence/non-maleficence, prudence, justice and dignity. There are important ethical issues to be integrated in the protection strategy against NORM exposure. Applying the system of protection is a permanent quest for decisions that do more good than harm (beneficence/non-maleficence), that avoid unnecessary risk (prudence), that establish a fair distribution of exposures (justice) and treat people with respect (dignity).

(18) While ionising radiation may be a consideration in terms of the protection of people and the environment from NORM, it is generally neither the only hazard nor the most dominant hazard. Indeed, many NORM residue and waste may contain toxic non-radiological

constituents that may be harmful to human health and/or the environment (e.g. heavy metals). The present Publication will not provide guidance on the management of these constituents, which may have to be controlled by environmental regulation. However, the Commission recommends the use of an integrated approach for the management of radiation and other hazards.

1.3. Structure of this publication

(19) Chapter 2 presents the characteristics of NORM exposures, an overview of the industries and practices where NORM exposure can occur, and elements related to the NORM cycle. Chapter 3 describes the Commission's system of radiological protection applied to NORM exposure, including the type of exposure situation, the category of exposure concerned and the basic principles to be applied. Chapter 4 provides guidance on the implementation of the system of radiological protection using an integrated and graded approach for the various exposed workers, public and the environment. Conclusions are provided in chapter 5. Appendix 1 completes Chapter 2 with more details about activities that may involve NORM exposure.

2. CHARACTERISTICS OF EXPOSURE FROM NORM

2.1. Ubiquity and variability

(20) Radionuclides from natural origin are ubiquitous and are present in almost all materials on Earth. They are in general not of radiological concern. Some human activities, however, have the potential to enhance radiation exposures from these materials.

(21) Many organisations have produced comprehensive reviews of industries that may cause NORM-related radiation exposure of workers, the public and the environment (UNSCEAR 1982, 2008; EC, 1999a; IAEA, 2006; EURATOM, 2013). Examples are given below. Further, previous industrial sites could have involved NORM, and these legacy sites may require attention. Details on these work activities are provided in Appendix 1.

1. Extraction of rare earth elements.
2. Production and use of metallic thorium and its compounds (i.e. for their metallic not fissile radioactive properties).
3. Mining and processing of ores (other than uranium or thorium for the nuclear fuel cycle).
4. Oil and gas recovery process.
5. Manufacture of titanium dioxide pigments.
6. The phosphate processing industry.
7. The zircon and zirconia industries.
8. Production of metal (tin, copper, iron, steel, aluminium, niobium/tantalum, bismuth, etc.).
9. Combustion of fossil fuel (mainly coal).
10. Water treatment.
11. Geothermal energy production.
12. Cement production, maintenance of clinker ovens.
13. Building materials (including building materials manufactured from residues or by products).

(22) Typical industries involving NORM process a wide range of raw materials with different levels of activity concentrations, producing a variety of products, by-products, discharges, residues and wastes. These industries may or may not be of radiological concern depending on the activity concentrations in the raw materials handled, the processes adopted, the uses of final products, the reuse and recycling of residues and the disposal of wastes.

(23) The range of process broadly leads to three scenarios for radiation exposure:

- From large quantities of material as an ore or a stockpile of raw material;
- From small quantities of material with concentrated radionuclides such as mineral concentrates, scales and sludge;
- From material that has been volatilised in high-temperature processes, like slags, precipitator dust and furnace fume.

(24) Work with NORM can give rise to external and internal radiation exposures. External exposures can arise from extended exposures to low (gamma) dose rates, from shorter exposures to high (gamma and sometimes beta) dose rates from performing maintenance on internals of equipment, slags, scales and sludges, or a combination of these. The potential for internal exposure is governed mostly by the way NORM occurs in the workplace, and the personal protective equipment worn by workers. Radon may be an important source of exposure in indoor or underground atmosphere (as mentioned above, radon exposure should be dealt with in accordance with *Publication 126* (ICRP, 2014b)). In large-scale mining and milling operations, airborne dust is a common industrial hazard, and

internal exposures from inhalation of NORM can be significant, especially where higher activity concentrations are present (e.g. above tens of Bq g^{-1}). In contrast, internal exposures from ingestion of NORM, including in water, are usually low (EC, 1999a). However, there can be considerable differences depending on workplace conditions, the radionuclides involved and the physical and chemical matrices in which the radionuclides are incorporated (UNSCEAR, 2016).

(25) Very large numbers of workers in the world may be exposed to NORM, and although the data are more limited than those for occupational exposures to man-made sources, the worldwide level of exposure for workers exposed to natural sources of radiation has been estimated to 30,000 man.Sv annually (around 13 million workers) (UNSCEAR, 2008). Until implementation of the International Basic Safety Standards for protection against ionising radiation in 1996 (IAEA, 1996) most countries had not been particularly concerned with assessing occupational exposure to natural sources of radiation. Table 2.1 (adapted from IAEA (2006)) gives recent ranges of exposures to workers in some industries involving NORM. In the majority of workplaces, both the average and the maximum assessed doses received by workers are below a few mSv per year but higher doses – in some cases as high as few tens of mSv – may occur in certain situations and in specific workplaces (around 100 mSv y^{-1} in very few underground mines).

Table 2.1. Examples of dose assessments for workers (external and internal from dust, excluding exposure to radon)

Activities	**Radionuclides with highest activity concentration**	**Annual effective dose (mS y^{-1})**			
		Minimum	**Mean**	**Maximum**	**Distribution**
Processing of thorium concentrate[a]	^{232}Th (in feedstock and product)	3.0		7.8	
Production of thorium compounds[b]				82	67% <1
Mining of rare earth ore[c]	^{238}U and ^{232}Th series (feedstock)		0.24 – 1		
Beneficiation of rare earth ore[c]			0.28 – 0.61		
Handling of monazite	^{232}Th series			0.3	
Rare earth separation and purification	^{228}Ra (residues)			0.3	
Decommissioning of a rare earths plant[d]	^{228}Ra (residues)	0.2	7.2	8.94	
Mining of ore other than uranium ore	^{238}U and ^{232}Th series (in general)	1.3	3	5	
Oil and gas production, offshore	^{226}Ra (scale/sludge)			0.5	
Oil and gas production, onshore				0.05	
Oil production, cleaning of pipes[c,e]			0.6	3	80% <1
Titanium dioxide pigment production	• ^{232}Th (feedstock) • ^{226}Ra, ^{228}Ra (scale)			0.27	
Phosphate ore storage	^{238}U series			0.28	
Phosphate fertiliser production	• ^{238}U (feedstock and product) • ^{226}Ra (residues)			0.5	
Zircon production	• ^{238}U series (feedstock)			0.4	
Bastnäsite (zirconia) production	• ^{210}Po (in dust precipitator)			0.4	
Manufacture and use of zircon		0		2.3	87% <1
Manufacture and use of refractory ceramics	• ^{238}U (in fused zirconia/product)	~0.01		1.5	98% <1
Manufacture of zircon/zirconia ceramics		Negligible			
Processing of Sn, Al, Ti and Nb ores	• ^{232}Th (feedstock, product and slag) • ^{228}Ra (residue)	0		3.2[f]	69% <1
Copper smelting	^{226}Ra (slag)			<1	
Recycling of metal scrap	^{210}Po, ^{210}Pb (precipitator dust)	Negligible			
Coal mining	• ^{238}U • ^{226}Ra, ^{228}Ra (for coal with high Ra inflow water)		2.75		
Combustion of coal	^{210}Po (scale)	0		0.4	
Combustion of coal				<1	
Combustion of coal				0.13	
Drinking water treatment	^{226}Ra (sludge)			<1	
Manufacture of mineral insulation[g]	n.a	0.0011		0.0173	

[a] Doses include contributions from inhalation of thoron.
[b] Doses >1 mSv y^{-1}, mainly due to dust inhalation, were identified in two of the six workplaces investigated. The assessment is being repeated after the implementation of dose reduction measures (equipping workers with respiratory protection, cleaning the workplaces periodically and installing air filtration).
[c] Dose from external exposure only.
[d] Doses received over a 9-month decommissioning period.
[e] Doses received over a 5-month refurbishment period.
[f] The maximum dose was 6 mSv prior to 2008.
[g] The minerals were coal, bauxite, basalt and cement.

(26) In terms of public exposure, direct external exposures (i.e. from NORM on the site) are usually negligible, although there are exceptions to this. For some specific industry involving NORM sites, it has been reported that some representative individuals in close proximity to the plant can receive annual doses in the millisievert range (UNSCEAR, 2008). In general, public doses from NORM mainly arise from radionuclides released to air and water as routine discharges, and the use of NORM-containing by-products in commodities such as building materials. A complete review is made difficult by the diversity of industries involved, the local circumstances associated with the exposures, and the overall lack of site-specific radiological assessments. Table 2.2 presents some data related to public exposures from NORM (adapted from IAEA (2010)). These estimates are subject to uncertainties and are often conservative. In Table 2.2 the annual effective dose from NORM to public is estimated to be far below 1 mSv per year, except in the situation of wide use of phosphogypsum in building material.

Table 2.2. Examples of dose assessments for members of the public (excluding exposure to radon).

