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Report on scientific rationales for improving regulatory approaches of NORM treatment and management

Work Package 5

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Executive Summary

The primary objective of Task 5.5 as a part of Work Package 5 (WP 5) was to describe standards and regulatory approaches focused on radiation risk mitigation measures applied in NORM involving industries and facilities and suggest their further development aiming at improved level of radiation protection for workers, the general public and the environment. The activities undertaken focused on reviewing, evaluating, and improving the overall mitigation of hazards caused by naturally occurring radionuclides (NOR) present at various stages of industrial processes. These hazards affect workers in NORM-involving industries as well as members of the public in situations where radioactive substances containing natural radionuclides are released from workplaces in operation (i.e. NORM site) in the form of waste. Attention was also given to risks to the population in cases where natural radionuclides are released in an uncontrolled manner or are part of legacy site. The scope of interest also included existing situations in which legacy site and its subsequent remediation efforts affects not only humans but the environment as a whole.

The industries, currently considered as NORM-involving, has existed for centuries, with particularly intensive operations over the past 200 years. However, systematic application of radiation protection requirements to these activities has only emerged in recent decades. Initially, these measures were applied inconsistently, but since 2019, a harmonised European framework has been established through the implementation of Council Directive 2013/59/Euratom (EU BSSD).

As a result of this regulatory evolution, radiation protection measures for workers at known NORM workplaces are now generally applied correctly, however options for significant improvement still exist. Moreover, exposures of the public remain a challenge – particularly in situations involving release of natural radionuclides in the form of waste, uncontrolled discharges from undocumented NORM activities, legacy contamination from historical industrial burdens.

These scenarios present ongoing challenges for improving radiation protection practices and enhancing the effectiveness of mitigation strategies. Addressing these issues requires not only technical improvements but also greater regulatory clarity, public awareness, and interdisciplinary collaboration to protect both human health and the environment.

While the use of artificial radionuclides typically involves a focused approach to protecting individuals from radiation exposure, the situation in the NORM-involving industry is significantly more complex. Individuals – whether workers or members of the public – are exposed to a broader range of harmful agents and risks, with radioactivity being only one of them. Moreover, radiation protection measures were considered in the overall protection system relatively late, and the affected individuals may not be sufficiently familiar with the associated issues.

From a legal standpoint, parallel regulatory frameworks exist, one addressing non-radiological hazards (e.g. the EU Waste Framework Directive, mining-specific directives, and health and safety at work regulations), and another dealing with radiological hazard (e.g. the EU Basic Safety Standards Directive, Directive on Radioactive Waste). A fundamental challenge is how to effectively combine these parallel systems so that both can be jointly and consistently applied in practice. This combination is particularly relevant in the management of waste, occupational safety, and legacy site remediation.

Additionally, the NORM industry encompasses a wide range of sectors that differ significantly in terms of operational practices. The materials handled are highly diverse, and the technologies used involve a broad spectrum of chemical and physical processes. As a result, a one-size-fits-all approach to problem-solving is probably not feasible.

A specific objective was aimed at developing final treatment strategies for NORM residues/waste based on existing or possible preventive actions and mitigation methods, considering existing circumstances

related to specific NORM-involving industries, technological processes, legacy sites, and environmental conditions and last but not least, NORM specific characteristics.

The knowledge of standards and regulatory approaches for both the radiological and non-radiological protection frameworks enabled us to formulate reasonable and scientifically justified suggestions for possible modifications to the existing system, improving its effectiveness and efficiency towards overall NORM management based on radiation protection principles.

Specific issues considered include:

- **Common (ordinary waste) regulations vs. NORM waste (options analysis and modification suggestions)**

Materials, residues, or waste classified as NORM have existed since the relevant industry began operations and are already subject to regulation and treatment within the framework defined by EU directives on waste and waste from extractive industries. The content of radionuclides is an additional property that has only recently begun to be systematically considered from the perspective of radiation protection. Analysed examples of existing waste treatment systems currently considered as NORM (e.g., red mud, coal combustion products, phosphogypsum) showed that integrating the radiological aspect of NOR into the existing waste management system appears to be the optimal option. In this case, necessary modifications to the existing system of waste treatment are limited to changes in regulation (e.g. adding additional requirements to the waste characterization process) and technical measures for waste treatment concerning radiation protection, particularly with regard to external exposure.

Criteria for assessing exposure connected with NORM waste management are available at the EU level in the EU BSSD. Existing procedures for exposure assessment could be supplemented or simplified by adopting specific clearance levels or derived criteria, as referenced in the body of the report.

Including NORM waste within the existing waste management system provides additional advantages such as:

- use of well-defined terms and processes,
- automatic inclusion of possible interactions with other pollutants/stressors and recovery options,
- utilization of an already developed complete waste management system, including mutual interactions with many other regulations dealing with the environment, occupational safety and health (OSH), classification and management of dangerous substances, and labour law.

An important prerequisite for implementing this approach is to ensure that stakeholders in the waste management sector are made aware that certain types of waste – NORM waste – may contain concentrations of radionuclides exceeding exemption levels, and that this does not necessarily mean the waste qualifies as radioactive waste.

- **Radioactive waste vs. NORM waste**

As the NORM survey showed, NORM residues are often classified as radioactive waste, sometimes regardless of the actual radionuclide activity concentration. This can lead to significant technical, organizational, and finally economic consequences during their disposal and makes recovery or reuse of NORM residues impossible. This occurs despite the fact that the activity levels of NORM waste are typically so low that, from a radiation protection perspective, complex and costly disposal in a radioactive waste repository is not necessary.

An in-depth analysis of the overall legislative context was conducted to identify a binding definition of radioactive waste and to assess its applicability to NORM waste. This analysis led to the conclusion that national authorities have the competence to decide what constitutes radioactive waste – i.e., NORM waste does not necessarily have to be classified as radioactive waste.

The above-mentioned proposal to distinguish between NORM waste with activity levels low enough to allow it to be managed as conventional waste, and radioactive waste takes this legal flexibility into account.

- **Legacy sites**

In the context of proposals suggestion for new options in NORM waste treatment, the issue of NORM-affected legacy sites was addressed. The differences between legacy sites affected by NORM and legacy sites contaminated by artificial radionuclides were emphasised in order to highlight the need for a site-specific approach tailored to NORM-affected areas. This involves, first, the identification of such sites within the large variety of post-industrial areas, and second, a balanced assessment that takes into account the fact that radioactivity is usually not the primary stressor in these environments.

The specific characteristics of NORM-affected legacy sites were discussed in detail to support a rationale for a sustainable approach to their management and remediation, avoiding an overemphasis on radioactivity-related issues.

A fundamental prerequisite for the successful management of NORM legacy sites is the parallel assessment of both radiological and non-radiological risks, including close cooperation between experts from both domains. This ensures that the proposed solution is appropriate for addressing all relevant risk factors as well as for protecting the environment.

- **Optimisation of the approach to regulatory control based on modifying exemption and clearance levels for planned exposure situations and reference levels for existing exposure situations**

Existing exemption and clearance levels are arbitrarily set and expressed in terms of parent radionuclides' activity concentration for the entire decay series. The rationale provided for this is based on a range of NORM activity concentrations observed in the natural environment. However, when applied in practice, these values can be problematic—especially in cases of disequilibrium within decay chains, which is common in NORM, both in wastewaters and solid residues resulting from various chemical processes. Efforts were made to fully characterise NORM, to identify possible disequilibria caused by specific technological processes, and to define typical radionuclides sub-series, and mutual relationships of specific radionuclides to propose optimised and easy-to-use clearance levels expressed in terms of activity concentration of identified, crucial for dose evaluation, members of decay series.
The reason why current exemption and clearance levels for NOR are not coherent with those expressed in terms of effective dose is the absence of a standard exposure scenario that could be universally applied to NORM, unlike in the case of artificial radionuclides. There are several reasons for this. First, as already noted, secular equilibrium cannot be assumed, and each NOR must be assessed individually. This applies not only to external exposure – where the contribution of each radionuclide can differ significantly – but even more to internal exposure. The evaluation of committed dose is based on a summation rule and must be performed for every identified radionuclide present in the material under assessment, regardless of whether equilibrium exists.

To optimise the approach to exemption and clearance levels, it is essential to emphasise that – except for chemically untreated natural materials – disequilibrium should be verified by measurement, and effective dose calculations should include all relevant NOR using a site or practice-specific exposure scenario. Naturally, this also places requirements on appropriate measurement techniques (e.g., gamma spectrometry, alpha spectrometry) and affects the cost of radiological characterisation.

However, in well-characterised and repeatable situations, follow-up measurements may be limited to radionuclides previously identified as relevant.

To simplify practice, it is recommended that for the most common scenarios—such as incineration of residues or landfill disposal under authorised release conditions – derived clearance levels be developed. Compliance with these derived levels would ensure that the general clearance levels expressed in terms of effective dose are not exceeded.

- **Treatment options focused reuse, recycle and on sourcing valuable elements (including radionuclides) or minerals from NORM residues.**

Research on NORM characterization has shown that:

- many types of NORM possess properties suitable for their use in the production of various materials, particularly construction products; and
- the processes that lead to NORM generation – typically involving mass reduction (e.g. combustion, metal smelting) or the accumulation of NORM in specific fractions – also result in the concentration of valuable elements or minerals that can be further recovered.

It is now necessary to create legally and economically favourable conditions for turning such options into practice, as no legal procedures (including approval processes) currently exist to support the reuse of NORM materials—despite strong interest within the EU in maximizing the use of all available resources.

- **The relationship between technical requirements for radiation protection and occupational safety and health (OSH) requirements**

When considered from the perspective of radiation protection in NORM-involving occupational exposure scenarios, the existing European OSH legislative framework may be regarded as complementary to the EU BSSD. It establishes a robust structure of obligations and preventive measures that, in many cases, can be effectively applied to workplaces involving NORM, without requiring substantial legislative revision. The application of standard OSH measures, such as ventilation, dust control, and personal protective equipment, can often contribute to a reduction in exposure to ionising radiation in NORM-involving industries.

System of radiation protection is based on integration of multiple exposure pathways, both internal and external, within the concept of effective dose. As defined by the ICRP, effective dose provides a risk-adjusted measure of total body exposure, enabling consistent application of dose limits, constraints, and reference levels across diverse exposure situations. While maintaining radiation protection as a distinct discipline with its own principles remains essential, closer combination with extant OSH frameworks could serve as a practical foundation for implementing radiation protection requirements in alignment with the broader system of worker health and safety protection.

The structure of OSH system based on individual directives covering different risk and hazards as well as different type of workplaces is providing wide possibility of such combination depending on the specific NORM involving activities. Radiation safety measures can be implemented in addition to the existing occupational safety and health provisions already in place at the workplace as an additional characteristic of the workplace or a specific hazard. Combined approach would support the graded regulatory control advocated by both the EU and international standards, allowing for proportionate measures based on the magnitude and nature of the exposure and would benefit with improvement of the overall protection system performance as well as in optimisation of resources necessary for that.

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Glossary

NORM waste	naturally occurring radioactive material (NORM) for which no further use is foreseen
Release	The action or process of setting free or being set free, or of allowing or being allowed to move or flow freely [1].
Discharge	Planned and controlled release of (usually gaseous or liquid) radioactive substances to the environment [1].
Authorised release/discharges	Material released from regulatory radiological control, with the approval of the competent authority.
Radioactive waste	means radioactive material in gaseous, liquid or solid form for which no further use is foreseen or considered by the Member State or by a legal or natural person whose decision is accepted by the Member State, and which is regulated as radioactive waste by a competent regulatory authority under the legislative and regulatory framework of the Member State [2].
Disposal	means the emplacement of spent fuel or radioactive waste in a facility without the intention of retrieval [2].
Disposal site	site for an engineered facility where waste is emplaced for disposal.
Storage	means the holding of spent fuel or of radioactive waste in a facility with the intention of retrieval [2].
Radioactive material	means material incorporating radioactive substances [2].
Radioactive source	means a radiation source incorporating radioactive material for the purpose of utilising its radioactivity [2].
Radioactive substance	means any substance that contains one or more radionuclides the activity or activity concentration of which cannot be disregarded from a radiation protection point of view [2].
Conventional waste	wastes that are not radioactive waste.
Inert waste	wastes that do not undergo any significant physical, chemical, or biological transformations when deposited in a landfill [3].

Acronyms

NORM	naturally occurring radioactive material
EU BSSD	Council Directive 2013/59/EURATOM [4]
EU Waste Directive	Council Directive Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste.
EU Extractive Waste Directive	Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC
EU RAW Directive	Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste.
NOR	naturally occurring radionuclides
International BSS	GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [5]
RP	radiation protection
OSH	occupational safety and health

Introduction

The history of radiation protection (RP) concerning naturally occurring radionuclides (NOR) spans several decades. Initially, attention was focused on uranium and its decay series, primarily due to its use in nuclear fuel production. In the 1970s, concerns arose about potential higher exposure to radon and its long-lived progeny in gas installations. Despite some claims that exposure to natural radionuclides posed less risk than artificial ones, in some countries, regulations were established in the late 1980s to address worker exposure mainly to radium from formation water and short-lived radon progeny.

The first formal EU regulation required attention to naturally occurring radionuclides and related occupational exposure as well as public exposure to ionizing radiation was set in force in 1996. Extensive research led to well-developed rules for evaluating and controlling exposure, based on the well-characterised natural decay chains of uranium and thorium. However, the complexity of these issues necessitated substantial simplification for effective management, especially for industries previously unaware of radioactivity.

In the early 21st century, dedicated limits based on the clearance and exemption concept were established, focusing on the activity concentration of uranium-238 and thorium-232, assuming secular equilibrium within the decay series. Due to their origin, NOR, contrary to artificial radionuclides are always present in mineral matrices or liquid solutions. Therefore, the general term NORM (naturally occurring radioactive materials) was introduced, emphasizing the presence of naturally occurring radionuclides, however leaving the decision of their significance to the user. Next, simple formulas, biased with many assumptions were developed to evaluate exposure under specific conditions, e.g. building materials. The general exposure limit, set at a level 100 times higher than for artificial radionuclides, was justified due to the ubiquitous background presence of natural radionuclides, making it technically and economically unfeasible to evaluate exposure at the same low levels as for artificial ones. Despite this, many still mistakenly believe that radiation from naturally occurring radionuclides is less dangerous.

Considering the need to address a new problem affecting various industries unfamiliar with radiation protection such approach was justified, assuming further progress according to growth of knowledge and experience in this matter. However, from today's perspective, it is evident that expected progress has been slow, and in some cases, there has been regression.

The term TENORM, which provided more informative definitions, is becoming obsolete. The overuse of the term NORM to describe all exposure scenarios has led to ambiguous statements such as "NORM concentration in raw material". NORM is qualitative, and there are no units to express its content in other materials. Additionally, many NORM currently considered for occupational and public exposure are altered, not natural. EU radiation protection regulators recognised this issue, and the term NORM is not used in EU regulations.

The overuse of the term NORM and simplified regulations have resulted in all members of the uranium and thorium decay series being grouped together, despite they are ten different elements, five of which have isotopes that can exist independently from their parents. This leads to discrepancies between exemption levels expressed as effective dose and radionuclide activity concentrations. The lack of good practices in NORM characterisation and the common assumption of secular equilibrium further exacerbates these problems. Natural background is considered differently, sometimes from measured gamma external dose total local background is subtracted, including radon and medical exposure, while others calculate Excessive Lifetime Cancer Risk for NOR activity concentration just about a few Bq/kg in soils using formula prepared for building materials.

Apart from research, efforts to regulate NORM have focused on developing special rules based on radiation protection principles, almost always overlooking that NORM resembles common waste and the fact that most NORM have been present since the activity inception of the relevant industries and are included in well-developed management systems.

This report deals with options of NORM management in the light of former and existing legislation and its possible interpretation as well as with complex NORM features affecting exposure situation, hazard characterisation, monitoring methods, measurement organisation and interpretation of measurement results.

This report consists of four separate parts – Part 1 covers the legislative requirements, Part 2 covers the legacy site management, Part 3 covers the rationale of clearance and exemption criteria, Part 4 covers occupational safety and health issue requirements and their relation to NORM-involving industries.

Constraints:

The presented solutions reflect opinion of the RadoNorm team responsible for WP 5.5. It cannot be considered as legally binding recommendation.

Part 1: Integration of NORM waste management into existing industrial waste management system

1. Introduction

The operational periods of most NORM involving industries and facilities are typically very long, often spanning decades or even centuries. Over this time, various by-products, residues, and waste materials containing NORM have accumulated and/or been managed or removed from these sites. These materials have never constituted a homogeneous group; their physical and chemical properties vary significantly depending on the raw materials used and the processing technologies applied. This, in turn, determines the appropriate methods for handling them. Requirements for the management of these NORM have understandably evolved and become more specific over time. When these materials are considered waste, the requirements for their management are primarily based on European waste directive (Directive 2008/98/EC) and the directive on waste from extractive industries (Directive 2006/21/EC), as well as national regulations derived from these directives. However, it should be noted that neither the directives themselves nor most Member States national legislations derived from them, explicitly account for the radioactivity of such waste.

NORM handled in industries and facilities involving naturally occurring radionuclides (NOR) may exhibit significantly elevated concentrations of natural radionuclides. Due to the need to protect the public (individuals from the general population) from exposure to these radionuclides, Council Directive 2013/59/EURATOM (EU BSSD) sets requirements regarding radionuclide content in these materials. The presence of natural radionuclides has thus become a parameter that must be considered when managing these materials.

At the same time, there are so-called radioactive waste (RAW) arising from nuclear activities. We use the phrase “so-called” deliberately to highlight the significant difficulties in finding a clear definition of radioactive waste that would allow for the classification of specific waste into any category of radioactive waste. Notwithstanding this, management of RAW is primarily governed by Council Directive 2011/70/EURATOM, which establishes a community framework for the responsible and safe management of spent fuel and radioactive waste. The requirements of this direction apply alongside those of the other directives mentioned above.

Lastly, given the current circular economy requirements (see 5.1.2.1), it is necessary to consider the possibility that natural radionuclides may re-enter circulation as part of re-use, via recycling or recovery of NORM waste, for example, as components of certain products, potentially increasing exposure to natural radionuclides for users of such products without any possibility to control them. This process is currently regulated at the European level only for certain types of construction products.

The results of surveys conducted in Poland, the Czech Republic, Finland, and France [6] on known waste from NORM industries and facilities, as well as findings from a questionnaire conducted under the RadoNorm project [7], have shown that waste management national regulations based on the above-mentioned European directives is far from consistent across EU Member States and displays a number of differences, ambiguities, and weaknesses.

The aim of the first part of this report is to analyse the legal framework for managing radioactive waste, general waste, and mining waste, and subsequently to propose a graded, optimised, and practically implementable system for managing waste originating from NORM industries and facilities and containing natural radionuclides (NORM waste). This system should consider all relevant properties of these wastes, including their radioactivity. Similar attention should also be given to the generation of products from NORM waste.

The content of this section of the report is primarily focused on the management of solid NORM. The conclusions apply to the management of NORM waste in EU Member States.

2. Legal and technical aspects of NORM treatment and management

2.1 NORM waste vs. radioactive waste – description of the current situation

Findings from surveys conducted in Poland, the Czech Republic, Finland, and France — focusing on known NORM waste streams and facilities — as well as data from a questionnaire conducted as part of the RadoNorm project [7], show that the management of NORM waste under the existing EU legislative framework is far from harmonised. Substantial differences, ambiguities, and weak points exist across Member States.

One part of the survey conducted within the RadoNorm project, described in the paper from Popic et al. [7] focused on mitigation and remediation measures. The questions were formulated to provide a general overview of current options for NORM management in European countries. The aim was to identify common features between the management of conventional residues and NORM residues, as NORM has far more in common with standard industrial waste than with radioactive waste [8]. It is also important to highlight that the management of NORM involving industries was different in the past.

Operators and regulatory authorities were asked whether NORM residues should be classified as any type of radioactive waste, taking into account current radiation protection legislation as well as conventional waste management rules [2], [9], [10].

"If classified as radioactive waste, residues are subject to very restricted treatments (e.g. storage in a dedicated repository) well regulated by Council Directive (2011)[2]. However, as treatment options for radioactive waste are commonly prepared for waste limited in volume (mass) existing in certain well-known chemical/physical forms. On the contrary, NORM residues can be present in big volumes and masses, in different aggregated states as well as in complex chemical/physical form. Therefore, application of rules developed for 'typical' radioactive waste to NORM is not always justified from an economical and applicable technical solutions perspective ***. In about 37 % of responding countries, NORM is never classified as radioactive waste, slightly above 12 % declare the use of same limits for NORM as for radionuclides used as radioactive sources (e.g. radium), whereas above these limits, waste is considered as radioactive waste regardless of the purpose of use, physical and chemical form. However, in 50 % of the responses, a special limit, expressed as a radionuclide activity concentration, has been established above which NORM residues are classified as radioactive waste. Sometimes, this activity concentration limit is so high (e.g. 1000 Bq/g for radium[1]) that the likelihood of it being exceeded in NORM is very low.*** *Moreover, a specific approach was noticed where NORM formally is not classified as radioactive waste, however, must be disposed of in the radioactive waste repository when dose evaluation indicates an excess of dose*

[1] Not mentioned in the original text, but refers to Ra-226

limits set either to workers or members of the public. It must be highlighted that such heterogeneous approaches among countries, however, can lead to equivocal situations in case of transboundary actions related to NORM." [7]

A further set of questions was asked to collect information on available NORM treatment options.

In the survey, final destinations for NORM, considered from legal perspective, were as:

- *conventional waste disposal site (inert, non-hazardous, hazardous),*
- *NORM dedicated disposal site,*
- *nuclear waste repository,*
- *reuse/recycling.*

*"**The majority of the respondents among regulators declared the final destination of NORM residues being disposal sites for conventional waste, i.e. landfills for hazardous or non-hazardous waste**. Disposal sites for municipal waste were not mentioned. Similar approaches were presented by **industry operators where options for conventional waste disposal as: deposit into or on to land, surface impoundment and permanent storage are applied for NORM in 73 % of answers provided**. The decision criteria in both cases are based on the clearance level as defined in EU BSS. **Only 11 % of regulators among answering countries and 9 % of industry operators declared a special disposal site developed for specific NORM** (CCP - coal combustion products or red mud) usually next to the industry of origin, and one developed especially for NORM from oil and gas industry. However, it was underlined that specific NORM disposal sites are well prepared to store NORM from other types of industries unless its physical form differs significantly from expected one, e.g. all waste are in barrels. Some countries declared makeshift solutions as a special heap, insulation by concrete layers or simply leaving NORM underground in case of subsurface mining. From a RP perspective, these solutions imply a special monitoring system to prove that no additional exposure occurs neither to humans nor to the environment." [7]*

Table 1: Methods which are used to treat NORM before or instead of final disposal. From Popic et al.[7] (responders were allowed to provide more than one option treatment for each category)

Method/percentage of responses per given method (to choose more than one option was allowed)	Radionuclides activity concentration (U and Th decay series)		
	<1 Bq/g	>1 Bq/g and <10 Bq/g	>10 Bq/g
Reprocessing (in frame one production process)	25	31	
Purification	19	13	6
Mixing/dilution (under conditions given in Directive 2013/59 Article 30 (40))	31	25	6
Reuse	31	13	
Recycling	44	13	
No treatment	44	31	31

2.2 European regulatory drivers behind differences in NORM waste classification among Member States

The content of the regulations that are binding for radioactive waste in EU Member States is discussed in this chapter. Regulations forming EU law in the area of general waste are discussed later in Chapter 5.

EU Member States are also members of the IAEA and are thus bound by IAEA regulations relating to RAW (Chapter 3.1-3.2). As will be shown in the following text, both of these regulatory frameworks allow room for different approaches in national legislation, which is further demonstrated by the application examples presented in Chapter 4.

Direct quotations from these documents are included in *italic*; sections that directly concern RAW or NORM waste are highlighted by **bold** text.

First, it is necessary to analyse the European legal documents that define the term “radioactive waste” and the requirements for such radioactive waste (hereinafter RAW). Based on this analysis, we can answer the question: “Is there a single, binding definition of RAW for EU Member States, or is the definition within the competence of each Member State, and therefore possibly different across the EU?”

Below are the relevant EU regulations concerning RAW:

2.2.1 The EURATOM Treaty [11]

The founding document for the use of nuclear energy and ionizing radiation in Europe is the Treaty establishing the European Atomic Energy Community (EURATOM). The EURATOM Treaty was signed by representatives of six founding states in Rome on 25 March 1957 and entered into force on 1 January 1958. The purpose of the Community is to contribute, by establishing the necessary conditions, to the rapid construction and growth of the nuclear industry in order to raise living standards in the Member States and to promote relations with other countries. One of its key aims is to establish uniform safety standards for the protection of the public and workers in this sector.

The consolidated version of this Treaty from 2016 includes the following provisions related to radioactive waste:

2.2.1.1 Quotations from legal text - The EURATOM Treaty [11]

Article 1

By this Treaty the HIGH CONTRACTING PARTIES establish among themselves a EUROPEAN ATOMIC ENERGY COMMUNITY (EURATOM).

It shall be the task of the Community to contribute to the raising of the standard of living in the Member States and to the development of relations with the other countries by ***creating the conditions necessary for the speedy establishment and growth of nuclear industries.***

Article 4

1. The Commission shall be responsible for promoting and facilitating nuclear research in the Member States and for complementing it by carrying out a Community research and training programme.

2. ***The activity of the Commission in this respect shall be carried out within the fields listed in Annex I to this Treaty.***

This list may be amended by the Council, acting by a qualified majority on a proposal from the Commission. The latter shall consult the Scientific and Technical Committee established under Article 134.

ANNEX I - FIELDS OF RESEARCH CONCERNING NUCLEAR ENERGY REFERRED TO IN ARTICLE 4 OF THIS TREATY

IV. Processing of radioactive material

1. Methods of extracting plutonium and uranium 233 from irradiated fuels, and possible recovery of uranium or thorium.

2. Chemistry and metallurgy of plutonium.

3. Methods of extracting and chemistry of other transuranic elements.

4. Methods of extracting and chemistry of useful radioisotopes:

(a) fission products,

(b) radioisotopes obtained by irradiation.

5. Concentration and storage of useless radioactive waste.

Article 37

Each Member State shall provide *the Commission with such general data relating* ***to any plan for the disposal of radioactive waste in whatever form will make it possible to determine whether the implementation of such plan is liable to result in the radioactive contamination of the water, soil or airspace of another Member State.***

The Commission shall deliver its opinion within six months, after consulting the group of experts referred to in Article 31.

Article 41

Persons and undertakings engaged in the industrial activities listed in Annex II to this Treaty shall communicate to the Commission investment projects relating to new installations and also to replacements or conversions which fulfil the criteria as to type and size laid down by the Council on a proposal from the Commission.

The list of industrial activities referred to above may be altered by the Council, acting by a qualified majority on a proposal from the Commission, which shall first obtain the opinion of the Economic and Social Committee.

ANNEX II - INDUSTRIAL ACTIVITIES REFERRED TO IN ARTICLE 41 OF THIS TREATY

1. Mining of uranium and thorium ore.

2. Concentration of such ores.

3. Chemical processing and refining of uranium and thorium concentrates.

4. Preparation of nuclear fuels, in any form.

5. Fabrication of nuclear fuel elements.

6. Production of uranium hexafluoride.

7. Production of enriched uranium.

8. Processing of irradiated fuels for the purpose of separating some or all of the elements contained therein.

9. Production of reactor moderators.

10. Production of hafnium-free zirconium or compounds thereof.

11. Nuclear reactors of all types and for all purposes.

12. Facilities for the industrial processing of radioactive waste, set up in conjunction with one or more of the facilities specified in this list.

13. Semi industrial installations intended to prepare the way for the construction of plants involved in any of activities 3 to 10.

2.2.1.2 Commentary

It is clear that the primary purpose of the EURATOM Treaty is to support and ensure the safe operation of **the nuclear industry**. NORM waste from NORM involving industry is therefore not the primary subject of this Treaty. The wording of Annex II, point 12, indicates that the term radioactive waste is addressed only when it relates to some phase of the nuclear fuel cycle (i.e., points 1–11 and point 13). The EURATOM Treaty thus imposes no obligation to consider NORM waste as radioactive waste.

2.2.2 1999/669/CE, Euratom Commission Recommendation on a classification system for solid radioactive waste [12]

In 1999, particularly in response to the need to monitor and report on the state of the environment as required by European treaties, and in view of the renewed EU Action Plan on radioactive waste management initiated in 1992 — which calls for coordination under the Treaty establishing the European Atomic Energy Community (EURATOM) and for convergence in procedures and regulations for safe radioactive waste (RAW) management — the European Commission issued the Recommendation on a Classification System for Solid Radioactive Waste (SEC(1999) 1302 final) (1999/669/EC, Euratom), hereinafter referred to as the "Recommendation."

The aim was for Member States to adopt within their nuclear industry a common system of radioactive waste classification to improve, national and international communication and facilitate information management in this field, and to apply it particularly when providing information on solid radioactive waste to the public, national and international bodies, and non-governmental organisations.

However, this classification system was not intended to replace technical criteria required for specific safety reasons, such as licensing procedures for facilities or other regulated activities.

According to the Recommendation, RAW should be categorised as follows:

2.2.3 Quotation from legal text – Commission Recommendation on a classification system for solid radioactive waste [12]

1. Transition radioactive waste

Type of radioactive waste (mainly from medical origin) which will decay within the period of temporary storage and may then be suitable for management outside of the regulatory control system subject to compliance with clearance levels.

2. Low and intermediate level waste (LILW)

In LILW the concentration of radionuclides is such that generation of thermal power during its disposal is sufficiently low. These acceptable thermal power values are site-specific following safety assessments.

2.1. Short-lived waste (LILW-SL)

This category includes radioactive waste with nuclides half-life less than or equal to those of Cs137 and Sr90 (around 30 years) with a restricted alpha long-lived radionuclide concentration (limitation of long-lived alpha emitting radio-nuclides to 4 000 Bq/g in individual waste packages and to an overall average of 400 Bq/g in the total waste volume).

2.2. Long-lived waste (LILW-LL)

Long-lived radionuclides and alpha emitters whose concentration exceeds the limits for short-lived waste.

3. High level waste

Waste with such a concentration of radionuclides that generation of thermal power shall be considered during its storage and disposal (The thermal power generation level is site-specific, and this waste is mainly forthcoming from treatment/conditioning of spent nuclear (fuel).

2.2.3.1 Commentary

The Commission 1999 Recommendation proposes a non-binding classification system for solid RAW. Although not legally enforceable, it provides an indicative framework based on activity levels and radionuclide half-lives. This Recommendation acknowledges that RAW can originate from non-nuclear industrial activities, but, as in the Euratom Treaty, it does not explicitly mention NORM waste, nor does it provide specific provisions for them, nor exclude them from the proposed system.

This system serves as a common reference across EU Member States to facilitate harmonisation and comparability. While national systems may vary, most are inspired by or aligned with this classification.

The annex of the Recommendation indicates some industrial activities (as well as research and medical activities) producing residual materials containing radionuclides. Following potential segregation, reuse in the nuclear industry and treatment, there are, in principle, two categories of such **materials** left.

- Category 1: **Materials that can be managed outside the system of regulatory control.**
- Category 2: Residual materials for which no further use is foreseen and which need specific management procedures based on their radioactive properties.

Only category 2 materials are regarded as 'radioactive waste', and this recommendation is only concerned with the latter [12].

Therefore, NORM waste is from category 2 and can be classified within the proposed system if their activity level justifies it.

2.2.4 Council Directive 2011/70/EURATOM of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste [2]

In 2011, the Council Directive 2011/70/EURATOM (hereinafter referred to as the "RAW Directive") was adopted. Its legal background is explained in the section titled Explanatory Memorandum, which states:

2.2.4.1 Quotation from legal text - Council Directive 2011/70/EURATOM [2]

„LEGAL ELEMENTS OF THE PROPOSAL

The Directive's objective as stated in its Article 1 is the establishment of a Community framework for responsible management of spent fuel and radioactive waste, ensuring that Member States make appropriate national arrangements for a high level of safety and maintain and promote public information and participation;

Its scope (Article 2) covers all stages of the management of civilian spent fuel and radioactive waste from generation to disposal*, but* ***not the management of specific types of waste, such as authorised releases and waste from extractive industries which may be radioactive, as already covered by existing European legislation*** *(i.e. OJ L 159, 29.6.1996, p.1 and 18 O J L 102, 11.04.2006, p. 15)."*

The content of the directive reflects this legal intent; see the following quotations of relevant provisions from the Directive:

Preamble

(8) ***Directive 2006/21/EC*** *of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries (8)* ***covers the management of waste from extractive industries which may be radioactive,*** *but* ***excluding such aspects*** *as are specific to radioactivity, which are matters dealt with* ***under the Euratom Treaty****.*

(19) While each Member State remains free to define its energy mix, all Member States generate ***radioactive waste from power generation or in the course of industrial, agricultural, medical and research activities, or through decommissioning of nuclear facilities or in situations of remediation and interventions.***

(21) ***Radioactive waste****, including spent fuel considered as waste,* ***requires containment and isolation from humans and the living environment over the long term****. Its specific nature, namely that it contains radionuclides, requires arrangements to protect human health and the environment against dangers arising from ionising radiation, including* ***disposal in appropriate facilities as the end location point. The storage of radioactive waste, including long-term storage, is an interim solution, but not an alternative to disposal.***

(22) A national radioactive waste classification scheme should support those arrangements, ***taking fully into account the specific types and properties of radioactive waste****.*

Article 2 - Scope

1. This Directive shall apply to all stages of:

(a) spent fuel management when the spent fuel results from civilian activities;

(b) radioactive waste management, from generation to disposal, when the radioactive waste results from civilian activities.

2. This Directive ***shall not apply to****:*

(a) ***waste from extractive industries which may be radioactive,*** *and which falls within the scope of Directive 2006/21/EC;*

(b) ***authorised releases****.*

Article 4 - General principles
1. Member States shall establish and maintain national policies on spent fuel and radioactive waste management. Without prejudice to Article 2(3), each Member State shall have ultimate responsibility for management of the spent fuel and radioactive waste generated in it.

2.2.4.2 Commentary

The RAW Directive **no longer refers exclusively to the nuclear fuel cycle but applies to all radioactive waste arising from civilian activities, whether or not they form part of that cycle**. It anticipates that RAW may also arise from energy production, industrial, agricultural, and laboratory activities, as well as from remediation and intervention actions.

Recital (21) Radioactive waste, including spent fuel considered as waste, requires containment and isolation from humans and the living environment over the long term. Its specific nature, namely that it contains radionuclides, requires arrangements to protect human health and the environment against *dangers arising from ionising radiation, including disposal in appropriate facilities as the end location point. The storage of radioactive waste, including long-term storage, is an interim solution, but not an alternative to disposal.* [2]

This requirement applies to all waste that, in accordance with the national RAW classification system, has been designated as RAW.

The RAW Directive explicitly states that **it does not apply to authorised releases** into the environment from a facility — which is the case for the release of NORM from NORM industries and facilities under Council Directive 2013/59/EURATOM, where there is no requirement for permanent isolation of NORM. **Thus, the threshold between RAW and NORM waste is whether the waste is sufficiently radioactive to require permanent isolation**. If a NORM waste meets this condition, it must comply with the management requirements defined for RAW (it must be isolated and cannot be released from the facility).

The RAW Directive also **does not apply to waste from the extractive industry (mining waste)**.

However, if a Member State chooses not to exclude from the RAW classification system those NORM wastes that could otherwise be released from a facility, or mining waste, and decides to consider them a priori as RAW, then such wastes must also meet the requirements for permanent isolation i.e., they must be disposed of in a RAW disposal facility.

Article 4 and the RAW definition in the Directive also refer to the **existence of a national legal and regulatory framework, without establishing a unified system for RAW classification and management at the EU level**. A Member State may thus, in view of its national circumstances, decide which waste shall be designated as RAW and which may be released, and how RAW shall be managed or disposed of.

The existence of independent legal systems for RAW management in individual Member States is most probably the reason why the questionnaire identified differences in which NORM wastes are classified as RAW across EU countries.

This situation is also described in studies later commissioned by the European Commission (EC). The most recent ones include the following:

2.2.5 Benchmarking Analysis of Member States Approaches to Definition of National Inventories for Radioactive Waste and Spent Fuel (2020) [13]

The study describes, among other points, that a natural consequence of the existence of different national systems introduced by Member States in accordance with Directive 2011/70/EURATOM is the use of different radioactive waste classification systems across the EU. Some of these classification schemes are inspired by, or directly based on, the IAEA document Classification of Radioactive Waste, General Safety Guide [14]. These classifications are typically also adapted to reflect the technical capabilities for RAW management and disposal in each respective country.

For the NORM area, the study states:

NORM remains an open and unresolved issue in the EU. Almost all Member States have industries that generate NORM residues (including uranium mining) which may be composed of reusable material (all NORM residues cannot be considered as NORM waste, being a resource from industrial side). How NORM residues and NORM wastes are managed differently between countries.

NORM residues/wastes mainly raise concerns about radiation protection and potential risks to the public. As a result, many Member States have put regulatory frameworks in place to address NORM.

Currently, 18 Member States include NORM waste in their radioactive waste regulations. But only 9 have assessed how much NORM waste they have and included it in their national inventories. Some countries, despite having industries that produce NORM waste, have not yet defined or regulated it.

Managing NORM waste was identified as a challenge. *Due to the large volumes of NORM wastes, their consideration among the radioactive waste management routes could have a major impact: raising costs and modifying waste acceptance issues and leading to fastest saturation of VLLW disposal facilities* [13].

At present, there is no specific EU-level legal framework for NORM. A coordinated European effort is required to decide how NORM waste should be considered — whether as radioactive waste or under separate rules with limited monitoring and safe storage. A clearer, harmonised approach is expected to emerge within the next decade.

The study makes the following finding (Finding #6): NORM currently appear as an "open" issue within EU, Member States are positioning themselves on how NORM wastes should be considered (either as a radioactive waste, or through limited monitoring/safe storage). The NORM consideration is expected to be clarified within the next decade. There is currently no specific European legal framework regarding NORM, a joint European reflection with Member States is required to conclude on the necessity to include NORM in the inventories. [13]

2.2.6 Study on radioactive waste classification schemes in the EU (2022) [15]

The Study on radioactive waste classification schemes in the European Union' [15] *aims to provide an overview of the current radiological waste classification system in each of the Member States and to assess how such systems compare with the 1999 Commission recommendation requiring Member States to provide with guidance on a common approach to the classification of radioactive waste* [12]. *The project's ultimate objective is to determine if there is any merit in adopting a holistic approach to waste classification across the Member States. Liaison, both verbally and via a questionnaire, was undertaken with the waste management organisations of each Member State, in addition to a selection of waste producers. This EU-wide assessment was complemented by a survey on the public's awareness of radioactive classification schemes. In general terms, the feedback from both waste management organisations and waste producers was that existing radioactive waste classification schemes are considered to adequately facilitate cross-border cooperation in relation to radioactive waste. It was apparent that all Member States have developed their waste management strategy on the basis of national conditions and generally have country-specific waste classification systems that ensure safe waste management. Most Member States believe that their current approaches are working in an adequate manner, especially as EU directives have been incorporated into their legislation. Notwithstanding this fact, suggestions have been made on how an EU-wide holistic approach to waste classification could be established.*

Conducted review of Member States' waste classification schemes found that none of the 27 Member States exactly followed the classification scheme set out in the Commission recommendation, although many utilised it and/or IAEA GSG-1 as the basis for the rules to which they currently adhere.