Activities	**Radionuclides with highest activity concentration**	**Annual effective dose (mSv)**
Mining of rare earth ore	^{232}Th (contaminated soil)	0.044
Beneficiation of rare earth ore	^{232}Th (contaminated soil)	0.043
Use of slag from rare earths and steel production in house bricks	^{226}Ra, ^{232}Th (bricks)	~0.2
Production of Th welding rods	N.A.	Negligible
Mining of ore other than uranium ore		Specified only as <1
Large mineral residue deposit, 1 Bq g^{-1} ^{238}U and/or ^{232}Th	^{232}Th and ^{238}U series	0.05–0.26
Oil and gas production	N.A.	Specified only as <1
Elemental phosphorus production		<0.04
Use of dicalcium phosphate animal feed	^{210}Po, ^{210}Pb (in chicken)	<0.02
Use of phosphogypsum for agriculture	^{226}Ra (in fertiliser)	Negligible
Use of phosphogypsum (PG) for construction of houses:	^{226}Ra (in the building material)	
Walls and ceilings, PG panels,		0.02 – 0.2
Walls, ceilings and floor, hollow PG panels		0.46
Walls, ceilings and floor, solid PG panels		4.5
Walls, PG plasterboard lining		0.15 (India) or insignificant (Australia)
Walls, PG in bricks and cement		≤1.4
Manufacture of zircon/zirconia ceramics		Negligible
Steel production	^{232}Th, ^{228}Ra (in dust/gaseous effluent)	<0.01
Use of metal recycling slag for road construction	^{223}Ra (slag)	Specified only as <1
Combustion of coal	N.A.	Negligible
Drinking water treatment	N.A.	Negligible
Disposal of water treatment residue in landfill	^{226}Ra (sludge)	0.01
Effluent water treatment, former U mine	N.A.	Specified only as <1
Use of common building materials for house construction	N.A.	<0.3 – 1

(27) *Publication 103* (ICRP, 2007a) introduced an approach for developing a framework to demonstrate radiological protection of the environment. However, there are as yet few examples of the assessment of the impact of NORM, outside of uranium mining activities (or similar) on the environment. Each case should be evaluated on an individual basis taking all the present hazards, all concerned species, main environmental conditions and other characteristics into the consideration.

2.2. The NORM cycle

(28) Several stages of production involving NORM can be identified – some industries may involve almost all these stages, others may involve only some of them:

1. Mineral extraction,
2. Mineral processing,
3. Fabrication of products,
4. Use of products and by-products,
5. Re-use and recycling of residues,
6. Management of wastes, and
7. Dismantling or remediation and rehabilitation.

(29) The presence of NORM with elevated radionuclide concentrations could be an issue at any stage and may lead to significant radiological exposures of workers and the public and contamination of the environment if not adequately controlled.

(30) By-products and residues from a one industry involving NORM can be used as feedstock by other industry involving NORM and/or in common practices (e.g. building materials). In that sense, after being brought to surface (or else introduced into the industrial sector by another means), NORM enters a cycle, which is possibly endless (i.e. NORM can be moved and/or reprocessed from place to place), and enhanced exposures due to NORM may occur during all stages of the cycle.

3. THE APPLICATION OF THE COMMISSION'S SYSTEM OF RADIOLOGICAL PROTECTION TO NORM

3.1. Types of exposure situations and categories of exposure

3.1.1. Types of exposure situations

(31) The Commission defines an exposure situation as a *network of events and situations* that begins with a natural or artificial radiation source, the transfer of the radiation or radioactive materials through various pathways, and the resulting exposure of individuals or the environment (ICRP, 2007a, Para. 169). Protection can be achieved by taking action at the source, or at any point in the exposure pathways of the exposed individuals.

(32) According to Para. 176 of *Publication 103* (ICRP, 2007a), the Commission intends its Recommendations to be applied to all sources in the following three types of exposure situations, which address all conceivable circumstances:

- *Existing exposure situations* are exposure situations resulting from a source that already exists, with no intention to use the source for its radioactive properties, before a decision to control the resulting exposure is taken. Decisions on the need to control the exposure may be necessary but not urgent. Characterisation of exposures is a prerequisite for their control;
- *Planned exposure situations* are situations resulting from the deliberate introduction and operation of sources, used for their radioactive properties. For this type of situation, the use of the source is understood, and as such the exposures can be anticipated and controlled from the beginning; and
- *Emergency exposure situations* are situations resulting from a loss of control of a source, or from intentional misuse of a source, which requires urgent and timely actions in order to avoid or mitigate exposure.

(33) The Commission considers human and environmental exposures resulting from industries involving NORM as existing exposure situations. The source is not deliberately introduced in the industrial process for its radioactive properties; it already exists in material used in the process or industry, and any protection decisions to control the exposure are made in that context. The process in which NORM in raw materials is concentrated, with changes of chemical-physical form resulting in production of radioactive release, residue and waste, is not for the purpose of introducing a new radioactive source; it is incidental even though it has to be managed. However, the Commission considers that when NORM is processed for its radioactive, fissile or fertile properties, it is a planned exposure situation.

(34) The philosophy of *Publication 103* (ICRP, 2007a) compared to *Publication 60* (ICRP, 1991) is to recommend a consistent approach for the management of all types of exposure situations. This approach is based on the application of the principle of optimisation using appropriate dose criteria. In existing exposure situations, because the source already exists when decisions on control are taken, the principle of application of dose limits is, a priori, not relevant. The relevant dose criteria is the reference level, and time may be needed to fully implement the protection strategy. For the protection of non-human species, the use of environmental reference levels based on Derived Consideration Reference Levels is also recommended (ICRP, 20014a). Whatever the type of exposure situation, however, the aim is to achieve a standard of protection that is proportionate to the level of risk.

(35) A graded approach, commensurate to the level of the risk as well as other considerations such as economic and societal, is appropriate and particularly relevant for industries involving NORM due to economic importance of industries, large volumes of residues and wastes and limited options for management, moderate level of doses, and potentially high cost of regulation in relation to reduction in exposure. Industries involving NORM are generally situations where multiple hazards and pollutants are present. The radiological risk may not be the dominant hazard, and consequently, there has often been no or only a limited radiological protection awareness. In such a context, the radiological protection system is not necessarily the driving force in safety. The graded approach should first take account of the existing knowledge and experience of these industries in the management of industrial hazards and then pragmatically integrate any additional measures necessary for the purposes of radiological protection.

(36) The doses resulting from the process in which NORM is concentrated are expected to remain relatively low whatever the circumstances. In the same way, the imaginable scenarios of loss of control of the radioactive material in industries involving NORM result in a limited impact in terms of doses and subsequent sanitary effects such as tissue reaction or immediate danger for life. Consequently, industries involving NORM present no real prospect of a radiological emergency, and thus are not likely to give rise to an emergency exposure situation, but releases and discharges may result in environmental damage.

3.1.2. Categories of exposure

(37) The Commission distinguishes between three categories of exposure: occupational, public and medical exposures. Occupational exposure is radiation exposure of workers incurred as a result of their work. However, because of the ubiquity of radiation, the Commission traditionally limits the definition of 'occupational exposures' to radiation exposures incurred at work as a result of situations that can reasonably be regarded as being the responsibility of the operating management. Medical exposure is the exposure of patients in the course of medical diagnosis and treatment. Public exposure encompasses all exposures other than occupational exposures and medical exposures of patients.

(38) Industries involving NORM can give rise to both occupational and public exposure, but not to medical exposure.

(39) In most cases the exposure of workers in industries involving NORM is adventitious because the presence of NORM in the material processed is a natural fact, without intentional addition for its radioactive purpose, and the workers are often not considered occupationally exposed. As indicated in *Publication 126*, referring to *Publication 65* (ICRP, 2014b, Para. 59), workers who are not regarded as being occupationally exposed to radiation are usually treated in the same way as members of the public. Exposure of workers who are not considered occupationally exposed should anyhow be considered. In such case, it is the responsibility of the operating management to integrate the radiation risk among the others hazards and to address all the hazards in accordance with the agreed standards on health and safety at work.

(40) As described in section 4.1, a graded approach is recommended for the protection of workers in industries involving NORM, based on the selection of the reference level as well as the selection and the implementation of reasonable protective actions. This approach should also take into account, as explained in the previous sub-section, the integration of radiological protection in the procedures for the control of other hazards in a more global and synergistic way of hazard management.

(41) In rare cases, the level of dose or the application of special working procedures is needed for radiological protection purposes., In these cases, the measures recommended for occupationally exposed workers would apply (ICRP, 1997). The Commission's recommendations should not be interpreted as requiring all elements of a protection program irrespective of the circumstances. The approach should be graded, based on the hazards present.

(42) Public exposure is addressed through the control of NORM discharge, waste, residue (including their recycling and reuse) and possible legacy sites, as explained in section 4.2.

(43) Industries involving NORM generate environmental exposure through extraction, transportation, storage, processing, effluents, discharges and also from accidental releases. As indicated in section 4.3, environmental exposure is dealt with on the basis of common environmental standards, starting with an environmental impact assessment (EIA) considering the presence of NORM.

3.2. Justification of protection strategies

(44) The principle of justification is one of the two fundamental source-related principles that apply to all exposure situations. The recommendation in Para. 203 of *Publication 103* (ICRP, 2007a) requires, through the principle of justification, that any decision that alters the radiation exposure situation should do more good than harm. The Commission goes on to emphasise that for existing exposure situations, the justification principle is applied in making the decision as to whether to take action to reduce exposure and avert further additional exposures. Any decision will always have some disadvantages and should be justified in the sense that it should do more good than harm. In these circumstances, as stated in Para. 207 of *Publication 103* (ICRP, 2007a), the principle of justification is primarily applied in industries involving NORM when making the decision as to whether or not to implement a protection strategy for radiation exposures.

(45) As such, the justification falls under the ethical values of beneficence, which means promoting or doing good, and non-maleficence, which means avoiding causation of harm (ICRP, 2018), in order to reach the overall goal of societies to contribute to the well-being of individuals and the quality of the living together with the preservation of biodiversity and sustainable development.

(46) As explained in Para. 208 of *Publication 103* (ICRP, 2007a), the responsibility for judging the justification usually falls on governments or other national authorities to ensure that an overall benefit results, in the broadest sense, to society and thus not necessarily to each individual. However, input to the justification decision may include many aspects that could be informed by the industry involving NORM, workers, the public and organisations other than the government or national authority. As such, justification decisions could benefit from a stakeholder involvement process. In this context, radiological protection considerations will serve as one input to the broader decision-making process.

(47) The need for a protection strategy controlling exposure from NORM is better understood after radiological characterisation and taking into account health, economic, societal and ethical considerations. Since many industries involving NORM already exist, the Commission recommends the establishment at national level of a list of industries involving NORM for which a radiological risk assessment should be undertaken in order to determine if a protection strategy is justified. The level of control may then be determined through the implementation of the optimisation principle. If an ongoing industrial process involving NORM, not previously identified on a national list, appears to be of concern, the justification

of a protection strategy may be addressed on a case by case basis with the involvement of the relevant stakeholders.

(48) For industries involving NORM in the national list, when a new process using NORM is to be implemented, the principle of justification should be applied in the same way as for on-going processes, i.e. primarily when making the decision as to whether or not to implement a protection strategy for radiation exposures. Industrial processes will usually produce such significant economic and social benefits, and the radiological risks involved is unlikely to result in a decision that the NORM process, as a whole, would need to be considered unjustified. Exceptions can be dealt with on a case by case basis.

3.3. Optimisation of protection

(49) When a decision has been taken to implement a protection strategy, then the principle of optimisation of protection becomes the driving principle to select the most effective actions for protecting the exposed public, workers and the environment. It is defined by the Commission as the process to keep the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures, as low as reasonably achievable (ALARA), guided by appropriate individual dose criteria, taking into account economic and societal factors. This means that the level of protection should be the best under the prevailing circumstances, adopting a prudent and reasonable attitude (see ICRP (2018)).

(50) To avoid serious inequity in the individual dose distribution, in line with the ethical value of justice (ICRP, 2018), the Commission recommends using individual dose criteria in the optimisation process (ICRP, 2007a, Para. 232). In addition to the reduction of the magnitude of individual exposures, a reduction of the number of exposed individuals should also be considered. The collective effective dose has been and remains a key parameter for optimisation of protection for workers, in comparing the exposures predicted from different options for protection strategies.

(51) The optimisation process should consider protection of the environment. The aim is to avoid deleterious effects on non-human species. Such approach should be commensurate with the overall level of risk and compatible with common standards of environmental protection, notably the optimisation of discharges in the environment. As is the case for human exposure, NORM processes may pose environmental risks from other constituents, and the radiological aspects have to be taken in an all hazard approach. In practice, the radiological impact should be included in the environmental impact assessment and monitored as necessary. The approach already developed by the Commission (ICRP, 2008, 2014a), through a set of Reference Animals and Plants and numerical values for DCRLs is useful guidance when assessing possible deleterious radiation effects on non-human species, their diversity, communities and ecosystems in general. The results contribute to decisions on the most appropriate option for controlling the source.

(52) In case of industries involving NORM, the optimisation process is implemented in generally the same way as for other industries. However, because of the prevailing circumstances and notably since in some circumstances the source cannot be controlled in the way it is for other sources, the options to reduce doses may be more limited and/or may require different resources. Such challenges suggest the need for flexibility and reasonableness in the implementation of the optimisation process.

(53) The involvement of relevant stakeholders early in the optimisation process will contribute to the transparency of the process and increase confidence in the outcome.

3.3.1. Dose criteria

(54) The Commission recommends the use of reference levels as dose criteria in existing exposure situations. The reference level represents the value of dose used to guide and drive the optimisation process. The selection of the reference level should consider the actual individual dose distribution, with the objective of identifying those exposures that warrant specific attention. Reference levels are guides for selecting amongst protective options in the optimisation process in order to maintain individual doses as low as reasonably achievable taking into account economic and societal factors, and thus prevent and reduce inequities in the dose distribution. Reference levels are also benchmarks against which the results of protective actions can be judged to determine if protection is reasonably optimised and effective.

(55) For existing exposure situations, the Commission recommends setting reference levels typically within the 1 to 20 mSv per year band as presented in Table 5 of *Publication 103* (ICRP, 2007a), and with the possibility that the reference level could be lower than 1 mSv per year. The 1 to 20 mSv per year band presupposes that the sources or the pathways can generally be controlled, and individuals receive direct benefits from the activities associated with the exposure situation, but not necessarily from the exposure itself. However, the selection of the reference level for a particular exposure situation should be made based upon the characteristics of the circumstances (ICRP, 2007a, Para. 234), considering the individual dose distribution, with the objective to identify those exposures that warrant specific attention and meaningfully contribute to the optimisation process. Industries involving NORM generally give rise to low levels of individual exposure and the appropriate reference level would in most cases be less than a few mSv per year. The selected reference level should be meaningful for protection purposes, not a generic value which would not help to identify individuals for whom some further consideration might be needed. Thus, according to the characteristics of the exposure situation, notably the actual and potential exposure pathways, the individual dose distribution and the prospect for optimisation, an appropriate reference level can be selected, either below a few mSv per year or above a few mSv if necessary, but very rarely will a reference level exceeding 10 mSv per year be necessary.

(56) Chapter 4 contains specific bands of reference levels that are recommended for the protection of NORM workers and the public, respectively. They are consistent with the approach recommended in *Publication 103*.

(57) The principle of individual dose limits applies only in planned exposure situations (ICRP, 2007a, Para. 203). In the case for NORM exposure, following characterisation of the situation, and optimisation of protection with reference levels, the protection program becomes established, with controls that are effective. The magnitude of exposures will often be relatively low, reflecting the optimisation of protection with reference levels.

(58) The Commission recognises that some authorities have already specified the application of dose limits for some industries involving NORM. Such use is understandable, as a limit is frequently used as one regulatory mechanism to judge the acceptability of a radiation control program. Such a use is not unacceptable in circumstances when the source is well characterised, and the control programs have been established. However, specifying a limit for regulatory purposes is not meant to imply that the situation has been, or needs to be, transformed into a planned exposure situation. In the vast majority of industries involving NORM, the application of 'limits' expressed in terms of dose provides no real additional protection for workers, and may entail administrative burdens that are not in keeping with efficient and effective use of resources.

3.3.2. The optimisation process

(59) Optimisation of protection of the human health and the environment in existing exposure situations is implemented through a process that involves (a) the assessment of the exposure situation; (b) identification of the possible protective options to maintain or reduce the exposure to as low as reasonably achievable taking into account economic and societal factors; (c) the selection and implementation of the most appropriate protective options under the prevailing circumstances; and (d) the regular review of the exposure situation to evaluate if there is a need for corrective actions, or if new opportunities for improving protection have emerged.

(60) In this iterative process, the Commission considers that the search for equity in the distribution of individual exposures is an important aspect (ICRP, 2006). It should be noted that, in industries involving NORM, the distribution of individual doses for both workers and members of the public may be very large. The protection efforts should focus individuals on the higher dose tail of the distributions, i.e. on the most exposed individuals, so as to determine if efforts are reasonable to reduce their exposures, while simultaneously trying to reasonably reduce the exposure of the whole exposed population.

(61) The decision making for control of industries involving NORM should be open and transparent. Stakeholders should be involved as necessary, including the workers, community and others as appropriate. Their concerns and ideas should be listened to and taken into account. A transparent system for decision making will allow for controversial issues to be properly addressed and resolved, although not necessarily with full agreement from all parties.

(62) The inclusion of natural or man-made radiation highlights the need to foster the development of an appropriate radiological protection culture within the organisation and community, enabling each individual to make well-informed choices and behave wisely in situations involving potential or actual exposure to ionising radiation (ICRP, 2006). It is a matter closely tied to the ethical concept of dignity (ICRP, 2018).

(63) Detailed advice of the Commission on how to apply the optimisation principle in practice has been provided earlier (ICRP, 1983, 1990, 1991, 2006), and remains valid.

4. IMPLEMENTATION OF THE SYSTEM OF RADIOLOGICAL PROTECTION TO INDUSTRIAL PROCESSES INVOLVING NORM

4.1. Protection of workers

4.1.1. General considerations

(65) Typical industries involving NORM process a wide range of raw materials and activity concentrations, and radiation exposure is adventitious, as the processes are not in any way intended to take advantage of the radioactive materials. Depending upon the circumstances, it may not be necessary to consider controls directly applicable to a particular individual in order to properly control exposures. This does not mean that protection is not warranted, but that the control is exercised on the workplace and the conditions of work rather than on the worker her/himself. It is not easy to define criteria applicable in all situations. Thus, a graded approach for the protection of workers is recommended.

(66) Three main exposure scenarios have been identified:

- Exposure to large quantities of material as an ore or a stockpile of raw material;
- Exposure to small quantities of material with concentrated radionuclides such as mineral concentrates, scales and sludge;
- Exposure to material that has been volatilised in high temperature processes, like slag, precipitator dust and furnace fume.

(67) The main exposure pathways for work with NORM are:

- External exposure (mostly due to gamma radiation, but occasionally beta radiation exposure to the lens of the eye and to the skin may also need to be considered);
- Internal exposure from inhalation dust and to a much lesser extent ingestion of radioactive dust, as well as exposures due to radon gas and its progeny, which can occur above ground or underground (e.g., the build-up of radon gas in underground workplaces) and sometimes thoron emanating from NORM. In practice, radon emanating from such materials is often indistinguishable from that already present (e.g. from the ground).

(68) The Commission considers that radon and thoron in the workplace, irrespective of the source, should be managed as a single source, i.e. as described in *Publication 126*. That Publication recommends an integrated approach for protection against radon exposure in all buildings, whatever their purpose and the status of their occupants. The strategy of protection in buildings, implemented through a national action plan, should be based on application of the optimisation principle using a reference level translated for practical reasons to concentrations in air, to facilitate implementation. The Commission recommends that national authorities to set a derived reference level that is as low as reasonably achievable in the range of 100 to 300 Bq m^{-3} taking the prevailing economic and societal circumstances into account. The corresponding effective dose depends on a number of factors such as breathing rates (see ICRP (2017)). As described in *Publication 126*, if Radon mitigation actions cannot reduce levels to less than the reference level, the exposure will need to be considered as part of the occupational exposure.