Two chapters which have direct or close connection to this Deliverable are cited bellow - 3.2.1. *Summary of international best practice* and findings of a brief assessment of the status of NORM waste within the various Member States (chapter 3.2.2.).

Summary of international best practice [15]*:*

The review of each Member State's waste classification scheme was complemented by a high-level summary of the international context of radioactive waste classification. Reviewing the international context showed that apart from the IAEA, other internationally recognised organisations have not provided guidance on how to adopt a radioactive waste classification scheme (although it should be recognised that the development of such a scheme would not have been in their remit). These organisations include the International Commission on Radiological Protection, the United Nations Scientific Committee on the Effects of Atomic Radiation and the European Nuclear Safety Regulators Group, although the last of these does reference the IAEA classification scheme shown in IAEA GSG1. OECD/NEA do refer to waste classification within their work and projects relating to waste inventories. OECD/NEA published a report in 2020 entitled National inventories and management strategies for spent nuclear fuel and radioactive waste (NEA No 7424). Although the study was focused on national inventories, it did touch on the subject of waste classification and made the following observation: ***'It should be noted that radioactive waste classification, along with the qualitative and quantitative criteria used, significantly depend on the current and/or planned short-term and long-term strategy of radioactive waste management in a given country and on its nuclear infrastructure and regulatory practices'****. A preceding study published in 2017 with the same report title (NEA No 7371) made an observation that* ***although many Member States have developed waste classification schemes in line with IAEA GSG-1, only a few have adopted the GSG in its entirety****. This was cited as being due to a number of factors, including the long-standing use of a different system and the logistical difficulties that would be encountered when switching to a new system. This point is worth revisiting when our current project provides recommendations about the merits of developing a harmonised waste classification across the 27 Member States. It is clear from these studies that the variances observed in the Member State's waste classification strategies will have an impact on how national inventories are constructed for each specific waste category (i.e. there will be little ability to make like-for-like comparisons). As Task 2 of the project provides an in-depth assessment of how each Member State's radioactive waste classification system adheres to IAEA GSG-1, only a high-level assessment of this document was undertaken within Task 1. This high-level assessment has shown that many of the 27 Member States have developed their waste classification system by taking cognisance of the guidance set out in IAEA GSG-1.*

Naturally occurring radioactive material waste [15]

Task 1 also made a brief assessment of the status of NORM waste within the various Member States. This assessment concluded that:

- *NORM waste, including that from the mining and processing of uranium ore, belongs to the very-low-level waste (VLLW) category, except in a few circumstances (scales from the oil and gas industries) where it has particularly high activity concentrations;*
- *disposal of NORM waste can generally be accomplished in a landfill facility identified for VLLW;*
- *the upper limits for VLLW are one or two orders of magnitude higher than exemption levels for artificial radionuclides;*
- *the appropriate category for ultrafiltration waste*[2] *is unclear.*

Factors influencing the regulatory decision to define NORM waste as radioactive waste may include the structure of the legal framework, availability of infrastructure for waste treatment and disposal, or risk perception by the public. ***The literature assessed indicates that most of the Member***

[2] Ultrafiltration (UF) is a variety of membrane filtration in which forces like pressure or concentration gradients lead to a separation through a semipermeable membrane. Suspended solids and solutes of high molecular weight are retained in the so-called retentate, while water and low molecular weight solutes pass through the membrane in the permeate [16].

States are trying not to dispose of NORM in their national disposal facilities as VLLW, because the volumes of NORM can be significant[3].

The Report summarises this general conclusion: *NORM (*waste*) is rarely classified as (*radioactive*) waste in the Member States, but is in some. It is, however, not included within the Commission recommendation* [15].

Comment: Although, NORM waste is not a priori covered by the Commission's Recommendation [15], it is also not excluded, unless an authorised release has been granted.

Chapter 8.5 of the Study proposes how the identified challenges might be addressed:

During the analysis of whether the waste classification system recommended in IAEA GSG-1 allows the harmonisation of the individual systems used in the Member States, it became clear that the classification systems were established against the background of the final solutions for the individual waste streams (i.e. the selected repository types). Although this makes it possible for higher-level reports to summarise data in such a way that they fit into an overarching classification system, in some cases, significant differences become apparent in the details. Radionuclide-specific definitions of waste classes, and the contraction or omission of classes make a comparison between national waste classification systems impossible.

For instance, the fact that some materials are declared as radioactive waste in some instances and as exempt material in others has caused some challenges for Member States. It was felt that a clearer distinction needed to be made between contaminated material and nuclear waste.

The possibility of defining VLLW, which is usually disposed of in surface facilities, allows for lower requirements for conditioning and packaging of the waste than when this waste is considered together with LILW. Usually, the lower requirements result in larger volumes of waste, which in turn are characterised by lower toxicity. This is particularly evident in countries where waste cannot be exempted or in countries where all waste is to be placed in geological repositories. The reported waste volumes in these cases differ by several orders of magnitude.

As the waste classes used in the individual Member States are based on the national programmes, which have existing licences built on facility-specific safety analyses and a national regulatory system as a basis, the classification systems used operationally cannot be changed. Thus, there will always be the difficulties mentioned above when reporting for higher-level international agreements.

One way to overcome these difficulties is seen in a classification based on the final solution for waste streams. An example for a waste classification scheme would be:

- ***non-radiotoxic waste for surface disposal;***
- ***very-low-level radiotoxic waste for surface disposal;***
- ***low-level radiotoxic waste for near-surface disposal***
- ***intermediate radiotoxic waste for intermediate-depth disposal;***
- ***higher intermediate radiotoxic waste for deep geological disposal;***
- ***HLW for deep geological disposal.***

It seems reasonable to define the waste classes along the disposal solutions. HLW can be divided into two subclasses: waste from reprocessing and directly disposed spent fuel. Non-

[3] Leading to early saturation of disposal capacity (priority should be given to waste arising from nuclear fuel cycle activities (including waste produced after the facility shut down by clean-up operations (soils, building structures)).

heat-generating waste can then be divided into waste for disposal in geological repositories, waste for disposal at intermediate depths, waste for disposal in near-surface repositories and waste for disposal in surface landfills. *It would also be important to estimate the amount of waste released in order to establish comparability with countries where release is not possible. It will certainly be a challenge to obtain historical data on release.*

With such a system, there is less demand for the technical expertise needed to simultaneously assess, for example, the importance of longevity and activity of radionuclides. In this way, communication with the public, drafting a common inventory allowing for comparison between countries, and cross boundary activities are supported. Nevertheless, if such a classification system were to be implemented, WMOs and regulators must be involved, as they will be responsible for reporting, and would be best able to identify the consequences and possible challenges.

In summary, as Member States appear to take greater cognisance of IAEA GSG-1 than the Commission recommendation, it may be logical to further align the latter with the former. However, prior to any updates to the recommendation to provide a more harmonised waste classification system, it may be necessary to better understand the potential obstacles or challenges Member States may face in making any changes to their existing classification system. Questions regarding this were not specifically asked or otherwise raised during the project. Although the authors of this report recognise the value of a harmonised waste classification system that is valid at all levels of radioactive waste management, care has to be taken when considering a potential new national classification system. An assessment of the impact of a new national classification system on the national programmes of the Member States is beyond the scope of this project, and can only be done with considerable involvement of the affected parties, especially waste producers, WMOs and regulators. Nevertheless, the authors see a clear chance that the application of the proposed waste classification system would allow for a simple translation matrix between national classification systems and the system for reporting at EU level.

In relation to having a harmonised waste classification system across the EU and how it would have an impact on their country-specific waste management, the WMOs provided mixed responses in the study. Although only two felt it would be detrimental, twice as many provided a neutral response, than provided a positive one.

The majority of waste producers did admit that, in principle, a harmonised approach to radioactive waste classification across the EU should be positive. Overall, the waste producers seemed to be more supportive of having a harmonised approach to waste classification across the EU than the WMOs. This may relate to the fact that any such harmonisation, and therefore potential change, might have more of an impact on the WMOs than the waste producers.

Two key recommendations are in close connection to the topic of this Deliverable:

Recommendation 4 - Assess potential obstacles and opportunities prior to any updates to the Commission recommendation

As Member States appear to take greater cognisance of IAEA GSG-1 than the Commission recommendation, it may be logical to further align the latter with the former, for example by including VLLW. However, prior to any updates to the Commission recommendation to provide a more harmonised waste classification system, it may be necessary to better understand the potential obstacles or challenges a Member State may face in making any changes to their existing classification system. Questions regarding this were not specifically asked or otherwise raised during the project. It is equally important, however, to not merely look at challenges but also consider any potential opportunities.

Recommendation 5 - Waste classes should be related with requirements for transport, processing, storage and disposal

Each waste class could be classified according to the process steps of transport, processing, storage and disposal. The classifications in turn could include radiological descriptions; descriptions of the biological, chemical and physical properties; descriptions of the dose rate and contamination; and descriptions of the packaging. Such structured documentation would allow a direct assessment of whether a waste stream can be accepted from a particular facility. It might even be possible to define higher-level safety requirements on this basis, which would support a uniform approach in Europe. Although this further detail may become too incomprehensible for the public, it may be helpful for professional exchanges to structure requirements. However, by linking the requirements to the waste classes, closed reporting is possible, which can present information based on the same data in ways that are appropriate for each target group. [15]

2.2.7 Report from the Commission to the Council and the European Parliament on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects [17]

This report was issued by the Directorate-General for Energy of the European Commission on 22 May 2024. It describes the latest status (i.e., the period 2018–2021) regarding the implementation of Directive 2011/70/EURATOM and provides an overview and trends in the generation of radioactive waste and spent fuel in EU Member States. The following has been selected from the report:

2.2.7.1 Quotation from the text - Report from the Commission to the Council and the European Parliament on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects [17]

2.1 Origin of radioactive waste and spent fuel

All Member States generate radioactive waste through various activities ranging from medical applications to electricity generation. A total of 17 Member States also manages spent nuclear fuel on their territory. Owing to its radiological properties and the potential hazard it poses to workers, the public and the environment, the safe management of such material from its generation to disposal must be ensured. ***This requires containment and isolation from humans and the living environment over periods of time ranging from several days to several hundreds of thousands of years, depending on the radioactivity content of the material.***

Most of the radioactive waste originates from nuclear power plants and associated nuclear fuel cycle activities. Smaller volumes of radioactive waste are generated as a result of non-power uses of radioactive materials, such as the manufacturing of radioisotopes for use in medical and industrial applications, or research facilities such as laboratories and research reactors.

Each Member State defines its own electricity generation mix and as of the reporting date nuclear power plants were in operation in 13 countries (Belgium, Bulgaria, Czechia, Finland, France, Germany, Hungary, the Netherlands, Romania, Slovakia, Slovenia, Spain and Sweden. In addition, although it has no nuclear power plant within its own national borders, Croatia co-owns the Krsko nuclear power plant with Slovenia). Two other Member States, Lithuania and Italy, had terminated their nuclear power programmes and were decommissioning their nuclear installations. At the end of the reporting period, ***these 15 Member States with nuclear power programmes together accounted for 99.5% in volume of the radioactive waste inventory in the EU.***

The former study** concluded that the standardised communication approach used between licensees and authorities appears to be efficient and to suit user needs. It also pointed out **that radioactive waste classification may not systematically apply for all reported waste in the national reports, and the approaches, methods and tools that Member States use to develop their inventories were not systematically published.** The latter study confirmed that there are **no apparent needs for adopting a harmonised waste classification system across the Member States, although the need for harmonised reporting remains.

Most Member States have presented their radioactive waste inventory using the classification scheme as per the IAEA safety guide GSG-1 [14] *or have provided matrixes enabling data to be converted from their national classification scheme into the classification scheme 5 recommended by the IAEA.*

At the end of 2019 the estimated total inventory of radioactive waste on the EU-27 territory was 2 334 000 m^3 (a 5 % increase since the previous reporting period, corresponding to an average yearly production of less than 40 000 m^3).

*Approximately 66% of this waste had been disposed of (1 552 000 m^3) and 34% (782 000 m^3) was in storage and will have to be managed in the future. **Data show that in those Member States where disposal routes are open for very-low-level and low-level waste, the process from generation to disposal appears generally flowing;** for these classes of waste the amounts in storage fell by 10% (28 000 m^3), while the amounts disposed of increased by 8% (122 000 m^3). Not surprisingly, the same was not observed for intermediate-level and high-level waste as well as spent fuel, as currently there are no operational disposal facilities to handle these waste classes.*

2.2.7.2 Commentary

This report builds on the findings of the two studies mentioned above. However, it does not address NORM waste at all, despite the fact that both referenced studies include findings related to NORM waste (see sections 2.2.5 and 2.2.6).

2.2.8 Commentary on Sections 2.2.1 - 2.2.7

The EU regulations described in sections 2.2.1- 2.2.7 outline the evolution of the EU's approach to RAW. There is no unified, binding classification of radioactive waste (RAW) across the EU. Nor is there any obligation to classify NORM waste as RAW by default. Each Member State develops its own RAW classification system, primarily based on:

a) the available nuclear infrastructure,
b) the types of radioactive waste generated,
c) the technical capabilities for RAW management and disposal.

There is no indication that this national discretion is expected to be restricted. However, it is evident that these differing national classification systems complicate the collection of RAW data at the EU level (this issue will not be addressed further here, as it falls outside the scope of Deliverable 5.13).

The documents in sections 2.2.1 - 2.2.2 agree that there is a category of waste intended for authorised releases, which should not be considered RAW. Similarly, the RAW Directive states that it does not apply to mining waste (waste from the extractive industry), even if such waste may be contaminated by naturally occurring radionuclides.

In this context, the study referenced in section 2.2.5 notes that the conditions for authorised releases are not harmonised across Member States and suggests that such harmonisation would be desirable. This view is fully supported and will be elaborated in the following text.

The condition of release from regulatory control of material arising from any authorised practice discussed in detail in Council Directive 2013/59/EURATOM.

2.2.9 Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation [4]

As previously noted, the RAW Directive does not apply to waste from extractive industries that may be radioactive and fall under Directive 2006/21/EC (i.e. mining waste), nor does it apply to radioactive materials that are subject to authorised releases.

The "authorised releases of radionuclides" are regulated by Council Directive 2013/59/EURATOM, which establishes rules for the radiological protection of the public in connection with the release of radionuclides from workplaces, including NORM workplaces. Below is a selection of relevant definitions and provisions from this Directive, followed by commentary.

It seems important to introduce (before presenting the Directive articles) the graded approach to regulatory control, exemption of practice from regulatory control as well as release from regulatory control of materials from authorised practice and associated clearance level (linked to the authorised release)

2.2.9.1 Quotation from legal text - Council Directive 2013/59/EURATOM [4]

PREAMBLE

15) ***Industries processing naturally-occurring radioactive material extracted from the earth's crust subject workers and, if material is released into the environment, members of the public to increased exposure.***

(16) ***Protection against natural radiation sources, rather than being addressed separately in a specific title, should be fully integrated within the overall requirements. In particular, industries processing materials containing naturally-occurring radionuclides should be managed within the same regulatory framework as other practices.***

(17) It is appropriate for this Directive to establish reference levels for indoor radon concentrations and for indoor gamma radiation emitted from building materials, and to introduce requirements on the recycling of residues from industries processing naturally-occurring radioactive materials into building materials.

(18) Regulation (EU) No. 305/2011 lays down harmonised conditions for the marketing of construction products.

(19) Building materials emitting gamma radiation should be within the scope of this Directive but should also be regarded as construction products as defined in Regulation (EU) No 305/2011, in the sense that that Regulation applies to construction works emitting dangerous substances or dangerous radiation.

(38) Member States should be able to grant specific exemption from authorisation for certain practices involving activities above the exemption values.

(39) ***Specific clearance levels, as well as corresponding Community guidance, remain important tools for the management of large volumes of materials arising from the dismantling of authorised facilities***

Article 2 Scope

1. *This Directive applies to any planned, existing or emergency exposure **situation which involves a risk from exposure to ionising radiation which cannot be disregarded from a radiation protection point of view** or with regard to the environment in view of long-term human health protection.*
2. *This Directive applies in particular to:*
   c) *human activities which involve the presence of natural radiation sources that lead **to a significant increase in the exposure** of **workers or members of the public**, in particular:*
      i) *the operation of aircraft and spacecraft, in relation to the exposure of crews;*
      ii) the processing of materials with naturally-occurring radionuclides;
   d) *the exposure of workers or members of the public to indoor radon, the external exposure from building materials and cases of lasting exposure resulting from the after-effects of an emergency or a past human activity.*
   e) *the preparedness for, the planning of response to and the management of emergency exposure situations that are deemed to warrant measures to protect the health of members of the public or workers.*

Article 26 Exemption from notification

1. *Member States may decide that justified practices involving the following do not need to be notified:*

(a) *radioactive materials where the quantities of the activity involved do not exceed in total the exemption values set out in Table B, column 3, of Annex VII, or higher values that, for specific applications, are approved by the competent authority and satisfy the general exemption and clearance criteria set out in Annex VII; or*

(b) *without prejudice to Article 25(4), radioactive materials where the activity concentrations do not exceed the exemption values set out in Table A of Annex VII, or higher values that, for specific applications, are approved by the competent authority and satisfy the general exemption and clearance criteria set out in Annex VII; or*

(c) *apparatus containing a sealed source, provided that:*
   (i) *the apparatus is of a type approved by the competent authority;*
   (ii) *the apparatus does not cause, in normal operating conditions, a dose rate exceeding 1 $\mu Sv \cdot h^{-1}$ at a distance of 0.1 m from any accessible surface; and*
   (iii) *conditions for recycling or disposal have been specified by the competent authority; or*

(d) *any electrical apparatus provided that:*
   (i) *it is a cathode ray tube intended for the display of visual images, or other electrical apparatus operating at a potential difference not exceeding 30 kilo volt (kV), or it is of a type approved by the competent authority; and*
   (ii) *it does not cause, in normal operating conditions, a dose rate exceeding 1 $\mu Sv \cdot h^{-1}$ at a distance of 0.1 m from any accessible surface.*

2. *Member States may exempt specific types of practices from the notification requirement subject to compliance with the general exemption criteria established in point 3 of Annex VII, on the basis of an assessment showing that exemption is the best option.*

Article 30 Release from regulatory control

1. Member States shall ensure that the disposal, recycling or reuse of radioactive materials arising from any authorised practice is subject to authorisation.

*2. **Materials for disposal, recycling or reuse may be released from regulatory control provided that the activity concentrations:***

a) ***for solid material do not exceed the clearance levels set out in Table A of Annex VII**; or*
b) *comply with **specific clearance levels** and associated requirements for specific materials or for materials originating from specific types of practices**; these specific clearance levels shall be established in national legislation or by the national competent authority, following***

__the general exemption and clearance criteria set out in Annex VII__, and taking into account technical guidance provided by the Community

3. Member States shall ensure that for the clearance of materials containing naturally-occurring radionuclides, __where these result from authorised practices in which natural radionuclides are processed for their radioactive, fissile or fertile properties__, the clearance levels comply with the dose criteria for clearance of materials containing artificial radionuclides.

4. Member States __shall not permit the deliberate dilution of radioactive materials__ for the purpose of them being released from regulatory control. The mixing of materials that takes place in normal operations where radioactivity is not a consideration is not subject to this prohibition. __The Competent Authority may authorise__, in specific circumstances, the __mixing of radioactive and non-radioactive materials for the purposes of re-use or recycling.__

ANNEX VII - Exemption and clearance criteria as referred to in Articles 24, 26 and 30

Exemption and clearance levels

(a) The total activity values (in Bq) for exemption apply to the total activity involved in a practice and are laid down in column 3 of Table B for artificial radionuclides and for some naturally occurring radionuclides used in consumer products. For other practices involving naturally occurring radionuclides, such values are, in general, not applicable.

(b) __The exempt activity concentration values (in kBq kg $^{-1}$__) for the materials involved in the practice are laid down in Table A, Part 1, for artificial radionuclides, __and in Table A, Part 2, for naturally occurring radionuclides.__ The values in Table A, Part 1, are given for individual radionuclides, where applicable, including short-lived radionuclides in equilibrium with the parent nuclide, as indicated. __The values in Table A, Part 2, apply to all radionuclides in the decay chain of U-238 or Th-232, but for segments of the decay chain, which are not in equilibrium with the parent radionuclide, higher values may be applied.__

(c) __The concentration values__ in Table A, Part 1, or __in Table A, Part 2,__ also apply to the __clearance of solid materials for reuse, recycling, conventional disposal or incineration__. __Higher values__ may be defined for specific materials or specific pathways, taking Community guidance into account, including, where appropriate, additional requirements, in terms of surface activity or monitoring requirements.

(d) For mixtures of artificial radionuclides, the weighted sum of nuclide-specific activities or concentrations (for various radionuclides contained in the same matrix) divided by the corresponding exemption value shall be less than unity. Where appropriate, this condition can be verified on the basis of best estimates of the composition of the radionuclide mix. __The values in Table A, Part 2, apply individually to each parent nuclide. Some elements in the decay chain, e.g. Po-210 or Pb-210, may warrant the use of higher values taking Community guidance into account__.

(e__) The values in Table A, Part 2, may not be used to exempt the incorporation into building materials of residues from industries processing naturally-occurring radioactive material__. For this purpose, compliance with the provisions of Article 75 shall be verified. The values laid down in Table B, column 3, apply to the total inventory of radioactive substances held by a person or undertaking as part of a specific practice at any point in time. However, the competent authority may apply these values to smaller entities or packages, for instance to exempt the transport or storage of exempted consumer products, if the general exemption criteria in section 3 are satisfied.

TABLE A PART 2

Naturally occurring radionuclides

Values for exemption or clearance for naturally occurring radionuclides in solid materials in secular equilibrium with their progeny:

Natural radionuclides from the U-238 series	*1 $kBq.kg^{-1}$*
Natural radionuclides from the Th-232 series	*1 $kBq.kg^{-1}$*
K-40	*10 $kBq.kg^{-1}$*

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3. General exemption and clearance criteria

(a) The general criteria for the exemption of practices from notification or authorisation or for the clearance of materials from authorised practices are as follows:

- *(i) the radiological risks to individuals caused by the practice are sufficiently low, as to be of no regulatory concern; and*
- *(ii) the type of practice has been determined to be justified; and*
- *(iii) the practice is inherently safe.*

(b) Practices involving small amounts of radioactive substances or low activity concentrations, comparable to the exemption values laid down in Table A or Table B are deemed to fulfil criterion (iii).

(c) Practices involving amounts of radioactive substances or activity concentrations below the exemption values laid down in Table A, Part 1, or Table B, are deemed to comply with criterion (i) without further consideration. ***This is also the case for the values in Table A, Part 2, with the exception of the recycling of residues in building materials or the case of specific exposure pathways, for instance, drinking water.***

(d) In the case of moderate amounts of material, as specified by Member States for specific types of practice, the activity concentration values laid down in Table B, column 2, may be used instead of the values laid down in Table A, Part 1, for the purpose of exemption from authorisation.

(e) For the purpose of exemption from notification or ***for the purpose of clearance****,* ***where amounts of radioactive substances or activity concentrations do not comply with the values laid down in Table*** *A or Table B, an assessment shall be made in the light of the* ***general criteria (i) to (iii) above****. For compliance with the general criterion (i), it shall be demonstrated that workers should not be classified as exposed workers, and the following criteria for the exposure of members of the public are met in all feasible circumstances:*

— For artificial radionuclides:

The effective dose expected to be incurred by a member of the public due to the exempted practice is of the order of 10 µSv or less in a year.

— ***For naturally-occurring radionuclides****:*

The dose increment, allowing for the prevailing background radiation from natural radiation sources, liable to be incurred by an individual due to the exempted practice is of the order of 1 mSv or less in a year. The assessment of doses to members of the public shall take into account not only pathways of exposure through airborne or liquid effluent, but also pathways resulting from the disposal or recycling of solid residues. ***Member States may specify dose criteria lower than 1 mSv per year for specific types of practices or specific pathways of exposure.***

For the purpose of exemption from authorisation, less restrictive dose criteria may be applied.

2.2.9.2 Commentary

The Directive distinguishes — unlike the IAEA documents referred to later — between general exemption and clearance criteria for artificial and natural radionuclides (order of 10 µSv or less per year, and order of 1 mSv or less, respectively), even though both types of practices are considered by both the Community and the IAEA as planned exposure situations.

Although the 2013/59/EURATOM Directive includes a definition of RAW (adopted from Council Directive 2011/70/EURATOM) and uses this term in the context of RAW storage or disposal, **it does not specify any requirements for RAW management**. However, **it includes NORM within its scope, including requirements to regulate exposures of members of the public resulting from releases from NORM workplaces**.

The general exemption and clearance criterion for NORM is an incremental dose to a member of the public "of the order of 1 mSv or less per year," taking into account:

- exposures from liquid and gaseous discharges,
- as well as exposures from recycling, reuse, or disposal of solid NORM residues by landfilling or incineration.

For easier initial decision-making on exemption and clearance, the directive provides levels in Table A, Part 2 expressed in terms of activity concentration of thorium and uranium decay series parent radionuclides. The interpretation whether **these apply individually to each parent radionuclide in the U-238 and Th-232 decay series** or **apply to all radionuclides in the decay chain of U-238 or Th-232** is not clearly expressed considering requirements b) and d) described in the directive's annex VII

For some progeny radionuclides, Annex VII allows the possibility of replacing the clearance level with a value of 10 *$kBq.kg^{-1}$* **if it is demonstrated that general exemption and clearance criterion are still met.** In this case, Po-210 and Pb-210 are mentioned, the activities of which could be adjusted to a level of up to 10 *$kBq.kg^{-1}$*. This procedure can be recommended especially for NORM waste, in which the excess of 1 *$kBq.kg^{-1}$* occurs only for these two radionuclides. This situation can be found, for example, in deposits from gas pipeline pigging, in some flue gas deposits etc. These NORM waste could then be released only on the basis of the fact that the level was not exceeded, without the need to determine the effective dose. No justification is given for this example, which appears to only consider external radiation. For internal exposure, the committed effective dose per unit intake for Po-210 and Pb-210 indeed is significantly lower than for e.g. thorium isotopes, while for radium isotopes these dose conversion factors are at the comparable or even slightly higher, hence no reason to consider Pb-210 and Po-210 in different manner. This example does not provide clear justification for this directive's recommendation. The issue is further examined in the following 20.1.

Notwithstanding the last remark, the above confirms that even in cases where **NORM released is treated as conventional waste** (i.e. incinerated or landfilled), **this may be done safely — provided the general criterion of "of the order of 1 mSv or less per year" effective dose is not exceeded.**

If a Member State use this option and set dose criteria below "in order 1 mSv/year" for specific activities or exposure pathways — e.g., specifically for disposal to conventional landfills or incineration — such cases can be considered "authorised releases of radionuclides." Accordingly, the resulting waste is excluded from the scope of the RAW Directive and should not be considered RAW.

As confirmed by responses to the RadoNorm questionnaire [7], some Member States apply exactly 1 mSv/year as the dose criterion. In other cases, if NORM waste exceeds the clearance level, it must be classified and managed as RAW.

However, the directive does not explicitly define what is meant by **"of the order of 1 mSv or less per year" effective dose — it does not specify an upper boundary, leaving it to Member States to determine what maximum effective dose to a member of the public is acceptable before a material becomes RAW and requires isolation** for the protection of human health and protection of environment.

If the limit of 1 mSv/year for public exposure is not to be taken as that boundary — or if exceeding the general clearance criterion in itself is not considered a trigger — then clearer guidance is needed.

It would be appropriate to support Member States by providing more precise descriptions of acceptable doses and procedures for the clearance of NORM waste for disposal, including framework procedures for establishing specific clearance levels.

The content of natural radionuclides in construction materials intended for occupancy is regulated by a separate criterion: the reference level of 1 mSv/year, which also applies when NORM is used to produce building materials for inhabited spaces.

2.2.10 Directive 2006/21/EC of the European Parliament and of the Council on the management of waste from extractive industries [9]

2.2.10.1 Quotation from legal text - Directive 2006/21/EC of the European Parliament and of the Council on the management of waste from extractive industries [9]

Preamble

(10) Moreover, while covering the management of waste from the extractive industries which may be radioactive, this Directive should not cover such aspects as are specific to radioactivity, which are a matter dealt with under the Treaty establishing the European Atomic Energy Community (Euratom).

2.2.10.2 Commentary

This Directive also applies to mining waste that is radioactive — but not to that portion of such waste which is declared as RAW in the meaning provided by Euratom Treaty (see the section 2.2.1). Other sources of RAW definition (identification) as such discussed in the sections 2.2.2 - 2.2.9 are not directly considered. Hence the actual scope of this directive applications in terms of radioactivity is not clear. On another hand, the extractive industries cover all activities related to exploitation of geological resources including any kind of mining, including oil and gas exploitation, thermal water as well groundwater sourcing for consumption that are well identified as NORM involving industries. A special case is coal mining, given that the positive list in Annex VI of Council Directive 2013/59/EURATOM does not include the coal mining, the exemption and clearance criteria for naturally occurring radionuclides cannot be applied to coal mining waste — unless Member States decide to include the coal mining industry in their national positive lists. If they do, the regulation of naturally occurring radionuclide content in coal mining waste could then be based on the exemption and clearance criteria laid down in that Directive. Otherwise application of the directive on waste from extractive industries can be applied, however it does not provide any detail concerning radioactivity beyond general declaration of the scope of application.

It is known that certain mining wastes — particularly mine waters (aside from uranium and thorium mining) — contain elevated concentrations of natural radionuclides [18], [19], [20], [21]. **Therefore, including the extractive industries and its associated wastes not included yet there on some national positive lists can be considered justified.**

To improve consistency between the two aforementioned directives, it would be beneficial to include the coal mining industry in Annex VI of Council Directive 2013/59/EURATOM. Until then, it is important that Member States include the coal mining industry in their national regulations just like other NORM activities.

Note: Directive 2006/21/EC was issued prior to Council Directive 2013/59/EURATOM.

3. IAEA framework for radioactive waste and for the release of radionuclides from workplaces

The key documents include IAEA Safety Standards Series No. GSG-1 for the classification of radioactive waste [14], and GSR Part 3 [5], as well as GSG-17 [22] and GSG-18 [23], which provide the framework for ensuring radiation protection in connection with the release of radionuclides from workplaces. These documents represent binding guidance for IAEA Member States and form the basis for their legislative actions in this area.

The relevant IAEA documents and provisions are presented in Chapters 3.1 through 3.4. As already noted in the study cited in Chapter 2.2.6, EU Member States often refer to these IAEA documents when defining their criteria for authorised release; however, they do not always adopt them in full.

3.1 Classification of radioactive waste: general safety guide [14]

3.1.1 Quotation from the GSR-1 [14]

*1.10. This Safety Guide provides guidance on the classification of the whole range of radioactive waste: from spent nuclear fuel, when it is considered radioactive waste, t**o waste having such low levels of activity concentration that it is not required to be managed or regulated as radioactive waste**. This **Safety Guide covers** disused sealed sources, when they are considered waste, **and waste containing radionuclides of natural origin**. The recommendations in this Safety Guide are applicable to waste arising from all origins, including waste arising from facilities and activities, waste arising from existing situations and waste that may arise from accidents.*

*1.11. **The classification scheme developed in this Safety Guide is focused on solid radioactive waste.** However, the fundamental approach could also be applicable to the management of liquid and gaseous waste, with appropriate consideration given to aspects including the processing of such waste to produce a solid waste form that is suitable for disposal.*

THE RADIOACTIVE WASTE CLASSIFICATION SCHEME OVERVIEW

2.1. A number of elements of the classification scheme previously set out3 have been retained. However, the scheme has been modified to address the shortcomings identified with the previous scheme (see para. 1.6) and to reflect experience gained in developing, operating and assessing the safety of disposal facilities. A comprehensive range of waste classes has been defined and general boundary conditions between the classes are provided. More detailed quantitative boundaries that take into account a broader range of parameters may be developed in accordance with national programmes and requirements. In cases when there is more than one disposal facility in a State, the quantitative boundaries between the classes for different disposal facilities may differ in accordance with scenarios, geological and technical parameters and other parameters that are relevant to the site-specific safety assessment.

2.2. In accordance with the approach outlined in the Appendix, six classes of waste are derived and used as the basis for the classification scheme (Figure 1):

*(1) **Exempt waste**[4] (EW): Waste that meets the criteria for clearance, exemption or exclusion from regulatory control for radiation protection purposes as described in Ref. [6].*

*[4] The term 'exempt waste' has been retained from the previous classification scheme (see footnote 3) for consistency; however, **once such waste has been cleared from regulatory control, it is not considered radioactive waste.***

(2) Very short-lived waste (VSLW): Waste that can be stored for decay over a limited period of up to a few years and subsequently cleared from regulatory control according to arrangements approved by the regulatory body, for uncontrolled disposal, use or discharge. This class includes waste containing primarily radionuclides with very short half-lives often used for research and medical purposes.

*(3) **Very low-level waste** (VLLW): Waste that does not necessarily meet the criteria of EW, but that does not need a high level of containment and isolation and, therefore, is suitable for disposal in near surface landfill type facilities with limited regulatory control. Such landfill type facilities may also contain other hazardous waste. Typical waste in this class includes soil and rubble with low levels of activity concentration. Concentrations of longer-lived radionuclides in VLLW are generally very limited.*

*(4) **Low level waste** (LLW): Waste that is above clearance levels, but with limited amounts of long-lived radionuclides. Such waste requires robust isolation and containment for periods of up to a few hundred years and is suitable for disposal in engineered near surface facilities. This class covers a very broad range of waste. LLW may include short lived radionuclides at higher levels of activity concentration, and also long-lived radionuclides, but only at relatively low levels of activity concentration.*

(5) Intermediate level waste (ILW): Waste that, because of its content, particularly of long-lived radionuclides, requires a greater degree of containment and isolation than that provided by near surface disposal. However, ILW needs no provision, or only limited provision, for heat dissipation during its storage and disposal. ILW may contain long lived radionuclides, in particular, alpha emitting radionuclides that will not decay to a level of activity concentration acceptable for near surface disposal during the time for which institutional controls can be relied upon. Therefore, waste in this class requires disposal at greater depths, of the order of tens of metres to a few hundred metres.

(6) High level waste (HLW): Waste with levels of activity concentration high enough to generate significant quantities of heat by the radioactive decay process or waste with large amounts of long-lived radionuclides that need to be considered in the design of a disposal facility for such waste. Disposal in deep, stable geological formations usually several hundred metres or more below the surface is the generally recognised option for disposal of HLW.

2.3. Quantitative values of allowable activity content for each significant radionuclide will be specified on the basis of safety assessments for individual disposal sites (which is outside the scope of this Safety Guide).

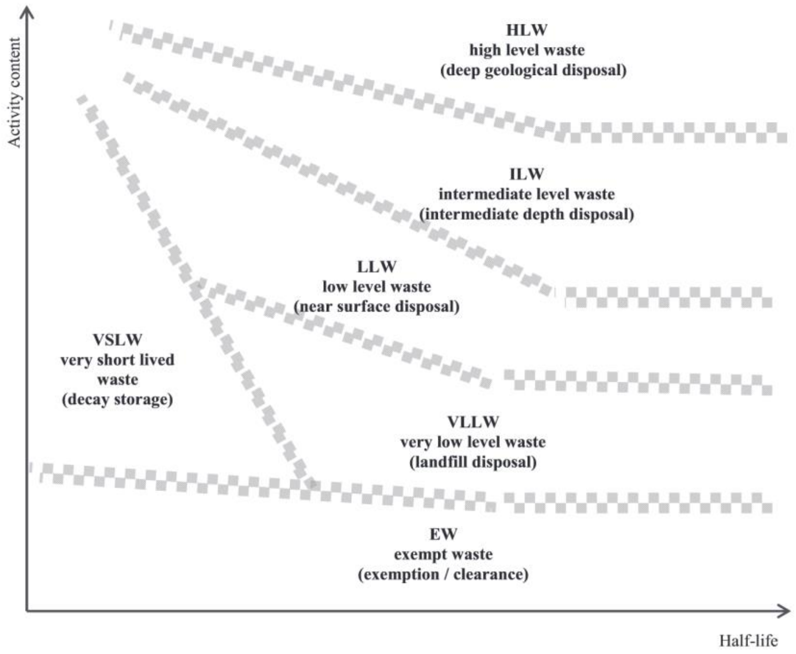

Figure 1: Conceptual illustration of the waste classification scheme [14].

Given that NORM waste is most likely to fall within the categories of EW (exempt waste), VLLW (very low-level waste), and LLW (low-level waste), the following points provide further details concerning these types of waste.

3.1.2 Quotation from the GSR-1 - Exempt waste EW [14]

2.8. Exempt waste contains such small concentrations of radionuclides that it does not require provisions for radiation protection, irrespective of whether the waste is disposed of in conventional landfills or recycled. Such material can be cleared from regulatory control and does not require any further consideration from a regulatory control perspective.

2.9. Liquid or gaseous effluents discharged to the environment under appropriate regulatory control are somewhat analogous to exempt waste, because as discharged material requires no further consideration from the perspective of radiation protection and safety. There are, however, some notable differences in the establishment of limitations on effluent quantities suitable for discharge and, in the case of discharge of effluents, confirmatory environmental monitoring is normally carried out [7].

2.10. Studies undertaken at the national and international levels have derived radionuclide specific levels of activity concentration for the exemption and clearance of solid material, and Ref. [6] provides explanation and guidance on the concepts of exclusion, exemption and clearance. Reference [6] gives values of activity concentration for radionuclides of both natural and artificial origin that may be used by the regulatory body for determining when controls over bulk amounts of solid material are not required or are no longer necessary.

2.11. The values of activity concentration for artificial radionuclides are derived on the basis of generic scenarios for the recycling and disposal of waste:

“The primary radiological basis for establishing values of activity concentration for the exemption of bulk amounts of material and for clearance is that the effective doses to individuals should be of the order of 10 μSv or less in a year. To take account of the occurrence of low probability events leading to higher radiation exposures, an additional criterion was used, namely, the effective doses due to such low probability events should not exceed 1 mSv in a year. In this case, consideration was also given to doses to the skin; an equivalent dose criterion of 50 mSv in a year to the skin was used for this purpose. This approach is consistent with that used in establishing the values for exemption provided in Schedule I of the BSS” [6].

For radionuclides of natural origin, a different approach was adopted: these values were determined on the basis of consideration of the upper end of the worldwide distribution of activity concentrations in soil [6].

2.12. Levels of activity concentration for exempt waste that are different from those recommended in Ref. [6] may be established by the regulatory body on a case by case basis, providing that consideration is given to specific national circumstances that will significantly influence exposure scenarios, or specific requirements or conditions are defined for the exemption or clearance of waste. Consideration should be given to any possible transboundary implications, if it is conceivable that the material in question might be exported. Levels of activity concentration established by the regulatory body will be highly dependent on the conditions under which exemption or clearance is granted.