(69) It is important to note that workers in industries involving NORM are exposed to radiation and also to other hazards. The radiological risk is often not the dominant hazard, and may historically not even have been a consideration. In such a context, there is often a lack of radiological protection awareness or a culture supporting such protection. However, such industries do have experience and expertise in the management of occupational health

and safety, and there is an opportunity to build a radiological protection culture in an integrated fashion. In many cases, actions to reduce workplaces hazards such as airborne dust, will also restrict radiation exposures, and an integrated approach to worker protection is recommended.

(70) Protection of workers in industries involving NORM should be based on a graded approach to control radiation exposures, according to the annual effective dose (due to the activities involving NORM) that is likely to be received and the scope for dose reduction that may be necessary.

(71) In practice, a graded approach can be realised through the selection of suitable dose reference levels, the selection of the requisites, i.e. appropriate protective actions, and the integrated implementation of these requisites. The practical implementation of this approach will also help to determine whether or not the workers should be considered as occupationally exposed to radiation.

(72) This approach can also serve as the basis for creating a common understanding between regulatory authorities and other stakeholders such as operators, workers and their representatives, as well as health, safety and environmental professionals, of the radiological aspects of the various processes involved and the ways in which these aspects can be addressed reasonably and effectively.

4.1.2. Selection of the dose reference level for workers

(73) Since the industries involving NORM are so diverse, there is no unique numerical value which is appropriate as a reference level for all of them. According to the characteristics of the exposure situation, notably the actual and potential exposure pathways, the individual doses distribution and the prospect for optimisation, the appropriate reference level can be selected:

- Below a few mSv per year for most cases, and
- Above a few mSv, but very rarely exceeding 10 mSv per year, when necessary because of the circumstances involved.

(74) Considering the current information about the dose distribution of doses of workers in many industries involving NORM, the selection of a reference level above 10 mSv per year would not be necessary in terms of radiological protection.

(75) As indicated above, these doses exclude exposures from radon or thoron.

(76) In most situations, the residual doses are not expected to exceed the reference level, particularly after the effective implementation of protective measures. The reference level remains useful to allow judgement on the appropriate functioning of the program, and to indicate if modifications of the program are needed.

4.1.3. Selection and implementation of requisites

(77) When considering measures to optimise exposures to NORM workers, the starting point should always be the existing industrial safety and hygiene controls, i.e. for non-radiological hazards in the workplace. Experience shows that a well-managed, safety-focused workplace will already have done much to reduce radiation exposures from NORM. Where additional radiological protection controls are considered necessary, as far as practicable these should be integrated into the wider safety strategy.

(78) The strategy for protection of workers as defined in Conventions from the International Labour Organisation (Convention 167, Convention 176), comprises three main steps:

(a) Eliminate the risk, for example by replacing hazardous substances by harmless or less hazardous substances wherever possible;
(b) Minimise the risk, for example by technical measures applied to the plant, machinery, equipment or process;
(c) In so far as the risk remains, undertake other effective measures related to the workers themselves, such as the use of personal protective equipment.

(79) The same scheme is relevant for the protection of workers in industries involving NORM. Control of the workplace and the conditions of work are to eliminate or minimise the risk, while the control of individuals enters when adequate protection has not already been achieved. Moving from controls of the workplace to individual controls needs to be carefully considered as these controls are costly, and the preference would be to have sufficient controls for the workplace so that individual controls are not needed. The requisites related to the workplace and the conditions of work, are described below.

(80) *Characterisation of the situation*: this characterisation – determining who is exposed, when, where and how – is an important starting point for the protection of workers. It includes the characterisation of the source, with the aim of identifying the distribution of NORM radionuclides and their activity concentrations throughout the industrial process, including mode of exposure, chemical and physical characteristics of particulates, NORM distribution and activity concentrations at all stages of the industrial process. Feed materials, intermediates, residues and wastes (including contamination of the plant), and discharges to the environment should be considered.

(81) Characterising the source will help identify the main exposure pathways to workers, the public and the environment. In terms of exposure to workers, the next step is to characterise exposed groups or individuals and make an initial assessment of the annual doses (effective doses arising from external exposure and internal exposure through inhalation) received from the work with NORM.

(82) The characterisation of the exposure situation may, of course, vary in detail according to the prevailing circumstances involved. In practice, external gamma radiation and internal exposures from radioactive dust inhalation are the two exposure pathways of interest (plus radon which is addressed separately). When considering the likely annual radiation exposure of workers in different industries involving NORM, it is important that these are based on realistic estimates, i.e. taking into account actual external radiation and airborne contamination levels in the workplace and actual working patterns and procedures. When estimating radiation exposures, the effect of existing occupational health and safety (OHS) provisions should be taken into account (e.g. industrial hygiene, industrial safety, workplace controls on airborne dust).

(83) It is important that this characterisation stage is fully documented, so as to provide a sound basis for any future decision-making.

(84) The characterisation will form the basis for the justification of the protection strategy, notably the need for specific requisites for radiological protection purposes, as well as for the scaling of the optimisation process.

(85) The initial characterisation should be subject to periodic review. The detail and frequency of this periodic review should be commensurate with the level of risk. When feedstocks, ores, production practices or other factors that can affect dose are expected to change significantly, a new characterisation should be undertaken.

(86) *Obtaining expert radiological protection advice*: such expertise is normally required from the beginning, i.e. to assist with the characterisation of the exposure situation. Typically, industries involving NORM have operated for many years before the issue of natural radioactivity has been addressed. As a result, there is often a complete lack of

knowledge about radioactivity and radiological protection. Consequently, the first step should be to seek expert advice on this issue, even where industries involving NORM already have their own technical support in a wide range of other areas. Such specific expertise can be provided either internally or by external consultants. Such radiological protection expertise should be sought by both operating management, and also by the national authorities where no specialised expertise exists. The need for advice from a radiological protection expert may be temporary (e.g. where it can be shown from an initial review and assessment that exposures are very low), or may be required on an on-going basis.

(87) *Initial actions to prevent or reduce the hazard*: this corresponds to the first step of the ILO approach. At the initial stage, it is useful to consider if there are any ways in which the hazards from NORM can be either eliminated from the process, or else substantially reduced. Examples include the selection of alternative feed materials (i.e. with much lower concentrations of NORM), or changes to the process designed to prevent the accidental accumulation or concentration of radionuclides. Whilst recognising that this is likely not practical or possible, particularly in long standing industries involving NORM, it nevertheless should be given some consideration.

(88) *Delineation of areas*: the delineation of areas is a well-established element of the control strategy in planned exposure situations. However, it is also part of a wider industrial health and safety strategy, i.e. to identify areas where additional safety measures (e.g. working procedures, ventilation requirements, use of personal protective equipment, limitation of access) are required. To be effective, area delineation requires warning signs and, in some cases, formal restrictions on access. The same approach is appropriate for industries involving NORM. Worker right-to-know protocols may determine the type of signage needed. The concept may already be in place in some industries, as there would, for example, be warnings and controls for dust.

(89) *Engineered controls*: as previously said, the characteristics of NORM are such that scenarios involving high doses from accidental exposures do not generally exist. Thus, the traditional engineering controls to prevent such exposures are not required. Instead, measures to restrict chronic exposures from NORM should be considered. These start with the design and layout of the facility, and then specific measures to control dust, such as containment and ventilation. Industries involving NORM such as mineral processing plants can be very dusty, and a dust control strategy and programme should already be in place in such facilities. Improvements to containment and ventilation systems should be considered holistically, i.e. in terms of their overall effect on radioactive and other materials.

(90) Specific engineering measures to restrict external radiation exposures (i.e. shielding) may be required: for example, local shielding around pipes and vessels containing NORM at very high activity concentrations may be considered. More commonly, however, protection is provided through adjustments to working patterns and, in some cases, relocation of materials, plant or persons (distance).

(91) *Working procedures*: these procedures, such as limiting time of exposure, can be very effective in restricting both internal and external doses, even where exposures are already low. Often, all that is required is observance of good industrial hygiene and simple safe working procedures, supported by an appropriate amount of training (see below) and supervision.

(92) The requisites listed above, complemented by at least a general information programme for workers (see below), may be sufficient for the protection of workers in most industries involving NORM. However, they can be complemented, as necessary, by requisites related to the individuals.

(93) *Information, instruction and training*: the information and training provided to workers should be proportionate to the radiation risk and the precautions that need to be taken. There is a basic need to share information and generally raise awareness about NORM within the workplace. Information should in particular be provided to pregnant and breastfeeding workers. NORM workers are key stakeholders in this process, and the principles of open communication and engagement should be applied at an early stage. Where special precautions to restrict exposures to radiation are required, the relevant workers should receive specific training to understand the nature of the radiological risks and the importance of protective actions, and practical instructions on how to implement these actions.

(94) *Personal protective equipment (PPE)*: this includes protective clothing and respiratory protective equipment (e.g. dust masks), and these are already widely used in NORM workplaces to protect against other hazards. PPE should be selected with due consideration of the hazards involved. The equipment should not only provide adequate protection but also be convenient and comfortable to use. The effectiveness of any existing PPE should be assessed before determining whether improved or additional PPE for radiological protection purposes is required. Engineered controls are the favoured option, with working procedures and, finally, protective respiratory equipment being considered only where further engineering controls are not effective or practicable. Consideration should also be given to the possibility of an increase in exposure caused by the additional constraints of the personal protective equipment.

(95) *Dose assessment*: an assessment of the exposure of workers is required as part of the initial characterisation described above. It is envisaged that this will be based on workplace measurements and other information (e.g. about the process and working practices), rather than individual dosimetry. In practice, although the level of dose may not be the only criterion, where worker doses are estimated to be higher than a few mSv per year, an ongoing programme of dose assessment should be implemented, according to a graded approach. Where doses are above a few mSv per year, it is expected that they will be estimated on the basis of workplace measurements. Individual dose assessment, for example through the use of personal dosimeters, may be useful as a means of providing information to help optimise exposures, but is not expected to be undertaken on a routine basis.

(96) Where doses are well above a few mSv per year, there is a need to undertake individual dose assessments. For external radiation, this should be done with personal dosimeters (passive or electronic). Assessment of internal exposures from dust inhalation is much more challenging; however, in very dusty NORM workplaces there may already be a dust monitoring programme which can be adapted to also provide estimates of radiation dose. If not, and if internal doses are high, arrangements with a suitable internal dosimetry service will need to be considered. It should be noted, however, that such exposures are unlikely to be considered optimised, and that suitable protective actions should be more than capable of reducing internal exposures.

(97) *Dose recording*: both workplace and individual data related to the estimation and assessment of worker doses should be recorded and kept for sufficient time. The recording may be carried out in different ways according to the situation. For instance, it could be by keeping track of ambient exposure in a given place of work and of people who frequented it, so as to be able to assess the doses of a given worker retrospectively if necessary. It could also be carried out by registering individual doses in the dedicated sheet in the medical record of each concerned worker.

(98) *Health surveillance*: in some industries involving NORM there is already a health surveillance programme for non-radiological reasons. It is considered unlikely that health

surveillance specifically for radiological protection purposes will be required, except in a very few cases where annual doses well above a few mSv per year are repeatedly received. If this is the case, then it is expected that existing provisions for the health surveillance of workers occupationally exposed to radiation will be used, and will be sufficient.

(99) Most of these requisites can be implemented more or less thoroughly. Workers are likely to be considered as occupationally exposed when, despite all reasonable efforts to reduce exposure, elevated individual doses persist and when the application of special working procedures are needed to perform the job. In such cases, education and training, individual radiation dose monitoring and recording, or health surveillance for radiological protection purposes may all need to be implemented as described in ICRP *Publication 75* (ICRP, 1997).

4.2. Protection of the public

(100) The general approach to the protection of the public should also start with a characterisation of the exposure situation (who is exposed, when, where and how), including analysis of exposure pathways and dose assessments. This characterisation forms the basis for the justification of a protection strategy. Then the optimisation process should be implemented, including the selection of a reference level, the selection and the implementation of the protective actions, the involvement of stakeholders in the decision-making process and the provision of a long-term monitoring of the situation if necessary.

(101) This process should be implemented in a reasonable way, keeping in mind the ethical values of beneficence/non-maleficence, prudence, justice and dignity. In more complex situations, working with stakeholders to identify their underlying interests for each ethical value can be very useful in working towards an acceptable and sustainable solution.

(102) The reference level for the protection of the public should be selected below a few mSv per year. In some cases of public exposure for industries involving NORM, a reference level less than 1 mSv per year may, in fact, be the most appropriate taking into account the distribution of doses that exists. The protection of the public should be addressed as a whole, i.e. taking into account the different pathways. In a given situation, the pathways need to be considered with respect to NORM discharge, waste, residue and possible legacy sites. In practice, the most exposed individuals to each pathway belong to different groups so that the reference level can generally be applied to any given pathway. The reuse and recycling of NORM residues may be starting point of a new NORM process.

4.2.1. Discharges from industries involving NORM

(103) Liquid and gaseous radioactive and/or non-radioactive effluents may be deliberately discharged from the normal operation of industries involving NORM. Radionuclides may also be precipitated onto particles in the stream of liquid or gaseous effluents (aerosols). In certain cases, such as oil and gas extraction, the phosphate processing industry and the combustion of coal, NORM discharges have been an issue for the protection of both people and the environment. Therefore, effluents should be properly controlled taking into account the radiological and non-radiological impacts and, if necessary, restricted in order to protect the public and the environment.

(104) A comprehensive site-specific control of the discharge should, from a radiological protection point of view, include the following steps:

(a) Radiological characterisation of discharge;

(b) Identification of potential exposure pathways and radionuclides mobility;
(c) Dose assessments and risk estimation;
(d) Justification of measures to control discharge;
(e) If so, selection of a reference level, and;
(f) Selection and implementation of measures within a protection strategy through an optimisation process (ALARA).

(105) The protection strategy should include preventive actions aimed at eliminating or reducing the quantity and the concentration of discharges, as well as mitigation actions aiming at reducing the impact of the discharge in term of public and environmental exposures. The optimisation process and the involvement of stakeholders are case specific and depend, in practice, on the operational characteristics of the NORM facility, discharge processes, radioactivity levels and estimated risk, the public groups involved, as well as societal and political aspects and public awareness. Optimisation in practice can be complex due to the fact that some processes such as effluent treatment may lead to the production of further waste in which there are increased concentrations of radionuclides, or else produce an increase in the overall volume of waste produced.

(106) Attention should also be paid to the issue of drinking water, to the environmental impact (see below), current and future land use in the area and to the possible presence of several facilities in the same area.

(107) The use of reference levels translated into a measurable quantity (for example, in terms of total activity and/or activity concentration) may be appropriate for industries involving NORM.

4.2.2. Waste

(108) Waste, both liquid and solid, is material with no further planned use. Industries involving NORM can produce wastes containing both radioactive and non-radioactive pollutants: both should be managed consistently. Globally, industries involving NORM produce waste ranging from small volumes of waste with high concentrations of radionuclides to large volumes of waste with low concentrations of radionuclides.

(109) All waste should be characterised in order to determine the proper methods for disposal. Waste treatment should be considered and performed as relevant in the optimisation process, although concentration of wastes to high levels can pose challenges. The issue of waste should be considered from its generation to final disposal when starting or designing a new project (‘from cradle to grave’).

(110) The method of disposal of NORM waste should be proportionate to the type and the level of hazard taking into account all types of pollutants in the presence (radioactive and non-radioactive). Depending on level of radioactivity and volume of waste, a graded approach should apply. Some waste could be treated as industrial or hazardous waste and disposed of accordingly in near surface landfills. The disposal of waste with higher concentrations of radionuclides should be consistent with the management of radioactive waste.

4.2.3. Residues

(111) Residues are materials which can be recycled and re-used. They are mainly coming from upstream of the NORM cycle (exploration, extraction of material) and the activity concentration in the residues may be significantly enhanced compared to the raw material. Like waste, they should be characterised and properly stored before potential reuse. There are

economic and ecological arguments for finding a use for NORM residues. By-products and residues of a given industry involving NORM can be used as feedstock by other industries involving NORM, as land-fill (if there are no chemical hazards or pathways to groundwater), and/or in commodities (e.g. building materials). Using residues as feedstock may be the starting point of a new NORM process. Recycling or re-use helps to reduce waste volumes. However, in some cases, it could result in exposure of workers, the public and the environment. Residues that are stockpiled for any length of time should be properly managed to prevent environmental contamination.

(112) The implementation of a protection strategy should be considered for reuse or recycling of NORM residues. The assessment should take account of various elements such as the level of exposure, the pollution of the environment, the alternatives, the future of the products or the societal acceptance. In rare cases, based on this assessment, the new process may not be justified and the residues may need to be treated as waste.

(113) When a protection strategy is justified, optimisation should be considered recognising that the scope for dose reduction may be limited.

4.2.4. Building materials

(114) Building materials may contain natural radionuclides originating from raw materials (e.g. extracted from quarries) or residues from industries involving NORM or a mixture of materials some of which are naturally radioactive (e.g. concrete). They can cause public exposures by direct external gamma radiation and by releasing radon into indoor air. Occupational exposures in the manufacture and handling of building materials are usually low but they should be managed in a graded approach as in any other industry involving NORM.

(115) The reference level for building materials should be of the order of 1 mSv y^{-1}, or less, expressed as effective dose caused by external gamma radiation to members of the public. A reference level of this order should also ensure that any radon exhalation from ^{226}Ra in building materials is unlikely to be the cause for the reference levels set for indoor radon concentration to be exceeded. The exhalation of thoron is not expected to be of concern. Radon exposures should be managed in line with *Publication 126* (ICRP, 2014b) irrespectively of its origin.

(116) Lists of building materials, raw materials and residues of concern may be found in various publications (EURATOM, 2013; IAEA, 2015). There are also different methodologies for screening building materials of concern and for assessing the dose caused by building materials (EC, 1999b; IAEA, 2005; EURATOM, 2013). A common screening method is the use of an activity concentration index derived from the reference level, the value of which is calculated on the basis of the concentrations of ^{226}Ra, ^{232}Th and ^{40}K. Where the value of the index is less than 1, the dose level of 1 mSv per year cannot be exceeded under any circumstances. Because of its very conservative assumptions, the index does not, however, provide information on the actual exposure caused by a building material. For assessing the dose, more elaborate methods need to be used in order to consider the actual concentrations and locations of a certain building material in a building (EC, 1999b; EURATOM, 2013; IAEA, 2015).

(117) A protection strategy should be established with the aim to promote building materials that do not exceed the reference level. The strategy may encompass measures such as providing information on the levels of exposure caused by different building materials, labelling of materials, suggesting the use of materials with low radioactive concentration or limiting the use of certain materials causing significant exposures. In keeping with the ethical

value of beneficence/non-maleficence, it is important to ensure that the measures envisaged are actually reasonable and feasible before deciding on them.

(118) Special attention should be paid to processes where residues with exceptionally high activity concentrations are incorporated into building materials. They should not be implemented for the purpose of intentional diluting or for bypassing more stringent requirements on the appropriate management of such residues. This applies irrespective of whether the reference level for building materials might be exceeded.