3.1.3 Commentary to Exempt waste

Exempt NORM waste contains such low levels of naturally occurring radionuclides that the activity concentration of all relevant radionuclides remains below 1 $kBq.kg^{-1}$, or 10 $kBq.kg^{-1}$ in the case of ^{40}K ("the values of activity concentration"). These values are set at the upper boundary of natural background concentrations in soil (based on global averages), and therefore no scenario is assigned to them. For this reason, unlike artificial radionuclides, the document does not explicitly specify which values of effective dose E correspond to these activity concentrations. Another unintended implication of this rule is that materials with activity concentrations of naturally occurring radionuclides exceeding the specified limits subject classification as radioactive waste. This results in a paradox regarding natural radionuclides, as only two categories are recognised: materials containing naturally occurring radionuclides at or below background levels, and all others that should be classified as radioactive waste.

Waste containing natural radionuclides below the specified values can be disposed of at a conventional landfill or recycled without any additional restrictions. Such waste is managed as if it were non-radioactive. The document notes that **the inclusion of exempted waste within the scope of radioactive waste was done purely for formal consistency with earlier regulations**, not due to any actual radiological hazard. What matters in practice is that these **wastes are not considered radioactive waste and therefore do not need to be classified as such in national legislation**.

Similarly, to EU BSSD, the document also **provides for the possibility that the regulatory authority may establish specific values of radionuclides’ activity concentration for exempted waste, provided these are based on specific scenarios or conditions.** However, based on the above, it is not clear what level of effective dose to members of the public national legislation should target in the case of exempted NORM waste.

The document also allows for the establishment of specific values by the regulatory body on a case-by-case basis. Specific clearance is based on an annual effective dose of approximately 1 mSv/year (see GSR Part 3, Annex I.13 [5]), which allows—for certain specific scenarios (e.g. landfill)—the inclusion of wastes with higher concentrations of natural radionuclides in the category of exempted waste. This means such wastes would fall outside the definition of radioactive waste and would remain within the regime of clearance from regulatory control at the workplace level.

In general, it can be stated that under the **clearance regime (i.e. comprises both compliance with clearance levels and authorised release)**, and under these conditions, the vast majority of NORM waste – typically in the activity range of 1–100 *kBq.kg*$^{-1}$ – can be removed from regulatory control. However, it remains an open question whether, in which cases, and by what regulatory measures long-term safety (e.g. of landfills) can be ensured, as the "lifetime" of NORM waste is likely to exceed the period that is declared for a landfill for conventional or hazardous wastes. However, it seems as being pure legal problem as dangerous, non-radioactive waste do not subject degradation (decay) due to time passage and the time horizons (e.g. in Poland usually 100 years) have been set for currently used landfills are set for different than safety reasons.

3.1.4 Quotation from the GSR-1 to Very low level waste (VLLW) [14]

2.17. Substantial amounts of waste arise from the operation and decommissioning of nuclear facilities with levels of activity concentration in the region of or ***<u>slightly above the levels specified for the clearance of material from regulatory control.</u>*** *Other such waste,* ***containing naturally occurring radionuclides, may originate from the mining or processing of ores and minerals.*** *The management of this waste, in contrast to exempt waste,* ***does require consideration from the perspective of radiation protection and safety, but the extent of the provisions necessary is limited in comparison to the provisions required for waste in the higher classes*** *(LLW, ILW or HLW).* ***Waste with such a limited hazard, which is nevertheless above or close to the levels for exempt waste, is termed very low-level waste.***

2.18. An adequate level of safety for VLLW may be achieved by its disposal ***in engineered surface landfill type facilities****.* ***This is the usual practice for waste from some mining operations and for other waste containing naturally occurring radionuclides from various operations involving minerals processing and other activities****. Some States also use this disposal method for waste with low levels of activity concentration arising from nuclear installations [8, 9].* ***The designs of such disposal facilities range from simple covers to more complex disposal systems and, in general, such disposal systems require active and passive institutional controls.*** *The time period for which institutional controls are exercised will be sufficient to provide confidence that there will be compliance with the safety criteria for disposal of the waste.*

2.19. In order to determine whether a particular type of waste can be considered to fall into the class of VLLW, acceptance criteria for engineered surface landfill type facilities have to be derived. This can be carried out either using generic scenarios similar to those applied in the derivation of exemption and clearance levels in Ref. [6] or by undertaking a safety assessment for a specific facility in a manner approved by the regulatory body. The criteria derived will depend on the actual site conditions and on the design of the engineered structures or, in the case of the use of generic scenarios, on assumptions made to take account of these factors. For this reason, generally valid criteria cannot be defined in this Safety Guide. Nevertheless, it is expected that with a moderate level of engineering and controls, a landfill facility can safely accommodate waste containing artificial radionuclides with levels of activity concentrations one or two orders of magnitude above the levels for exempt waste, for waste containing short lived radionuclides and with limited total activity. This applies as long as expected doses to the public are within criteria established by the regulatory body. ***In general, for waste containing naturally occurring radionuclides, acceptable levels of activity concentration will be expected to be lower than those for waste containing artificial radionuclides, in view of the long half-lives of naturally occurring radionuclides.*** *Depending on site factors and the design, it may still be possible to demonstrate the safety of waste with higher levels of activity concentration.*

2.20. Another management option for some waste falling within this class, such as waste rock from mining operations, may be the authorised use of the material (e.g. for road construction). In this case, criteria can be derived by using approaches similar to those set out in Ref. [6] for the definition of general clearance values (see para. 3.1 of Ref. [6]).

3.1.5 Quotation from the GSR-1 to Low level waste (LLW) [14]

2.21. In previous classification schemes, low level waste was defined to mean radioactive waste that does not require shielding during normal handling and transport[6]. Radioactive waste that requires shielding but needs little or no provision for heat dissipation was classified as intermediate level waste[7]. A contact ***dose rate of 2 mSv/h was*** *generally used to distinguish between the two classes of waste. Contact radiation dose rate is not used to distinguish waste classes in the present, revised classification scheme, which is based primarily on long term safety. However, it remains an issue that has to be considered in handling and transporting the waste, and for operational radiation protection purposes at waste management and disposal facilities, but is not necessarily a determining factor for the long-term safety of a disposal facility.*

2.22. In the classification scheme set out in this Safety Guide, low level waste is waste that is suitable for near surface disposal. This is a disposal option suitable for waste that contains such an amount of radioactive material that robust containment and isolation for limited periods of time up to a few hundred years are required. This class covers a very wide range of radioactive waste. It ranges from radioactive waste with an activity content level just above that for VLLW, that is, not requiring shielding or particularly robust containment and isolation, to radioactive waste with a level of activity concentration such that shielding and more robust containment and isolation are necessary for periods up to several hundred years.

2.23. Because LLW may have a wide range of activity concentrations and may contain a wide range of radionuclides, there are various design options for near surface disposal facilities. These design options may range from simple to more complex engineered facilities, and may involve disposal at varying depths, typically from the ***surface down to 30 m****. They will depend on safety assessments and on national practices, and are subject to approval by the regulatory body.*

2.24. Low concentrations of long-lived radionuclides may be present in LLW.

Although the waste may contain high concentrations of short-lived radionuclides, significant radioactive decay of these will occur during the period of reliable containment and isolation provided by the site, the engineered barriers and institutional control. Classification of waste as LLW should, therefore, relate to the particular radionuclides in the waste, and account should be taken of the various exposure pathways, such as ingestion (e.g. in the case of long-term migration of radionuclides to the accessible 6 See footnote 2.

[7] See footnote 3 biosphere in the post-closure phase of a disposal facility) and inhalation (e.g. in the case of human intrusion into the waste). Thus, radioactive waste suitable for disposal near the surface and at intermediate depths may, in most instances, be differentiated on the basis of the need for controls over time frames for which institutional control can be guaranteed and thus human intrusion into the waste can be prevented. The suitability of a disposal facility for a particular inventory of waste is required to be demonstrated by the safety case for that facility [5].

2.25. In many States it is assumed that institutional controls can be relied upon for a period of up to ***around 300 years****. Under this assumption, bounding values for low level waste in terms of activity concentration levels can be derived by estimating doses to exposed individuals after this period of institutional control.* ***A special situation arises for waste from the mining and processing of uranium and other materials containing significant amounts of radionuclides of natural origin,***

for which the activity content will not decrease significantly over such timescales. Since the management of such waste in near surface facilities is in many cases the only practicable option, longer periods of institutional control have to be postulated, with periodic safety review of the facility.

2.26. A precise boundary between LLW and intermediate level waste (ILW) cannot be provided, as limits on the acceptable level of activity concentration will differ between individual radionuclides or groups of radionuclides. Waste acceptance criteria for a particular near surface disposal facility will be dependent on the actual design of and planning for the facility (e.g. engineered barriers, duration of institutional control, site specific factors). Restrictions on levels of activity concentration for long lived radionuclides in individual waste packages may be complemented by restrictions on average levels of activity concentration or by simple operational techniques such as emplacement of waste packages with higher levels of activity concentration at selected locations within the disposal facility. It may be possible for a regulatory body to provide bounding levels of activity concentration for LLW on the basis of generic site characteristics and generic facility designs, as well as specified institutional control periods and dose limits to individuals.

2.27. The regulatory body should establish limits for the disposal of long-lived radionuclides on the basis of the safety assessment for the particular disposal facility. A ***limit of 400 Bq/g on*** *average (and up to 4000 Bq/g for individual packages****) for long lived alpha emitting radionuclides has*** *been adopted in some States [10–12]. For long lived beta and/or gamma emitting radionuclides, such as* ^{14}C, ^{36}Cl, ^{63}Ni, ^{93}Zr, ^{94}Nb, ^{99}Tc *and* ^{129}I*, the allowable average activity concentrations may be considerably higher (up to tens of kilobecquerels per kilogram.*

ADDITIONAL CONSIDERATIONS

2.32. If the classification scheme is used, the specific types and properties of radioactive waste should be taken into account. The precise criteria according to which waste is assigned to a particular waste class will depend on the specific situation in the State in relation to the nature of the waste and the disposal options available or under consideration. One important type of waste that requires specific consideration is disused sealed sources. Another important type of waste that requires specific consideration is waste containing elevated levels of radionuclides of natural origin, in view of the bulk quantities arising and the different regulatory approaches that have been adopted. Annex III provides an overview of important types of radioactive waste and discusses the special considerations necessary when using the classification scheme for these different types of waste. Figure 2 is a logic diagram illustrating the use of the classification scheme to assist in determining disposal options, explained further in Annex III

A.11. ***Dose criteria used for the management of waste containing naturally occurring radionuclides may be different from those used for the management of waste arising in nuclear installations and may be developed on the basis of considerations of optimisation of protection. Such differences may influence the disposal option selected for large volumes of waste containing naturally occurring radionuclides such as tailings from mining and minerals processing.***

3.1.6 Commentary to Very low-level and Low-level waste

Most of the NORM waste that could not be removed as exempt waste would fall into the VLLW (very low-level waste) category. This waste contains radionuclides with long half-lives, that subject to successive decay resulting in creation of new radionuclides (elements) being different type of radiation emitters. This issue is further discussed in the section on NORM characterisation (19). Such waste can be disposed of in near-surface facilities, which is also the disposal method considered for conventional waste under the EU Waste Directive. If this approach could be applied, it might also be feasible to manage such waste under the exempt waste regime, unless the final composition of radionuclides in it would change its exemption status.

3.2 Policies and Strategies for Radioactive Waste Management, IAEA Nuclear Energy Series No. NW-G-1.1 [24]

The chapter of this document dedicated to NORM waste states the following:

3.2.1 Quotation from the NW-G-1.1 [24]

NORM

NORM occurs as a by-product, residue or waste from activities such as uranium mining and milling; coal burning; oil and gas extraction; tin, iron, niobium and non-metal mining; and milling and water treatment. NORM contains radionuclides of the uranium and thorium decay chains and is characterised by very large volumes. NORM often contains other toxic substances such as heavy metals and, for this reason, both radiological and non- radiological aspects have to be taken into account for its management. In some countries, NORM is regulated as a radioactive waste and in others as a chemically toxic waste.

9.8.1. Processing of NORM

Processing consists of pile stabilisation by various processes in order to increase the safety of storage and disposal sites. Solid, large pieces of NORM waste, such as pipes from the oil industry, are fragmented for handling and transport purposes. Liquid NORM waste is treated to reduce its radionuclide content and mobility. Decontamination and recycling may be effective options for reducing the volume of this waste [35, 36].

9.8.2. Disposal of NORM

NORM waste is generally deposited in consolidated and over-covered piles or sludge beds, or purpose designed repositories with lined cells and protective capping [37]. As it is not feasible to move such large amounts of material, the waste tends to be disposed of on the site of its generation.

Capping and some engineered structures may be used to prevent erosion and to limit the leakage of radioactive gases. In some cases, the waste has been disposed of by using it to backfill disused underground mines.

3.3 Application of the Concept of Exemption (GSG-17 [22]) and Clearance (GSG-18 [23])

It is clear from the above that the concepts of exemption and clearance are essential for the management of NORM waste. These terms are defined in the IAEA documents GSG-17 [22] and GSG-18 [23]. The GSR Part 3 [5] – International BSS – document classifies mining and processing of raw materials—which covers most NORM industries (with the option for the regulatory body to include additional sectors)—as planned exposure situations and applies both concepts, exemption and clearance. The regulatory approach is therefore similar to that of EU BSSD, and the exemption and clearance levels for naturally occurring radionuclides are identical.

3.3.1 Quotations from GSR Part 3 – International BSS

3.1. The requirements for planned exposure situations apply to the following practices:

(a) The production, supply, provision and transport of radioactive material and of devices that contain radioactive material, including sealed sources and unsealed sources, and of consumer products;
(b) The production and supply of devices that generate radiation, including linear accelerators, cyclotrons, and fixed and mobile radiography equipment;
(c) The generation of nuclear power, including any activities within the nuclear fuel cycle that involve or that could involve exposure to radiation or exposure due to radioactive material;
(d) The use of radiation or radioactive material for medical, industrial, veterinary, agricultural, legal or security purposes, including the use of associated equipment, software or devices where such use could affect exposure to radiation;
(e) The use of radiation or radioactive material for education, training or research, including any activities relating to such use that involve or could involve exposure to radiation or exposure due to radioactive material;
(f) The mining and processing of raw materials that involve exposure due to radioactive material;
(g) Any other practice as specified by the regulatory body.

3.2. The requirements for planned exposure situations apply to exposure due to sources within practices, as follows:

(a) Facilities that contain radioactive material and facilities that contain radiation generators, including nuclear installations, medical radiation facilities, veterinary radiation facilities, facilities for the management of radioactive waste, installations for the processing of radioactive material, irradiation facilities, ***and mineral extraction and mineral processing facilities that involve or could involve exposure to radiation or exposure due to radioactive material****;*
(b) Individual sources of radiation, including sources within the types of facility mentioned in para. 3.2(a), as appropriate, in accordance with the requirements of the regulatory body.

3.3. The requirements for planned exposure situations apply for any occupational exposure, medical exposure or public exposure due to any practice or due to a source within a practice as specified in paras 3.1 and 3.2.

3.4. Exposure due ***to natural sources is, in general, considered an existing exposure situation*** *and is subject to the requirements in Section 5. However,* ***the relevant requirements in Section 3 for planned exposure situations apply to:***

(a) Exposure due to material[17] in any practice specified in para. 3.1 where the activity concentration in the material of any radionuclide in the uranium decay chain or the thorium decay chain is greater than 1 Bq/g or the activity concentration of ^{40}K is greater than 10 Bq/g;
(b) Public exposure due to discharges or due to the management of radioactive waste arising from a practice involving material as specified in (a) above;

[17] A situation of exposure due to radionuclides of natural origin in food, feed, drinking water, agricultural fertiliser and soil amendments, construction materials and residual radioactive materials in the environment is treated as an existing exposure situation regardless of the activity concentrations of the radionuclides concerned.

Regulatory control should be commensurate with the magnitude and likelihood of exposures resulting from practices [4], [5]. Notification, authorisation (i.e. registration and licensing) as well as inspection and the possible exemption from notification or authorisation serve to this purpose.

‘**Exclusion’** means the deliberate exclusion of a particular category of exposure from the scope of an instrument of regulatory control on the grounds that it is not considered amenable to control through the regulatory instrument in question. Such exposure is termed excluded exposure.

‘**Exemption’** means the determination by a regulatory body that **a source or practice** need not be subject to some or all aspects of regulatory control on the basis that the exposure (including potential exposure) due to the source or practice is too small to warrant the application of those aspects.

‘**Clearance’** means the **removal of radioactive materials or radioactive objects** within authorised practices from any further regulatory control by the regulatory body. Removal from control in this context refers to control applied for radiation protection purposes.

While exemption is *a priori* act – the government or the regulatory body shall determine which justified practices or sources within justified practices are to be exempted from some or all of the regulatory requirements, clearance is the process of release of material coming from notified or authorised practices from regulatory control.

From the perspective of NORM waste management, which is the focus of this part of the Deliverable 5.13, the concept of “clearance” is essential. It serves as the basis for distinguishing between waste that can be released from regulatory control from the standpoint of radiation protection, and waste that cannot be released and must instead be isolated and kept under regulatory control as radioactive waste (RAW).

3.3.2 Quotations from GSR Part 3 – International BSS - Clearance

*3.12. The regulatory body shall approve which sources, including materials and objects, within notified or authorised practices may be cleared from regulatory control, using as the basis for such approval the criteria for **clearance specified in Schedule I** or **any clearance levels specified by the regulatory body on the basis of these criteria.** By means of this approval, the regulatory body shall ensure that sources that have been cleared from regulatory control do not again become subject to the requirements for notification, registration or licensing unless it so specifies.*

Schedule I

*I.11. Material may be cleared without further consideration under the terms of para. I.10(a) provided that in reasonably foreseeable circumstances the effective dose expected to be incurred by any individual owing to the cleared material is **of the order of 10 µSv or less in a year**. To take into account **low probability scenarios, a different criterion can be used, namely that the effective dose expected to be incurred by any individual for such low probability scenarios does not exceed 1 mSv in a year.***

I.12. Radioactive material within a notified practice or an authorised practice may be cleared without further consideration provided that:

- *(a) The activity concentration of an individual radionuclide of artificial origin in solid form does not exceed the relevant level given in Table I.2 (p. 124)[62]; or*
- ***(b) The activity concentrations of radionuclides of natural origin do not exceed the relevant level given in Table I.3 (p. 128)[63]; or***
- *(c) For radionuclides of natural origin in residues that might be recycled into construction materials[64], or the disposal of which is liable to cause the contamination of drinking water supplies, the activity concentration in the residues does not exceed specific values derived so as to meet a dose criterion of the order of 1 mSv in a year, which is commensurate with typical doses due to natural background levels of radiation.*

I.13. Clearance may be granted by the regulatory body for specific situations, on the basis of the criteria of paras I.10 and I.11, with account taken of the physical or chemical form of the radioactive material, and its use or the means of its disposal[65]. Such clearance levels may be specified in terms of activity concentration per unit mass or activity concentration per unit surface area.

[62] The exemption levels set out in Table I.1 (p. 111) and the exemption and clearance levels set out in Table I.2 are subject to the following considerations: (a) they were derived using a conservative model based on (i) the criteria of paras I.2 and I.11, respectively, and (ii) a series of limiting (bounding) scenarios for use and disposal (see Refs [25, 26] in the case of Table I.1 and Ref. [27] in the case of Table I.2); (b) if there is more than one radionuclide, the derived exemption level or derived clearance level for the mixture is determined as specified in paras I.7 and I.14.

[63] These values of activity concentration may also be applied for the clearance of materials arising from practices subject to the clearance criteria given in para. I.11, pending establishment of radionuclide specific values for the radionuclides of natural origin given in Table I.3.

[64] Regulatory control of construction materials incorporating radionuclides is addressed in Section 5 as an existing exposure situation.

[65] For example, specific clearance levels may be developed for metals, for rubble from buildings and waste for disposal in landfill sites.

3.3.3 Commentary and Quotation from NW-G-3.4

Instead of providing commentary by the authors of the report, we cite the relevant sections from a recently published IAEA document Policies and strategies for the management of NORM residues and wastes – NW-G-3.4 [25].

In particular, the regulatory framework for the safe management of NORM residues can be based on these safety requirements.

GSR Part 3 establishes that:

"The government shall ensure that existing exposure situations that have been identified are evaluated to determine which occupational exposures and public exposures are of concern from the point of view of radiation protection."

Nevertheless, GSR Part 3 also specifies that (footnote 17 is omitted in quote) [14]:

"Exposure due to natural sources is, in general, considered an existing exposure situation and is subject to the requirements in Section 5.

Finally, clearance is "Removal of regulatory control by the regulatory body from radioactive material or radioactive objects within notified or authorised facilities and activities" [1].

Materials are cleared on the basis that radiation risks arising from the cleared material are sufficiently low as not to warrant regulatory control, or continued regulatory control of the material would yield no net benefit.

The application of these concepts is discussed in detail in Ref. [13], which has since been revised as two separate publications covering, respectively, exemption [11] and clearance [12]. Both refer extensively to the application for NORM. In brief, the same approach as in IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [14] is followed: ***a case-by-case <u>exemption</u> is applied for bulk materials containing radionuclides of natural origin, using an individual dose criterion of the order of 1 mSv in a year,***

whereas 1 Bq/g for uranium and thorium series radionuclides and 10 Bq/g for ^{40}K are proposed as <u>generic clearance levels for most situations</u>

Further details on the use of clearance levels for naturally occurring radionuclides are provided below:

3.7. Paragraph I.12(b) of GSR Part 3 [1] specifies that material containing radionuclides of natural origin can be cleared provided that the activity concentrations do not exceed the clearance levels given in table I.3 of GSR Part 3 [1]. ***These clearance levels apply to each individual radionuclide in the decay chains of ^{238}U and ^{232}Th, regardless of whether the decay chains are in secular equilibrium.*** *Hence, the approach to mixtures of radionuclides described in para. I.14 of GSR Part 3 [1] is not appropriate for clearance of materials containing radionuclides of natural origin. Instead, the activity concentration of each radionuclide of natural origin should be compared with the clearance levels in table I.3 of GSR Part 3 [1], and if each one is less than or equal to the clearance level then the material can be cleared. For example, for a material containing radionuclides from the ^{238}U decay chain, the clearance level of 1 Bq/g would apply to each radionuclide present. Where the secular equilibrium is significantly disturbed (e.g. owing to thermal processes) or only parts of the decay chain are present, use of the clearance levels given in table I.3 of GSR Part 3 [1] might be too restrictive. In such cases, the regulatory body or operating organisation might derive more appropriate values (i.e. specific clearance).*

3.8. For clearance of solid bulk material containing a mixture of radionuclides of natural origin and radionuclides of artificial origin, the conditions given in paras I.12(b) and I.14 of GSR Part 3 [1] are required to be satisfied (see para. I.15 of GSR Part 3 [1]). The decision on clearance should therefore contain the following steps:

- *(1) The summation rule in para. I.14 of GSR Part 3 [1] (or in para. 3.5 of this Safety Guide) is applied to the radionuclides of artificial origin.*
- *(2) The clearance levels in table I.3 of GSR Part 3 [1] are applied to each radionuclide of natural origin.*
- *(3) If both the radionuclides of artificial origin and the radionuclides of natural origin meet the clearance criteria, then the material can be cleared. If the radionuclides of artificial origin or the radionuclides of natural origin fail to meet the clearance criteria, then the material cannot be cleared.*

3.4 Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [26]

The Joint Convention is the first legal instrument to address the issue of safety in the management of spent fuel and radioactive waste on a global scale. It does so by establishing fundamental safety principles and introducing a system of "peer review," similar to that under the Convention on Nuclear Safety.

The Convention applies to spent fuel resulting from the operation of civilian nuclear reactors and to radioactive waste arising from civilian applications. It also covers spent fuel and radioactive waste from military or defence programmes, if such materials are permanently transferred to exclusively civilian programmes and are managed within those programmes, or if they are declared by the Contracting Party concerned as spent fuel or radioactive waste for the purposes of the Convention. Furthermore, the Convention applies to discharges of radioactive materials, in liquid or gaseous form, into the environment from regulated nuclear facilities, provided such discharges are planned and controlled.

The Convention was opened for signature on 29 September 1997 and entered into force on 18 June 2001.

3.4.1 Quotation from Joint convention [26]

Definitions

"Radioactive waste" means radioactive material in gaseous, liquid or solid form for which no further use is foreseen by the Contracting Party or by a natural or legal person whose decision is accepted by the Contracting Party, and which is controlled as radioactive waste by a regulatory body under the legislative and regulatory framework of the Contracting Party;

ARTICLE 3. SCOPE OF APPLICATION

1. This Convention shall apply to the safety of spent fuel management when the spent fuel results from the operation of civilian nuclear reactors. Spent fuel held at reprocessing facilities as part of a reprocessing activity is not covered in the scope of this Convention unless the Contracting Party declares reprocessing to be part of spent fuel management.

2. ***This Convention shall also apply to the safety of radioactive waste management when the radioactive waste results from civilian applications. However, this Convention shall not apply to waste that contains only naturally occurring radioactive materials and that does not originate from the nuclear fuel cycle, unless it constitutes a disused sealed source or it is declared as radioactive waste for the purpose of this Convention by the Contracting Party.***

3.4.2 Commentary

Although NORM is considered radioactive material when it exceeds general clearance levels, NORM waste may or may not be classified as radioactive waste, depending on the legislation of the respective country.

4. National policy for spent fuel and radioactive waste and classification of NORM waste in national programmes for the management of these materials in the EU

All EU countries generate radioactive waste, and 17 of them also manage spent fuel on their territory [27]. In regard to its radiological properties and the potential hazard it poses, it is important to ensure the safe management of radioactive waste and spent fuel at all stages. This requires containment and isolation from humans and the living environment over a long period of time.

Article 11 of the EU's Radioactive Waste and Spent Fuel Management Directive (2011/70/Euratom) requires that all EU countries have a national policy for spent fuel and radioactive waste management and that they draw up and implement national programmes for the management of these materials. Article 14 of the Directive 2011/70/Euratom requires Member States to submit report on the status of implementation of the Directive and the inventory and the future prospects of RAW and spent fuel on their territory. Report should be submitted each 3 years. Reports are available here https://energy.ec.europa.eu/topics/nuclear-energy/radioactive-waste-and-spent-fuel_en#national-programmes-and-reports

We present several examples of how Member States approach the classification of NORM waste, based on information from the above-mentioned website.

4.1 Czech Republic

Natural materials produced in the course of mining and treatment of uranium ores are managed subject to the Act No. 157/2009 Coll., on mining waste management, Act No. 263/2016 Coll., Atomic Act, as sources of ionizing radiation and therefore they are not covered by this report. Such natural facilities are gathered in waste dumps and mud pits, which are supervise by SÚJB, due to the present radioactive substances to ensure radiation protection of workers and population. Disposal facilities containing solely natural radionuclides are not considered nuclear installations under the Atomic Act. [28]

4.2 Denmark [29]

Radioactive waste in Denmark is generated from decommissioning on the former nuclear facilities at the Risø site and to a limited degree by users of radioactive substances in research, industry and in the medical sector in Denmark. In industry, the largest amount, by mass, of radioactive waste is generated from oil and gas extractive activities. NORM waste is either managed and stored by the responsible licensees (oil and gas industry) at their sites or by Danish Decommissioning at the Risø site.

In accordance with Danish law, radioactive materials, including NORM (Naturally Occurring Radioactive Materials) without any foreseen use are to be considered as radioactive waste. Radioactive waste in Denmark is presently stored by Danish Decommissioning. NORM waste resulting from the oil and gas extraction is stored by responsible licensees and by Danish Decommissioning. Classification of radioactive waste in Denmark refers to the IAEA Safety Guide "Classification of Radioactive Waste", GSG-1, 2009. The use of the category "Very Low-Level Waste" (VLLW) is subject to approval by the regulatory authorities.

NORM waste stored at Dansk Decommissioning represents 65% (by mass) of the national inventory of NORM waste. The NORM waste stored at Danish Decommissioning consists of 1130 tons of tailings and 53 tons of materials received from external generators throughout the operational lifetime of the nuclear facilities. Of the remaining 35% of the NORM inventory, 34% originates from oil and gas extraction activities and is stored by one licensee, while NORM waste from geothermal heat extraction and contaminated materials makes up only 1%. The combined amount of NORM waste at these locations is approximately 600 tons. Routine maintenance and operational activities in oil and gas-extractive industries generate in the order of 50 m^3/year of NORM waste, which is stored at the sites of the licensees.

According to Parliamentary Resolution B90/2018, a disposal solution could also be considered for NORM designated as waste, which is currently stored by responsible licensees until a long-term management and disposal solution is decided upon.

4.3 Germany [30]

In the Federal Republic of Germany, a distinction is drawn between radioactive waste that is nuclear fuel and handled on the basis of licences under the Atomic Energy Act or other radioactive substances that require a handling licence under radiation protection law on the one hand, and waste only containing naturally occurring radioactive material (NORM) on the other hand. For NORM, some of the applicable requirements (e.g. with regard to release from control under radiation protection law) are principally different from requirements applicable to radioactive waste from nuclear installations or from other handling which is licensed under nuclear or radiation protection law. In Germany, NORM is not considered as radioactive waste and therefore does not fall under the reporting obligation.

4.4 Italy [31]

With regards to NORM (Natural occurring radioactive material), the Legislative Decree no. 101/2020 has made substantial changes to the previous regulatory provisions relating to the management of materials containing radionuclides of natural origin, both as regards industrial activities that use materials containing radionuclides of natural origin, both with regard to sites contaminated by NORM which currently fall under Title XI concerning existing exposure situations (and in the repealed Legislative Decree no. 230/95 fell within the scope of the provisions concerning prolonged exposures). In particular, with regard to the management of residues contaminated by NORM, Legislative Decree no. 101/2020 introduced important innovations:

a. *the introduction of the definition of "residue" understood as a waste material, in solid or liquid form, from industrial productions using naturally occurring radioactive material, from which exposure of workers or the population is not negligible from a radiation protection point of view;*
b. *the classification of residues contaminated by NORM divided into two categories; "Exempt", if they comply with certain conditions and pre-established levels in terms of mass concentration that allow them to be removed without restrictions of a radiological nature, "not exempt" if they do not meet the aforementioned conditions and levels;*
c. *the disposal of exempt residues must take place in compliance with the general provisions for waste;*
d. *the disposal of non-exempt residues, which may take place, pursuant to Part IV of Legislative Decree no. 152/2006, in authorised landfills pursuant to Legislative Decree n. 36/2003;*
e. *the disposal of non-exempt residues is subject to prior authorisation issued by the Prefect of the Province involved, who governs the conditions and methods for conferring residues, of operation of the plant and the technical requirements that the plant must meet to ensure the protection and safety of the environment, workers and the population;*
f. *the operating conditions and the minimum technical requirements that non-exempt waste disposal plants must meet for the purpose of conferment.*

The aforementioned provisions should therefore resolve the problems up to now present in the contaminated sites connected to the competing regimes of the remediation of polluted sites, the management of nonradioactive waste and the applicable radiation protection.

4.5 The Netherlands [32]

The waste producers can be divided into six sectors: nuclear, industry, medical, NORM industry, research and miscellaneous. In the Netherlands, radioactive waste is divided into four categories: high level radioactive waste, low level and intermediate level radioactive waste (including NORM waste), short-lived waste and exempt waste. These categories are based on activity and half-life.

NORM waste is a special category of low level and intermediate level radioactive waste (LMRA waste) This waste must be managed as LMRA waste. Under certain conditions, and if there is no increased risk for man and the environment (Bs, article 110a), NORM material may be mixed with other materials for reuse. However, mixing is forbidden if its sole purpose is to reduce the activity concentration (the amount of radioactivity per gram of material) (Bs, article 38). Waste with an activity concentration that is more than 10 times higher than the exemption threshold must be entrusted to COVRA. NORM waste with an activity concentration of up to 10 times higher than the exemption threshold need not be entrusted to COVRA, but can be safely dumped as very low-level waste (ZELA) at special licenced dumpsites. Although ZELA is beyond the scope of this national programme, for the sake of completeness, it is considered in the following section.

In the new European basic standard (BSS, Directive 2013/59/ Euratom), the release and exemption thresholds have been updated. This updating can have consequences for the volume of radioactive waste (in particular NORM waste and therefore also ZELA). The radioactive waste stored at COVRA is *of Dutch origin, or was produced in the Netherlands. At present, 86 m^3 of high-level radioactive waste (HRA) are stored at COVRA, together with 11,000 m^3 of LMRA and 17,000 m^3 of NORM waste. HRA represents just 0.3% of the total volume but still represents the largest proportion of total activity.*

4.6 Poland [33]

In accordance with Article 3(22) of the Nuclear Law Act, 'radioactive waste' means solid, liquid or gaseous materials containing radioactive substances or contaminated by such substances for which no further use is planned or considered, classified under the waste categories referred to in Article 47, including spent fuel intended for disposal.

However, in accordance with Article 47(4) and (5) of that Act, the following are not classified as radioactive waste:

1. soil or rock masses moved for the extraction of minerals from deposits;

2. mining waste;

3. uncontaminated soil and other materials in their natural state excavated during construction works;

4. waste in the form of sludge from industrial wastewater treatment containing naturally occurring radioisotopes with a total radioactive concentration of Ra-226 and Ra-228 isotopes not exceeding 1 000 kBq/kg, and industrial wastewater containing naturally occurring radioisotopes with a total radioactive concentration of Ra-226 and Ra-228 isotopes not exceeding 1 000 kBq/m^3.

4.7 Spain [34]

Management of residual materials with radioactive content of natural origin Another action considered in the national system is the removal by Enresa of NORM (Naturally Occurring Radioactive Material) materials managed as radioactive waste (RW), present in facilities and activities not subject to the authorisation regime of nuclear legislation. In Spain, as in many other countries, some industrial activities use and process raw materials with naturally occurring radioactive content, resulting in the generation of residual materials with radioactive content. Following EU standards, Spanish regulations in the radiological field address such activities and establish conditions under which oversight is necessary for radiological reasons.

Order IET/1946/2013, of 17 October, regulating the management of waste generated in activities using materials containing natural radionuclides, establishes concentration activity values (exemption/declassification levels) that, if not exceeded, allow conventional waste management. Otherwise, the activity licensee must conduct a radiological impact study to determine the resulting annual effective dose for the public and workers. If certain values are exceeded, the materials must be managed by Enresa as radioactive waste (RW).

The types of radioactive waste (RW) removed through this mechanism are varied, and the volumes are generally not significant, although the experience acquired cannot be considered representative of potential future removal processes.

Within the scope of the "Collaboration Protocol on Radiological Monitoring of Metallic Materials" and the technical-administrative specifications for the acceptance of radioactive waste (RW) corresponding to transfer authorisations granted to NORM facilities, the volume of NORM radioactive waste (RW) removed by Enresa has not exceeded 20 m^3 to date.

However, it is foreseeable that there will be a need to manage larger volumes of this type of waste in the near future. Since there is currently no reliable forecast of NORM waste generation, an update of the inventory of activities and companies conducted in 2010 has been initiated, based on the "Registry *of work activities with exposure to natural radiation" maintained by MITECO. The purpose is to quantify the volume of materials that may require management as radioactive waste (RW). The estimate of this inventory relies heavily on the definition of conditional declassification levels that take into account origins, types and possible management routes, contributing to minimisation through separation, melting or decontamination techniques. The result of this inventory will determine the solutions to be adopted and submitted for authorisation, if necessary, regarding potential storage needs at El Cabril Disposal Facility.*

For their management at El Cabril Disposal Facility, these types of waste must necessarily comply with the requirements established in the operating permit of said facility.

El Cabril is a low and intermediate-level waste disposal facility (El Cabril DF). It has systems for the treatment and conditioning of solid and liquid waste. These systems are designed to treat and condition all waste that requires it prior to disposal in the facility. Most of the waste treated and conditioned at the El Cabril DF comes from the operation and decommissioning of nuclear facilities, from radioactive facilities (facilities for industrial, medical, agricultural or research purposes), from incidents occurring in industries processing metallic materials, from industries producing NORM waste, or is generated at the facility itself [35].

The diversity of approaches adopted by individual Member States regarding the classification of NORM waste in relation to radioactive waste (RAW) was also illustrated by RadoNorm e-survey. Results of RadoNorm e-survey [7] showed that among respondents in about 37 % of countries, NORM is never classified as radioactive waste, slightly above 12 % declare the use of same limits for NORM as for naturally occurring radionuclides used as radioactive sources (e.g. radium), whereas above these limits, waste is considered as radioactive waste regardless of the purpose of use and physical and chemical form. However, in 50 % of the responses, a special limit, expressed as a radionuclide activity concentration, has been established above which NORM residues are classified as radioactive waste. Sometimes, this activity concentration limit is so high (e.g. 1000 Bq/g for radium) that the likelihood of it being exceeded in NORM is very low. Moreover, a specific approach was noticed where NORM formally is not classified as radioactive waste, however must be disposed of in the radioactive waste repository when dose evaluation indicates an excess of dose limits set either to workers or members of the public.

The topic of NORM waste clearance is also addressed in great detail in the HERCA report "Application of the concepts of exemption and clearance to the regulation of naturally occurring radioactive material (NORM) across HERCA countries" [36]. This report provides the following summary on classification of NORM waste as RAW:

"According to national legislations, NORM waste (i.e. waste with activity concentrations above the exemption/clearance levels) may or may not be regulated as radioactive waste. The situation by country is as follows:

A. Denmark, France, Lithuania, the Netherlands, Norway, Poland, Slovenia and Sweden and the UK define all NORM waste as radioactive waste;

B. Austria, Czech Republic, Finland, Germany, Hungary, Ireland, Italy, Luxembourg, Romania and Switzerland do not define any NORM as radioactive waste;

C. In Belgium and Spain, NORM waste is regulated as radioactive waste when management through conventional waste management routes would result in doses to workers and/or the public above certain dose thresholds or exceeds activity concentration values consistent with such thresholds.

As per the questionnaire, around 80% of HERCA member countries (including France, the Netherlands, Norway, Sweden and the UK, besides all group B and C countries) allows disposal of NORM waste below a certain activity concentration in landfills or repositories that are not licensed as radioactive waste repositories, subject to notification or approval by the competent authority. Landfill or repository operators accepting NORM waste, in their turn, are subject to registration or licensing, depending on the country, and need to comply with different requirements, depending on the country, pertaining to waste traceability and workplace and environmental monitoring.

Out of the countries where NORM waste is legally defined as radioactive waste, France may allow disposal in non-hazardous and hazardous waste landfills when the activity concentration of the uranium and thorium-series radionuclides is below 20 kBq/kg. The same holds for Sweden for an activity concentration value of 10 kBq/kg. Norway establishes the same 10 kBq/kg threshold for disposal of NORM hazardous waste either in hazardous waste landfills or in landfills or repositories licensed for radioactive waste." [36]

From the description above, we can observe that some countries classify all NORM waste as radioactive waste (RAW), whereas others do not classify it as such. In two countries, NORM waste is considered RAW only if the activity exceeds certain levels, which are higher than the clearance levels established for natural radionuclides.

It is also worth noting that in some Member States, NORM waste considered to be RAW is disposed of at landfills or repositories that are not licensed as RAW facilities. According to the authors of this report, this practice does not fully align with the intent of EU directives concerning RAW management or the general EU approach to RAW disposal. It is clear that certain NORM wastes contain such low levels of natural radionuclides that permanent isolation is not necessary. On the other hand, in countries that never classify NORM waste as radioactive waste (RAW), or consider it RAW only under certain conditions (i.e. groups B and C), mechanisms exist to allow for the disposal of NORM waste with high activity as RAW.

Although this diverse practice does not strictly adhere to the EU legal framework governing RAW management defined in the two mentioned directives, it shows that all countries are seeking reasonably justified approaches to prevent the accumulation of NORM waste that would occur in the absence of practical technical solutions. These solutions are consistent with radiation protection principles aimed at maintaining public exposure at an acceptable level (by establishing specific criteria above clearance levels, i.e., specific clearance levels). The second understandable reason for disposing of NORM waste outside of radioactive waste disposal facilities is typically the large volume of NORM waste.

According to the authors, the EU legal framework for waste and RAW management provides a reasonable and generally practical scheme for managing solid waste containing natural radionuclides. This scheme can be paraphrased as follows:

- All NORM waste that, considering its properties (including hazardous characteristics as per the EU Waste Directive, radioactivity, and volume), can be safely disposed of at facilities compliant with the EU Waste Directive, should be managed accordingly.
- NORM waste that exhibits characteristics (including high radioactivity) of RAW, should be disposed of at RAW facilities for permanent isolation.
- High-volume NORM waste that cannot be disposed of at standard EU Waste Directive facilities or RAW facilities due to capacity limitations should be disposed of at specially built, large-scale facilities designed for this purpose and secured in accordance with the activity and other properties of the stored NORM waste (EU Waste Directive, EU Extractive Waste Directive, and EU Water Framework Directive 2000/60/EC, as applicable).

Following the above clarification of the relationship between RAW and NORM waste in European legal frameworks, and based on the fact that the core of NORM waste management lies in its proper and safe disposal under the EU Waste Directive or the EU Extractive Waste Directive, the remainder of this text will address the regulation of radiation risks when managing NORM waste outside the EU legal regime for RAW.

5. EU requirements for the management of conventional waste

5.1 Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

5.1.1 Quotation from the legal text

Article 1 - Subject matter and scope

This Directive lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use.

Article 2 - Exclusions from the scope

1. *The following shall be excluded from the scope of this Directive:*

   (a) gaseous effluents emitted into the atmosphere;
   (b) land (in situ) including unexcavated contaminated soil and buildings permanently connected with land;
   (c) uncontaminated soil and other naturally occurring material excavated in the course of construction activities where it is certain that the material will be used for the purposes of construction in its natural state on the site from which it was excavated;
   (d) radioactive waste;
   (e) decommissioned explosives;
   (f) faecal matter, if not covered by paragraph 2(b), straw and other natural non-hazardous agricultural or forestry material used in farming, forestry or for the production of energy from such biomass through processes or methods which do not harm the environment or endanger human health.

2. ***The following shall be excluded from the scope of this Directive to the extent that they are covered by other Community legislation****:*

   (a) waste waters;
   (b) animal by-products including processed products covered by Regulation (EC) No 1774/2002, except those which are destined for incineration, landfilling or use in a biogas or composting plant;
   (c) carcasses of animals that have died other than by being slaughtered, including animals killed to eradicate epizootic diseases, and that are disposed of in accordance with Regulation (EC) No 1774/2002;
   (d) waste resulting from prospecting, extraction, treatment and storage of mineral resources and the working of quarries covered by Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries.

Article 3 - Definitions

For the purposes of this Directive, the following definitions shall apply:

1. 'waste' means any substance or object which the holder discards or intends or is required to discard;

2.'hazardous waste' means waste which displays one or more of the hazardous properties listed in Annex III;

Article 4 - Waste hierarchy

1. The following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy:

- ***(a) prevention;***
- ***(b) preparing for re-use;***
- ***(c) recycling;***
- ***(d) other recovery, e.g. energy recovery; and***
- ***(e) disposal.***

Article 5 - By-products

1. A substance or object, resulting from a production process, the primary aim of which is not the production of that item, may be regarded as not being waste referred to in point (1) of Article 3 but as being a by-product only if the following conditions are met:

- *(a) further use of the substance or object is certain;*
- *(b) the substance or object can be used directly without any further processing other than normal industrial practice;*
- *(c) the substance or object is produced as an integral part of a production process; and*
- *(d) further use is lawful, i.e. the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts.*

2. On the basis of the conditions laid down in paragraph 1, measures may be adopted to determine the criteria to be met for specific substances or objects to be regarded as a by-product and not as waste referred to in point (1) of Article 3. Those measures, designed to amend non-essential elements of this Directive by supplementing it, shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 39(2).

Article 7 - List of waste

1. The measures designed to amend non-essential elements of this Directive relating to the updating of the list of waste established by Decision 2000/532/EC shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 39(2). ***The list of waste shall include hazardous waste and shall take into account the origin and composition of the waste and, where necessary, the limit values of concentration of hazardous substances. The list of waste shall be binding as regards determination of the waste which is to be considered as hazardous waste.*** *The inclusion of a substance or object in the list shall not mean that it is waste in all circumstances. A substance or object shall be considered to be waste only where the definition in point (1) of Article 3 is met.*

2. ***A Member State may consider waste as hazardous waste where, even though it does not appear as such on the list of waste, it displays one or more of the properties listed in Annex III.*** *The Member State shall notify the Commission of any such cases without delay. It shall record them in* *the report provided for in Article 37(1) and shall provide the Commission with all relevant information. In the light of notifications received, the list shall be reviewed in order to decide on its adaptation.*

3. Where a Member State has evidence to show that specific waste that appears on the list as hazardous waste does not display any of the properties listed in Annex III, it may consider that waste as non-hazardous waste. The Member State shall notify the Commission of any such cases without delay and shall provide the Commission with the necessary evidence. In the light of notifications received, the list shall be reviewed in order to decide on its adaptation.

4. The reclassification of hazardous waste as non-hazardous waste may not be achieved by diluting or mixing the waste with the aim of lowering the initial concentrations of hazardous substances to a level below the thresholds for defining waste as hazardous.

5. The measures designed to amend non-essential elements of this Directive relating to the revision of the list in order to decide on its adaptation pursuant to paragraphs 2 and 3 shall be adopted in accordance with the regulatory procedure with scrutiny referred to in Article 39(2).

6. Member States may consider waste as non-hazardous waste in accordance with the list of waste referred to in paragraph 1.

7. The Commission shall ensure that the list of waste and any review of this list adhere, as appropriate, to principles of clarity, comprehensibility and accessibility for users, particularly small and medium-sized enterprises (SMEs).

Article 12 - Disposal

***Member States shall ensure that, where recovery in accordance with Article 10(1) is not undertaken, waste undergoes safe disposal operations which meet the provisions of Article 13 on the protection of human health and the environment**.*

Article 13 - Protection of human health and the environment

Member States shall take the necessary measures to ensure that waste management is carried out without endangering human health, without harming the environment and, in particular:

(a) without risk to water, air, soil, plants or animals;
(b) without causing a nuisance through noise or odours; and
(c) without adversely affecting the countryside or places of special interest.

Article 17 - Control of hazardous waste

***Member States shall take the necessary action to ensure that the production, collection and transportation of hazardous waste, as well as its storage and treatment, are carried out in conditions providing protection for the environment and human health** in order to meet the provisions of Article 13, **including action to ensure traceability from production to final destination** and control of hazardous waste in order to meet the requirements of Articles 35 and 36.*

Article 35 - Record keeping

1. The establishments or undertakings referred to in Article 23(1), the producers of hazardous waste and the establishments and undertakings which collect or transport hazardous waste on a professional *basis, or act as dealers and brokers of hazardous waste, shall keep a chronological record of the quantity, nature and origin of the waste, and, where relevant, the destination, frequency of collection, mode of transport and treatment method foreseen in respect of the waste, and shall make that information available, on request, to the competent authorities.*

2. For hazardous waste, the records shall be preserved for at least three years except in the case of establishments and undertakings transporting hazardous waste which must keep such records for at least 12 months.

Documentary evidence that the management operations have been carried out shall be supplied at the request of the competent authorities or of a previous holder.

3. Member States may require the producers of non-hazardous waste to comply with paragraphs 1 and 2.

ANNEX I - DISPOSAL OPERATIONS

D 1 - Deposit into or on to land (e.g. landfill, etc.)

D 2 - Land treatment (e.g. biodegradation of liquid or sludgy discards in soils, etc.)

D 3 Deep injection (e.g. injection of pumpable discards into wells, salt domes or naturally occurring repositories, etc.)

D 4 Surface impoundment (e.g. placement of liquid or sludgy discards into pits, ponds or lagoons, etc.)

D 5 Specially engineered landfill (e.g. placement into lined discrete cells which are capped and isolated from one another and the environment, etc.)

D 6 Release into a water body except seas/oceans

D 7 Release to seas/oceans including sea-bed insertion

D 8 Biological treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations numbered D 1 to D 12

D 9 Physico-chemical treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations numbered D 1 to D 12 (e.g. evaporation, drying, calcination, etc.)

D 10 Incineration on land

*D 11 Incineration at sea (*1)*

D 12 Permanent storage (e.g. emplacement of containers in a mine, etc.)

*D 13 Blending or mixing prior to submission to any of the operations numbered D 1 to D 12 (*2)*

D 14 Repackaging prior to submission to any of the operations numbered D 1 to D 13

*D 15 Storage pending any of the operations numbered D 1 to D 14 (excluding temporary storage, pending collection, on the site where the waste is produced) (*3)*

*(*1) This operation is prohibited by EU legislation and international conventions.*

*(*2) If there is no other D code appropriate, this can include preliminary operations prior to disposal including pre-processing such as, inter alia, sorting, crushing, compacting, pelletising, drying, shredding, conditioning or separating prior to submission to any of the operations numbered D1 to D12.*

*(*3) Temporary storage means preliminary storage according to point (10) of Article 3.*

ANNEX II - RECOVERY OPERATIONS

*R 1 Use principally as a fuel or other means to generate energy (*1)*

R 2 Solvent reclamation/regeneration

*R 3 Recycling/reclamation of organic substances which are not used as solvents (including composting and other biological transformation processes) (*2)*

R 4 Recycling/reclamation of metals and metal compounds

*R 5 Recycling/reclamation of other inorganic materials (*3)*

R 6 Regeneration of acids or bases

R 7 Recovery of components used for pollution abatement

R 8 Recovery of components from catalysts

R 9 Oil re-refining or other reuses of oil

R 10 Land treatment resulting in benefit to agriculture or ecological improvement

R 11 Use of waste obtained from any of the operations numbered R 1 to R 10

*R 12 Exchange of waste for submission to any of the operations numbered R 1 to R 11 (*4)*

*R 13 Storage of waste pending any of the operations numbered R 1 to R 12 (excluding temporary storage, pending collection, on the site where the waste is produced) (*5)*

*(*1) This includes incineration facilities dedicated to the processing of municipal solid waste only where their energy efficiency is equal to or above:*

— 0,60 for installations in operation and permitted in accordance with applicable Community legislation before 1 January 2009,

— 0,65 for installations permitted after 31 December 2008,

using the following formula:

Energy efficiency = (Ep - (Ef + Ei))/(0,97 × (Ew + Ef))

In which:

Ep means annual energy produced as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2,6 and heat produced for commercial use multiplied by 1,1 (GJ/year)

Ef means annual energy input to the system from fuels contributing to the production of steam (GJ/year)

Ew means annual energy contained in the treated waste calculated using the net calorific value of the waste (GJ/year)

Ei means annual energy imported excluding Ew and Ef (GJ/year)

0,97 is a factor accounting for energy losses due to bottom ash and radiation.

This formula shall be applied in accordance with the reference document on Best Available Techniques for waste incineration.

*(*2) This includes gasification and pyrolysis using the components as chemicals.*

*(*3) This includes soil cleaning resulting in recovery of the soil and recycling of inorganic construction materials.*

*(*4) If there is no other R code appropriate, this can include preliminary operations prior to recovery including pre-processing such as, inter alia, dismantling, sorting, crushing, compacting, pelletising, drying, shredding, conditioning, repackaging, separating, blending or mixing prior to submission to any of the operations numbered R1 to R11.*

*(*5) Temporary storage means preliminary storage according to point (10) of Article 3.*

ANNEX III - PROPERTIES OF WASTE WHICH RENDER IT HAZARDOUS

H 1 'Explosive': substances and preparations which may explode under the effect of flame or which are more sensitive to shocks or friction than dinitrobenzene.

H 2 'Oxidizing': substances and preparations which exhibit highly exothermic reactions when in contact with other substances, particularly flammable substances.

H 3-A 'Highly flammable'

—liquid substances and preparations having a flash point below 21 °C (including extremely flammable liquids), or

—substances and preparations which may become hot and finally catch fire in contact with air at ambient temperature without any application of energy, or

—solid substances and preparations which may readily catch fire after brief contact with a source of ignition and which continue to burn or to be consumed after removal of the source of ignition, or

—gaseous substances and preparations which are flammable in air at normal pressure, or

—substances and preparations which, in contact with water or damp air, evolve highly flammable gases in dangerous quantities.

H 3-B 'Flammable': liquid substances and preparations having a flash point equal to or greater than 21 °C and less than or equal to 55 °C.

H 4 'Irritant': non-corrosive substances and preparations which, through immediate, prolonged or repeated contact with the skin or mucous membrane, can cause inflammation.

H 5 'Harmful': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may involve limited health risks.

H 6 'Toxic': substances and preparations (including very toxic substances and preparations) which, if they are inhaled or ingested or if they penetrate the skin, may involve serious, acute or chronic health risks and even death.

H 7 'Carcinogenic': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce cancer or increase its incidence.

H 8 'Corrosive': substances and preparations which may destroy living tissue on contact.

H 9 'Infectious': substances and preparations containing viable micro-organisms or their toxins which are known or reliably believed to cause disease in man or other living organisms.

H 10 'Toxic for reproduction': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce non-hereditary congenital malformations or increase their incidence.

H 11 'Mutagenic': substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce hereditary genetic defects or increase their incidence.

H 12 Waste which releases toxic or very toxic gases in contact with water, air or an acid.

*H 13 (*1) 'Sensitizing': substances and preparations which, if they are inhaled or if they penetrate the skin, are capable of eliciting a reaction of hypersensitisation such that on further exposure to the substance or preparation, characteristic adverse effects are produced.*

H 14 'Ecotoxic': waste which presents or may present immediate or delayed risks for one or more sectors of the environment.

H 15 Waste capable by any means, after disposal, of yielding another substance, e.g. a leachate, which possesses any of the characteristics listed above.

Notes

1. *Attribution of the hazardous properties 'toxic' (and 'very toxic'), 'harmful', 'corrosive', 'irritant', 'carcinogenic', 'toxic to reproduction', 'mutagenic' and 'eco-toxic' is made on the basis of the criteria laid down by Annex VI, to Council Directive 67/548/EEC of 27 June 1967 on the approximation of laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances (1).*
2. *Where relevant the limit values listed in Annex II and III to Directive 1999/45/EC of the European Parliament and of the Council of 31 May 1999 concerning the approximation of the laws, regulations and administrative provisions of the Member States relating to the classification, packaging and labelling of dangerous preparations (2) shall apply.*

Test methods

The methods to be used are described in Annex V to Directive 67/548/EEC and in other relevant CEN-notes.

5.1.2 Commentary

NORM waste that meets national clearance criteria or is exempted, is not considered radioactive waste (RAW) and is managed in accordance with the Directive 2008/98/EC (hereinafter referred to as EU Waste Directive). Below, we comment on those parts of the Directive that are considered relevant from the perspective of NORM waste.

5.1.2.1 Waste Management Hierarchy

The EU Waste Directive obliges Member States to transpose into their national legislation the binding requirement to follow the hierarchy of waste management methods, as described in Article 4 of the EU Waste Directive.

Waste prevention is the priority, followed by preparing for <u>re-use</u> (i.e. products or their parts that are not waste are used again for the same purpose), <u>recycling</u> (waste is reprocessed into products, materials, or substances for the original or other purposes; this excludes energy recovery and reprocessing into materials to be used as fuel or for backfilling), <u>other recovery</u> (waste serves a useful purpose by replacing other materials that would otherwise be used for a specific purpose, <u>including energy recovery</u> – i.e. use of waste as a fuel to generate electricity), and, if none of these options is feasible, disposal [37].

For NORM waste, this means that options for recovery must be explored before disposal can be considered. In practice, naturally occurring radionuclides present in released NORM do not necessarily end up as waste, but may instead become part of processes or products aligned with the waste hierarchy. In addition to by-products, they may be incorporated into products or processes involving energy recovery or incineration. Therefore, when considering scenarios for determining the effective dose E in the context of NORM clearance, all of these options must be taken into account, and scenarios should be prepared to cover the full range of potential management routes (see Annex II of the Waste Directive) for cleared NORM.

In view of the current circular economy requirements, it can be expected that the proportion of waste sent for disposal will decrease, while the proportion of recovered waste will increase. As a result, new products containing NORM, and thus also naturally occurring radionuclides, will emerge.

Figure 2: Waste hierarchy – preventing waste is the first option, and sending waste to landfill should be the last resort [38]

5.1.2.2 Waste types

The EU Waste Directive distinguishes between non-hazardous waste (including municipal waste) and hazardous waste – i.e. waste that exhibits at least one hazardous property (e.g. flammability, explosiveness, toxicity...). A special sub-group of non-hazardous waste is inert waste. The list of hazardous properties is defined in Annex I of the Waste Directive. Some of these wastes are already directly designated as hazardous in the List of Wastes [39].

Hazardousness is demonstrated by testing. Member States must take the necessary measures to ensure that all management of hazardous waste is carried out under conditions that protect human health and the environment. They must also ensure the traceability of hazardous waste from its production to its final destination (see Article 17 of the EU Waste Directive).

Radioactivity is not listed among the hazardous properties of waste, despite its carcinogenic, teratogenic, and mutagenic effects. It is also worth to mention that the hazardous properties of waste, namely HP7 (Carcinogenic), HP10 (Toxic for reproduction), and HP11 (Mutagenic) typically addressed to the radioactivity are based on the classification of substances according to their chemical properties and their known biological effects. These classifications are aligned with the criteria set out in the CLP Regulation [40].

Waste is categorised based on its origin. The full list and classification procedure is set out in the List of Wastes [39]. The list is structured according to the sector from which the waste originates (e.g. waste from oil processing) and the characteristics of the waste (e.g. oils). Waste is assigned a six-digit code from the list, where the first two digits indicate the waste group, the next two the sub-group, and the final two the specific waste type. Hazardous wastes are identified in the List of Waste by asterisk (*). The proper classification of waste is the responsibility of the waste producer. NORM waste can be found across many industrial sectors and can therefore be expected to occur across most waste categories. As such, NORM waste cannot be clearly identified based on waste category alone.

NORM waste can be found across many industrial sectors and can therefore be expected in many categories of waste. As such, NORM waste cannot be clearly identified based solely on waste category. However, the sector from which the waste originates when compared with the positive list of NORM involving industries can provide a hint with waste category are at least subject to be considered as NORM. A preliminary approach for such classification was already done.

5.1.2.3 Waste Disposal

Possible operations for waste disposal (disposal operations) are listed in Annex I of the EU Waste Directive. The most common include surface or sub-surface disposal (e.g. landfilling), incineration, and permanent storage (e.g. in containers placed in mines, etc.). Relevant exposure scenarios can be linked to these disposal operations for calculating doses from disposed NORM waste.

5.1.2.4 Record keeping

The EU Waste Directive requires the keeping of records on hazardous waste in accordance with Article 35 and allows Member States to extend this requirement to other types of waste. These records provide, on a national level, data on waste generation as well as information on waste flows through the waste management system, including data on the facilities where the waste was disposed of.

Unfortunately, these records do not include information on NORM waste, as such waste is neither classified as a specific waste group under the EU Waste Directive nor does it possess any particular waste property defined by the EU Waste Directive.

5.1.2.1 Landfilling

The European Union regulates landfilling through the Landfill Directive (Directive 1999/31/EC) [41], which sets requirements to minimise environmental and health risks. Landfills are categorised into three types: hazardous waste landfills, non-hazardous waste landfills, and inert waste landfills. Each category has specific acceptance criteria, and only waste that has been treated may be landfilled unless further provisions of Article 6(a) apply. *'Treatment' means the physical, thermal, chemical or biological processes, including sorting, that change the characteristics of the waste in order to reduce its volume or hazardous nature, facilitate its handling or enhance recovery.* Treatment is not required procedure for inert waste nor for any other waste for which treatment does not contribute to environmental protection goals.

The Directive prohibits the disposal of certain waste types, including untreated waste, flammable, explosive, liquid, or corrosive materials, used tyres, and infectious clinical waste. Moreover, landfilling of recyclable or recoverable waste will be banned from 2030, and the share of municipal waste landfilled must be reduced to 10% or less by 2035. Municipal waste may go to landfills for non-hazardous waste.

National authorities must ensure that the price operators charge for disposing of waste covers all the costs involved from opening to final closure of the site. Landfill operators must obtain permits. To do so, following information must be provided: the identity of the applicant, and, in some cases, the operator; a description of the type and quantity of waste to be deposited; the capacity and a description of the site, including operating, monitoring and control plans; ways of preventing and reducing pollution; and details of closure and after-care procedures. Annex I of the Directive sets out specific technical criteria for the construction and operation of landfills, i.e. provisions for site selection, design, construction incl. requirements on geological barrier, impermeable base layers and leachate collection systems to prevent contamination of soil and groundwater. Annex II describe waste acceptance criteria and procedures, further developed by the Decision 2003/33/EC [42] which lays down the criteria and procedures for the acceptance of waste at landfills. Waste must undergo basic characterisation, compliance testing, and on-site verification. Acceptance depends on leachability, composition, and environmental risk. The basic national list of waste to be accepted or refused at each class of landfill should be prepared by Member States. Annex III to the Directive provides basic requirements on control and monitoring procedures in operation and after-care phases. After-care and monitoring should be maintained for at least 30 years after closure.

The Directive does not address the issue of radioactivity within its regulatory scope.

5.1.2.2 Incineration

Incineration of waste in the EU is subject to strict technical and environmental requirements under Directive 2010/75/EU on Industrial Emissions [43], which replaced the earlier Directive 2000/76/EC on Waste Incineration. All incineration and co-incineration plants must obtain a permit from the competent authority, which specifies the types and quantities of waste that may be treated, the plant's capacity, and the procedures for monitoring emissions. Two term might be of interest to the reader - *'waste incineration plant'* which is a technical unit dedicated to thermal treatment of waste with or without recovery of the combustion heat generated; '*waste co-incineration plant*' which is a technical unit whose main purpose is the generation of energy or production of material product and which uses waste as a regular or additional fuel or in which waste is thermally treated for the purpose of disposal through the incineration.

Chapter IV of the Directive sets out comprehensive requirements on incineration and co-incineration plants. Requirements of Chapter IV does not apply to plants treating only specified types of wastes, incl. radioactive waste (see Article 42). Operating conditions for both waste incineration and co-incineration plants are prescribed by the Directive in Article 50; technical provisions including air emissions limits are prescribed by Article 46 and Annex VI of the Directive. According to Article 50, incineration plants must maintain combustion gases at a temperature of at least 850°C for two seconds. To ensure complete combustion and to minimise the formation of harmful substances such as dioxins and furans, the temperature must be increased to 1100°C if the waste contains more than 1% halogenated organic substances. The Directive also requires automatic waste feed cut-off if the prescribed temperature is not maintained, prohibits the incineration of waste during start-up or shut-down phases unless the required temperature is achieved. Facilities must be equipped with flue gas cleaning systems, and emissions must be continuously monitored as per Article 48. Additionally, Article 53 requires that residues from incineration (e.g. bottom ash, fly ash, and slag) be minimised, treated, and tested for hazardous properties before disposal or reuse. Operators must obtain a permit under Article 45, which includes list of all types of waste which may be treated, quantity of each type of waste, operating parameters, sampling and measurement procedures and emission controls. Results of monitoring must be reported to competent authorities. Information on annual emissions from large combustion plants (LCPs) and other industrial sources is also available through the Industrial Emissions Portal [44].

The EU also enforces Best Available Techniques (BAT) through the Waste Incineration BREF (BAT Reference Document), which sets binding performance standards installations across Europe. These standards include BAT-Associated Emission Levels (BAT-AELs) for pollutants such as mercury, nitrogen oxides, ammonia, hydrogen chloride, sulphur dioxide, volatile organic compounds, and dioxins and furans [45].

European Waste Catalogue Codes for waste from incineration or pyrolysis of waste are as follows [39]:

19 01 wastes from incineration or pyrolysis of waste
19 01 02 ferrous materials removed from bottom ash
19 01 05* filter cake from gas treatment
19 01 06* aqueous liquid wastes from gas treatment and other aqueous liquid wastes
19 01 07* solid wastes from gas treatment
19 01 10* spent activated carbon from flue-gas treatment

19 01 11* bottom ash and slag containing hazardous substances
19 01 12 bottom ash and slag other than those mentioned in 19 01 11
19 01 13* fly ash containing hazardous substances
19 01 14 fly ash other than those mentioned in 19 01 13
19 01 15* boiler dust containing hazardous substances
19 01 16 boiler dust other than those mentioned in 19 01 15
19 01 17* pyrolysis wastes containing hazardous substances
19 01 18 pyrolysis wastes other than those mentioned in 19 01 17
19 01 19 sands from fluidised beds
19 01 99 wastes not otherwise specified

The Directive does not address the issue of radioactivity within its regulatory scope.

5.2 Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC

As this Directive address somehow the radioactivity of extractive waste, it was discussed in the section 2.2.10.

6. Approach of Member States to the Conditions for the Clearance of Solid NORM Waste – Dose Criteria and Scenarios According to Annex VII of Directive 2013/59/EURATOM

The contents of this Directive are discussed in more detail in Chapter 2.2.9. The following section addresses the application of clearance levels and general clearance criteria when releasing natural radionuclides from authorised practices (NORM facilities), as described in Annex VII of the directive. The values set out in Part 2, Table A of Annex VII apply to the clearance of solid materials for the purposes of reuse, recycling, conventional disposal, or incineration. These values apply to each parent radionuclide in the decay chain; for certain elements in the decay chain, higher values may be used (hereafter referred to as clearance levels).

If the activity of the material to be released does not comply with the clearance levels, the specific clearance scenario is evaluated based on the general criteria defined in items i) through iii) of Section 3 of the Annex VII. To meet the general criterion i), it must be demonstrated that workers should not be classified as radiation workers (i.e. their effective dose should not exceed level chosen by MS, what usually 1 mSv/year). Under criterion ii), the practice must be justified, and under criterion iii), the practice must be intrinsically safe. Where these three conditions are met, it must additionally be demonstrated that for natural radioactivity, the incremental dose—taking natural background into account—received by an individual due to the exempted practice does not exceed approximately 1 mSv/year. The dose assessment for a member of the public must consider not only exposure pathways from airborne or liquid discharges but also exposure from the disposal or recycling of solid residues. Member States may set lower dose criteria than 1 mSv/year for certain types of practices or exposure pathways. This method is hereafter referred to as authorised release.

The publication “Application of the concepts of exemption and clearance to the regulation of naturally occurring radioactive material (NORM) across HERCA,” published in 2021 [36] compiled, among other things, the results of a questionnaire survey conducted among HERCA members regarding how the requirements of Annex VII of Directive 2013/59/EURATOM for exemption and clearance for natural radionuclides have been implemented in national regulations of Member States. The results show that while all countries responding to the questionnaire adopted the dose criterion of 1 mSv/year for workers, the dose criteria adopted for members of the public varied between countries (see Table 2).

Table 2: Dose criteria for public exposure used by HERCA countries for exempting notified practices from authorisation [36]

Austria, Belgium, Czech Republic, Denmark, France, Germany, Hungary, Ireland, Lithuania, Poland, Romania, Slovenia	*1 mSv/year*
Italy, the Netherlands (on-site), Spain, UK*	*0.3 mSv/year*
Finland	*0.1 mSv/year*
Luxembourg, the Netherlands (off-site)	*0.01 – 0.03 mSv/year*
Norway, Sweden	*All NORM involving practices subject to authorisation*

** 0.1 mSv a^{-1} if the drinking water pathway is affected*

6.1 Quotations from the HERCA document [36] and comments:

„Dose assessments supporting exemption must account for the relevant pathways of radiation exposure associated to the practice (including waste disposal and recycling scenarios, where applicable) and, generally, should use ICRP dose coefficients. ICRP has recently updated its dose coefficients for natural radionuclides both for occupational internal exposure (Publication 137; OIR part 3), based on ICRP Publication 103, and for external exposures to environmental sources (ICRP Publication 144).

Different exposure scenarios to NORM were considered in the document RP 122, part II (EC, 2001).

The NORM exposure pathways considered for the members of public are the following:

- *External gamma radiation exposure*
- *Inhalation (excluding radon indoors)*
- *Ingestion (excluding consumption of drinking water)*

The following exposure scenarios for members of public were considered:

- *NORM as surface layer in public places/sport grounds*
- *Dweller of a house built with building materials containing NORM*
- *Dweller of a house built with undiluted NORM as unshielded surface cover*
- *Dweller of a house near a heap or landfill.*

Concerning the groundwater pathway for public exposure, the drinking water directive (2013/51/EURATOM) limits the amount of natural radionuclides in drinking water by setting a parametric value for the total indicative dose of 0.1 mSv a^{-1}. Individual supplies providing on average less than 10 m3 a day, or serving fewer than 50 persons, may be exempted from the directive. In case monitoring of water intended for human consumption indicates non-compliance with the parametric value, Member States should consider whether consumption of such water poses a risk to human health and, where necessary, take remedial action to improve the quality of the water. In general, remediation of drinking *water that exceeds the parametric indicative dose is costly and NORM residues might be produced in the treatment process. As per the questionnaire, only in a few HERCA countries (Belgium, Finland, Italy, Spain, Switzerland, the Netherlands and the UK) must the drinking water pathway be considered, when appropriate, in long-term dose assessments, in order to grant exemption from notification or authorisation of NORM involving practices.*

Countries must ensure a safe and sound management of NORM residues generated from notified and authorised NORM facilities, accounting for the NORM waste inventory in the country. <u>Besides NORM waste produced</u> at the operating industries, a substantial part of the national inventory might come from the <u>dismantling of old facilities or the remediation of contaminated sites</u>, for which no radiation protection considerations related to waste treatment, storage and disposal had been previously made.

Application of clearance concepts is key in ensuring that NORM waste management is done in an optimised way and is commensurate to radiation risk, and that reuse, recycling and recovery solutions are promoted while guaranteeing radiation safety.

The EU BSSD defines clearance levels as values established by the competent authority or given in national legislation, and expressed in terms of activity concentrations, at or below which materials arising from any practice subject to regulatory control may be released from the requirements.

According to the IAEA BSS (Schedule I), the general criteria for clearance, supporting the general or specific clearance levels, are the following:

- *Radiation risks arising from the cleared material are sufficiently low as not to warrant regulatory control, and there is no appreciable likelihood of occurrence for scenarios that could lead to a failure to meet the general criterion for clearance; or*
- *Continued regulatory control of the material would yield no net benefit, in that no reasonable control measures would achieve a worthwhile return in terms of reduction of individual doses or reduction of health risks.*

Risk assessments should account for recycling, reuse, recovery and disposal of NORM, and be made using conservative assumptions, covering a wide variety of dose modelling scenarios. For this reason, clearance values might be over-conservative for some specific scenarios or disposal routes. To avoid undue burdens, an authorisation may be granted by the competent authority for releasing materials of regulatory control subject to specific requirements and conditions. <u>This authorisation is known as specific (conditional) clearance.</u>

It may be granted for materials from a specific facility or industrial sector or for a certain type of material, provided that the two above mentioned requirements are complied with, and that the necessary arrangements have been made to ensure that the conditions are met (for example, by overseeing the transport to the specified destination).“

Publication presents a few examples of the use of this regulatory tool in Denmark, Italy and the Netherlands in the management of wet sludge from the oil and gas industry. *“Clearance levels higher than the general exemption/levels are applied, subject to restrictions on their final disposal. In particular, values for wet sludge from RP-122, part II, table 2 have been adopted.“*

The procedure and conditions for issuing specific clearance levels for the disposal of wet sludge from oil and gas production and geothermal facilities in the Netherlands were constructed as follows: (see Table 3). The higher specific clearance levels are only applicable under the condition that the material is disposed of at specific, controlled, landfill sites which are constructed such that they can safely store hazardous waste (i.e. landfill has a water treatment system and a construction that ensures that leaching into the groundwater does not occur, a monitoring system to ensure that this requirement is met, closure of the landfill is conducted by a protective multi-layer system).

Table 3: The specific clearance levels for wet sludges from oil and gas production and geothermal facilities. The general clearance levels are included for comparison. [36]

Radionuclide	*Specific clearance level (kBq.kg^{-1})*	*General clearance level (kBq.kg^{-1})*
^{40}K	*100*	*10*
^{210+}Pb	*100*	*1*
^{210}Po	*100*	*1*
^{226+}Ra	*5*	*1*
^{228+}Ra	*10*	*1*
^{228+}Th	*5*	*1*
$^{232sec}Th$	*5*	*1*
$^{235sec}U$	*10*	*1*
$^{238sec}U$	*5*	*1*

^{210+}Pb = ^{210}Pb, ^{210}Po
^{226+}Ra = ^{226}Ra, ^{222}Rn, ^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po
^{228+}Ra = ^{228}Ra, ^{228}Ac
^{228+}Th = ^{228}Th, ^{224}Ra, ^{216}Po, ^{212}Pb, ^{212}Bi, ^{212}Po (64.1%), ^{208}Tl(35.9%)
$^{232sec}Th$, $^{235sec}U$, $^{238sec}U$ = or individual radionuclide of the decay series.

When these specific clearance levels and the listed conditions are complied with, the general dose criterion for the clearance of NORM, as defined in Dutch regulations, is guaranteed not to be exceeded. This dose criterion is 0.3 mSv/year (for both the public and workers), which is equal to the value provided in European Commission publication RP 122 part II [46] and complies with the dose limit “of the order of 1 mSv/year” stated in EU BSSD, Annex VII-3.

The use of specific clearance levels as a practical method to meet the general dose criterion for public exposure used by countries for exempting notified practices from authorisation and to reduce administrative and financial burden on NORM waste producers has been adopted and incorporated into national legislation by several European countries.

HERCA’s publication presents a summary of these examples as follows [36]:

- *For large volumes of relatively low activity waste (e.g. < 5* kBq.kg^{-1}*), such as mining tailings or phosphogypsum, in-situ confinement.*
- *For moderate amounts of low activity NORM waste (e.g. < 5-10* kBq.kg^{-1}*) disposal in controlled landfills for non-hazardous or hazardous waste, authorised for accepting NORM waste.*
- *For low and intermediate volumes of high activity NORM waste (e.g. > 10* kBq.kg^{-1}*), such as scales or residues from the extraction of rare earths, disposal in repositories specifically licensed for NORM waste or in near surface radioactive waste repositories.*

A similar approach may be applied for setting specific clearance levels for the disposal or recovery of NORM waste by incineration (e.g. practice in the UK).

This practice demonstrates that Member States regard the establishment of specific clearance levels for certain types of NORM waste management or disposal as a useful and practical tool for both controlling and facilitating the overall process of releasing natural radionuclides from authorised practices in the case of NORM.

6.2 Commentary on the management of NORM waste according to the Directive 2008/98/EC (EU waste Directive) and Directive 2013/59/EURATOM

Both directives are binding for all Member States. The EU Waste Directive does not apply to radioactive waste management; however, it can be used for managing solid waste that contains natural radionuclides at activity levels that do not lead to exposure of individuals above the general dose criterion for clearance (hereinafter referred to as the general clearance criterion). This criterion can be implemented by Member States in their national legislation pursuant to Directive 2013/59/EURATOM to meet the requirements of Annex VII—namely, that the effective dose to a member of the public remains on the order of 1 mSv/year or less. Subsequently, for the reuse or disposal procedures of hazardous and non-hazardous waste as defined by the EU Waste Directive, it is possible to set specific clearance levels for individual radionuclides so that, taking into account the conditions of reuse or disposal, the general clearance criterion is respected. This practice may apply to most NORM waste, as their activity concentrations are typically lower (tens of $kBq.kg^{-1}$) than those requiring isolation as radioactive waste (i.e. disposal in a radioactive waste repository).

Setting specific clearance levels appears to be good practice, as it reduces the burden on NORM waste producers by eliminating the need to assess the effective dose to a member of the public for each case of reuse or disposal and verify each time whether the national general clearance criterion has been met. Similarly, it would also reduce the burden on waste management facility operators and authorities, which would otherwise need to engage frequently in ad hoc authorisation processes. The clearance process would thereby also become more understandable for non-experts in radiation protection.

There is also room for possible harmonisation of this approach at the EU level.

If agreement could be reached on a specific value for the generic clearance criterion for releasing natural radionuclides from authorised practices at the EU level (1 mSv/year or 0.3 mSv/year as previously suggested by RP 122 Part II), this value could be incorporated into EU Directive 2013/59/EURATOM in place of the current formulation "on the order of 1 mSv/year." Subsequently, for reuse and disposal methods standardised at the EU level (i.e. inert, non-hazardous, and hazardous waste landfills, incineration/energy recovery), numerically defined specific clearance levels could be established and included in EU legislation (e.g. in the EU Waste Directive).

As an alternative, if agreement between Member States proves unachievable for any reason (political, technical), an EU Recommendation could be issued in this area. This recommendation could outline procedures for calculating specific clearance levels for various values of the generic clearance criterion and for different types of reuses and disposal of waste.

7. Uncertainties in the management of NORM waste under the clearance regime according to the EU Waste Directive and the EU Extractive Waste Directive

The EU Waste Directive, as already noted in Chapter 5.1, does not apply to radioactive waste, and the same is true for the EU Extractive Waste Directive. Radioactive waste is characterised in the EU RAW Directive as follows:

"***Radioactive waste***, *including spent fuel considered as waste,* ***requires containment and isolation from humans and the living environment over the long term****. Its specific nature, namely that it contains radionuclides, requires arrangements to protect human health and the environment against dangers arising from ionising radiation, including* ***disposal in appropriate facilities as the end***

location point. The storage of radioactive waste, including long-term storage, is an interim solution, but not an alternative to disposal." [2]

The definition of "radioactive waste" is as follows: *'Radioactive waste' means radioactive material in gaseous, liquid or solid form for which no further use is foreseen or considered by the Member State or by a legal or natural person whose decision is accepted by the Member State, and which is regulated as radioactive waste by a competent regulatory authority under the legislative and regulatory framework of the Member State*. [2]

Most of the waste generated during NORM-involving activities, including mining waste, meets the exemption and clearance criteria defined in Annex VII of the EU BSSD. That means that their management does not need radioprotection measures (i.e. the waste is considered not containing radioactive substance as defined in the 2013 Directive). It therefore does not need to be managed as set out in the EU RAW Directive. These wastes are managed or disposed of under the EU Waste Directive (and possibly also under the EU Extractive Waste Directive).

However, the EU Waste Directive was not originally designed to consider the content of natural radionuclides in NORM waste and their potential impact on human health and the environment. This was not because the impact was confirmed to be negligible, but rather because it had not been assessed when the foundations of the Directive were laid. This may result in the requirements laid down by the Directive being insufficient for the management of NORM waste from a radiological perspective, which means that the negligible nature of the impact should be verified for all management routes defined in the EU Waste Directive. On the other hand, the EU Waste Directive does apply to so-called hazardous waste (hazard properties H1–H15) and ensures that the protection of human health and the environment is met. It is likely that the requirements of this directive for hazardous waste management are, to some extent, applicable and usable for wastes containing natural radionuclides.