(119) There may be a need to apply a similar approach for other construction materials such as those used for foundations of houses, surfaces of yards, playgrounds, streets and roads, as well as, bridges and other similar structures. Dose assessments and separate derived activity concentration indexes may need to be considered.

4.2.5. Legacy sites

(120) Industries involving NORM account for many current legacy sites with radioactive contamination. NORM legacy sites have been identified more frequently with the rising awareness of industries involving NORM and related radiological protection issues. This situation shows that the dismantling of facilities when shutdown is sometime not sufficiently considered from a radiological protection point of view. Technologies and methods already exist and should be implemented in order to avoid legacy sites.

(121) The issue of legacy sites is in the scope of a future ICRP Publication in preparation, therefore the present publication provides only a few general considerations. The assignment of responsibility or liability for maintenance and remediation of old legacy sites may be an issue due to the elapsed time and often lost information. Sites with no known responsible party are often called orphan sites. New legacy sites should be avoided through a proper dismantling of the industries involving NORM and durable administrative control if necessary.

(122) The justification of the remediation of legacy sites is not only driven by radiological protection considerations. As in active industries involving NORM, other hazards such as heavy metals may also be present. The reference level should be in the lower range of the band 1-20 mSv y^{-1}. The reference level is not the endpoint of the remediation. The endpoint should be an optimised level of dose below the reference level, determined on a case by case basis taking into account the prevailing circumstances (including the situation pre-disturbance), the future use of the site (when it can be predicted) and the possible conditions (or restrictions) of use.

(123) The implementation of the optimisation principle is often a challenge, for example because it is occasionally difficult to make a distinction between NORM contamination and the natural background radioactivity. The challenge may also be due to a lack of societal acceptance. The involvement of stakeholders in the decision process is of great importance for the management of legacy sites.

(124) The workers involved in the remediation process may need to be specifically trained for working with radiation. As such, they should be considered as occupationally exposed.

(125) If common workers or members of the public are participating in the remediation (in their home or in places open to the public), relevant information and recommendations should be communicated to them as well as some protective equipment, such as dust masks, as relevant.

4.3. Protection of the environment

(126) Large quantities of NORM may be present in the environment in form of mixed material together with other contaminants. Through the time, different geochemical and physical processes in the environment disturb the NORM radionuclides equilibrium. It is well known that mechanisms such as selective dispersion, leaching and transfer, fractionation, bioaccumulation, and reaction with other contaminants can result in changes in environmental impact over time. In this kind of environmental exposure, it can be difficult to use a simple approach for risk assessments to evaluate the possible risk and effects for the non-human species.

(127) The optimisation process should address the protection of the environment, i.e. the protection of non-human species and not only the prevention of exposure of humans through environmental pathways (ICRP, 2007a). Mechanisms to control releases of effluents, in particular, can be informed by the prediction of dose for non-human biota. The selected controls, may, or may not, be specifically driven by radiological protection for non-human species, but the relative contribution for different options is useful information. However, the information on elevated NORM activity concentration in the certain environmental compartment does not necessarily mean effects in non-human species, and the assessment of impact must consider a variety of factors beyond just the estimated dose.

(128) Over last decades, considerable international and national efforts have been made to develop an approach for radiological protection of the environment. To raise awareness about radioactivity in industrial activities has become important at both national and international levels. Industries involving NORM have been generally following common standards to protect the environment from other pollutants than radioactivity. Depending on the legal requirements, an environmental impact assessments (EIA) may be performed to demonstrate compliance with environmental standards. Radiological impact from NORM should be included in an EIA. In situations where there is not the requirement to perform an EIA, a specific assessment for NORM should be considered including both radiological and non-radiological impact and provide an input to decisions on controls.

(129) The EIA should consider the total impact of NORM activity, which for the specific purpose of protecting the environment from the harmful effects of radiation entails:

(a) Radiological characterisation of NORM discharge, including the data on background NORM levels;
(b) Identification of environmental pathways and mobility of radionuclides;
(c) Analyses of key non-human species uptake;
(d) Modelling and evaluation of potential radiation effects to doses by using the approach with Reference Animals and Plants (RAPs), Representative Organism and the corresponding bands of derived consideration reference levels (DCRL), or specific environmental reference levels derived for the purpose of the assessment (ICRP, 2008, 2014b);
(e) Risk estimation, taking into account the actual species present or likely to be present, and management using the appropriate reference levels to inform optimisation decisions.

(130) For radiological characterisation of NORM released in the environment, it is necessary to perform the site-specific analysis of radionuclides with respect to their physical and chemical forms and activity concentrations in source, but also at environmental media of concern (air, water, sediment, soil). To be able to assess exposure of non-human species, it is further necessary to identify the mobility of radionuclides, their spatial and temporal variation, environmental pathways to plants and animals and their bioavailability. An approach with reference animals and plants (RAPs) and derived consideration reference

levels has been developed (ICRP, 2008, 2014b). Dosimetry models to calculate specific exposure doses from chosen radionuclides and for ecosystems and organisms of concerns have been available for site-specific use. A degree of precaution may be considered necessary because of the importance of the site or habitat, or the importance of the actual species present or likely to be present. It is important to note that, in many cases, other constituents are which present hazards to plants and animals will also be present. The Commission emphasises its recommendations that an all hazard approach be undertaken.

(131) Regarding dose criteria for protection of non-human species, risk characterisation and proper optimisation, bands of environmental derived consideration reference levels can be considered as reference dose rates intervals within which there is some chance of deleterious effect from ionising radiation occurring to individuals of that type of RAPs.

(132) The EIA can be used as a basis for the justification of actions aiming at the protection of non-human species, practically of the need to further restrict discharges. The involvement of stakeholders is recommended. The long-term preservation of the environment is a global concern of the society, to which the application of the ethical values of radiation protection can usefully contribute.

(133) When dealing with NORM discharges in the environment, special requisites concerning radionuclides, time interval for analysis, samples to be analysed, organisms of concern, record keeping, and monitoring plan should be specified by considered in order to ensure the protection of the non-human species. Long-term environmental monitoring should be performed for regular check if the protection criteria are still met.

5. CONCLUSIONS

(134) NORM in industrial processes may be an issue from a radiological protection point of view. The corresponding industries are diverse, they do not correspond to a sector in itself, and they are generally big industries of economic importance. The way to address radiological protection in industries involving NORM has been a concern for some decades. It is a matter of justice and equity, which are ethical values of the system of radiological protection, to consider radiological aspects as well as other industrial and chemical hazards. Doses from industries involving NORM are variable, but they can be comparable, or greater than, those arising from other human activities already applying the system of radiological protection.

(135) Industries involving NORM are generally licenced, although in most cases not for radiological purposes, and these industries are used to managing risks. They should be able to apply the criteria and requisites set for radiological protection purpose. However, experience shows that the system of radiological protection is very specific and perceived to be difficult to include in the management of other hazards. In such a context, the Commission recommends a realistic and pragmatic attitude.

(136) Industrial processes using NORM, although diverse, have specificities that have to be taken into account in a protection strategy. Often, such industries have been on-going for a long time, while the concern about radiological protection is relatively recent. They are multi-hazards situations and in most cases the radiological risk is not dominant. While industries involving NORM have experience in risk management, they have generally a poor awareness of radiological protection; this can and should be developed. Industries involving NORM can cause damages requiring remediation; however, they present no real prospect of a radiological emergency.

(137) Industries involving NORM may need to be controlled, and the system of protection, including the principles of justification and optimisation of the protection, as well as the corresponding dose criteria and requisites, can be applied. In order to be adapted to the features of industries involving NORM, the Commission recommends considering as a starting point the protection strategies already implemented by these industries to manage the hazards they are facing and then estimating, after characterisation, the need for further action for the protection against radiation. Such integrated approach can then be graded with a proper balance between the different hazards, adopting a reasonable and prudent attitude and taking into account economic and societal consideration. The involvement of the relevant stakeholder in the decision process is also crucial.

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ANNEX A. ACTIVITIES GIVING RISE TO NORM EXPOSURES

(A 1) The main activities giving rise to NORM exposure are the following.

(A 2) **Extraction of rare earth elements**. The most important source of rare earth elements are monazite (Ce, La, Nd, Th)PO_4 and bastnaesite. The crystal structure of monazite accepts uranium and thorium and is the most common radioactive mineral on Earth. Activity concentration ranges from 5,000 – 350,000 Bq kg^{-1} of ^{232}Th, and 10,000 – 50,000 Bq kg^{-1} of ^{238}U (UNSCEAR, 2008). During the extraction process to obtain rare earth elements (by mechanical or chemical means), inhalation of dust and external gamma radiation to workers may occur. Furthermore, effluents, residues and waste from the extraction process contain thorium, radium and uranium at concentration higher than in the feedstock (EC, 1999a). Waste in the form of mill tailing can be used for landfill material or may need specific management.

(A 3) **Production and use of metallic thorium and its compounds**. Thorium under an oxide form occurs in many minerals, notably monazite. It can be extracted by concentrating minerals and decomposing them with acid to obtain thorium salts; which is the raw material for the production thorium under metallic form. Thorium is used in a number of materials, usually as an additive (e.g. thoriated tungsten isolated welding electrodes, that usually contain 100,000 Bq kg^{-1} of ^{232}Th and ^{228}Th (EC, 1999a)) or alloy (e.g. magnesium thorium used in jet engines; activity about 70,000 Bq kg^{-1}) and as thorium nitrate in the manufacture of gas mantles. Small quantities of thorium can be found in many products: glass, airport runaway lights, lamp starters etc. Producing material containing thorium can give rise to external gamma exposure and internal exposure through the inhalation of dust. The process also generates solid wastes and effluents that may need to be monitored and controlled.