Reflecting the above, it is appropriate to examine whether there are any additional requirements that should be incorporated into the waste management framework to ensure adequate protection of human health and the environment in the case of managing NORM waste under the clearance regime.

7.1 Hazardous properties of waste – chemical toxicity of naturally occurring radionuclides

As previously described, the mere presence of NOR is not, in itself, a reason to classify a waste as hazardous. However, hazardous waste, when landfilled (in a hazardous waste landfill), is subject to stricter requirements (greater isolation of deposited waste from the surroundings, more precise localisation of the waste within the landfill, greater restrictions on future land-use of the closed landfill), which may, in practice, allow for the disposal of higher activities on such better-secured landfills than on landfills for non-hazardous waste.

The hazardous properties of waste are demonstrated by tests, i.e. by comparing the concentration of substances in the waste or the results of waste tests with criteria and threshold values of indicators defined for those properties. In some cases, leaching tests are used, and waste is considered hazardous if it meets certain classifications based on those tests. For individual hazardous properties and substances, these tests follow a prescribed procedure (e.g. for heavy metals), but they do not include the determination of naturally occurring radionuclides.

Nevertheless, there is a connection between hazardous properties and the presence of natural radionuclides in waste. Some natural radionuclides are chemically toxic, and the waste in which they are present may exhibit hazardous properties such as HP 5 – Specific Target Organ Toxicity, Inhalation

Toxicity, HP 6 – Acute Toxicity, H7 – Carcinogenic , H10 – Toxic for reproduction, H11 – Mutagenic, H14 – Ecotoxic, and potentially also HP15.

An example of a chemically toxic, naturally occurring radionuclide is uranium, which may be present in some waste in high concentrations (e.g. filter media used for the targeted removal of uranium from drinking water). Although the mandatory tests described above do not include uranium determination, its concentration should be determined in wastes where an elevated uranium content can be expected. For the industries listed in Annex VI of the EU BSSD there should already be data for the uranium concentration in waste (activity concentration of uranium-238 can be easily converted to mass concentration of uranium and vice versa), as these industries need to be characterised for natural radionuclides according to the EU BSSD. The results of the mass concentration of uranium assessment should be assessed according to Regulation (EC) No. 1272/2008 of the European Parliament and of the Council of 16 December 2008 on classification, labelling and packaging of substances and mixtures, amending and repealing Directives 67/548/EEC and 1999/45/EC and amending Regulation (EC) No. 1907/2006.

If we consider the basic criterion for the toxicity of natural uranium, this value is likely to be exceeded in used filter media applied for uranium removal (e.g. GEH, ion exchange resins), uranium glass, used chemicals, and in all wastes with uranium activity above this level. It should be noted that, for example, no wastes from water treatment – where increased uranium levels can be expected – are currently labelled as hazardous.

A waste can simultaneously exhibit multiple properties, including different types of hazardous properties. When deciding on its reuse, recycle or disposal, all such properties must be considered; the waste must be assessed comprehensively, and the selected solution must be suitable for all of its characteristics. For example, in the case of uranium, radioactivity may not be the most significant concern—its chemical toxicity may be the determining factor. It cannot be excluded that other naturally occurring radionuclides may also have toxic properties, e.g. lead. Typically for industrial waste containing both chemical hazards and natural radioactivity, the chemical hazard is the more important health concern due to potentially acute effects. This is somehow justified, as acute effects caused by the chemical toxicity has deterministic nature while radiation induced effects are stochastic, at least at such exposure level one should expect in case of NORM.

7.2 Radioactive equilibrium in the decay chains of U-238 and Th-232

The presence or absence of radioactive equilibrium among the radionuclides in the natural decay chains of U-238 and Th-232 in solid NORM waste is primarily influenced by the origin of the processed NORM and the technologies used for its treatment. In general, one cannot assume radioactive equilibrium in any type of solid NORM waste [47], [48], [49], [50], [51], [52] without verification by measurement.

Radioactive equilibrium between members of both decay chains is typically established in extracted minerals and rocks and remains intact if these raw materials are subsequently processed using only physical or mechanical methods, such as crushing or screening. In such cases, measurements should confirm that the activity concentrations of parent and daughter radionuclides are approximately equal. However, this rule is not without exceptions. If the geological material was previously exposed to water, combustion, or similar processes before being removed from its deposit, radioactive equilibrium may be disturbed, as some radionuclides may have been separated from the material based on their differing chemistry.

According to the experience of the National Radiation Protection Institute (SÚRO, v.v.i.), radioactive equilibrium in the decay sub-chains (for the uranium-radium series, equilibrium refers to radionuclides from U-238 to Ra-226) can generally be expected in samples originating from the Czech Republic in the following types of NORM:

- materials generated during cement production, including clinker kiln maintenance residues,
- combustion products of coal and biomass (fly ash, slag, bottom ash),
- wastes from the processing of zircon and zirconium (zircon sands and abrasives),
- mining activities (minerals, rocks not exposed to water over extended periods).

For solid NORM exposed to chemical processes—whether due to processing technologies or long-term exposure to aqueous environments—radioactive equilibrium is frequently disrupted. Based on experience, this applies particularly to:

- water treatment sludges and filtration materials from water treatment plants,
- scale deposits on pipe walls,
- oil and gas extraction, processing, and transport,
- phosphate fertiliser production and the manufacture of titanium dioxide–based pigments
- hydrometallurgical facilities (both waste and products).

The presence of radioactive equilibrium in NORM may also influence decisions regarding which natural radionuclides need to be determined in NORM samples. For NORM with disrupted radioactive equilibrium, it is necessary to identify all significant members (i.e. all long-lived members) of the decay chain and compare the activity of each with the applicable clearance levels. On the other hand, for NORM in which radioactive equilibrium is maintained (as in only mechanically treated mineral materials), a simplified approach may be considered—similar to the procedure used for assessing natural radioactivity in construction materials, where one representative from each decay chain and K-40 are measured (more details are provided in the section19).

7.3 Inertness of waste, leachability

A significant portion of NORM waste is of mineral nature and possesses suitable physical and mechanical properties that allow its use as construction materials, landfill construction components, or backfilling material. Without addressing the legal framework under which such use occurs, it is essential that NORM used in this manner meets the criteria for inert waste. There are also landfills for inert waste that are used for disposing of inert waste, including NORM. Disposing of inert waste is generally less expensive than disposing of other types of waste.

To verify the suitability of the above-mentioned types of use/disposal, it is necessary to demonstrate inertness. This is done using leaching tests, which, similar to tests for hazardous properties, do not focus on the leachability of natural radionuclides. The topic of leaching tests is addressed in detail in the publication Naturally Occurring Radioactive Materials in Construction [53].

To avoid restricting the practical reuse of NORM waste as inert waste, it should be considered whether the currently used leaching tests are also suitable for natural radionuclides, or whether new tests need to be developed, including establishing criteria for evaluating results, and making their use mandatory in practice.

7.4 NORM waste management routes

The objective introduced by Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste, states: “*(8) In order to ensure proper application of the waste hierarchy, appropriate measures should be taken to apply, as of 2030, restrictions on landfilling to all waste that is suitable for recycling or other material or energy recovery. Those restrictions should not apply where it can be demonstrated that waste is not suitable for recycling* *or other recovery and that landfilling would result in the best overall environmental outcome in accordance with the waste hierarchy laid down in Directive 2008/98/EC*."

7.4.1 Waste Incineration

Another significant category of NORM waste is combustible waste. With increasing emphasis on energy recovery from waste, there is an expected effort to ensure that combustible waste, which is currently landfilled but has sufficient calorific value, can be used for energy recovery in the future. Both non-hazardous and hazardous waste can be incinerated or used for energy recovery, and the landfilling of hazardous waste should also be minimised in the future. Annex VII of Directive 2013/59/Euratom states that general criteria can also be applied to incineration. It is therefore advisable to also prepare specific exemption levels for incineration of NORM waste and the conditions under which they may be applied. Some countries (e.g. the UK [36]) have already taken this approach. Given the limited number of references on scenarios for the incineration of natural radionuclides, we note the possible need to address these scenarios further at the technical level to verify the safety of NORM incineration. To avoid unnecessary exaggeration of this problem e.g. applying specific exemption level in the strict meaning provided in IAEA GSG-17 [21] that implied entire process analysis including dose evaluation, the use a mass reduction factor after incineration as parameter to calculate initial NOR activity concentration ensuring the exemption level in ash is not exceeded.

The determination of specific exemption levels should encompass the entire process, including the handling of the resulting ash and the regulatory regime under which it will be managed. It must be clearly defined whether this ash requires monitoring or not – that is, whether it falls under exemption, clearance, or (RAW) regime. At the same time, it should be noted that incinerator ash is disposed of in hazardous waste landfills, which are likely able to accommodate higher activity levels than landfills designated for other types of waste.

7.4.2 Recycling/reuse of scrap metal waste with deposits containing natural radionuclides

This type of contaminated scrap metal waste may arise particularly from mining operations, water treatment, spa facilities, and chemical processing of mineral raw materials. It can include metal pipes and dismantled components of production technologies. The removal of deposits from metal materials is neither technologically straightforward nor inexpensive. Except for certain exceptions, most producers of such contaminated metal waste are not equipped with technologies for effective removal of these deposits, and such technologies are not commonly available at the national level.

On the other hand, scrap metal processors applying the material as secondary raw material often impose strict requirements on the radiological activity of the material. In practice, this can result in contaminated (or insufficiently cleaned) metal waste being rejected by processors. In this situation, the conditions under which metal waste ceases to be waste, as defined by Council Regulation (EU) No. 333/2011 of 31 March 2011 establishing criteria determining when certain types of scrap metal cease to be waste under Directive 2008/98/EC of the European Parliament and of the Council, are not fulfilled, and the material must be disposed of.

However, this disposal obligation may conflict with the objective introduced by Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste.

7.4.3 Long-term landfilling of NORM waste

Landfilling NORM waste in appropriate types of landfills, depending on the properties of the waste, is currently the most common and accessible method of NORM waste disposal. However, it is necessary to consider the potential risk posed by NORM waste containing NOR with long half-lives. As a result, their activity does not significantly decrease over the typical operational life of a landfill (around 100 years), and the radiological risk associated with their presence may persist even after the landfill has been closed and remediated. Therefore, it is important to consider what will happen to the landfill area after its closure, whether it will be monitored and for how long, and what the durability of the impermeable landfill barriers will be over time. However, this is also true for materials containing chemical hazards e.g. heavy metals (that do not decay) and/or many persistent organic chemicals; in this respect the content of NOR is just another additional hazard in the waste. In this context, it is very important to preserve information about the disposed waste, maintain records of the existence of the landfill in the land registry and spatial planning documentation, and ensure that the existence of the landfill and the radioactive content is considered in future land use planning. If, during future use, the common condition not to disturb the closed landfill body is respected and the area is used only at the surface, the closed landfill should not pose a hazard.

During the operation of the landfill, its closure, and post-closure, landfill leachate monitoring is typically carried out. The situation here is similar to leaching tests, as these tests generally do not consider the possible presence of natural radionuclides. It is necessary to consider whether, in cases where non-inert NORM waste was deposited in the landfill, such tests should be introduced.

A risk, on the other hand, may instead be posed by old, unregistered illegal dumps, where NORM waste may have been disposed of in the past without any knowledge of its activity levels. The fact that NORM waste was deposited at such sites is generally no longer known today.

7.5 Administrative requirements for managing NORM waste (record keeping)

EU Waste Directive includes a requirement to ensure the traceability of hazardous waste from its production to its final destination. Member States may apply a similar requirement to non-hazardous waste. Since radioactivity is not a tracked property under EU Waste Directive, it is currently not ensured that information accompanying waste in the waste management system includes a record indicating that the waste is NORM waste, nor does it include data on activity concentration of particular radionuclides or the conditions under which and in what facilities it can be disposed of, i.e. conditions of clearance.

Such information and its preservation should be newly incorporated into EU legislation as part of the mandatory requirements for waste record-keeping.

7.6 Materials requiring safeguards

For materials where specifically, uranium or thorium are significantly accumulated during industrial processing (regardless of the concentrations of the daughter nuclides), there can additional requirements from safeguards if nuclear materials are formed. For example, in Finland, processed materials with combined natural uranium and thorium more than 0,5 kg/tonne (the uranium and thorium mass concentrations are added together before comparing to the limit) are defined as nuclear materials that require either notification or licensing according to the Nuclear Energy Act, depending on the total amounts present. There are obligations for reporting about various nuclear materials to the European Commission and IAEA, in addition to national authorities [54].

Safeguards must be considered if uranium compounds are recovered as products or side-products in any type of NORM-involving industry, or from previously formed waste. An example is the uranium recovery from a hydrometallurgical process at a Ni-Cu-Zn-Co – mine resulting in yellow cake production in a fuel-cycle facility ([54], also case study in RadoNorm deliverable 5.11 Appendix J). The same industrial complex can have multiple materials where some are regulated as NORM and others as nuclear materials. Consideration should be given to the holistic integration of regulation of these materials especially with regard to worker exposure as the same workers can be handling both type of materials.

8. Draft suggestions to EU legislation concerning the management of NORM waste

8.1 Basis for defining new requirements

- The definition of what is considered as radioactive waste is the responsibility of each Member State, to be determined within its national legislative and regulatory system, in accordance with Council Directive 2011/70/Euratom.
- RAW management is regulated by the EU RAW Directive, which excludes from its scope:
    - extractive waste according to the EU Mining Waste Directive (even if it is radioactive),
    - and so-called authorised releases under EU BSSD

  → This means that neither extractive waste nor NORM waste that qualifies for authorised release under EU BSSD should be considered RAW.

- The term *authorised release* is defined in EU BSSD. Annex VII, point 2(c), of EU BSSD describes which residues containing natural radionuclides and under what conditions may be released for reuse, recycling, conventional disposal, or incineration. This directive does not apply to the management of RAW.
- Another relevant directive is the EU Waste Directive. It states that it does not apply to RAW. However, since the authorised release conditions set out in EU BSSD include waste disposal and treatment routes covered by the EU Waste Directive, it is clear that the EU Waste Directive **does apply** to NORM waste subject to authorised release. This framework appears internally consistent. The subjects of each directive are clearly delimited and do not overlap. However, the distinction between NORM waste released under authorised release and NORM RAW is **not explicitly stated or described in either directive**. This lack of clarity may lead to misunderstanding among NORM waste producers and other stakeholders involved in NORM waste management.
- The definition of specific conditions (including dose limits for public exposure during waste or RAW disposal) is the responsibility of individual Member States under both EU BSSD and the EU RAW Directive.
- The basic requirements for waste classification, as well as recovery and disposal (e.g. the List of Wastes under EC regulation, the Landfill Directive), are also set at the EU level. This applies equally to the waste hierarchy [37] and the obligation to prioritise recovery over disposal where possible.
- Solid NORM waste often contains natural radionuclides above the clearance levels, yet in most cases it still meets the conditions for authorised release. This type of waste occurs in larger quantities than RAW from the nuclear sector or from institutional use of ionising radiation, and it is therefore not always feasible to dispose of it in RAW repositories. Only a small portion of NORM waste has an activity level so high (and volume small enough) that it cannot be safely released from the workplace other than under RAW conditions.
- Although the EU legal framework in this area can be regarded as clear and logical, its implementation in national legislation differs in ways that may cause confusion and ambiguity. This is especially true where waste is classified as RAW or non-RAW without considering the actual activity level or the disposal options available in a given Member State. This is linked to the legal requirement that NORM waste declared as RAW must be disposed of in a facility designated for RAW, even if its activity level does not require it. Conversely, NORM waste that, due to its properties, should be disposed of in a RAW facility cannot be accepted there if it is not officially declared as RAW.

- Of course, Member States have clear authority regarding authorised release and RAW, and they have reasons for exercising this competence. The system for managing both types of waste should reflect national conditions, meaning the local industrial context, NORM waste production and properties, and technical options for RAW disposal. However, taking these specificities into account **should not blur the distinction** between authorised release and RAW as established in the EU legal framework.
- We also note that the term *radioactive waste* (RAW) carries a negative connotation in the context of general waste management. RAW is commonly perceived by the public as hazardous and exceptional in nature. According to the EU definition, this perception is accurate — RAW must be permanently isolated. Labelling NORM waste that meets authorised release conditions as RAW may unnecessarily alarm the public, waste management operators, and other stakeholders, complicating otherwise safe practices. We recommend avoiding such situations and refraining from classifying NORM waste as radioactive waste (RAW), unless it is strictly necessary for reasons of radiation protection. The symbolic dimension of the term RAW is also discussed in **The Symbolic Dimension of Radioactive Waste Management** [55]**.**

8.2 Policies and Strategies for NORM waste management within the EU legal framework

Based on the above foundations, we propose a strategy for managing NORM waste, which is built on the requirements and content of the following EU directives: the EU RAW Directive, the EU Waste Directive, the EU Extractive Waste Directive, and EU BSSD.

The EU RAW Directive, in its preamble and Article 2, states [2]:

(21) ***Radioactive waste****, including spent fuel considered as waste,* ***requires containment and isolation from humans and the living environment over the long term****. Its specific nature, namely that it contains radionuclides, requires arrangements to protect human health and the environment against dangers arising from ionising radiation, including* ***disposal in appropriate facilities as the end location point. The storage of radioactive waste, including long-term storage, is an interim solution, but not an alternative to disposal.***

(22) A national radioactive waste classification scheme should support those arrangements, ***taking fully into account the specific types and properties of radioactive waste****.*

Scope

1. This Directive shall apply to all stages of:

(a) spent fuel management when the spent fuel results from civilian activities;
(b) radioactive waste management, from generation to disposal, when the radioactive waste results from civilian activities.

2. This Directive ***shall not apply to****:*

(a) ***waste from extractive industries which may be radioactive,*** *and which falls within the scope of Directive 2006/21/EC;*
(b) ***authorised releases****.*

From the above, it follows that the legal framework established by the EU directives distinguishes between NORM waste that:

- is classified as **mining waste** and therefore cannot be considered RAW, or
- is subject to **authorised releases** (as per the EU BSSD Directive) and is disposed of in accordance with the EU Waste Directive or the EU Extractive Waste Directive, or

- is declared **RAW** (in cases where it has properties requiring containment and long-term isolation from humans and the environment) and is therefore managed under the EU RAW Directive.

An advantage of this legal framework, which is implemented/transposed by EU Member States into their national legislation, is that it clearly distinguishes between different regimes for managing NORM waste, thereby facilitating practical handling.

At the same time, the framework gives Member States sufficient flexibility to reflect national conditions when implementing it, in particular:

- in the national definition of RAW, which may consider whether NORM waste is generated in the country that requires long-term isolation in a RAW repository (considering activity levels and volume), and the infrastructure available for RAW management, including disposal (supported by National Programmes for RAW), and
- in deciding how to set the conditions for authorised release from NORM workplaces (i.e., whether to rely solely on the clearance levels defined in Annex VII, Table A, Part 2 of the EU BSSD, or to apply the general criteria listed therein, allowing for authorised releases at levels of exposure on the order of 1 mSv/year or less). Within this framework, Member States may make decisions on authorised release when managing mining waste.

Member States also decide which activities will be included on the list of NORM activities. They may set the level of exposure to natural radionuclides both for workers (exemption) and for members of the public (clearance).

The advantage of such a framework is that, if properly implemented, it simplifies the practical management of NORM waste, reduces uncertainty and administrative burden, and allows for the application of specific national conditions. This approach fulfils the requirements of the graded approach, as its level of complexity is proportionate to the risk associated with the management of the respective NORM waste.

8.2.1 Points for consideration

One ambiguity in the current legal framework is that although the EU Waste Directive states it does not apply to radioactive waste (RAW), it does not explicitly mention that in addition to RAW, there are also wastes containing (natural) radionuclides at levels that allow their authorised release, and that are thus handled under this EU Waste Directive. During transposition of the EU Waste Directive, this ambiguity can influence national waste legislation. Therefore, consideration should be given to that the EU Waste Directive:

- explicitly acknowledges the existence of NORM waste, and
- requires record-keeping similar to that required for other types of waste, especially hazardous waste, and
- references the concept of authorised release defined in Directive 2013/59/EURATOM.

This would serve to remove uncertainty over whether these wastes can be accepted at waste management facilities and would also ensure their release under conditions defined in national radiation protection regulations. Furthermore, it would ensure that waste containing (natural) radionuclides is subject to all requirements imposed by the EU Waste Directive — and, by extension, national waste legislation — for the management of inert, non-hazardous, and hazardous waste. This would provide a comprehensive framework for safe NORM waste management, covering both radiological and other (including hazardous) waste properties.

However, since waste arises across various waste categories and often the industry operator is not aware of the problem of NORM to date, the crucial issue is to identify waste of interest. For this purpose, besides existing national approaches determined by the EU BSS requirements, which include a list of

NORM-involving industries (activities) expected to lead to NORM waste generation and needing to be addressed in terms of radiation protection, a more targeted approach may be developed. The List of Waste or its national version, which is a hierarchical waste catalogue giving a code to any kind of waste based on a combination of what they are and the process or activity that results in its creation, provides an opportunity to identify waste that can be considered as containing NORM in non-negligible amounts. The legal framework of waste management requires the holder of waste to take all reasonable steps to identify waste using the relevant code. Moreover, the List of Waste provides a standard framework for the comparison of waste data across all EU Member States. Hence, such information added will make all stakeholders involved in the waste management process aware that certain waste needs additional considerations in terms of radiation protection. Well-prepared completion of the List of Waste will ensure no NORM waste is overlooked, even if a waste owner/producer has not been aware of the problem before. Considering this, such modified List of Waste can help Members states complete the NORM inventory which is strictly required by EU BSSD. The initial approach to such modification of the List of Waste showed that among 674 individual waste types already identified, 257 are at least suspected of being NORM, mainly from group 01: waste resulting from exploration, mining, quarrying, physical and chemical treatment of minerals; group 06: waste from petroleum refining, natural gas purification, and pyrolytic treatment of coal; and group 10: waste from thermal processes [56].

It is important to note that, contrary to existing waste identification as hazardous based on a similar approach, this additional property added to waste should be a precaution requiring follow-up proceedings, not definitive waste categorization. Moreover, introducing a new property as “radioactivity” appears risky because if this were the only identified hazardous property of NORM waste, the waste would become classified as hazardous, limiting its disposal options. This would unnecessarily increase disposal costs and consume valuable space in expensive landfills for hazardous waste. It would also limit the possibility of using such waste as landfill construction material. Therefore, to identify a new category, it would be better to use a simple term, e.g., NORM. On the other hand, considering the containment properties of landfills for hazardous waste, it could be practical to classify NORM waste as hazardous when the activity concentration of natural radionuclides exceeds the specific clearance level for landfills for non-hazardous waste but remains below the specific clearance level for landfills for hazardous waste. However, the decision on whether waste identified as NORM in the List of Waste is hazardous or not could be a matter of further waste assessment.

In the following section titled "Options for improving the legal framework", we present proposals for consideration aimed for enhancing safe NORM waste management.

A questionnaire survey conducted within this project [7] revealed that most of the responding Member States adopted a general clearance criterion of 1 mSv/year or 0.3 mSv/year. For various types of NORM waste disposal (e.g., landfilling in landfills for inert, non-hazardous, or hazardous, waste incineration, reuse as landfill construction material), specific clearance levels in Bq/g or kBq/kg can be calculated for individual radionuclides, and additional conditions for applying these levels in practice can be set. As several countries have adopted this approach, it can be considered beneficial. Member States are therefore encouraged to apply this approach as often as possible to facilitate decision-making in practice. Ad hoc assessment of individual NORM waste management cases would then be limited to non-standard situations, simplifying, reducing the cost of, and making NORM waste management more accessible and less administratively burdensome.

The design of landfills and waste incineration plants is governed by uniform or similar rules across the EU (Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control)). It is therefore possible to consider establishing specific clearance levels for certain values of E (i.e. the generic clearance criterion), for example in the form of an EU

Recommendation — similarly to what was done in RP 122 Part II [46]. This Recommendation could include calculation methods for determining specific clearance levels, e.g. suggested exposure scenarios. These values could then be incorporated into national legislation or referred to in Member States' practical implementation.

If consensus were reached at the EU level on a specific generic clearance value for the authorised release of natural radionuclides (e.g., 1 mSv/year, 0.3 mSv/year), it could be integrated into EU BSSD.

8.3 Options for improving the legal framework and management of NORM waste managed under the EU Waste Directive and the EU Extractive waste Directive

8.3.1 Hazardous properties of waste, chemical toxicity of natural radionuclides

Hazardous properties of waste, as defined by the EU Waste Directive, are demonstrated through testing — specifically by comparing the concentrations of substances in the waste or the results of tests with the criteria and threshold values established for these properties. In some cases, leachability tests are used; waste is then considered hazardous if it meets the defined hazardous property criteria. Specific procedures are prescribed for these tests depending on the substance or property involved (e.g., for heavy metals). However, these established procedures for waste toxicity testing do not account for the toxicity of natural radionuclides.

Some natural radionuclides may also be chemically toxic. A typical example is uranium, whose chemical toxicity has a greater impact on human health than its radioactivity (see Toxicological Profile for Uranium [57]).

- Consideration should be given to including the chemical toxicity of natural radionuclides in relevant monitoring procedures, where it is significant.
- At the same time, for those waste types in the List of Wastes where the presence of toxic natural radionuclides can be expected, the possibility of classifying such waste as hazardous should be added (for example, the List of Wastes does not consider the possibility of hazardous waste arising from water treatment at all — even though the removal of uranium from water during the production of drinking water generates filter material enriched with uranium).

Another very important aspect is that waste may exhibit multiple properties simultaneously, including various types of hazardous characteristics. When deciding on its reuse or disposal, all of these properties must be considered; the waste must be assessed comprehensively, and the selected solution must be appropriate for all of its relevant characteristics. As a result, radioactivity does not necessarily carry the greatest weight. This also places high demands on cooperation among experts from multiple disciplines.

8.3.2 Inertness of waste, leachability of natural radionuclides

A large proportion of NORM waste is of mineral origin and has suitable physical-mechanical properties that allow its use as construction materials, landfill engineering elements, or backfilling material. A condition for such uses is that the NORM waste must be inert. There are also landfills designated for inert waste that are used to dispose of inert NORM waste. Disposing of inert waste is generally less costly than disposing of other waste types. In these cases, it is essential to correctly assess the inertness of the waste in terms of the potential leachability of natural radionuclides. Currently, such assessments do not appear to be performed with regard to natural radionuclide content.

To avoid unnecessary restrictions on the use of NORM waste as inert material in practice, it is necessary to consider whether the leachability tests currently in use are also suitable for natural radionuclides, or whether new tests and corresponding assessment criteria need to be developed and subsequently made legally binding.

8.3.3 Waste Incineration

Another significant group of NORM waste includes combustible waste. Given the increasing focus on energy recovery from waste, there is an expectation that combustible NORM waste, which is currently landfilled but has sufficient calorific value, will be used for energy recovery in the future. Waste incineration/energy recovery is allowed for both non-hazardous and hazardous waste, while the landfilling of hazardous waste is expected to be further minimised. Annex VII of the EU BSSD states that general clearance criteria may also be used for incineration. Therefore, it is worth considering the development of specific clearance levels for the incineration of NORM waste, including the conditions under which they may be applied.

Given that published data for incineration scenarios involving natural radionuclides are limited, we highlight the potential need for further technical assessment of these scenarios to verify the safety of incinerating natural radionuclides. A recommended starting point is using the mass reduction factor after combustion to predict NOR accumulation in combustion products.

8.3.4 Long-term landfilling of NORM waste

The disposal of NORM waste in appropriate types of landfills, depending on its properties, is currently the most commonly used and accessible method of NORM waste management. However, attention must be paid to the potential long-term risks that may arise from landfilling waste containing natural radionuclides, due to their long half-lives. As a result, their activity hardly decreases over the operational lifespan of a landfill (typically around 100 years), and the radiation risk from their presence may persist even after the landfill been closed and rehabilitated. This is similar with chemical hazards. Heavy metals do not decay at all, and some chemicals are persistent over 100 years. This issue is also addressed through multi-barrier system with sorption layers [58].

Therefore, it is important to consider what happens to the landfill after its closure, whether it will be monitored and for how long, and how long the impermeable barriers will remain effective. In this context, it is particularly important to preserve information on the waste disposed of, maintain records of the landfill's existence in land registries and spatial planning documents, and take into account the landfill's presence and its contained activity in any future land use. Provided that the typical condition of not disturbing the closed landfill body is respected and the site is only used at the surface level, the closed landfill should not pose a hazard.

One possible solution may be to generally prefer hazardous waste landfills for the disposal of non-inert NORM waste, as these offer more durable containment over the long term. Such landfills are prepared to provide sufficient protection against waste toxicity, which automatically cover NORM waste radiotoxicity. Remaining problem to be solved technically is protection against external exposure to gamma (and beta, to some extent) radiation. However, this option should be professionally assessed.

During landfill operation, closure, and post-closure phases, leachate monitoring is typically carried out. The situation here is similar to routine leaching tests, which do not usually account for the possible presence of natural radionuclides. It should be evaluated whether such tests should be introduced in cases where non-inert NORM waste has been deposited in the landfill.

8.3.5 Metal waste with deposits containing natural radionuclides

This surface-contaminated metal waste may arise primarily from mining activities, water supply, spa operations, and chemical processing of mineral raw materials. It may include metal piping and dismantled parts of industrial equipment. The removal of scale from metal materials is neither technologically simple nor cost-effective. With few exceptions, most producers of contaminated metal waste are not equipped with technologies for effective scale removal, and such technologies are generally not readily available at the national level.

On the other hand, processors of metal waste as secondary raw material typically impose strict requirements on its radioactivity. In practice, this may result in contaminated (or insufficiently cleaned) metal waste not being accepted for processing. This raises the question of whether such refusal for processing (unsuitability for processing) constitutes a sufficient justification for landfilling of metal waste contaminated by natural radionuclides, especially given that the EU Waste Directive requires the Member States to ensure that by 2030, no waste that is suitable for recycling or other recovery is accepted at a landfill.

When carrying out modifications and reconstructions of technological systems where deposits may form — resulting in metal contaminated with naturally occurring radionuclides — it is advisable to consider the use of materials that reduce the risk of deposit formation.

8.4 Contents of the EU Recommendation

As evident from the HERCA Report [36], many Member States would welcome an EU Recommendation on the management of NORM waste, which would clarify certain legal and technical aspects of both reuse and disposal of such waste.

In addition to the topics already mentioned above, such a Recommendation could include procedures for selecting generic clearance levels, as well as models and methodologies for deriving specific clearance levels for different waste management routes, conditions for their use, and methods for verifying their application in practice. The Recommendation could also include suitable methods and procedures for measuring natural radionuclides contained in NORM, interpretation of measurement results, and selection of radionuclides relevant for exposure scenarios.

Until these issues are resolved at the legislative level, the Recommendation could address topics such as toxicity, inertness, etc.

The Recommendation could also include technical content related to the use of NORM in products.

Beyond the scope of Deliverable 5.13, we propose that the EU Recommendation also cover liquid discharges from NORM workplaces and the regulation of natural radionuclides in such discharges. Even more questions exist in this area regarding the implementation of EU BSSD, and the approaches of Member States in this regard vary significantly [36], with many of them not addressing liquid discharges from NORM workplaces at all in their national legislation.

8.5 Use of NORM waste in products

Efforts to promote the use of waste over its disposal when possible, this could raise a comment on the need either to ensure that there will be no long-term reuse of NORM waste, or to verify that any potential future reuse of NORM waste would not result in doses exceeding the accepted threshold value (currently set to the level of 1 mSv/year). Due to their properties, NORM waste (or by-products arising from NORM activities) appears to be suitable as input material for products used primarily in construction, landscaping, remediation works, etc. However, under current EU legislation, the content of natural radionuclides is considered only for certain construction materials (see para. 75 of Directive 2013/59/EURATOM). If content of natural radionuclides is not also appropriately monitored in other relevant products, there is a risk of uncontrolled contamination of such products with natural radionuclides, or, conversely, use of NORM in products may be unnecessarily restricted due to a disproportionate application of the precautionary principle. Neither of these outcomes is desirable. However, just as is currently done for waste and construction materials (Article 75 of Directive 2013/59/EURATOM, which sets out the requirements for indoor external exposure by gamma radiation emitted by the building material), it is possible to define acceptable levels of natural radionuclides for these products.

The procedures considered in Deliverable 5.13, which relate to the disposal of NORM waste under the authorised release regime, could similarly be applied to products. This particularly applies to specific clearance levels, as well as to unresolved issues such as toxicity and inertness.

9. Part 1 – Summary

The management of NORM should follow a pragmatic approach. Regulations must enable the identification of situations allowing for the reuse or recycling of NORM, as well as those permitting disposal in conventional landfills without unjustified regulatory burdens. Acute effects for the public resulting from short-term exposure to NOR are not the main concern when dealing with NORM at exemption-level activity. The real issue is linked to long-term/prolonged exposure, especially when the radiological characteristics of the materials have been forgotten.

In conclusion, we would like to emphasise the following points:

- NORM waste reuse, recycling, and incineration as preferred ways of NORM waste management and if not possible, the disposal are effective if all parties involved are pragmatic, free of radiophobia, and apply legal requirements appropriately.
- Demonstrating compliance with dose criteria is simplified by using specific clearance levels (in terms of activity concentration), under which the waste can be accepted at landfills or incineration plants. Experience from Germany shows that with a criterion of 10 $kBq.kg^{-1}$ for landfill disposal, the 1 mSv/year dose for landfill workers was not exceeded in any case.
- A positive impact on the understanding of NORM waste (and radioactivity in general) can be significantly improved through effective communication between the regulatory authority responsible for radiation protection and stakeholders in waste management, including competent authorities. Although exposure of workers during the variety of NORM waste handling scenarios according to established rules is unlikely to be significant, it is advisable to monitor the radiation field conditions.
- Integrating NORM waste management with the already well-established conventional waste management system, built on clearly defined terms and processes, automatically ensures alignment with a wide range of other regulations, such as those related to environmental protection, occupational health and safety (OSH), hazardous substances, and labour law. Additional necessary activities related to radioactivity can be integrated into existing systems for monitoring, reporting, OSH, prevention, mitigation, and communication, often benefiting from the synergies between these areas. Finally, incorporating NORM into the existing waste management framework also helps to address potential interactions with other pollutants or stressors.

The treatment of NORM waste is considered completed when the waste is disposed of or subject to recovery in accordance with a pre-approved plan based on clear and unambiguous conditions from the perspective of radiation protection. Only then can it be ensured that the waste will not re-enter the market through unauthorised channels. In contrast, the absence of, or insufficient or ambiguous, legal regulation worsens the situation and increases the risk of unauthorised handling of NORM waste as e.g. scrap metal from oil and gas industry, uranium ion exchangers, natural gas filter, mine sediments, resulting in significant exposure. The radiological risks through reuse of NORM waste in building materials production, as another example, is not so spectacular and not high, compared to the psychological effect of a building labelled as a building with contaminated building materials.

Part – 2: Legacy sites

10. Introduction

About 80% of Europe's land surface has been shaped by human activities: covered with buildings, roads, industrial infrastructure or used for agriculture [59]. In many EU countries heavy industry has been developing since Industrial Revolution age beginning [60]. Hence, the history of heavy industry in EU member states reaches more 200 years [61], [62]. Considered as a precursor to the European Union the European Coal and Steel Community (ECSC) was established in 1951. It was the first major attempt at European economic integration, with the aim of pooling the coal and steel industries of France, Germany, Italy, Belgium, the Netherlands, and Luxembourg under a single authority. Currently in EU industrial transformation is going on and mining and mineral processing industries burdening the environment are in decline [63]. All of that resulted in large post-industrial areas needs remediation or revitalisation emerging. Existing relevant regulations rarely consider NORM to be included in the post-industrial areas' evaluation and further remediation what is due to the exclusivity of the provisions applicable to waste and radiation protection. There is no direct driving force obliging for NORM identification and proper acting. As many industries are not aware the NORM issue to date, often problem of NORM is not considered at all, what introduce an additional complexity into NORM affected legacy sites identification. It must be underlined that in the light of the relevantly new requirements and standards concerning natural radioactivity ([4], [5], [64], contaminated sites already classified as a legacy site due to occurrence of other than radioactivity stressors (post-industrial areas) often should be re-evaluated in terms of radiation protection.

Taking into consideration NORM affected legacy sites characteristics and specifications provided by the EU BSSD (Article 100 and Indicative list of Annex XVII [4]) and International BSS [5], NORM affected legacy sites fall under the category of existing exposure situations as they are a result of either (a) past activities that were never subject to regulatory control or were regulated inappropriately and/or not in accordance with the currently existing standards, or (b) the presence of residues from past activities for which the responsible party is no longer legally accountable.

The problem of NORM affected legacy sites in terms of available solutions and technologies applicable for their remediation is discussed in RadoNorm Deliverable 5.11 [6]. This report is focussed on specific features of such sites analysed in terms, first identification and then optimisation of efforts spent on their overall management.

11. Identification of NORM affected legacy sites

Before any kind of action focused on mitigation of an impact or remediation of NORM affected legacy sites crucial is to identify the cases of concern. In case of sites contaminated evidently by radioactivity the situation is obvious, all cases of areas somehow related to nuclear industry, nuclear fuel cycle, nuclear weapon test field, of finally, most spectacular, areas affected by any kind of nuclear disaster or radiation accident are obviously considered. Moreover, the number of such site over the world is relevantly limited, what make sites of concern identification simple.

In case of NORM situation is not so simple and number of sites that should be taken into consideration is by far bigger as significant part of areas affected by industrial activities, in the light of the current knowledge about NORM, is at least suspected to be falling into the scope of the concern. However, the natural radioactivity is out of concern when an evaluation of post-industrial areas is carried out in case of non-nuclear activities, radioactivity also is not considered when local spatial development plans are prepared, in general. Is out of concern European Spatial Development Planning (ESDP) that acts as a framework for spatial planning policies at European, national, regional and local level [65]. NOR are only considered when a legacy site is subject to remediation and removed material is intended to be used in construction, based on separate requirements implied by EU BSSD [4]. A little better the problem looks from the perspective of radiation protection regulation. The recent ICRP recommendation on NORM underlines a possibility of NORM affected legacy sites identification by verification of former sites where currently identified NORM involving industries had been operating. The assumption is that radiological protection was not considered sufficiently when facilities were shut down and dismantled. Moreover, it is also underlined that 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 (ICRP 142, paragraph , 128 [64]).

It results that to date there no systematic approach to identification of potential NORM affected legacy sites. Identification is done case by case [66], [67], [68] rather in frame of research than routine activity, and hardly ever is dealing with a typical legacy site where solid waste was deposited. The reason is, likely as in case of NORM waste, apparently primarily legal, however can be simply solved by asking authorities whose competence covers post-industrial areas management to include NOR in their scope of the responsibility. The simplest, temporary method to get quick effect regardless changing higher level regulations, is including the test on NOR activity concentration in the scope of national requirements concerning quality evaluation of soil and ground in sites affected by former activity of enclosed in the whitelist NORM involving industries, which is already present in each national regulation due to requirement set by EU BSSD. To facilitate the overall process the application of tier 2 and tier 3 in the methodology developed for NORM sites identification is recommended [69].

12. General characterisation of a legacy site contaminated by radionuclides

Considering legacy sites characteristics in terms of radiation protection there are two typical scenarios possible that differ in the basic appearance, exposure pathway and endangered receptors. Currently available experience and knowledge have been gathered based mainly on sites affected by artificial radioactivity or uranium extraction, processing, and utilisation of uranium [70], and it is therefore necessary to be very careful expanding such experiences on sites affected by NORM. However, since uranium mining is a well-established area with extensive remediation experience in many countries, and because these sites often share characteristics with those affected by the extraction of other raw materials, they can serve as a sort of model for developing appropriate solutions for NORM-affected legacies. This was discussed in the Deliverable 5.11 all together with also similar, from the source of contamination, sites contaminated by radium used directly for painting watch and aviation instruments dials [6].

The first considered in terms of mostly investigated radiation protection legacies are areas, where radionuclides were dispatched homogenously due to radioactive fallout. Usually, there are not visible (mechanical) borders between contaminated-non-contaminated areas and there are, to some extent, neither agents destroying mechanically the area nor other, non-radioactive pollutants. Therefore, most subsequent detriments on the environment present there can be attributed to radioactivity. Depending on land use, endangered receptors cover whole spectrum of environmental compartments, including humans. Regardless the contaminated areas dimensions, exposure scenario is in general described as an existing ecosystem affected by radionuclides considering all possible irradiation pathways. Such situations typically are caused by a nuclear or radioactive accident e.g. Chernobyl Exclusion Zone (CEZ) or former military nuclear test.

The second group of legacies are related to any kind of uranium extractions, nuclear installation, spent nuclear fuel and/or radioactive waste repository. A site area is usually smaller, and sources of radioactivity are present in different forms, usually inhomogeneous however, well recognised.

Environment present there is strongly affected due to many changes introduced to make such site usable for assumed purpose. Usually there is not any ecosystem performing a service so important to be especially protected. Many of such sites became contaminated because of poor either practice, or design, or adherence to former RP standards that were less stringent than those valid today. Moreover, some actions had been taken then are not justified in terms of nowadays RP. The borders of the site are physically set, and contamination is, at the moment of a site creation, present only on-site. The problem usually is exaggerated by some failures of installations/objects and further uncontrolled dispersion of radionuclides also into neighbouring areas [71], [72].

Both scenarios are relatively easy to simulate. If only artificial radionuclides are considered, monitoring and evaluating results is simpler since distinguishing between background and contamination is unnecessary. Existing radioecology research has established radionuclide behavior in these contexts, and significant efforts have been made to develop remediation strategies. While radioactivity is initially prioritised during remediation, the diversity of such sites may require attention to other contaminants to determine if radioactivity should remain the primary concern [73].

13. NORM affected legacy site

Extending above mentioned these scenarios on NORM affected legacy sites one should remember that even from the first sight may seems to be similar, but actual situation is completely different. Contrary to first type legacy sites, NORM affected legacies are occupying relatively smaller area, where physical borders often exist. Only rough similarity is that contamination may be distributed homogenously in both cases. When comparing to the second group of legacies discussed, we can find many similarities only when comparing the NORM legacy site with the remains of uranium mining and processing. In cases of nuclear installations, spent nuclear fuel, and/or radioactive waste repositories, NORM affected legacies differs regarding with source of contamination overall characterisation of contamination source, including spatial distribution as well as homogeneity.

13.1 Physical features of contaminants

However, the main differences are introduced into the scenarios by specific NORM features. Total amount of solid NORM usually exceeds amount of any kind of radioactive waste, including spent nuclear fuel and they are present in form of semi liquid and greasy or granular bulk material often disposed directly into a land and eventually the whole area of an affected site is covered by a contaminant.

Therefore, when addressing a NORM-affected legacy site, the impact on the local environment caused by both the large volume of disposed materials and related supporting activities (e.g. transport) must be taken into account at the beginning of the assessment. In contrast, contamination at a nuclear site can, to some extent, be regarded as a 'spike' - introducing mainly radioactivity into the scenario, typically without additional environmental side-effects.

When a huge amount of NORM is exposed to environmental conditions, different process leading to the dispersion of such material into neighbourhoods must be considered – at least air or water erosion. Considered these, NORM affected legacy site as an objective of monitoring or remediation may be considered as constituting of two parts extremely different in properties and subject to different actions: on-site where NORM is directly disposed and off-site where some influence of NORM disposed on-site may occur. This is crucial assumption for appropriate recognition and identification of protection objectives and all further activities focussed on existing/related hazard evaluation, criteria applied as well as remediation decisions.

Considering the features of NORM, situation where the existing ecosystem was contaminated by release of NOR is limited to fallout of radionuclides emitted in gaseous form or as dust particles what is rarely noticed. Contamination of surface and groundwater sources caused by uncontrolled wastewater discharge, seepage or leachates from contaminated geological environments are also occurring and the effects of these contaminants should also be taken into account in the assessment, however, these problems are more complex, exceeding the scope of this report.

13.2 Chemical features of contaminants

Besides overall appearance of NORM affected legacy sites and physical properties of NORM, disposed there, additional complexity is introduced into the problem by chemical properties of NORM and wide variety of possible matrices where NOR are enclosed. Information about source i.e. the type of-industry as well as technological processes applied will allow to obtain preliminary information on the chemical properties of NORM of concern and identify them among other waste disposed together with NORM.

13.3 Site evaluation

Considering all the above, it is essential to rank existing hazards (stressors) in each situation, since radioactivity might not always be the primary threat. Moreover, the main vulnerable targets can vary - such as biota, fauna, landscapes, or water resources. For that, a multi-stage process should be initiated with consideration of different factors interrelationships, which include other types of hazards (such as metals, asbestos, organics, physical threats), the works performed during site creation, management operations to deal with wastes determined by other contaminants presence (if any), effluent waters seepages, upsurge of contaminated groundwater, the proximity of human populations and their local activities, as well as all associated uncertainties caused by lack of data. Keeping in mind that each agent may have impacted, is currently impacting, or could impact site conditions in the future, it is essential to identify and prioritise protection objectives. This should be accompanied by a set of assumptions regarding how these objectives will be achieved during subsequent site treatment.

Such an approach is particularly important given the potential synergy between site characterisation and remediation efforts—for example, the behaviour of radionuclides can be inferred by investigating their stable isotopes, and measures taken to mitigate chemical impacts may also prove effective for radionuclides. This limits the automatic application of research methods, assessment protocols, and simulation tools originally developed for sites affected by artificial radioactivity. However, it allows for the adaptation of frameworks standardised for conventionally contaminated areas, provided they are properly adjusted to account not only for metal contamination but also for radionuclides and their radiation emissions.

To avoid unintended errors when conducting evaluations focused on radiation protection at NORM-affected sites, it is essential to consider site-specific external conditions, environmental, economic, and social. The integrated approach to NORM waste management proposed in the first part of this report would facilitate these considerations.

Depending on existing situation, NORM affected legacy sites can be considered in term of mitigation, i.e. to minimise off-site impact, or remediation (according to IAEA definitions) or better revitalisation, to bring back the affected site to a new life, as discussed in the RadoNorm project Deliverable 5.11 [6].

14. Considerations for improvement

For development of an optimised approach for a more detailed and specific characterisation, monitoring and possible actions towards NORM affected legacy sites, important features must be considered, such as:

- **Demarcating areas that fall within the NORM affected legacy site complex.** Each NORM affected site can be divided into two parts. First, the place (plot) where NORM is directly deposited, for these considerations called on-site, and second, those areas that surround the directly impacted on-site, called off-site. It is important to underline the former category falls under the regulatory and assessment regime pertaining to occupational exposure, where human presence is normally more strictly controlled, whereas the latter pertains to exposure of the general public and environment. Hazard indices and reference levels concerning these categories may need to be defined separately, best justified are criteria used for planned exposure of workers and members of the public. Less conservative option is possible to use criteria for existing exposure scenario based on IAEA GRS 3 recommendation allowing use of such criteria to “exposure due to contamination of areas by residual radioactive material deriving from past activities that were never subject to regulatory control or that were subject to regulatory control but not in accordance with the requirements of these Standards”. However, the local background as reference value for comparison is the best criterion for concluding about radioactivity importance in each such case, while communicating with layman as members of the local public and stakeholders.

Notwithstanding criteria applied, this demarcation should be achievable not just by the characterisation based on the physical properties of NORM, but through the consideration that access to on-site, is or can be restricted.

Based on such approach, during the preliminary evaluation, the situation can be considered only from the off-site perspective. If there is either no effect observed in the off-site directly caused by the on-site, or observed effects are negligible from radiation protection perspective, and on-site is planned to be permanently closed for the public, ‘no action’ solution can be justified and decision about remediation, if any, is driven by other than radiation protection needs, factually regardless level of the exposure in the on-site. First, other contamination should be considered, however economy usually plays important role. Otherwise, i.e. the proved impact of on-site on the off-site is non-negligible in terms of radiation protection, mitigation or remediation is expected. The action taken should be aimed at ensuring proper level of radiation protection for member of the public living in the off-site. However, if the on-site facility is intended for public use, the area must be remediated to meet radiation levels acceptable for public exposure. Additional aspect which must be considered, is protection of workers involved in any of remediation work planned.

- **Collect site-specific information on ecosystem functionality.** After the creation of a disposal site, any ecosystem that might have been previously present in the on-site, may have disappeared completely being entirely covered by NORM or suffered significant loss of a range of ecosystem functions, regardless NORM radioactivity. Similarly, non-radiological factors that burden the ecosystem may also significantly prevail outside the on-site. For example, the transport of large amounts of bulk materials can cause substantial detriment as habitats become physically disturbed. In some cases, a secondary biological succession can occur over time in both the on-site and the off-site, and a (often degraded) ecosystem may be re-established. The question then becomes which specific attributes of this new ecosystem are potentially at risk and should be protected, or even whether this degraded ecosystem should warrant protection at all. This decision-making is often strongly influenced by the public, who may prefer the removal of the legacy site or, on the contrary, demand its preservation in order not to have to endure the temporary deterioration of the natural conditions on the site. Incidentally, a “waste heap” covered with transgressing vegetation can create a good test field for the observation of external exposures, radionuclide transfer to biota, accumulation in biota and finally the effects on a specific ecosystem receptor. But it is clear, that empirical data collected there are very site specific, and hence observations cannot be easily generalised. This point is especially relevant when considering cases where wild organisms have been affected, or ecosystems degraded, substantially owing to overall industrial activities. However, such data will help reduce modelling uncertainties and improve impact assessments for a particular site. Regardless advantages that can be obtained by radioecological research, it must be underlined that a secondary biological succession occurring in such a site does not need to be protected against the contamination present there. On the other hand, biota transgressing into NORM affected site often can be considered as a kind of phytostabilisation process limiting dispersion of NORM via different erosion processes.

Considering human exposure, it is no matter what was the first (contamination or biota), current exposure situation is determining radiation protection measures applied. Usually, there are no justified, regular human activity, therefore only occupational exposure should be considered in time of remediation works. In such case, criteria for practices should be applied.

- **The need to understand critical processes and events responsible for radionuclide transfer/transport and further migration into off-site.** Features, event and processes (FEP) analysis can be applied for this purpose [74], however, two main groups of processes driven by different NORM properties and leading to the migration of NOR, within the assessment of radiological impact, may be considered the most important. The first group of processes consists of different types of erosion when NORM particulates are moved from the ground surface into the surrounding environment (e.g., due to rain or wind). In this case, physical NORM properties, apart from their radioactivity, are the most important. The radioactive contamination of the surrounding area must be considered in terms of mechanical mass transport. The second process is leaching when NORM is exposed to environmental conditions, mainly to the rainfall. In this case as well as all subsequent processes e.g. migration to biota, chemical properties of NORM residues and in particular chemical form of radionuclides are crucial. Leaching and the resulting contamination of the aquatic environment must be considered due to possible contamination of drinking water sources (both surface and groundwater sources), and in the case of surface waters contamination by NOR should be considered also because of the potential severe risks to aquatic biota. Defining the main processes provides the foundations for all derived parameters necessary for the implementation of a proper risk assessment scheme. It is worth being mentioned that mechanical mass transport determines both, radionuclides, and other contamination migration as well as processes ruled by chemical properties are going in the same manner for radionuclides and their stable isotopes. If considered properly, this can limit significantly efforts necessary for a site characterisation and remediation options development. However, criteria for both radiation levels and non-radioactive contamination in different environmental matrices, based on reference levels concerning these categories may need to be defined separately based on local regulation on soil/ground/water/food quality and exemption/clearance levels for chemicals and radioactivity respectively. However, comparison with the local or national background is the most imaginative explanation.

- **The understanding of the multi-stressor context in NORM affected legacy sites (an on-site as well as an off-site)** Ionizing radiation at legacy sites usually is not the most important stressor. Risk of radioactivity should be assessed in parallel with the risks of other potential toxic elements (PTE). Mutual interaction with other contaminants should be taken into consideration at all stages of the assessment especially concerning migration process and possible mutual chemical interactions improving/limiting migration abilities and the total (bio)availability. For human and environmental exposure to occur and an effect to be produced, chemicals need to be in direct contact with an organism (with an environmental compartment, in general). This does not apply to ionizing radiation, where, in addition to the internal, external exposure of an individual, human or animal (or its statistical representative) is taken into account.

However, chemicals also can affect biota remotely through the alteration of biotope chemical properties, e.g. pH. Keeping in the mind that every species of biota has been evolved and eventually adapted to the specific habitat any kind of its alternation will affect whole population of a species, not only individuals. From this perspective, such hazard is by far more serious. When habitat changes, less adapted species are doomed to extinction, and from long term perspective, it does not matter how much radiation is present. Otherwise, if habitat is convenient (sufficiently good), biota species (ecosystem), may be exposed to radiation without affecting the population. Evaluating radiation hazard, the on-site exposure evolution, e.g. due to radioactive decay (see the section ..) must be considered, while other contaminants are usually resistant to the passage of time. That is why long lived NOR should identified individually unless the secular equilibrium state in whole uranium and thorium decay series are sufficiently justified.

• **A balanced approach to assessing the existing situation.** For example, considering both hazards, concentrations in environmental media can be taken as a manifestation of relevant risk. However, it must be emphasised that only the occurrence of a potentially hazardous substance does not guarantee that exposure of organisms will occur. Therefore, the proper identification of existing situation in a NORM affected legacy is important using a proper term as contamination and pollution to avoid unnecessary problem exaggeration.

Contamination is simply the presence of a substance where it should not be or at concentrations above background. Pollution is contamination that results in or can result in adverse biological effects to resident communities [75]. All pollutants are contaminants, but not all contaminants are pollutants and commonly, further evaluations are necessary. Differentiating pollution from contamination cannot be done solely based on chemical analyses and existing agents' concentrations. It must be underlined that considering occurrence of radionuclides and its non-radioactive isotopes usually radiotoxicity is dominating, it means that the mass of radionuclide is not big enough to manifest their chemotoxicity (or to launch a chemical process as e.g. precipitation when solubility level is exceeded) while radiation is big enough to cause an effect. An example is lead, content of stable lead isotopes in soil is usually required to be in the range of 100 - 300 mg/kg, which corresponds 300 up to 900 GBq/kg of Pb-210 isotope, while the exemption or clearance level is suggested as 1 kBq/kg, resp. 10 kBq/kg. Opposite situation, i.e. chemotoxicity is important earlier than radiotoxicity, is quite rare and well known for U-238, regardless that uranium does not have stable isotopes.

Therefore, additional information about the characteristics of environmental media in which agents of concern are contained is crucial. Combined with the chemical and physical properties of these agents, such information helps determine their interactions with living organisms, and ultimately whether they result in harm to biota.

Effects-based measures such as laboratory or field (radio)toxicity tests and measures of the status of resident, exposed communities would provide key information. However, residents communities are usually characterised by innate natural variability and it cannot be easily distinguished between adaptation to contamination (a genetic process) and acclimation (a physiological process that may decrease energy reserves, possibly reducing such critical population-level parameters as reproduction) what introduce additional complexity when e.g. a comparison of biocenosis in on- and off-site is planned. Moreover, contaminant effects may not only be direct but also indirect causing an alternation of habitat as discussed above. Predicting such all effects requires exhausting characterisation of the system under study as well as appropriate use of no-effect concertation with respect to the effect that is studied/assumed. Investigations aimed at determining whether contamination constitutes pollution or may become pollution in the future can yield two types of outcomes: definitive conclusions about pollution, or indications that further studies are needed to reach such conclusions. In practice, the decision to halt the evaluation process is often driven by economic considerations and the interests of involved stakeholders.

15. Improved exposure characterisation and assessment scheme

The characterisation of a NORM affected legacy site, including the collection of radiological and ancillary data, can be considered an essential prerequisite for a decision on current site status in terms of RP and local spatial development plan. Then subsequent implementation of mitigation and remediation measures can be decided. An important question that needs to be addressed, concerns the level of complexity that should be considered in this characterisation process and the pursuant model development and application. For characterisation at NORM affected legacy sites, depending on the given conditions in a particular case, specific details may be required [76]. However, level of complexity should be optimised based on discussed features to avoid overestimation of the radiation hazard issue. Actually, the situation in the on-site is important only in case of remediation taken (or planned) or consideration concerning the reuse of disposed waste. Information on chemical and physical characteristics of the surrounding environment (the off-site) that may lead to selective radionuclide mobility, accumulation and thus disequilibrium in the radionuclide chains and hydrometeorological conditions that might potentially lead to elevated radionuclide migration let one decide on mitigation needs. Given that there are currently no formal radiological protection criteria for biota at either the EU or national level and that sites of concern are typically located in areas heavily altered by human activity, where ecosystem services are already limited, the primary focus of a radiological impact assessment should be on protecting human health rather than biota. The suggested pragmatic approach to the management of NORM affected legacy site can be based on rules defined for NORM classification using the concept of clearance, regardless of the formal definition of clearance levels considered for the process oriented on residues/waste resulting from a practice release from the site. The is no formal obstacles for that, as legacy sites were created due to former activities that currently, according to the state-of-the-art radiation protection, would be categorised as practices.

In on-site of a NORM affected legacy usually (besides remediation, if decided) usually there are no regular human activities as well as biota is depressed. Therefore, there is no need to evaluate the exposure in terms of effective dose, hence the necessity for further activities related to radiation protection can be decided on clearance level expressed as NOR activity concentration (note: the use of modifications proposed in this section are required). If the verified NOR activity concentration is below these clarence levels no more activities related to RP are necessary unless the contamination of drinking water is possible.

A rationale provided for that is all processes responsible for possible migration of radionuclides (as any kind of erosion, leachates, or seepages) finally are leading to dilution of radionuclides activity concentration. Only in the case of drinking water, NOR introduced can either contribute to the committed dose due to direct drinking or accumulate in some residues in water treatment plant.

Current criteria applied for clearance do not ensure compliance with requirements concerning NOR presence in building materials. Hence, special attention must be paid to recycling materials removed from a site in building materials (as mentioned in the EU BSSD Annex VII). However, in some countries e.g. in Poland and Czechia such requirement already exists. To ensure the NOR does not cause any harm in terms of radiation protection RP lower clearance limit can be used, as for example proposed in frame of TENORM HARM project (0.2 Bq/kg for U and Th decay series). However, such value is not supported by any existing regulation.

If the clearance levels assumed are exceeded, implementation of RP measures would be obligatory starting from dose evaluation focussed on a critical group of people potentially affected by releases from a site. Standard models can be used for that such as e.g. RESRAD [77]. Again, all RP measures applied should be focussed on human exposure (including potential contamination of human trophic chain) unless a site of concern can affect an extraordinary environment/ecosystem as such areas classified into Special Protection Areas (SPA) or Special Areas of Conservation (SAC) based on EU directives [78], [79] or e.g. national parks decided upon national regulations.

Beyond addressing current needs, a key objective of such investigations is to support the development of conceptual frameworks for protective measures and land reclamation strategies. In the present context, marked by a lack of regulation addressing this issue, as noted in the introduction, careful consideration of fit-for-purpose approaches can help establish a central principle for developing a radiological impact assessment methodology applicable to NORM regulation.

Exposure pathways significantly affect the selection of appropriate remediation techniques and monitoring methods, and, therefore, decision-making should always include their analysis accounting for site-specific features. The approaches used for considering exposures following releases from nuclear installations may have a broad relevance to cases involving NORM, and have been used within the EC's radiation protection guidelines [80], [81]. On the other hand, a set of realistic, but enveloping exposure scenarios for NORM-involving industries considered in these recommendations seems to be too complex when applied for NORM affected legacy sites, apart from specific actions (practices) related to land remediation. Hence, it may be more pragmatic to start with detailed lists of exposure pathways, then select the most suitable ones and find relevant scenarios. This adjusted approach may be especially important for legacy sites caused by liquid NORM releases subject to environmental processes such as sedimentation. This requires a case-by-case approach exceeding the scope of this report.

The justification for remediation is not always driven solely by radiological protection considerations. In most cases, other environmental hazards are also present, and certain remediation measures may incidentally reduce radioactivity or, conversely, may cause greater environmental harm than non-intervention when evaluated from a radiation protection perspective. Therefore, the remediation endpoint should be an optimised exposure dose level below a limit (or reference level), determined by taking into account the prevailing circumstances, the future use of the site and the possible conditions of use, and falling within the range of legally binding values. However, the implementation of the optimisation principle is often a challenge, as occasionally it will be difficult to make a distinction between NORM contamination and the natural background radioactivity (ICRP 142 [64]).

While the impact related with NORM legacy sites is valued economically, all effects associated should be incorporated into the decision-making process of cost-benefit analysis. Human and infrastructure resources necessary should be evaluated, however not always it is easy to valuate economically social or ecological impact, hence to date there exist no universal solution for the selection of remediation strategy at NORM legacy sites. Factors affecting the decision on remediation strategy include the level of present hazards, availability of funds, remediation technologies, waste management resources, societal and economic impacts. Usually, an iterative strategy that would allow accounting for new information and process optimisation with time is preferable. Economic and social factors are also relevant and need to be evaluated based on a good understanding of the area of interest. These problems are still under discussion in frame of IAEA Network of Environmental Management and Remediation – ENVIRONET [82], also for other legacies affected by radioactivity.

16. Part 2 – Summary

NORM legacy sites remain a prevalent issue, as many post-industrial areas are likely to be contaminated by naturally occurring radionuclides (NOR), given current understanding of the various industries impacted by this problem. A systematic identification procedure is essential to ensure that all such sites are properly recognised.

An ad hoc solution to facilitate the identification of NORM-affected legacy sites could involve NOR in routine ground and soil quality assessments. Future regulations may be built on waste management strategies for NORM, as proposed in the first part of this report.

It is important to distinguish between on-site locations where NORM waste is disposed of, and off-site areas potentially affected by accumulated NORM waste. This distinction helps preventing overestimation of the associated hazard.

Following a detailed analysis of the characteristics of NORM-affected sites, a streamlined evaluation process and subsequent remediation decision-making approach are proposed, based on existing, or updated as suggested in the first part of this report, clearance criteria. Collected data on NOR activity concentration in waste from NORM-involving industries (as referenced in RadoNorm Deliverable 2.11[4] and related submitted articles[5],[6],[7]) suggest that most post-industrial areas that would be identified as NORM-affected may have potential to meet these rigorously justified criteria. In such cases, sites could be released from radiation protection control following relatively simple verification procedures. This approach optimises the process, simultaneously ensuring commensurate level of radiation protection.

For verification of compliance with assumed clearance levels an organisational structure with clear allocation of responsibilities and adequate resources should be established to plan and conduct monitoring to verify compliance with exemption criteria in a timely and effective manner. The corresponding management arrangements to be considered must include crucial features listed in the Appendix II of IAEA General Safety Guide GSG-17 [22] unless the organisation is certified according to the ISO 17025 standard.

[4] Mrdakovic Popic, J., Dvorzhak, A., Michalik, B. (2025): Overview of NORM exposures sites in Europe and characterisation of most relevant NORM exposure scenarios. Deliverable D 2.11 of project RadoNorm – under verification

[5] Naturally occurring radioactive materials (NORM) in energy production sectors: oil and gas, coal, and geothermal energy production, under review in Environment International

[6] Overview of Naturally Occurring Radioactive Materials (NORM) in mineral processing Industries and first steps to consider Ionising Radiation in Life Cycle Assessment – Part I. NORM inventory submitted to (Radiation and Environmental Biophysics)

[7] Overview of Naturally Occurring Radioactive Materials (NORM) in mineral processing industries and first steps to consider Ionising Radiation in Life Cycle Assessment – Part II. NORM Impact Assessment – under preparation

Part – 3: Clearance and Exemption criteria

17. Introduction

From the end user perspective, the most often used and pragmatic are criteria set for the exemption and clearance. While exemption is used as part of a process to determine the nature and extent of regulatory control, clearance is intended to establish which material under regulatory control can be removed from this control. Therefore, a decision on granting clearance usually takes place during or after the planned activities with a source within a practice, while exemption refers instead to an *a priori* decision. Clearance is therefore different from exemption, even though the general criteria on which the concepts are based are very similar [5].

The concepts of exemption and clearance have been established within the framework of a graded approach to authority control. This methodology, initially developed by the IAEA, aims to ensure that radiation protection measures are implemented at a level appropriate to current exposure risks and the feasibility of effective management. The defined exemption and clearance levels are intended to be used:

- in the definition of the scope of national regulations of RP,
- for the notification process,
- in the management of practices and sources within practices,
- to define exposure situations, planned or existing,
- to define radioactive material or waste,
- to determine whether material within a practice can be released from regulatory control.

17.1 Rationale for exemption and clearance levels

17.1.1 The first approaches to management of NOR

The approach to the problem of NOR regulation presented in the newest recommendations results from many years of international debate starting in the eighties of the twentieth century. First international recommendations addressing problem of non-negligible exposure to NOR were provided by ICRP in the form of “Principles for Limiting Exposure of the Public to Natural Sources of Radiation” (ICRP 39 [83]). In this report Commission recognised that over the last few years, increasing information from extensive measurements in many countries has shown that the doses caused by natural radiation are in many ways influenced by man’s activities. That is why it is explicitly stated that exposure to NOR should be included in the dose limits recommended, but only in cases when levels of natural radiation which might have to be controlled, to an extent practicable, in much the same way as for artificial sources. Important for further discussion in this report are data about average exposure to natural sources of radiation (*Table 4*) showing significant differences in the exposure to NOR depending on the decay series considered.

Table 4: Estimates of human exposure to natural sources of radiation [52]

Source	Average annual effective dose equivalent (mGy)	Fraction of total (%)	Range of doses	Readily controllable
Extraterrestrial				
External exposure	0.3	15		
Internal exposure	0.01	0.5	narrow	yes
Terrestrial				
External exposure				
Outdoor	0.06	3	medium	no
Indoor	0.29	14	large	no
Internal exposure				
K-40 and Rb-87	0.19	9	narrow	yes
U-238 series				
Outdoor inhalation	0.06	3	medium	yes
Indoor inhalation	0.77	38	very large	no
Ingestion	0.14	7	medium	no
Th-232 series				
Outdoor inhalation	0.03	1.5	unknown	yes
Indoor inhalation	0.17	9	large	no**
Ingestion	0.02	1	medium	no**

** “Very large” means a variation by a factor of the order of 1000 between extremes, “large” a factor of up to 100, “medium” a factor of about 10, and “narrow” a variation by less than a factor of 5.*

*** Reducing this type of exposure usually means moving geographically. This may be possible but is often impracticable. Avoiding new situations will usually be less difficult.*

ICRP Publication 60 [84] is following previous recommendations and directly requires exposure to NOR should be considered in terms of occupational exposure as contributing to the dose limits. To provide some practical guidance, the Commission recommends that there should be a requirement to include exposure to natural sources as part of occupational exposure only in the cases radon and operations with and storage of materials not usually regarded as radioactive, but which contain significant traces of natural radionuclides and which have been identified by the regulatory agency. However, there are no NOR oriented limits or constraints and the definition of quantified specifications are decided to be dependent on the local circumstances. As a very general guide, operations in spas, in most uranium mines, including open-cast mines, in many other underground mines and caves, and in some other underground workplaces are listed as likely to constitute examples where exposure to NOR should be considered. Doses from radon in dwellings and in the open air, radioactive materials, natural or artificial, already in the environment, and other natural sources are outside the scope of the dose limits for public exposure.

Issued in 1996 IAEA International Basic Safety Standards [85] marked the first real steps taken at the international level to deal with protection against exposure to natural sources of radiation. The practices for which the Standards are intended include among others: the entire cycle of related activities from the mining and processing of radioactive ores to the operation of nuclear reactors and fuel cycle facilities and the management of radioactive wastes; **and activities, such as the underground mining of coal**

and of phosphatic and other minerals, that may enhance exposure to naturally occurring radioactive substances. Situations that may require intervention include chronic exposure to naturally occurring sources of radiation such as radon in dwellings, and to radioactive residues from past activities and events; and emergency exposure situations such as might result from accidents or from deficiencies in existing practices. This safety standard provides values for the exemption levels as exempt activity concentrations and exempt activities of radionuclides, including NOR.

The guidance exemption levels set forth in this Standard are subject to the following considerations:

(a) They have been derived using a conservative model based on general exemption criteria and a series of limiting (bounding) use and disposal scenarios. The values of activity concentration and total activity represent the lowest values calculated in any scenario for a moderate quantity of material as described in Radiation Protection 65 [86]. For radionuclides subject successive decay products‘ contribution to the dose is included. Accurate values and dominant exposure scenario are presented in the Table 5.

(b) The application of exemption to natural radionuclides, where these are not excluded, is limited to the incorporation of naturally occurring radionuclides into consumer products or their use as a radioactive source (e.g. Ra-226, Po-210) or for their elemental properties (e.g. thorium, uranium),

(c) In the case of more than one radionuclide, the appropriate sum of the ratios of the activity or activity concentration of each radionuclide and the corresponding exempt activity or activity concentration shall be taken into account,

(d) Unless the exposure is excluded, exemption for bulk amounts of materials with activity concentrations lower than the guidance exemption levels may nevertheless require further consideration by the Regulatory Authority.

Table 5: Summary of exemption activities and activity concentration (RP 65 -unrounded *[86]*)

Nuclide	Activity concentration Bq/g	Critical pathway for exempt activity concentration	Activity Bq	Critical pathway for exempt activity c
Pb-210+	*5.21*	*ING ACC(P)*	*51 000*	*ING ACC(P)*
Po-210	*16.1*	*ING ACC(P)*	*15 700*	*ING ACC(P)*
Ra-224+	*9.88*	*EXT(W)*	*120 000*	*ING ACC(P)*
Ra-226+	*4.67*	*ING ACC(P)*	*454010*	*ING ACC(P)*
Ra-228+	*15.2*	*EXT(W)*	*35 500*	*ING ACC(P)*
Th-228+	*1.5*	*INH (W)*	*8 780*	*INH ACC(P)*
Th-232sec	*84.9*	*INH (W)*	*1 550*	*ING ACC(P)*
Th-234+	*311*	*EXT(W)*	*185 000*	*SKIN(W)*
U-234	*4.29*	*INH (W)*	*25 700*	*INH ACC(P)*
U-235+	*4.34*	*INH (W)*	*6 110*	*INH ACCF(W)*
U-238+	*4.76*	*INH (W)*	*28 400*	*INH ACC(P)*
U-238sec	*1.83*	*INH (W)*	*2 570*	*SKIN(W)*

Critical pathway ACTIVITY CONCENTRATIONS:

- *EXT(W) external in workplace from 1m cubed source*
- *EXTG(W) external in workplace from gas bottle*
- *INH(W) inhalation in workplace*

- *ING ACC(P) accidental ingestion to public from landfill*

ACTIVITIES:

- *SKIN(W) skin dose in workplace*
- *EXT(W) external in workplace (effective skin + point source)*
- *INH ACCF(W) inhalation in workplace from fire*
- *INH ACC(P) accidental inhalation to public from landfill*
- *ING ACC(P) accidental ingestion to public from landfill*

The Normal Use (workplace) scenario represents the use of small amounts of radionuclides in industry etc., in the manner for which they are intended, involves external exposure, skin contamination and inadvertent intakes of radioactive materials. Exposures to the public arising from normal releases of activity are adequately covered by this workplace scenario.

(b) The Accidental (workplace) scenario represents abnormal procedures or incidents that might occur during the routine use of small amounts of radionuclides. These situations may lead to exposures via a range of external, inhalation and ingestion pathways.

(c) The Disposal (public) scenario represents a member of the public becoming exposed after subsequent disposal of the source. This situation may lead to external, inhalation and ingestion pathways. Both normal and accidental situations are considered.

Development of important EU documents are presented in the Figure 3. A notable progress is the publication in 1996, of Directive 96/29/Euratom of the Council of the European Union [87] , which placed specific legal requirements on European Member States for the control of work activities involving a significant increase in exposure to natural sources.

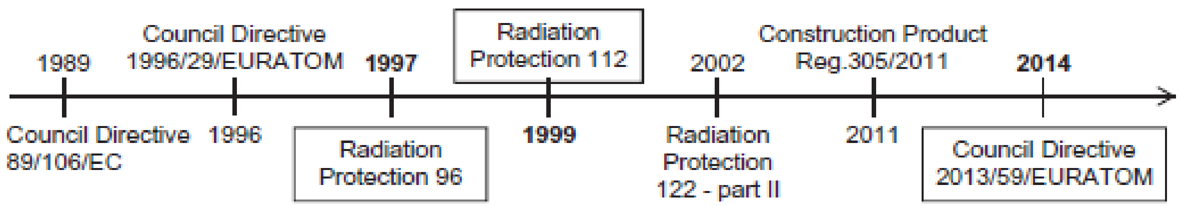

Figure 3: The progress in the development of EU recommendations and regulations dealing with NOR [88]

Notwithstanding that both documents IAEA BSS and aforementioned directive were published more or less simultaneously, recommended exemption levels (Table 6) are consistent as being developed by rounded data provided by RP 65.

Table 6: Exemption levels for NOR from the Council Directive 96/29/EURATOM of 13 May 1996 [87]

Nuclide	Quantity Bq	Concentration Bq/g
PB-210+	*10^4*	*10*
Po-210	*10^4*	*10*
Ra-224+	*10^5*	*10*
Ra-226+	*10^4*	*10*
Ra-228+	*10^5*	*10*
Th-228+	*10^4*	*1*
Th-232sec	*10^3*	*1*
Th-234+	*10^5*	*10^3*
U-234	*10^4*	*10*
U-235+	*10^4*	*10*
U-238+	*10^4*	*10*
U-238sec	*10^3*	*1*

Pb-210 Bi-210, Po-210
Rn-220 Po-216
Rn-222 Po-218, Pb-214, Bi-214, Po-214
Ra-223 Rn-219, Po-215, Pb-211, Bi-211, Tl-207
Ra-224 Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)
Ra-226 Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
Ra-228 Ac-228
Ac-227 Fr-223 (0.0138)
Th-228 Ra-224, Rn-220, Po-216, Pb-212, Bi-212,Tl-208 (0.36), Po-212 (0.64)
U-235 Th-231
U-238 Th-234, Pa-234m

And a special case for:
Th-232sec - Ra-228 Ac-228 Th-228 Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64), and
U-238sec - Th-234, Pa-234, U-234, Th-230, Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210 for whole decay series.

17.1.2 Commentary to the section 17.1.1

The main conclusions from the briefly analysed documents important for further discussion are:

- Exposure to natural radionuclides under normal condition varies significantly and significant differences in contribution of radionuclides from uranium and thorium decay series are noticeable. All decay series are considered, including actinium decay series.
- In terms of occupational exposure NOR were considered equally with artificial radionuclides, no special limits or constraints were set for NOR, one dose limit for all kind of source was recommended.
- To avoid exaggeration of exposure to NOR, only NOR manageable were considered in terms of source exposure.
- exemption levels provided are based on calculations of activity or activity concentration expecting to result in effective doses to the critical group of exceeding neither around 0.01 mSv per year for the total exposure, nor 50 mSv per year to irradiated areas of the skin.

- The application of these exemption levels to natural radionuclides, where these are not excluded, is limited to the incorporation of naturally occurring radionuclides into consumer products or their use as a radioactive source (e.g. Ra-226, Po-210) or for their elemental properties (e.g. thorium, uranium),
- In the case of more than one radionuclide present, the appropriate sum of the ratios of the activity or activity concentration of each radionuclide and the corresponding exempt activity or activity concentration shall be taken into account, regardless radionuclides are natural of artificial origin.
- The calculated values apply to practices involving small scale usage of activity where the quantities involved are at most of the order of a tonne. The values take into account use, misuse and subsequent disposal.
- Unless the exposure is excluded, exemption for bulk amounts of materials with activity concentrations lower than the guidance exemption levels may nevertheless require further consideration by the Regulatory Authority.

17.1.3 Further development of NOR management

It is generally considered, a major step forward was achieved with the publication in 2004 of the IAEA Safety Guide RS-G-1.7 on Application of the Concepts of Exclusion, Exemption and Clearance [89]. This safety guide provides a new set of exemption levels. Justification for that was provided such as:

> *3.6. Many studies undertaken at the national and international levels have derived radionuclide specific levels for the exemption and clearance of solid material. The values of activity concentration presented in this Safety Guide draw on the extensive experience gained in undertaking these studies and on independent calculations performed under the auspices of the IAEA (Safety Reports Series No. 44* [90]*).*

The calculations reported in the Safety Reports Series No. 44 [90] were carried out in similar manner as in previously discussed RP 65, i.e. based on the evaluation of a selected set of typical exposure scenarios for all material, encompassing external irradiation, dust inhalation and ingestion (direct and indirect). However, compared to RP 65, the number of exposure scenarios considered are noticeably limited. The resulting activity concentration values were derived on the basis of these scenarios as the lower of the values obtained from:

(a) The use of realistic parameter values applying an effective dose criterion of 10 µSv/a;

(b) The use of low probability parameter values applying an effective dose criterion of 1 mSv/a and a skin equivalent dose limit of 50 mSv/a.

It was assumed that the results derived from the scenario calculations are sufficient to ensure an adequate degree of protection in both occupational and public exposure.

Likely as in RP 65 special attention was devoted to radionuclides subject successive decay. Knowing that if material containing these radionuclides remains together for a prolonged period of time, the scenarios occurring many years after release of the material from regulatory control can lead to higher doses than those calculated for the first year after release, owing to the ingrowth of progeny radionuclides. Therefore, the dose contribution from progeny radionuclides is included in the calculations in order not to underestimate the effective doses. This is ensured by adding the dose coefficients of the progeny radionuclides to the dose coefficients of the parent radionuclides, using the appropriate weighting factors for the dose coefficients of the progeny radionuclides. The weighting factors for the progeny nuclides are taken as the maximum activity ratio that the respective progeny radionuclides will reach during a time span of 100 years. A time span of 100 years is necessary to ensure that material that does not exceed the activity concentration values at a certain time will also not do so at any later point in time, within a reasonable time frame. However, it was underlined that, contrary to radionuclides of artificial origin (and to the methodology used in RP 65) such a rule was not used for calculating activity concentration values for radionuclides of natural origin.