(A 4) **Mining and processing of ores (other than uranium)**. According to International Labour Organization, mining is an extensive industry that account for about 1 % of the world workforce (that is to say about 30 million workers, including some 12 million in the coal mining). The main source of exposure in mining operation is radon, however, exposure due to long-term radionuclides through gamma external exposure and the inhalation and ingestion of mineral dusts can be important in certain situations.

(A 5) The processing of ores may be also concerned by the use of NORM and the exposure situations for workers differ considerably with respect to the type of industry, the conditions at workplaces, the radionuclides involved and their physical and chemical forms etc. The natural radionuclides involved in extractive industries end up in the products and/or in the effluents and/or wastes. Sediment discharges in waste water into the environment have been measured with activity up to 55,000 Bq kg^{-1} of ^{226}Ra and 15,000 Bq kg^{-1} of ^{228}Ra (IAEA, 2003).

(A 6) **Extraction of oil and gas**. The water contained in oil and gas geological formations contains ^{228}Ra, ^{226}Ra and ^{224}Ra dissolved from the reservoir rock, together with their decay progenies. When this water is brought to the surface with the oil and gas, changes in temperature and pressure can lead to the precipitation of radium rich sulphate and calcium carbonate scales on the inner walls of production equipment (pipes, valves, pumps etc.). Depending on the age of the scale, significant amount of ^{210}Pb and ^{228}Th may grow in with their respective radioactive parents (IAEA, 2006). In any case, the activity concentrations in scale are difficult to predict and activity concentration has been reported as being less than 1,000 to around 1,000,000 Bq kg^{-1} of ^{226}Ra (EC, 1999a). The radium isotopes and their progeny can also appear in sludges in separators and skimmer tanks (more details can be found in Table 5 of IAEA (2003)). The main radiological protection issue associated with the scale are external gamma exposure of workers, especially where scales are deposited and internal exposure by staff removing the scale during maintenance and decommissioning. Figures related to activity concentration in oil, gas, scale and sludge are given in Table A.1 (IAEA, 2003, 2011).

(A 7) Operators may try to prevent deposition of scales through the application of chemical scale inhibitors in the water. As a result, the radium isotopes will pass through the production system and be released with the produced water. In the same way, the new technique of 'fracking' (hydraulic fracturing) for gas production also releases NORM in drill cuttings and water. For example, US Geological Survey shows median activity concentration for produced water of 200 Bq L^{-1} (USGS, 2011).

Table A.1. Range of concentrations of radionuclides in oil, gas and by-products.

	Crude oil (Bq kg^{-1})	**Natural gas** (Bq m^{-3})	**Produced water** (Bq L^{-1})	**Hard scale** (Bq kg^{-1})	**Sludge** (Bq kg^{-1})
^{238}U	0.0001 – 10		0.0003 – 0.1	1 – 500	5 – 10
^{226}Ra	0.1 – 40		0.002 – 1200	100 – 15,000,000	5 – 800,000
^{210}Po	0 – 10	0.002 – 0.08		20 – 1500	4 – 160,000
^{210}Pb		0.005 – 0.02	0.05 – 190	20 – 75,000	100 – 1,300,000
^{222}Rn	3 – 17	5 – 200,000			
^{232}Th	0.3 – 2		0.0003 – 0.001	1 – 2	2 – 10
^{228}Ra	3 – 17		0.3 – 180	50 – 2,800,000	500 – 50,000
^{224}Ra			0.5 – 40		

(A 8) **Manufacture of titanium dioxide**. Titanium can be extracted from ilmenite (which contain monazite as impurity) and rutile which may contain elevated levels of both ^{232}Th and ^{238}U. The radiological exposure from titanium dioxide production varies with the type and source of ore and the process. Ore concentration activity of ^{238}U and ^{232}Th ranges from 7 to 9,000 Bq kg^{-1} (EC, 1999a). The separation process could give rise to radiological hazards from dust inhalation and external gamma radiation emanating from large stockpiles of material. Precipitate containing isotopes of radium may occur during the process and be found in the waste (at activity concentration up to 1,600,000 Bq kg^{-1} (IAEA, 2006)).

(A 9) **The phosphate processing industry**. Phosphate rock is the starting material for the production of all phosphate products and is the main source of phosphorous for fertilisers. The radionuclides content of the ore varies greatly depending of its origin (IAEA, 2003) and is generally less than 3,000 Bq kg^{-1} of uranium. The phosphate processing can be divided into the mining and milling of phosphate ore – there is no significant enhancement of activity concentration during this phase, but exposure through inhalation and external exposure may occur – and the manufacturing of phosphate products by wet or thermal process.

(A 10) Most phosphate rock is treated with sulphuric acid to produce phosphoric acid (wet process). The phosphoric acid can be combined with ammonia to make ammonium phosphate which is the basis of mixed fertiliser. The production of phosphoric acid generates large quantities of phosphogypsum – evidence suggests that radium isotopes are more readily retained in the phosphogypsum (EC, 1999a). Phosphogypsum is also used as building material and in agriculture. Environmental protection issues (regarding radiological impact and toxicity) may arise from the disposal of phosphogypsum in stockpile or by discharge into surface water bodies.

(A 11) Furthermore, radium scales and sediments can be formed inside equipment during the wet process, and the radium activity concentrations in the scales vary from values similar to those in the original ore up to 1,000 times greater (IAEA, 2006), leading to possible exposure by external gamma radiation and/or inhalation of dust during maintenance and decommissioning.

(A 12) In the thermal process, phosphate is crushed and mixed with silica and coke to be burnt in furnace at 1500° C. At this temperature, phosphorus vapour is produced and can be condensed and removed as liquid or solid. The elemental phosphorus can be used for the production of high purity phosphoric acid and other phosphorus products. During this process, volatile radionuclides like ^{210}Pb and ^{210}Po are produced as well and become concentrated in the precipitator (typical concentration are 50,000 to 500,000 Bq kg^{-1} (EC, 1999a)) while thorium and uranium are retained in the slag (activity concentration ranges between 1 and 3000 Bq kg^{-1}). Dust and slag may present NORM exposure to workers and to public when used as construction material in cement.

(A 13) **The zircon and zirconia industries**. Zircon (or zirconium silicate) is recovered from beach sands. The sand is pre-processed in very large quantities by gravimetric and electromagnetic sorting to separate the mineral sands. Exposure from NORM to workers may arise due to the inhalation of dust and external irradiation from the large amount of material. When chemical processing of zircon is used, effluents may contain NORM. A very large range of activity concentrations are reported for zirconium silicate, from 200 – 74,000 Bq kg^{-1} of ^{238}U and 400 – 40,000 Bq kg^{-1} of ^{232}Th (EC, 1999a; IAEA, 2012). Most zircon sand is used as opacifier in fine ceramics, enamels, glazes and sanitary ware. Zircon sands can also be manufactured as refractory component by mixing the sand with alumina and sodium carbonate and smelting the mixture. ^{210}Pb and ^{210}Po are volatilised and end up in the fume collection system (up to 200,000 Bq kg^{-1} of ^{210}Pb and 600,000 Bq kg^{-1} of ^{210}Po (IAEA, 2006)).

(A 14) **Production of metal**. Largely depending on the origin of metal ore, the extraction of many metals may give rise to exposure to NORM because smelting and refining at high temperatures may volatilise ^{210}Pb and ^{210}Po from ore that can lead to exposure by inhalation during the process and later when these radionuclides have been precipitated and concentrated (up to 200,000 Bq kg^{-1} (IAEA, 2006, 2013)). Non-volatile radionuclides may be concentrated in the slag (concentration range from less than 1000 to more than 10,000 Bq kg^{-1}). Such exposures could be found in the production of tin, copper, iron, steel, aluminium, niobium/tantalum, bismuth, etc.

(A 15) **Extraction and combustion of coal**. Most fossil fuels and notably coal contain uranium and thorium and their decay products, as well as ^{40}K. The activity concentrations are generally not elevated and depend on the region of origin and its geology (examples of figures are given in p. 184 of UNSCEAR (2016)). However, UNSCEAR 2016 estimated that occupational exposure due to coal mining was 23,000 man.Sv for the 2002-2003 period and that annual average effective dose for Chinese coal miners (90% of the workforce) was 2.75 mSv per year. Due to the amount of material, the quantities of radionuclides involved are noteworthy. For example, over 8,000 millions of tons of coals where extracted in 2014 (according to British Petroleum Statistical Review of World Energy) and by considering the lower values of 4 ppm of uranium and 10 ppm of thorium, 32,000 tons of uranium and 80,000 tons of thorium can be considered as being extracted as well.

(A 16) The combustion of coal fuel to produce heat and electricity will generate fly ash and the heavier bottom ash or slag. The concentration of radionuclides in the bottom ash and slag tends to be higher than in the coal (around 10 times), but generally do not exceed 5,000 Bq kg^{-1} (IAEA, 2006) – range of radionuclides activities in ashes are presented in Table A.2

(UNSCEAR, 1982). The volatile materials such as lead and polonium can be released to the atmosphere or, in modern power stations, retained and can accumulate in fly ash as well as the inner surface of the burner (^{210}Po activity concentration above 100,000 Bq kg^{-1} in the deposited scale have been reported). Gas desulphurisation results in additional sludge and gypsum. The use of coal combustion residues (ash, gypsum) in cement or concrete is a worldwide practice.

Table A.2. Ranges of radionuclides activities in coal ash and slag.

	Potassium (Bq kg^{-1})	**Thorium series** (Bq kg^{-1})	**Uranium series** (Bq kg^{-1})
Bottom ash (slag)	240 – 1200	44 – 560	48 – 3900
Fly ash (collected)	260 – 1500	30 – 300	30 – 2000
Fly ash (escaping)	260	100 – 160	20 – 5500

(A 17) **Water treatment**. Treatment of underground water is a common practice to remove salts and other contaminants. Various processes may be used; such as filters or ion exchange resins. Radionuclides of natural origin present in the water may accumulate in water treatment wastes (filter sludge). The activity concentration in such waste is generally moderated but can reach 10,000 Bq kg^{-1} (IAEA, 2006).