In selecting values for exemption levels for material that contains NOR, a major issue considered was that high levels that would exclude the majority of natural material in the environment would also allow a number of situations, such as the release of materials containing enhanced levels on NOR, to be excluded without further consideration. Conversely, selecting a low value would trigger an unnecessary application of the regulation. That is why, instead of calculations as used in RP 65, the values of exemption levels for NOR were based on consideration of the worldwide distribution of concentrations of radionuclides of natural origin. The rationale for that was provided as if activity concentration values for NOR are derived on the basis of the same radiological criteria as for artificial radionuclides, the values will in many cases be lower than NOR activity concentrations that occur in much natural environmental materials. Thus, many human activities previously unregulated from a radiological perspective could be subject to regulation. Establishing levels for radionuclides of natural origin that entail such widespread regulatory consideration, in circumstances where in many cases it is unlikely to achieve any improvement in protection is contradictory to the optimisation rule.

Th safety report is providing a series of data about NOR activity concentration, mainly based on UNSCEAR Report [91] that are summarised, to some extent in the Figure 4. Consequently, they are valid for the natural decay chains in secular equilibrium; that is, those decay chains headed by U-238, U-235 or Th-232, with the value given to be applied to the parent of the decay chain. The values can also be used individually for each decay product in the chains or for the head of subsets of the chains, such as the sub chain with Ra-226 as its parent.

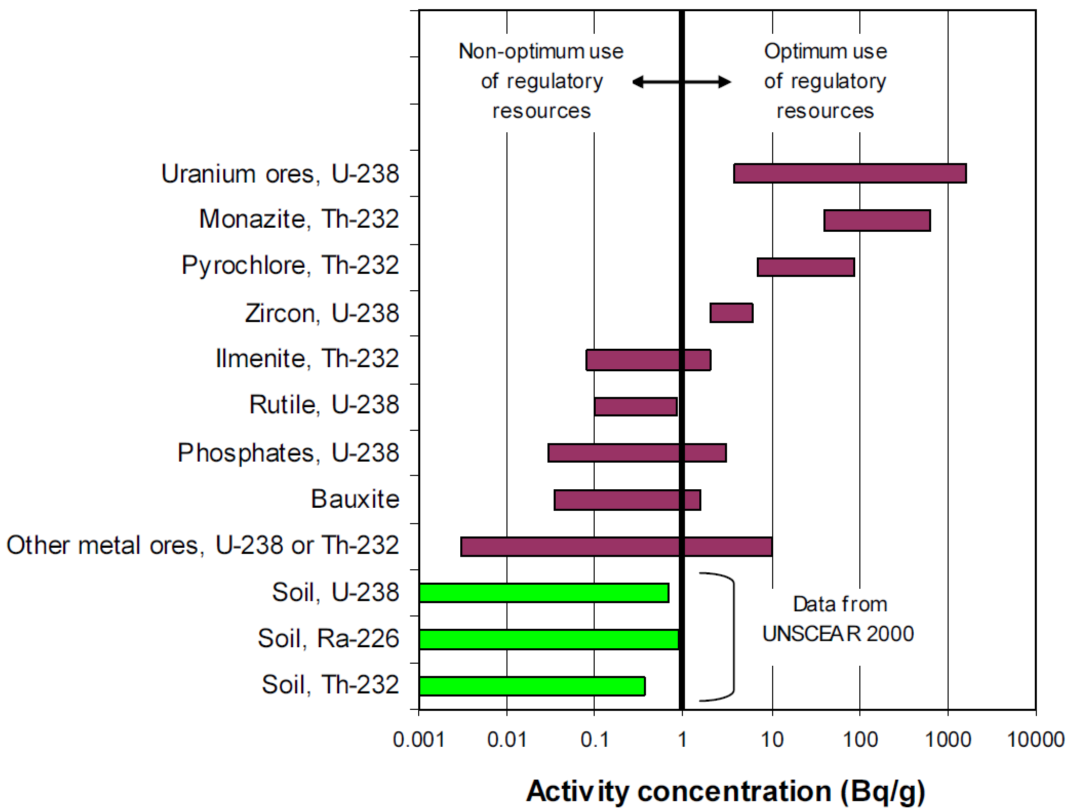

Figure 4: Rationale for currently used clearance and exemption levels expressed in terms of NOR activity concentration [92]

Compared with the values included in the Council Directive 96/29/EURATOM of 13 May 1996 (Table 6) these criteria are more conservative. However, considering the general sense of such criterion it is justified as the lowest value previously set for only limited number of NOR, now is recommended to be used for all of them. Apart from the appropriateness of the numbers used, this ensures the possible risk cannot be underestimated and also maintains an appropriate margin of safety regarding potential risk. In the opposite situation, a possibility is left to apply higher NOR activity concentration as a limit, ensuring the general exemption criterion, expressed as effective dose, is fulfilled.

Eventually, the Safety Guide RS-G-1.7, in the context of naturally occurring radionuclides (NOR) advises, among others, that:

> "*It is usually unnecessary to regulate…" material containing radionuclides of natural origin at activity concentrations below 1 Bq/g for radionuclides in the uranium and thorium decay series and below 10 Bq/g for 40K*.

From a pragmatic perspective there is a significant benefit in having a criterion for the release from authority control any kind material which is relatively easy to apply. Considering that this criterion should ensure that the radiation risk related to any use or treatment of material (waste) cleared based on it is negligible, the further statement where this Safety Guide adds, however, that:

> *"… there are some situations (such as the use of some building materials containing natural radionuclides) for which exposures from materials due to radionuclides with activity concentrations below [these values] would necessitate consideration by the regulatory body for some types of regulatory control*"

The proposed values of activity concentration are put in the question mark. It would be justified to have clearance level significantly lower, at the level required for NORM intended to be applied for building materials. The EU-project TENORMHARM [93] "Final report on work package 2 "*Dose assessment, mitigation methods, remedial actions and monitoring strategies*" suggested levels 0.2 Bq/kg for each radionuclide in the uranium and thorium decays series assuring negligible radiation risk assuming any exposure scenarios, reasonably bigger than median of NOR activity concentration in the top layer of Earth crust.

Notwithstanding this, it has been concluded that the values recommended in this the Safety Guide RS-G-1.7, presented in the Table 7 can be used both as default exemption values, assuming replacing the activity concentration values laid down in Annex I to Directive 96/29/Euratom in further development of it, referring to individual radionuclides in the decay series and as general clearance levels, replacing the values recommended by the Commission in Radiation Protection No 65 including its further development in the Radiation Protection No 122 [46], [80].

Table 7: Values of activity concentration for radionuclides of natural origin [89]

Radionuclide	Activity concentration (Bq/g)
K-40	10
All other radionuclides of natural origin	1

17.1.4 Commentary to the section 17.1.3

Derivation of activity concentration values for radionuclides of natural origin subject to exemption, presented in above discussed recommendations, is based on a methodology that places greater emphasis on optimisation of protection, including optimisation of regulatory resources. It could be well justified in case of exposure of members of the public to sources containing NOR that are, in majority, unable to control. However, this approach is leading to unnecessary simplification of the rules abandoning well developed and scientifically justified criteria developed in the previous recommendations and regulations. Additionally, setting exemption levels for NOR at the upper end of the global distribution of NOR concentrations represent a significant overextension of the range of exempted materials. While this may let one achieve the objective of exempting the most natural environmental materials, it also risks excluding materials with elevated NOR levels without adequate assessment. Apart from the sense of such approach, given that the activity concentration distribution of radionuclides is lognormal, utilizing the median or even the mean as a benchmark would be far more justifiable.

Choosing the different methodology for exemption levels calculation in case of NOR consequently leads to unnecessary differentiation of approaches to natural and artificial radionuclides:

- Considering NORM present in a technological/production process the assumption that it is unable to control is difficult to be justified. All materials such as feedstock, by-products, product waste and residue, no matter how it is called, are subject to strict operations where all parameters identifying their current state are well defined. This allows for precise definition of exposure scenarios and accurate calculation of derived doses. Consequently, applying different criteria for exemption level calculation in case of radionuclides of artificial origin versus those of natural origin lacks sufficient justification.
- The general presumption that only doses from NORM exposures exceeding background levels fall within the remit of radiological protection is of limited validity for both the public and workers. Particularly regarding occupational exposure, any dose received is attributable to sources present in the workplace, regardless of whether they are artificial or natural. The rationale that occupational exposure to NOR substitutes for background exposure at home, while artificial radioactivity does not, can only be justified based on the differing properties of radiation emitted by natural and artificial radionuclides.
- A further example of divergent approaches can be observed when material containing mixtures of radionuclides is evaluated for exemption and clearance. Safety Reports Series No. 44 mandates that exemption levels for materials containing mixed radionuclides be determined via distinct methodologies: for artificial radionuclides, a summation rule is applied, as follow:

$$\sum_{i=1}^{n} \frac{activity\ concentration\ of\ radionuclide\ (i)}{exemption\ value\ of\ radionuclide\ (i)} \leq 1$$

- whereas for natural radionuclides, the exemption condition must be verified individually for each member of a decay series, using an exemption value of 1 Bq/kg per nuclide. Material may be exempted only if both conditions are satisfied. This method differs from RP 65 and is inconsistent with committed dose evaluation, which employs dose conversion factors for each long-lived decay product. and finally contradicts the stated explanation:

> *"It is worth noting that this is a conservative approach since the pathways of exposure of the critical group of exposed individuals are not necessarily the same for each nuclide, because of partitioning or separation of nuclides by processes".*

17.1.5 Current IAEA recommendations

The current approach for implementing clearance and exemption levels within authority control is outlined in the latest IAEA recommendations published in 2023: Application of the Concept of Exemption (GSG-17 [22]) and Clearance (GSG-18 [23]), as detailed in the section 3.3. These documents are classified as General Safety Guides, offering recommendations and guidance to facilitate compliance with safety requirements set in IAEA Safety Standards Series No. GSR Part 3 [5]. They reflect an international consensus on the necessity of adopting the suggested measures or equivalent alternatives. Safety Guides encapsulate recognised international practices and increasingly represent best practices, supporting users in achieving high standards of safety. Recommendations in these guides are articulated as 'should' statements. The primary audience for IAEA safety standards comprises regulatory bodies and other pertinent national authorities within Member States. Both documents GSG 17 and GSG 18 are aimed at the development of implementation the concept of clearance and exemption in frame of practices. For further consideration in this section, the definition of the scope of application of this Safety standards towards NOR is crucial. To underline the criteria used, first and foremost the IAEA requires the application of a graded approach. Therefore, it is stated the application of the requirements for practices must be commensurate with the characteristics of the practice or the source within a practice and with the likelihood and magnitude of exposures. The GSR Part 3 establish criteria and applicable requirements depending on the radionuclide activity concentrations, as follows:

a) If, in any process material, the activity concentration of any radionuclide in the U-238 decay series or the Th-232 decay series exceeds 1 Bq/g, or if the activity concentration of K-40 exceeds 10 Bq/g, the industrial activity is regarded as a practice and the requirements for planned exposure situations apply.

b) If, in every process material, the activity concentrations of all radionuclides in the 238U decay series and theTh-232 decay series are 1 Bq/g or less and the activity concentration of 40K is 10 Bq/g or less, the material is not regarded as naturally occurring radioactive material, the industrial activity is not regarded as a practice and the requirements for existing exposure situations apply.

The general criteria for exemption of a practice or a source within a practice from some or all of the requirements of [GSR Part 3] are that:

(a) Radiation risks arising from the practice or from a source within the practice are sufficiently low as not to warrant regulatory control, with no appreciable likelihood of situations arising that could lead to a failure to meet the general criterion for exemption; or

(b) Regulatory control of the practice or the source would yield no net benefit, in that no reasonable measures for regulatory control would achieve a worthwhile return in terms of reduction of individual doses or of health risks."

There are some problems with the proper interpretation of these statements, especially the first one, where the term general is used towards exemption when formulating the objective of the expected definition as well as in the definition provided (a). However, it can be assumed that these statements are defining the function of the exemption level expressed as radionuclides activity concentration in comparison with the general criterion expressed in terms of effective dose.

Defining exemption levels, a distinction is made between moderate amounts of material and bulk amounts of material. The term 'moderate amounts' refers to "practices involving small scale usage of activity where the quantities involved are at most of the order of a tonne". The term 'bulk amounts' can be taken as quantities of material that are greater than moderate amounts. For moderate amount of material artificial, as well as natural radionuclides, are considered in the same manner and exemption *levels are expressed for each individual radionuclide (Table 8), while for NOR only long-lived ones are considered together with all progenies they can achieve secular equilibrium with, as below:*

- Pb-210 Bi-210, Po-210
- Rn-220 Po-216
- Rn-222 Po-218, Pb-214, Bi-214, Po-214
- Ra-223 Rn-219, Po-215, Pb-211, Bi-211, Tl-207
- Ra-224 Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)
- Ra-226 Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
- Ra-228 Ac-228
- Ac-227 Fr-223 (0.0138)
- Th-228 Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)
- U-235 Th-231
- U-238 Th-234, Pa-234m

Table 8: Levels for exemption of moderate amounts of material without further consideration: exempt activity concentrations and exempt activities of radionuclides [22] (b – parent radionuclides and their progeny, see above)

Radionuclide	Activity concentration (Bq/g)	Activity (kBq)
U-238 [b]	10	10
U-234	10	10
Th-230	1	10
Ra-226 [b]	10	10
Pb-210 [b]	10	10
Po-210	10	10
Th-232	10	10
Ra-228 [b]	10	100
Th-228 [b]	1	10
Ra-224 [b]	10	100
U-235 [b]	10	10
Ac-227 [b]	0.1	1000
Pa-231	1	1000
Ra-223 [b]	100	100

Exemption of bulk amounts of material for NOR is considered in different manner, it is required to be evaluated on a case-by-case basis by using a dose criterion of the order of 1 mSv in a year, commensurate with typical doses due to natural background levels of radiation.

This dose criterion does not include the contribution from the exposure to radon, which must be dealt with separately, however, it is worth noting that all pathways (including the inhalation of radon) need to be summed to verify the compliance with the effective dose limit of 20 mSv per year. Otherwise, for industrial activities involving NORM and managed as existing exposure situation, the International Safety Standards ask Member States to set appropriate Reference Levels (RLs) for the protection of workers against radon exposure in terms of radon annual activity concentration in air, whose value cannot greater than 1000 Bq/m^3. More details were described in the section 3.3.

17.1.6 Current EU regulations

The EU approach to implementing the graded approach and use clearance and exemption levels within authority control is included in Council Directive 2013/59/EURATOM of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionizing radiation [4]. The European Union Basic Safety Standards introduced provisions on industrial activities involving NORM. The 2013 EU BSSD ask Member States to identify which classes or types of practice involving NORM may be subject to the regulatory control of planned exposure situations, as they may result in exposure of workers or the members of the public that cannot be disregarded from a radiation protection perspective. Such identification is carried out considering a list of industrial sectors given in included in this directive. Applying the regulatory control Member States should adopt a graded approach in the regulatory control by using Exemption/Clearance Levels for solid materials (defined in terms of activity concentrations of radionuclides of U-238 and Th-232 series and K-40) and general Exemption/Clearance criteria for workers and members of the public set in terms of effective doses. Specifically, a dose increment of 1 mSv per year respecting the prevailing background radiation from natural radiation sources is established as general Exemption/Clearance criteria for workers and for members of the public. There is no mention of whether and how to consider the dose due to radon in these exposure scenarios. More details are described the section 2.2.9.

17.1.7 Commentary to the Current IAEA recommendation and EU regulations

Concerning NOR both IAEA recommendation and EU regulations are based on compilation RP 65 and IAEA International Basic Safety Standards for Protection Against Ionizing Radiation and for the Safety of Radiation Sources from 1996 as well as on Safety Reports Series No. 44. Exemption criteria are provided separately for bulk materials and materials of moderate amounts. The "LEVELS FOR EXEMPTION OF MODERATE AMOUNTS OF MATERIAL WITHOUT FURTHER CONSIDERATION: EXEMPT ACTIVITY CONCENTRATIONS AND EXEMPT ACTIVITIES OF RADIONUCLIDEs" and "**Total activity values for exemption (column 3) and exemption values for the activity concentration in moderate amounts of any type of material (column 2)" in IAEA and EU documents respectively** are based on rounded exemption values provided in RP 65 (Table 6). However, it is significant that, for moderate amount of materials there is neither value for crustal uranium, nor uranium in secular equilibrium with the whole decay series. Moreover, values for Th-232 are provided with no regard to its progeny. On the other hand, U-235 and Ac-227 are included.

For bulk materials values were taken from the previous IAEA BSS as in the Table 7. The scope of radionuclides subject to this requirement was limited to K-40 and members of the thorium and uranium decay series considered all together by IAEA (Table 9) or separately by EU (Table 10). IAEA distinguishes exemption and clearance process, explaining that for radionuclides of natural origin, exemption of bulk amounts of material is necessarily considered on a case-by-case basis by using a dose criterion of the order of 1 mSv in a year, commensurate with typical doses due to natural background levels of radiation. This was justified as material containing radionuclides of natural origin at an activity concentration of less than 1 Bq/g for any radionuclide in the uranium decay chain or the thorium decay chain and of less than 10 Bq/g for 40K is not subject to the requirements for planned exposure situations hence, the concept of exemption from the requirements of these Standards does not apply for such material. On the other hand, IAEA requires Member States to apply relevant requirements for practices when: "

"Exposure due to material in any practice specified where the activity concentration in the material of any radionuclide in the uranium decay chain or the thorium decay chain is greater than 1 Bq/g or the activity concentration of 40K is greater than 10 Bq/g;

This approach is not clear, as it was already underlined, not providing any additional value as the numbers of both criteria are the same, eventually introduces additional complexity to the system.

Table 9: Levels for clearance of material: activity concentrations of radionuclides of natural origin (IAEA) [5]

Radionuclide	Activity concentration (Bq/g)
K-40	10
Each radionuclide in the uranium decay chain or the thorium decay chain	1

Table 10: Values for exemption or clearance for naturally occurring radionuclides in solid materials in secular equilibrium with their progeny (EU) [4]

Radionuclide	Activity concentration (Bq/g)
K-40	10
Natural radionuclides from the U-238 series	1
Natural radionuclides from the U-238 series	1

In both cases, approach to the evaluation of materials containing a mixture of radionuclides is overtaken from previous IAEA BSS from 1996 as described in the section 17.1.4. There is no explanation in the EU directive how to solve the simultaneous presence of both decay series in materials as exemption and clearance levels are set separately for each one. On the other hand, listing exactly only two decay series and potassium automatically eliminates other possible NOR, including those ones participating in the actinium decay series. As the regulation is dealing with NOR, the depleted or enriched uranium is excluded hence U-238/U-235 ratio is stable and related U-235 decay series contribution to the effective dose determining exemption/clearance level should be considered, which makes exemption level for U-238+U-235 significantly lower (what is showed in the section 20.1). Currently, the approach to evaluation of bulk materials and these ones occurring in moderate amount can be considered as not coherent because there is neither need expressed to use contribution from U-235 decay series for dose evaluation nor criteria used for an activity classification into practices category are based only on U-238 and Th-232 decay series (points a) and b) in the section 17.1.5).

It should be noted that in the case of exclusion, recommendations are given on basis a qualitative description of the concept, leaving much of the interpretation to national regulators. In general, any exposure, whose magnitude or likelihood is essentially unamenable to control through the requirements of radiation protection means is deemed to be excluded from the scope of. Examples of excluded exposure given in the IAEA, as well as EU regulations, are exposure from K-40 in the human body, from cosmic radiation at the surface of the Earth and from unmodified concentrations of radionuclides in most raw materials.

In general, and regardless ambiguous interpretation of limits expressed in terms of activity concentration by IAEA and EU directive, existing exemption and clearance levels are arbitrary set and expressed in terms of parent radionuclides' activity concertation for the whole decay series. The rationale provided for that are based on a range of NOR activity concentration observed in natural environment. Set in such way are source of problems with proper interpretation in case of disequilibrium, what is very common in NORM. Moreover, these exemption levels are not coherent with the exemption level expressed as effective dose, where, especially concerning internal exposure, committed dose evaluation is based on summation rule and the dose is calculated for every radionuclide identified, that are do not have to be in secular equilibrium. This is discussed in the further parts of this report (section 18).

Important gaps to be addressed are:

- Considerations on NOR activity concentration summation rule applied for exemption and clearance criteria.
- Nuclide (sub-series) specific clearance and exemption criteria.
- Considerations on U-235 contribution to overall exposure to NOR.
- Background interpretation in exposure evaluation.
- Integration of radiation protection applied in NORM involving industries with existing OS&H systems.

It must be noted that it is significant regress compared with the first solutions and criteria set for the management of NOR related hazard at the end of the twentieth century. Introduced simplifications could be justified considering the needs to address a new problem affecting various industries unfamiliar with radiation protection. However, after more than 20 years and knowing current progress according to growth of knowledge and experience in this matter, more precise recommendations are expected to follow the general principles of radiation protection.

18. Characteristic features of exposure to NORM

ICRP 142 [94] is dealing with sources of natural radiation defined as cosmic radiation, and gamma radiation from natural radionuclides in soil and building materials as well as radon in indoor air. The main attention is paid to NOR in industrial processes that can lead to increased radiation doses, necessitating the application of principles of justification, optimisation, and dose limitation, as well as radiological protection management plans and environmental monitoring. Finally provides a comprehensive framework for managing NORM (Naturally Occurring Radioactive Material) in various industrial processes, emphasizing the importance of awareness, characterisation, and regulatory approaches to ensure safety and compliance.

The report defines an exposure situation, in general, 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, 2007, Para. 169)[95]. Protection can be achieved by taking action at the source, or at any point in the exposure pathways of the exposed individuals. This definition is underlining the features of each exposure situations und underlines NORM features which should be considered. It is emphasised that during the extraction of minerals and their processing, the radionuclides may be dispersed and/or their physicochemical properties changed so that they become unevenly distributed between the products, by-products, discharges, residues, or wastes arising from the process(es).

(69) 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 the skin may 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).*

And following recommendations, but not limited to, specifies details needed:

(82) This characterisation, determining who is exposed, when, where, and how, is an important starting point for the protection of workers. It includes characterisation of the source, with the aim of identifying the distribution of NORM radionuclides[8] 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 in both operational and maintenance conditions. Feed materials, intermediates, residues, wastes (including contamination of the plant), and discharges to the environment should be considered, as well as radon and thoron.

(83) Characterising the source will help to identify the main exposure pathways to workers, the public, and the environment. In terms of exposure of 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 through inhalation) received from work with NORM.

(84) 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. In particular, inhalation of radon and thoron has to be considered, although it is recommended that this should be 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 provisions should be taken into account (e.g. industrial hygiene, industrial safety, and workplace controls on airborne dust).

(139) In the case of complex situations, the radiological characterisation of NORM released in the environment may be performed by the analysis of radionuclides with respect to their physical and chemical forms and activity concentrations both to the source and in the environmental media of concern (air, water, sediment, soil). To be able to assess exposure of non-human species, it may be further relevant to identify mobility of radionuclides, spatial and temporal variation, environmental pathways to plants and animals, and bioavailability. An approach with RAPs and DCRLs has been developed (ICRP, 2008, 2014b). Dosimetry models to calculate specific exposure doses from chosen radionuclides and for ecosystems and organisms of concern have been available for site-specific use. A degree of precaution may be considered necessary because of

[8] It should be 'distribution of naturally occurring radionuclides….' However, the text is a direct citation from the source document

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 which present hazards to plants and animals will also be present. The Commission re-emphasises its recommendation that an all-hazard approach should be undertaken.

All such recommendation requiring an exhaustive NORM characterisation while no practical clues concerning real quantities, processes or phenomena which should be considered are provided.

Moreover, directly in the light of existing problem discussed, this document does not taka advantages from the concept of exemption nor clearance that is developed on basis a preliminary screening of reference levels expressed in terms of NOR activity concentration, all quantitative criteria or reference are expressed in terms of dose for human as well as for non-human biota.

Regardless, high quality of this Publication, establishment of a really effective framework requires further development – particularly in providing direct guidance on quantities, processes, and phenomena which should be considered when characterizing NORM.

19. NORM characterisation

Naturally occurring radionuclides (NOR) activity concentration is the most important parameter used for the characterization of NORM when the problems related are considered from the perspective of radiation protection. Besides there are many naturally occurring radionuclides present in the Earth curst radiation protection is focused on these ones with a are contributing to the natural background significantly, there are abundant enough and are considered when subject to natural or human related processes can cause nonnegligible exposure to radiation.

NOR relevant to radiological protection (RP) primarily include members of the uranium U-238 decay series (refer to Figure 5) and the thorium Th-232 decay series (refer to Figure 6).

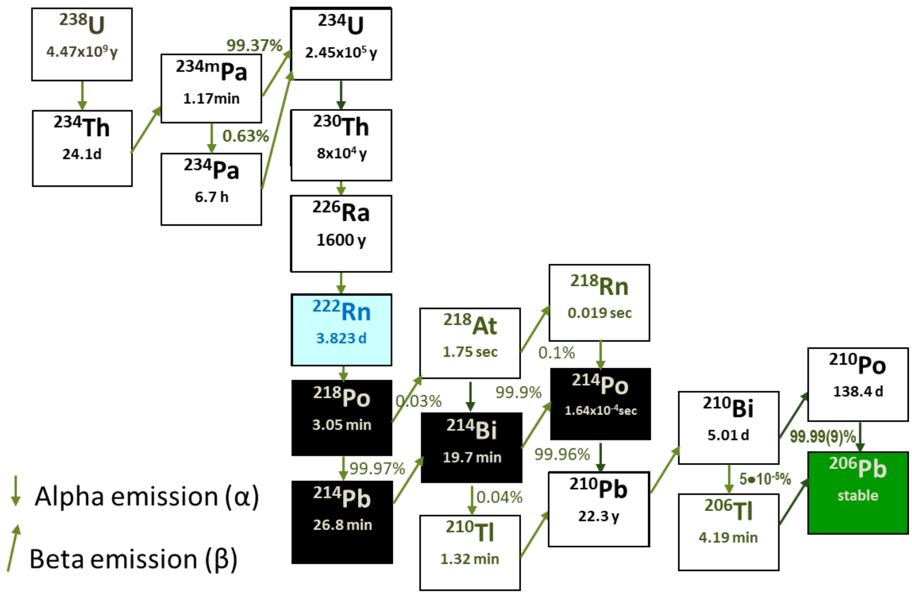

Figure 5: Uranium decay series

As it was discussed in the section 17.1, the third decay series, originating from uranium isotope U-235 (known as the actinium decay series - Figure 7), considered at very beginning, has been lost along successive iterations of regulation and currently generally is not considered. Rational for that is being provided as U-235 comprises only approximately 4.5% by activity relative to U-238 and its contribution to exposure scenarios involving elevated NOR levels are deemed negligible, what is really not true to some extent especially concerning the committed dose, it is later discussed in the section 20.1.

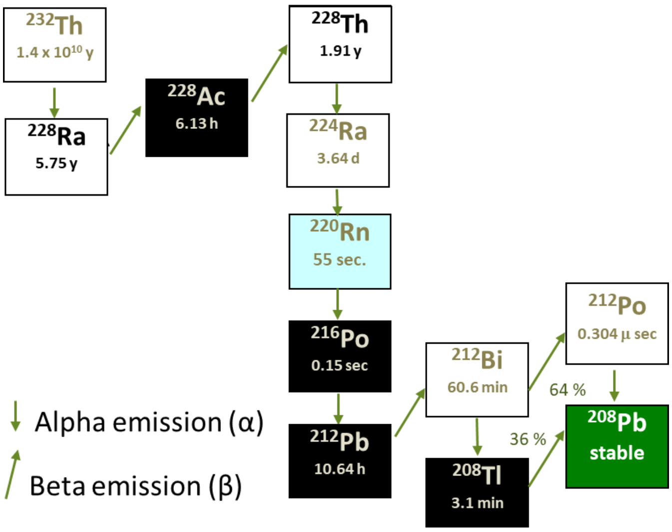

Figure 6: Thorium decay series

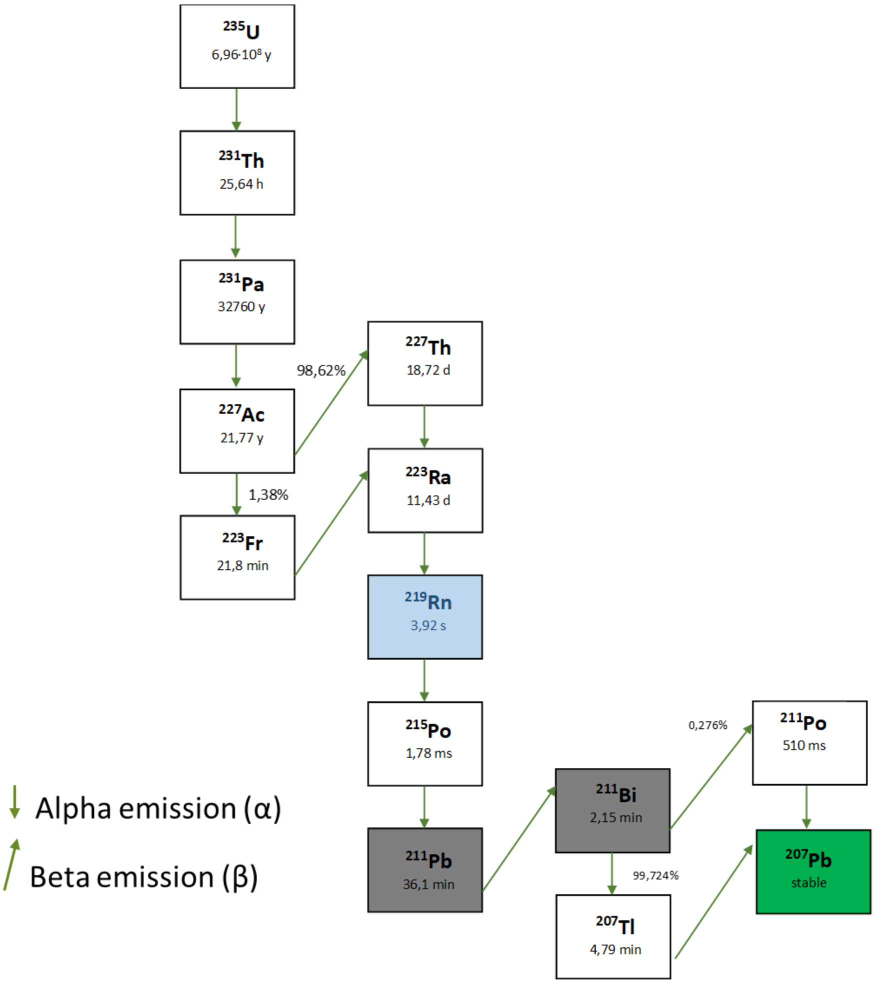

Figure 7: Actinium decay series

Radionuclides in decay series are typically found together in environmental samples. While the radioactive decay law allows for the assumption that all members have equal activity under certain conditions, this is rarely true in practice. The ratio of their activity concentrations varies with the source and type of material being examined.

19.1 Disequilibrium in decay series and sub-series formation

Decay series arise from successive radioactive decay, where a radioactive nuclide transforms into another that is also radioactive. This process can continue through multiple generations of decay products until it results in a stable nuclide, such as Pb-206 and Pb-208, which are the end products of the uranium and thorium decay series, respectively.

Harry Bateman's 1910 paper in the Proceedings of the Cambridge Philosophical Society (Vol. 15, pp. 423-427) [96] presents the solution to a system of differential equations that arise in the study of radioactive transformations. These equations model how the amounts of different radioactive substances in a decay chain change over time. Bateman's work provided a crucial analytical solution to these equations, which are now known as Bateman equations. These equations let one calculate the activity of each radionuclide in a series at any given time, based on initial activity of the parent radionuclide, half-life (or decay constants) of each decay product and the decay scheme. Without going into details of the calculations, the main practical implications crucial for NOR characterization are discussed below.

The smallest decay series includes at least two radionuclides: a parent nuclide with and a daughter nuclide produced from its decay. A decay series persists as long as the parent nuclide remains; consequently, decay products with short half-lives will continue to appear until the last parent nucleus decays. For practical purposes, it is generally assumed that after a time period equivalent to ten half-lives of the parent radionuclide, the entire decay series has effectively ended. In a decay series, members typically do not exist independently; both a parent radionuclide and at least one decay product are present, unless the decay product has a longer half-life than the parent. In general, mutual relationships among members of a decay series considered in terms of activity are determined by the ratio of their half-life. According to the decay law there are three situations that may occur such as: secular radioactive equilibrium, transient equilibrium and no equilibrium are possible:

- The half-life of the parent radionuclide (A_1) is significantly longer than its decay product (A_2), **$T_{1/2}$ A_1 >>> $T_{1/2}$ A_2**; the activity of the decay product (A_2) increases for a period equal to 10 times its half-life and then activity of A_2 = activity of A_1. Then the activity of A_1+ A_2 decrease according to $T_{1/2}$ of A_1**. It is the secular equilibrium state** – see Figure 8**.**

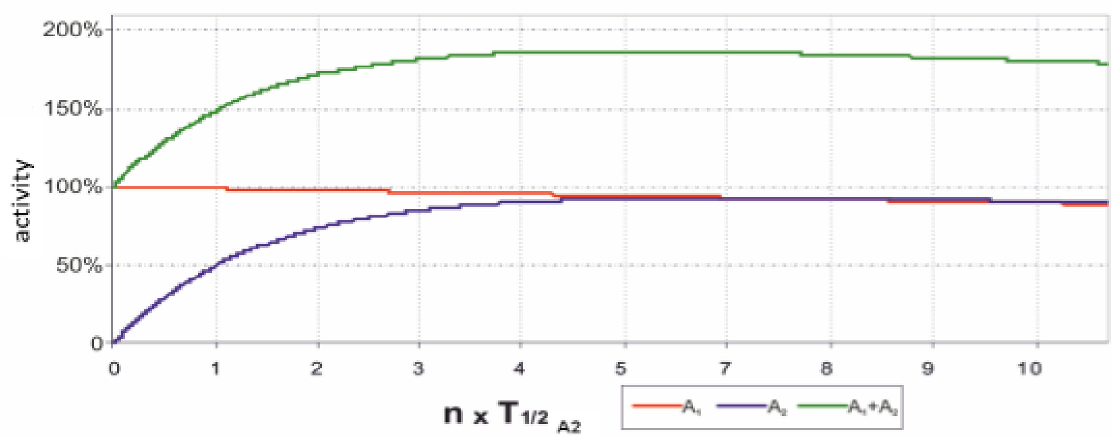

Figure 8: Secular equilibrium occurs when all radionuclides in a decay series have equal activity, which declines at the rate of the parent radionuclide's decay.

- In the case when the half-life of the parent nuclide (A_1) is only slightly longer than the half-life of the decay product (A_2), **$T_{1/2}$ A_1 > $T_{1/2}$ A_2**; the activity of the decay product (A_2) increases for a period equal to about twice its half-life and then its activity is going to be bigger than activity of the parent radionuclide (A_1) eventually reaching stable A_2/A_1 determined by their half-life ratio, then activity of A_1+ A_2 decrease according to the half-life of the parent radionuclide (A_1). **It is so called the transient equilibrium state** (see Figure 9**).**

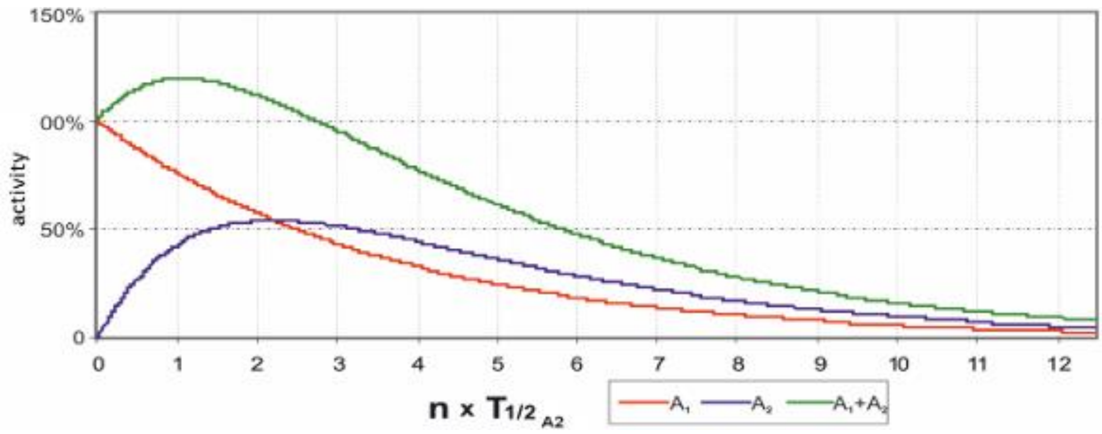

Figure 9: Transient equilibrium occurs when the decay product's activity exceeds that of the parent radionuclide, and both decay at the parent's rate.

- When the half-life of the parent nuclide (A_1) is shorter than the half-life of the daughter nuclide (A_2), $\mathbf{T_{1/2}\ A_1 < T_{1/2}\ A_2}$ the situation is similar as in case before, however, the activity of A_1+A_2 decrease according to (A_2) half-life, eventually reaching situation when (A_1) disappear at all while (A_2) is still present. There is **no equilibrium** (see Figure 10**).**

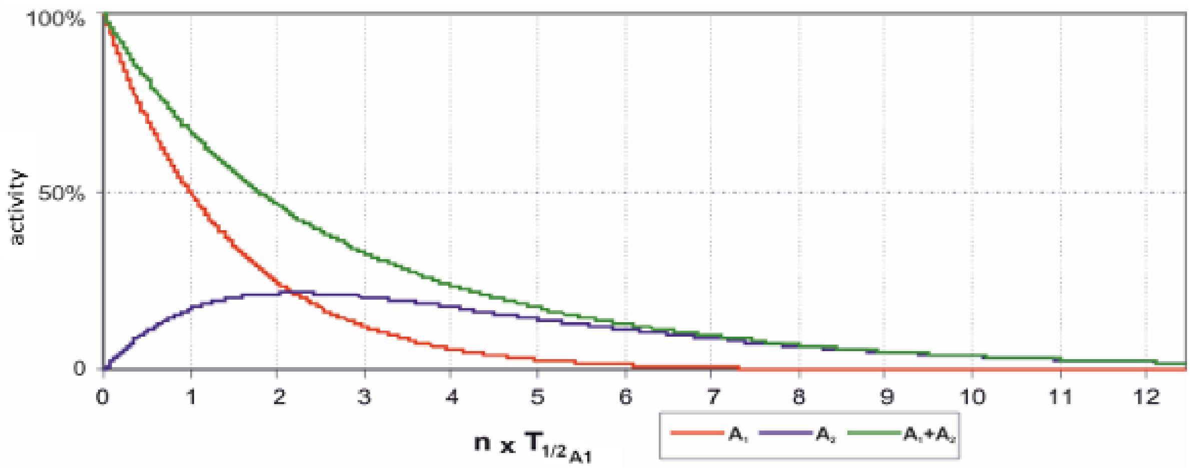

Figure 10: In the absence of equilibrium, the activity of the decay product(s) eventually exceeds that of the parent, and remains after the parent has fully decayed.