(A 18) **Building materials**. The use of some building materials may lead to elevated indoor radiation levels when they contain elevated levels of radionuclides including particularly ^{226}Ra, ^{232}Th and ^{40}K. The building material may be of natural origin or contain materials derived from industrial processes such as those listed above. Values for activity concentration in Bq kg^{-1} in some building materials are given in Table A.3 (UNSCEAR, 1982; IAEA, 2003).

(A 19) Activity concentration guidelines for the use of NORM in building material have been developed in Europe through the use of an Activity Concentration Index, ACI, considering ^{226}Ra, ^{232}Th and ^{40}K activity in the material (EC, 1999b; EURATOM, 2013).

Table A.3. Examples of activity concentration in Bq kg^{-1} for some building materials.

Material	**^{226}Ra**	**^{232}Th**	**^{40}K**
Concrete	1 – 250	1 – 190	5 –1570
Aerated concrete	11,000	1 – 220	180 – 1,600
Clay bricks	1 – 200	1 – 200	60 – 2,000
Sand-lime bricks and sandstone	18,000	11,000	5 – 700
Natural gypsum	<1 – 70	<1 – 100	7 – 280
Granite	100	80	1,200
Lithoid tuff	130	120	1,500
Pumice stone	130	130	1,100
Cement	7 – 180	7 – 240	24 – 850
Tiles	30 – 200	20 – 200	160 – 1,410
Phosphogypsum	4 – 700	19,000	25 – 120
Blast furnace slag stone and cement	30 – 120	30 – 220	-

(A 20) **Legacy sites**. There are also several sites with residues from former installations around the world. Most of these sites are contaminated with natural radionuclides from former industries involving NORM. In some cases, these sites have been identified and successfully remediated. However, it is almost certain that a significant number of contaminated sites from former industries involving NORM have yet to even be identified.

(A 21) From the above paragraphs, industries involving NORM process a wide range of raw materials with large variation of activity concentrations, producing a variety of products, by-products and wastes, which also have an even larger variation in activity concentrations. These industries may or may not be of concern depending on the activity concentrations in the raw materials handled, the processes adopted, the uses to which final products are put, the re-use and recycling of residues and the disposal of wastes.

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GLOSSARY

Adventitious

Happening as a result of an external factor or chance rather than design or inherent nature. In this report, the word is used in a sense close to inadvertent, coincidental, unintentional, unintended.

Categories of exposure

The Commission distinguishes between three categories of radiation exposure for humans: occupational, public, and medical, and also considers environmental exposure for flora and fauna. Distinction made between human and non-human biota takes into account the context in which they are exposed.

Contamination

The presence of unwanted levels of radioactive material on or in structures, areas, objects, biota and people.

Discharge

Controlled release of (usually gaseous or liquid) radioactive material to the environment.

Dose criteria

Quantitative values for the practical implementation of the radiological protection system, expressed in terms of dose or derived quantities.

Effluent

Fluid - treated or untreated - that flows out of a treatment plant, sewer, or industrial outfall.

Emergency exposure situations

An exposure situation resulting from a loss of control of a source, or from intentional misuse of a source, which requires urgent and timely actions in order to avoid or mitigate exposure.

Employer

An organisation, corporation, partnership, firm, association, trust, estate, public or private institution, group, political or administrative entity, or other persons designated in accordance with national legislation, with recognized responsibility, commitment, and duties towards a worker in her or his employment by virtue of a mutually agreed relationship. A self-employed person is regarded as being both an employer and a worker.

Environmental exposure

Radiation exposure of biota in the natural environment resulting from human activities.

Environmental reference level

This term refers to the Derived Consideration Reference Level (DCRL) introduced in *Publication 108*, which is a band of dose rate within which there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals of that type of reference animal or plant (derived from a knowledge of defined expected biological effects for that type of organism) that, when considered together with other relevant information, can be used as a point of reference to optimise the level of effort expended on environmental protection, dependent upon the overall management objectives and the relevant exposure situation.

Existing exposure situations

An exposure situation resulting from a source that already exists, with no intention to use the source for its radioactive properties, before a decision to control the resulting exposure is taken. Decisions on the need to control the exposure may be necessary but not urgent.

Exposure pathway

A route by which radiation or radionuclides can reach humans and non-human biota and cause exposure.

Graded approach

The scheme recommended for implementing the system of radiological protection in a way that is proportionate to the magnitude and likelihood of the risk, and the complexity of the exposure situation and the prevailing circumstances.

Medical exposure

Exposure incurred by patients as part of their own medical or dental diagnosis or treatment, by persons, other than those occupationally exposed, knowingly, while voluntarily helping in the support and comfort of patients; and by volunteers in a programme of biomedical research involving their exposure.

Member of the public

Any individual who is subject to a public exposure.

NORM (naturally occurring radioactive material)

Material containing no significant amounts of radionuclides other than naturally occurring radionuclides, in which the activity concentrations of the naturally occurring radionuclides have been changed by some process and giving rise to enhanced exposure to human and non-human species.

Occupational exposure

Exposure incurred by individuals as a result of their work in circumstances for which the exposure can be reasonably considered as deserving to be managed individually. This has to be evaluated on a case by case basis. There is no single answer that is always applicable. It is a value judgement. Factors to be considered include the level of exposure, the potential for unforeseen circumstances or large exposures because of the characteristics of the source.

Operating management

The person or group of persons that directs, controls, and assesses an organization at the highest level. Many different terms are used, including chief executive officer, director general, managing director, and executive group.

Planned exposure situations

An exposure situation resulting from the deliberate introduction and operation of radiation sources, used for their radioactive properties. For this type of situation, the use of the source is understood, and as such the exposures can be anticipated and controlled from the beginning.

Principle of justification

Decisions that alter (i.e. introduce, reduce or remove) the radiation exposure situation should, overall, do more good than harm. This means that, by introducing a new radiation source, or by overall reducing existing or emergency exposures, one should achieve sufficient individual or societal benefit to offset any harm including radiation detriment to humans and the environment.

Principle of optimisation

The likelihood of incurring exposures, and the magnitude of their individual doses, should be kept as low as reasonably achievable, taking into account societal, economic and environmental factors. In order to avoid inequities in the dose distribution, there must be consideration of the number of people exposed and restrictions on individual doses.

Protection strategy

The set of combined protective actions implemented, for a given exposure situation and prevailing circumstance, to keep or reduce exposure as low as reasonably achievable.

Protective action

Action taken in an exposure situation to reduce or prevent exposure. The action can be taken at the source, at points in the exposure pathway, or occasionally by modifying the location, habits or working conditions of the exposed individuals.

Public exposure

Exposure incurred by individuals from radiation sources, other than occupational and medical exposure.

Reference animal or plant

A hypothetical entity, with the assumed basic biological characteristics of a particular type of animal or plant, as described to the generality of the taxonomic level of Family, with defined anatomical, physiological, and life-history properties, that can be used for the purposes of relating exposure to dose, and dose to effects, for that type of living organism.

Reference level

The value of dose used to drive the optimisation process in existing and emergency exposure situations. The value of a reference level will be selected within the bands recommended by the Commission according to the prevailing circumstances. This selection should consider the actual individual dose distribution, with the objective of identifying those exposures that warrant specific attention and should be reduced as low as reasonably achievable.

Representative organism (non-human biota)

An organism or group of organisms receiving a dose that is representative of the doses to the most exposed individuals in an exposed group from a given source, excluding extreme habits.

Residue

Radioactive materials that have remained in the environment from early operations and from accidents. Residue from one industry may be used as feedstock in another industry, and as such are not classified as waste.

Stakeholder

A stakeholder is a person, a group or organisation with an interest or concern in an issue.

Waste

Any radioactive material that will be or has been discarded, being of no further use.

Worker

Any person who is employed or self-employed, whether full time, part time or temporarily, by an employer, and who has recognised rights and duties in relation to her/his job.

ACKNOWLEDGEMENTS

At its meeting in Berlin (Germany) in October 2007, the Main Commission of the International Commission on Radiological Protection (ICRP) approved the formation of a Task Group 76, reporting to Committee 4, to develop guidance on radiological protection against exposure from naturally occurring radioactive material (NORM).

The terms of reference of the Task Group were to develop a report on the application of the 2007 Commission's recommendations (ICRP, 2007a) on radiological protection of workers, the public and environment to exposures resulting from industrial processes with NORM. The aim of the Task Group was to develop recommendations to cover the broad range of activities associated with the processing, manufacturing or use and disposal of materials with enhanced levels of naturally occurring radionuclides. The report should also clarify the issues concerning the type of exposure situation, the categories of exposure, and the basic principles to be applied for the management of NORM.

The initial membership of Task Group 76 was as follows:

P. Burn, Chair	G. Loriot	L. Setlow
A. Canoba	M. Markkanen	
A. Liland	S. Romanov	

The corresponding members were:

Å. Wiklund	D. Wymer

A new membership was designated in 2013, as follow:

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D. da Costa Lauria	F. Liu	
P. Egidi	M. Markkanen	

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Committee 4 critical reviewers were:

A. Canoba	T. Pather (2013-2017)	Gillian Hirth (2017-2021)

Main Commission critical reviewers were:

C-M. Larsson	S. Romanov

In addition, Sylvain Andresz (CEPN) acted as secretary of the Task Group and provided fruitful scientific assistance. A helpful contribution was also received from Luiz Matta, Jelena Popic, Bo Wang, a French mirror group, and through the ICRP consulting process.

The membership of the Main Commission at the time of approval of this publication was:

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