For the decay series constituting more than two radionuclides, the possible equilibrium state is determined by the half-life of a parent radionuclide and a decay product which has the longest half-life. Such rule let uranium and thorium decay series to reach a secular equilibrium state, where the activity of all radionuclides is equal. The ratio of parent radionuclide half-life and the “longest” decay product also determine the time required for the entire decay series to reach a secular equilibrium state, after it was disrupted for some reasons e.g. by separation of the parent radionuclide. Namely, assuming that in the moment t_0 there are only a parent radionuclide, the period needed to create entire decay series in the secular equilibrium state is equal to 10 times half-life of the “longest” decay product, if it is possible at all, i.e. the half-life of the “longest” decay product is significantly shorter than the one of the parent radionuclide. For uranium decay series it is about 2.5 million of year while for thorium decay series it is only about 60 years.

The α and β decay are a kind of **nuclear transmutation** resulting in **decay products** containing a different number of protons or neutrons (or both) in its nucleuses. A change in the number of protons (Z) leads to the formation of a nucleus of a different chemical element, while a change in mass number (A) produces a new isotope of the parent radionuclide. In a decay series, this process results in a sequence involving various isotopes and elements. The uranium decay series comprises 10 elements, present in two aggregate states (9 solids and 1 gas). Within this series, there are 13 alpha emitters, 11 beta emitters, and 4 notable gamma emitters. The thorium decay chain includes 8 elements, also in two aggregate states (7 solids and 1 gas). It contains 7 alpha emitters, 5 beta emitters, and 4 notable gamma emitters. The specific activity, i.e. activity of 1 gram of pure radionuclide, spans from 1.24×10^4 Bq for crustal uranium up to 1.21×10^{22} Bq for Po-214, and from 4×10^3 Bq for Th-232 to 6.44×10^{27} Bq for Po-212 for uranium and thorium decay series, respectively. Wide range of specific activities reflects also the rage of half-life that vary from microseconds up to billions of years. Such a big variability of quantities characterizing NOR is plenty with consequences when individual NOR behaviour is considered, multilateral relationships between NOR and finally on measurement procedures applied as well as measurement results interpretation.

Elements possess distinct chemical and physical properties and respond differently when subjected to external conditions. As a result, decay series—particularly those consisting of multiple decay products (i.e., various elements)—are affected by interactions with external agents; some elements may be removed, potentially disrupting the initial secular equilibrium within a decay series. Furthermore, if an isotope's half-life is sufficiently long relative to the duration of the process impacting the decay series, a subseries may form. The potential subseries that could arise from uranium or thorium decay series under external influences are outlined in the *Table 11*.

Table 11: Parent radionuclides and their progeny whose dose contributions are taken into account in the dose calculations (thus requiring only the exemption level of the parent radionuclide to be considered)

Parent radionuclide	**Decay Products**	**Period necessary to get secular equilibrium**
U-238	Th-234, Pa-234m, Th-230, Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210	2 500 000 years
U-238	Th-234, Pa-234m	240 days
U-234	Th-230, Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210	800 000 years
Th-230	Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210	16 000 years
Ra-226	Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210	38 days
Rn-222	Po-218, Pb-214, Bi-214, Po-214	4.5 hours
Pb-210	Bi-210, Po-210	3.7 years
Th-232	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36)	58 years
Ra-228	Ac-228	2.5 days

Ra-228	Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)	Transient
Th-228	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)	36 days
Ra-224	Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)	4 days
Rn-220	Po-216	1.5 second
Pb-212	Bi-212, Tl-208 (0.36), Po-212 (0.64)	Transient equilibrium

In practice, elements crucial for further sub-series behaviour are uranium, thorium, radium and lead [97]. For further evaluation what would happen after some subseries are created is period necessary to achieve an equilibrium state in a particular subseries (see the *Table 11*). This parameter is crucial for:

- the proper evaluation of existing exposure situations, i.e. the composition of a radionuclide's suite must be considered. It is crucial for any kind of radionuclides migration where elemental properties of radionuclides are crucial and mutual relationship in a source media are not reflected in the receiving media unless the period necessary to achieve equilibrium is relatively short compared to the length of the process responsible for migration [68], [98]. For example, in biota content of Ra-226 and Pb-210 does not reflect the ratio of these radionuclides in soil as both of them are subject different transfer processes and the ingrowth of Pb-210 in biota due to the decay of Ra-226 transferred is negligible unless one is dealing with an old tree. That is why in such cases both radionuclides must be considered individually, however keeping in mind that both are parent radionuclides of their sub-series (*Table 11*). Processes influencing the equilibrium state as well as subseries formation cover very wide scope including hydro-geological processes going on in Earth crust or simply weather conditions, natural processes observed on the border between abiotic matter and biota, those ones entirely ongoing in living matter as well as process related to human activity, especially industrial processes focused on sourcing and processing mineral raw materials. The features of these processes mean that one must take into account situations where the reaction is almost immediate or the duration of the process is counted in millions of years. Therefore, additional information about origin of a material and its history is crucial to make assumptions about its composition, especially important in case of radionuclides not detected by the routine measurement by gamma spectrometry.
- measurement planning and measurement results interpretation – NOR are in majority alpha and beta emitters, only very few of them are emitters of gamma radiation, which are easy to be measured by gamma spectrometry (Figure 5 and Figure 6, boxes in black). Under natural conditions and when the influence of any external factors can be excluded all radionuclides in a decay series are in secular equilibrium state that means activity concentration of all them are equal to each other. In such a situation, it is enough to measure the activity concentration of only one radionuclide per a decay series (the easiest one to measure) and then the conclusion concerning activity concentration of all other ones can be drawn. In case of relatively short period needed to get equilibrium state measurement procedure can be adjusted relevantly to evaluate a parent radionuclide activity by of progeny. It is commonly applied in the case of Ra-226 determination based on Pb-214 and Bi-214, and in case of Ra-228 and Ac-228 can be applied automatically, as usually sampling process and sample preparation overtakes period long enough to get equilibrium between those radionuclides (see the *Table 11*). However, it must be underlined that for Th-232, Th-230, U-234 and U-238 (besides U-238 and Th-234 subseries) such a possibility is completely not justified especially after a sampled material is resulting from any process causing radionuclides migration. The time needed to get equilibrium with any decay product is so long that these radionuclides must be measured directly (see the *Table 11*). It must be underlined the assessment of Th-232 activity based on Ac-228 or Tl-208

is commonly overused. The problem is discussed in the report from interlaboratory comparison on measurement of NORM samples organised by IAEA [50]

- effective dose evaluation - for external exposure the current ratio among all radionuclides is determining all radiation emitted, hence the external dose rate can be evaluated based on individual radionuclides activity concentration regardless of mutual relationships determined by the successive decay [99], while for the committed dose, possible equilibrium state eventually reached is crucial. Because the committed dose is calculated for 50 or 70 years after intake, for adults and children respectively, intake of radionuclides heading a subseries that are getting secular equilibrium state in shorter or comparable period must be considered together with all its decay products, what is really included in the dose conversion factors [100]. That is why, contrary to the external exposure where direct contribution of Th-232 is negligible, for the committed dose this radionuclide is considered with all its decay products and become of one the most intensive contributors to the internal dose.
- prediction of situation evolution – knowing the composition of radionuclides in a source after either a secular equilibrium state was broken, or a new subseries has been created the changes in radionuclides activity can be predicted. It must be underlined that contrary to the whole uranium and thorium decay series where secular equilibrium state is sooner or later achieved, in subseries one must expect that secular equilibrium is not established, and other options must be considered. One of the examples is a subseries starting with Ra-228, where only the transient equilibrium state is possible due to relatively long Th-228-half-life when compared to Ra-228 one and considering very short half-life of Ac-228, parent radionuclide of Th-228. This makes evaluation of materials containing such subseries complex [101], and usually to make proper interpretation of measurement results of such materials additional information about a sample history is necessary. Processes occurring in materials containing a sub-series of NOR can influence both the exposure situation and, for example, waste categorization. This is due to changes in the total activity resulting from progeny ingrowths or alteration of chemical composition as decay leads to the formation of a new element. In both the uranium and thorium decay series, no radionuclide decays directly into an isotope of the same element (Figure 5 and Figure 6). An example of NOR activity evolution for subseries starting with Ra-226 and starting with Ra-228 have been separated is presented in the Figure 11 [102]. It must be underlined that the situation presented is very common in cases, where formation water followed by creation of sediments or scales is considered, i.e. oil and gas industry, as well as majority of underground mining. The most significant changes in the total activity concentration and radionuclide composition occur during the first few years after the material is generated. That is important not only for waste treatment plans, but also for evaluation of occupational exposure. In addition to predictions, the observed relationships between radionuclides activity concentration in a sample can also provide insight into the origin and age of the tested material.
[103].

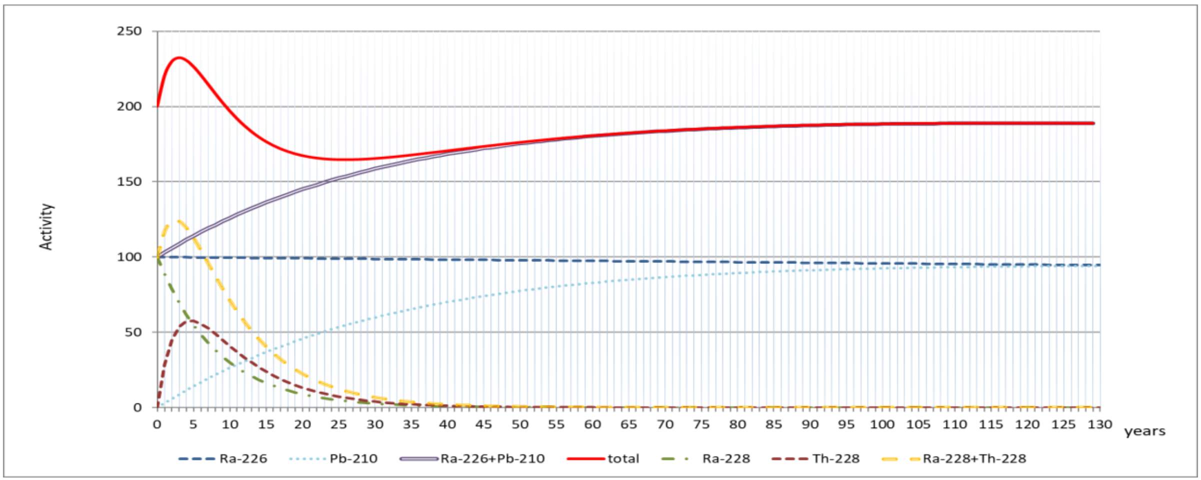

Figure 11: Relative changes (in %) of NOR composition and activity concentration in material where at the beginning only radium isotopes Ra-226 and Ra-228 were present, e.g. scales precipitated from radium rich water

19.2 Interaction with surrounding environment

Besides mutual relationships among decay series members driven by successive radioactive decay as well as their chemical properties, external circumstances also may significantly affect radionuclides activity and lead to the situation which in terms of decay law are impossible. The three cases of equilibrium afore described are analysed under the assumption that the process occur in confined space with no exchange of the matter with surrounding environment. Such a situation is limited to some stages of a technological process, or to a sample of material already collected (to some extend). In reality, especially considering the process responsible for the decay series fractionation as mentioned above, lead to that input/output of radionuclides enclosed in different matrices must be considered. The best example, however, not limited to, can be shown using the example of thoron (Rn-220) and its decay products. Assuming there are no exchanges of matter between the confined volume into which thoron activity is injected, thoron activity systematically decreases due to decay according to decay law. Due to specific ratios of thoron and its decay products half-life, it is possible to observe two typical cases of radioactive equilibrium. No radioactive equilibrium, when thoron decayed completely, but the decay products still exist. Transient radioactive equilibrium, when the activity of bismuth Bi-212 reaches the activity of lead Pb-212 (parent radionuclide), after a period of time Bi-212 activity exceeds the activity of Pb-212 to reach the stable ratio Bi-212/Pb-212. After this moment, the decay further continues approximately according to the half-life of lead Pb-212 (*Figure 12*).

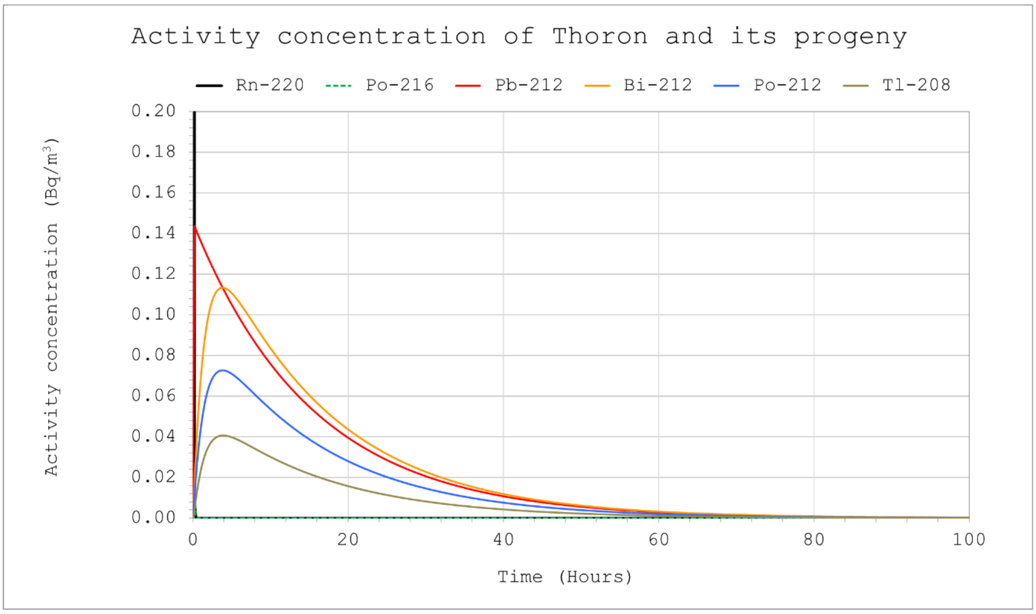

Figure 12: Transient equilibrium. Single injection of thoron followed by its progeny ingrowth caused solely by the decay law, differences in Po-212 and Tl-208 are caused by the decay ratio

The situation is different in the case of systematic introduction of thoron into the space. In such a situation the decrease of thoron activity due to radioactive decay is compensated by the thoron inflow, hence in the chamber some stable activity of thoron can be achieved. This created a possibility for thoron decay products to reach equilibrium with thoron likely as radioactive secular equilibrium (*Figure 13*). However, it must be underlined that it is a dynamic situation, determined by the thoron inflow and strictly valid only for a specific situation. The difference is that while radioactive equilibrium (no matter secular, transient or no equilibrium) is ruled by the decay law and does not depend on external conditions at all, the dynamic equilibrium depends, in general, on current local circumstances. What would happen, in case of discussed example, when conditions are changed e.g. inflow of thoron is stopped is presented in the *Figure 14*, thoron decayed quickly and there is no equilibrium with its progeny, while Pb-212 is in transient equilibrium with the Bi-212 reaching stable ratio of Bi-212/Pb-212 activity about 1.1. The situation is similar as in the *Figure 12*, however in the starting point activity of thoron and all thoron decay products are equal each other, taking into account necessary correction for Po-212 and Tl-208 due to Bi-212 decay ratio (see Figure 6).

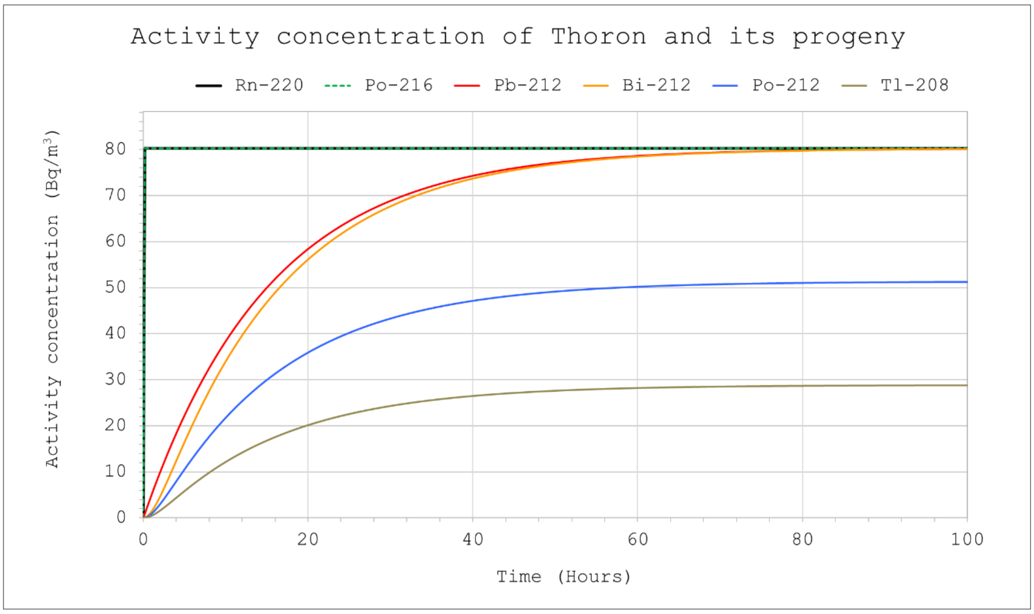

Figure 13: Thoron and its decay products activity concentration in a chamber, stable inflow of thoron from outside compensating decrease of thoron activity due to radioactive decay, differences in Po-212 and Tl-208 are caused by the Bi-212 decay ratio, for equilibrium evaluation the sum of these radionuclides must be considered.

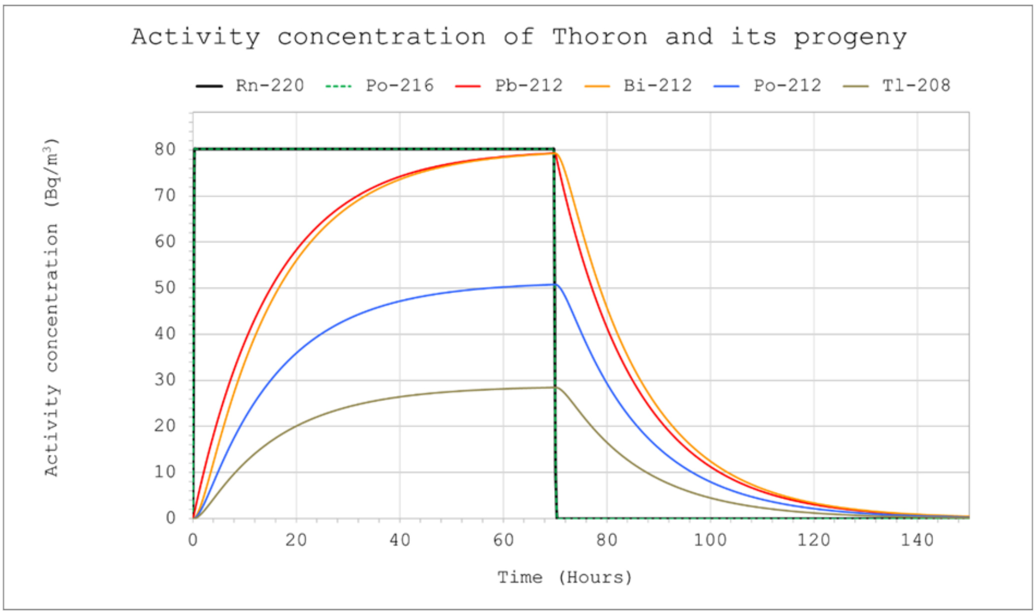

Figure 14: Stable inflow of thoron from outside compensating decrease of thoron activity due to radioactive decay, when the dynamic equilibrium was reached at the seventieth hour, thoron inflow was stopped.

In addition to thoron-related cases, analogous situations arise involving radium isotopes found in formation water, which is in fact among the most prevalent sources of increased exposure to NOR. Although formation waters are typically millions of years old, radium isotopes persist due to ongoing leaching from the surrounding geological strata [104]. The dynamics shift when formation water is extracted from an underground aquifer or when a water sample is collected. At this stage, radioactive decay becomes the primary mechanism affecting radionuclides activity. This process may be further influenced by the physical and chemical properties of radium decay products, which can result in either radon exhalation or the precipitation of radium, ultimately leading to sediment formation. Comparable phenomena occur at the interfaces between environmental compartments and within boundaries of biotopes and biocenoses. Often, these processes are continuous and can only be confirmed as halted once a sample has been collected.

19.3 Isotope fractionation

In natural decay series, a radionuclide never decays directly to an isotope of the same element; there is always at least one intermediate nuclide of a different element, at least (see Figure 5 and Figure 6). This allows for isotopic fractionation, as decay products with different chemical properties may be removed from the system before its decay. The accumulation of these products can form subseries, leading to isotopes of the same element ending up in separate phases or having unexpected activity ratios compared to secular equilibrium. Alpha recoil during alpha decay can further displace these decay products from mineral lattices, enhancing their presence in surrounding water or other phases. These effects are significant for elements like uranium, thorium, and radium and occur only among isotopes linked within the same decay series. Isotopes of the same element in separate decay series, such as Th-230 and Th-228, do not undergo such fractionation. However, redox processes, complexation, or preferential dissolution can also affect isotopes of an element behaviour [105], [106].

20. Practical aspects

Based on the graded approach to radiation hazard control, limits were established to exempt a practice or clear a material from regulatory control in terms of radiation protection. For NOR, clearance and exemption levels are expressed in the activity concentration of uranium and thorium decay series parent radionuclides. Notwithstanding that the uranium and thorium decay series members are ten different elements, five of which have isotopes that can exist independently from their parents, for clearance or exemption activity concentration of each radionuclide must be individually compared with the level set for the entire decay series. No activity concentration summation rule is considered to verify that the conditions are met. Moreover, taking EU BSSD literally, separate limits are set for both, uranium and thorium decay series, that is leading to more doubts about how interpret simultaneous presence of both of them. Notwithstanding details, lack of summation rule is leading to significant situation overestimation when only a subseries is present or, on the other hand, underestimation when entire decay series is present in secular equilibrium. Based on the previously mentioned disequilibria, it follows that for the purposes of clearance and exemption, the material must be assessed in detail, not solely on the basis of the activity of the parent radionuclides.

20.1 Specific consideration of the committed dose in the context of a practice exemption

This simplification facilitates practice authorization; however, it leads to discrepancies when one expects exemption based on the criterion expressed as an effective dose, as assumed in the regulations. To evaluate the effective dose, caused either by external exposure or by radionuclides intake, dose conversion factors must be used. Dose conversions are provided for each radionuclide or for a few subseries, respectively, for external exposure (ICRP 144) [99] and for committed dose (IAEA GSR Part 3, ICRP 137) [100]. This requires the application of the summation rule when multiple radionuclides are present in the exposure source.

Dose conversion varies significantly between elements and their isotopes present in decay series (*Figure 15* and *Figure 16*). It is caused by chemical properties (see an example in the Table 12) of element as well as type of decay, radiation emitted and half-life. For members of the public, dose conversion for committed dose via inhalation ranges over two orders of magnitude for each decay series, depending on the radionuclide and the exposed person's age (see Table 13 to Table 15). In the case of occupational exposure, dose conversion variations are at the level of two or one order of magnitude for radionuclides from the uranium and thorium decay series, respectively (see tables Table 19 and Table 20). This highlights the potential for significant underestimation or overestimation of existing exposure when the real composition of the source of exposure is not known or secular equilibrium state in a decay series is a priori assumed.

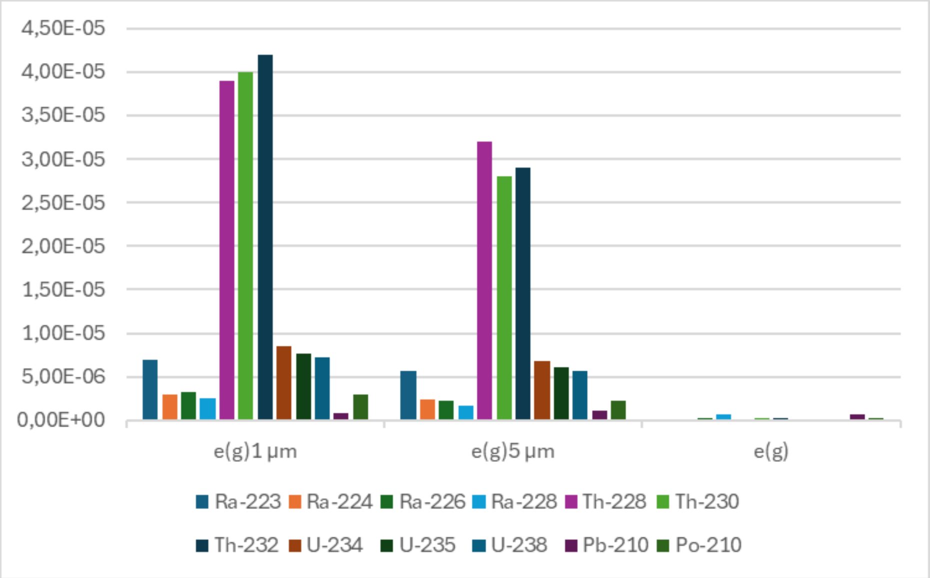

Figure 15: Dose conversion factors (dose per unit intake) for NOR (Sv/Bq)

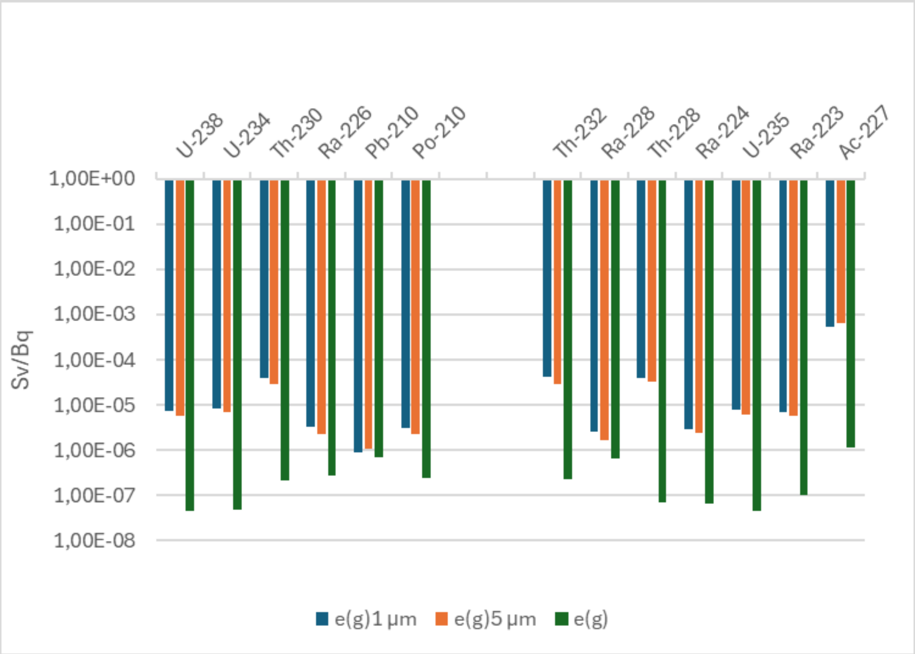

Figure 16: Dose conversion factors (dose per unit intake) for NOR including Ac-227 (Sv/Bq)

Table 12: Compounds and values of gut transfer factor f_1 used to calculate committed effective dose per unit intake via ingestion for workers

Element	Gut transfer factor f_1	Compounds
Lead	0.200	All compounds
Polonium	0.100	All compounds
Radium	0.200	All compounds
Actinium	5.0×10^{-4}	All compounds
Thorium	5.0×10^{-4} 2.0×10^{-4}	All unspecified compounds Oxides and hydroxides
Protactinium	5.0×10^{-4}	All compounds
Uranium	0.020	All unspecified compounds
	0.002	Most tetravalent compounds, e.g. UO_2, U_3O_8, UF_4

Dose conversion (dose per unit intake) for committed dose calculation for parent nuclides of a decay series as well as subseries were developed assuming ingrowth and then relevant contribution of all potential decay products (see the *Table 11*) in the period for which effective dose is calculated (50 or 70 years, for adults and children respectively). It must be underlined that this approach covers only the contribution of decay products of a parent radionuclide emerging after intake. Assuming secular equilibrium in a decay series in external media (air for inhalation, food, in general, for ingestion) all long lived radionuclides must be accounted as equally contributing to the total intake, expressed in NOR activity. Otherwise, factual activity of such radionuclides must be used for committed dose calculation, based on direct measurements or mutual relationships assumed as discussed in the sections 18 and 19. The long-lived radionuclides in each decay series, which subject intake, are listed in tables: Table 13 to Table 21. All these tables are taken from IAEA GRS Part 3 [5].

Table 13: MEMBERS OF THE PUBLIC: COMMITTED EFFECTIVE DOSE PER UNIT INTAKE e(g) VIA INHALATION Sv/Bq (uranium decay series)

Radionuclide	Physical half life		f1	Age ≤ 1 a	f1 for	Age 1–2 a	2–7 a	7–12 a	12–17 a	>17 a
		type		e(g)		e(g)	e(g)	e(g)	e(g)	e(g)
U-238	4.47×10^{9} a	F	0.040	1.9×10^{-6}	0.020	1.3×10^{-6}	8.2×10^{-7}	7.3×10^{-7}	7.4×10^{-7}	5.0×10^{-7}
		M	0.040	1.2×10^{-5}	0.020	9.4×10^{-6}	5.9×10^{-6}	4.0×10^{-6}	3.4×10^{-6}	2.9×10^{-6}
		S	0.020	2.9×10^{-5}	0.002	2.5×10^{-5}	1.6×10^{-5}	1.0×10^{-5}	8.7×10^{-6}	8.0×10^{-6}
U-234	2.44×10^{5} a	F	0.040	2.1×10^{-6}	0.020	1.4×10^{-6}	9.0×10^{-7}	8.0×10^{-7}	8.2×10^{-7}	5.6×10^{-7}
		M	0.040	1.5×10^{-5}	0.020	1.1×10^{-5}	7.0×10^{-6}	4.8×10^{-6}	4.2×10^{-6}	3.5×10^{-6}
		S	0.020	3.3×10^{-5}	0.002	2.9×10^{-5}	1.9×10^{-5}	1.2×10^{-5}	1.0×10^{-5}	9.4×10^{-6}
Th-230	7.70×10^{4} a	F	0.005	2.1×10^{-4}	5.0×10^{-4}	2.0×10^{-4}	1.4×10^{-4}	1.1×10^{-4}	9.9×10^{-5}	**1.0×10^{-4}**
		M	0.005	7.7×10^{-5}	5.0×10^{-4}	7.4×10^{-5}	5.5×10^{-5}	4.3×10^{-5}	4.2×10^{-5}	4.3×10^{-5}
		S	0.005	4.0×10^{-5}	5.0×10^{-4}	3.5×10^{-5}	2.4×10^{-5}	1.6×10^{-5}	1.5×10^{-5}	1.4×10^{-5}
Ra-226	1.60×10^{3} a	F	0.600	2.6×10^{-6}	0.200	9.4×10^{-7}	5.5×10^{-7}	7.2×10^{-7}	1.3×10^{-6}	**3.6×10^{-7}**
		M	0.200	1.5×10^{-5}	0.100	1.1×10^{-5}	7.0×10^{-6}	4.9×10^{-6}	4.5×10^{-6}	3.5×10^{-6}
		S	0.020	3.4×10^{-5}	0.010	2.9×10^{-5}	1.9×10^{-5}	1.2×10^{-5}	1.0×10^{-5}	9.5×10^{-6}
Pb-210	22.3 a	F	0.600	4.7×10^{-6}	0.200	2.9×10^{-6}	1.5×10^{-6}	1.4×10^{-6}	1.3×10^{-6}	9.0×10^{-7}
		M	0.200	5.0×10^{-6}	0.100	3.7×10^{-6}	2.2×10^{-6}	1.5×10^{-6}	1.3×10^{-6}	1.1×10^{-6}
		S	0.020	1.8×10^{-5}	0.010	1.8×10^{-5}	1.1×10^{-5}	7.2×10^{-6}	5.9×10^{-6}	5.6×10^{-6}
Po-210	138 d	F	0.200	7.4×10^{-6}	0.100	4.8×10^{-6}	2.2×10^{-6}	1.3×10^{-6}	7.7×10^{-7}	6.1×10^{-7}
		M	0.200	1.5×10^{-5}	0.100	1.1×10^{-5}	6.7×10^{-6}	4.6×10^{-6}	4.0×10^{-6}	3.3×10^{-6}
		S	0.020	1.8×10^{-5}	0.010	1.4×10^{-5}	8.6×10^{-6}	5.9×10^{-6}	5.1×10^{-6}	4.3×10^{-6}

Table 14: MEMBERS OF THE PUBLIC: COMMITTED EFFECTIVE DOSE PER UNIT INTAKE e(g) VIA INHALATION Sv/Bq (thorium decay series)

Radionuclide	Physical half life		f1	Age ≤ 1 a	f1 for	Age 1–2 a	2–7 a	7–12 a	12–17 a	>17 a
		type		e(g)		e(g)	e(g)	e(g)	e(g)	e(g)
Th-232	1.40×10^{10} a	F	0.005	2.3×10^{-4}	5.0×10^{-4}	2.2×10^{-4}	1.6×10^{-4}	1.3×10^{-4}	1.2×10^{-4}	**1.1×10^{-4}**
		M	0.005	8.3×10^{-5}	5.0×10^{-4}	8.1×10^{-5}	6.3×10^{-5}	5.0×10^{-5}	4.7×10^{-5}	4.5×10^{-5}
		S	0.005	5.4×10^{-5}	5.0×10^{-4}	5.0×10^{-5}	3.7×10^{-5}	2.6×10^{-5}	2.5×10^{-5}	2.5×10^{-5}
Ra-228	5.75 a	F	0.600	1.7×10^{-5}	0.200	5.7×10^{-6}	3.1×10^{-6}	3.6×10^{-6}	4.6×10^{-6}	9.0×10^{-7}
		M	0.200	1.5×10^{-5}	0.100	1.0×10^{-5}	6.3×10^{-6}	4.6×10^{-6}	4.4×10^{-6}	2.6×10^{-6}
		S	0.020	4.9×10^{-5}	0.010	4.8×10^{-5}	3.2×10^{-5}	2.0×10^{-5}	1.6×10^{-5}	1.6×10^{-5}
Th-228	1.91 a	F	0.005	1.8×10^{-4}	5.0×10^{-4}	1.5×10^{-4}	8.3×10^{-5}	5.2×10^{-5}	3.6×10^{-5}	2.9×10^{-5}
		M	0.005	1.3×10^{-4}	5.0×10^{-4}	1.1×10^{-4}	6.8×10^{-5}	4.6×10^{-5}	3.9×10^{-5}	3.2×10^{-5}
		S	0.005	1.6×10^{-4}	5.0×10^{-4}	1.3×10^{-4}	8.2×10^{-5}	5.5×10^{-5}	4.7×10^{-5}	4.0×10^{-5}
Ra-224	3.66 d	F	0.600	1.5×10^{-6}	0.200	6.0×10^{-7}	2.9×10^{-7}	2.2×10^{-7}	1.7×10^{-7}	**7.5×10^{-8}**
		M	0.200	1.1×10^{-5}	0.100	8.2×10^{-6}	5.3×10^{-6}	3.9×10^{-6}	3.7×10^{-6}	3.0×10^{-6}
		S	0.020	1.2×10^{-5}	0.010	9.2×10^{-6}	5.9×10^{-6}	4.4×10^{-6}	4.2×10^{-6}	3.4×10^{-6}

Table 15: MEMBERS OF THE PUBLIC: COMMITTED EFFECTIVE DOSE PER UNIT INTAKE e(g) VIA INHALATION (Sv/Bq) - actinium decay series

Radionuclide	Physical half life			Age ≤ 1 a	f1 for	Age 1–2 a	2–7 a	7–12 a	12–17 a	>17 a
		type	f1	e(g)		e(g)	e(g)	e(g)	e(g)	e(g)
U-235	7.04×10^{8} a	F	0.040	2.0×10^{-6}	0.020	1.3×10^{-6}	8.5×10^{-7}	7.5×10^{-7}	7.7×10^{-7}	**5.2×10^{-7}**
		M	0.040	1.3×10^{-5}	0.020	1.0×10^{-5}	6.3×10^{-6}	4.3×10^{-6}	3.7×10^{-6}	3.1×10^{-6}
		S	0.020	3.0×10^{-5}	0.002	2.6×10^{-5}	1.7×10^{-5}	1.1×10^{-5}	9.2×10^{-6}	8.5×10^{-6}
Pa-231	3.27×10^{4} a	M	0.005	2.2×10^{-4}	5.0×10^{-4}	2.3×10^{-4}	1.9×10^{-4}	1.5×10^{-4}	1.5×10^{-4}	1.4×10^{-4}
		S	0.005	7.4×10^{-5}	5.0×10^{-4}	6.9×10^{-5}	5.2×10^{-5}	3.9×10^{-5}	3.6×10^{-5}	3.4×10^{-5}
Ac-227	21.8 a	F	0.005	1.7×10^{-3}	5.0×10^{-4}	1.6×10^{-3}	1.0×10^{-3}	7.2×10^{-4}	5.6×10^{-4}	5.5×10^{-4}
		M	0.005	5.7×10^{-4}	5.0×10^{-4}	5.5×10^{-4}	3.9×10^{-4}	2.6×10^{-4}	2.3×10^{-4}	**2.2×10^{-4}**
		S	0.005	2.2×10^{-4}	5.0×10^{-4}	2.0×10^{-4}	1.3×10^{-4}	8.7×10^{-5}	7.6×10^{-5}	7.2×10^{-5}
Ra-223	11.4 d	F	0.600	3.0×10^{-6}	0.200	1.0×10^{-6}	4.9×10^{-7}	4.0×10^{-7}	3.3×10^{-7}	1.2×10^{-7}
		M	0.200	2.8×10^{-5}	0.100	2.1×10^{-5}	1.3×10^{-5}	9.9×10^{-6}	9.4×10^{-6}	7.4×10^{-6}
		S	0.020	3.2×10^{-5}	0.010	2.4×10^{-5}	1.5×10^{-5}	1.1×10^{-5}	1.1×10^{-5}	8.7×10^{-6}

Table 16: MEMBERS OF THE PUBLIC: COMMITTED EFFECTIVE DOSE PER UNIT INTAKE e(g) VIA INGESTION (Sv/Bq) - uranium decay series

Radionuclide	Physical half life		Age ≤ 1 a	f_1 for *g>1a*	Age 1–2 a	2–7 a	7–12 a	12–17 a	>17 a
		f_1	e(g)		e(g)	e(g)	e(g)	e(g)	e(g)
U-238	4.47×10^{9} a	0.040	3.4×10^{-7}	0.020	1.2×10^{-7}	8.0×10^{-8}	6.8×10^{-8}	6.7×10^{-8}	**4.5×10^{-8}**
U-234	2.44×10^{5} a	0.040	3.7×10^{-7}	0.020	1.3×10^{-7}	8.8×10^{-8}	7.4×10^{-8}	7.4×10^{-8}	4.9×10^{-8}
Th-230	7.70×10^{4} a	0.005	4.1×10^{-6}	5.0×10^{-4}	4.1×10^{-7}	3.1×10^{-7}	2.4×10^{-7}	2.2×10^{-7}	2.1×10^{-7}
Ra-226	1.60×10^{3} a	0.600	4.7×10^{-6}	0.200	9.6×10^{-7}	6.2×10^{-7}	8.0×10^{-7}	1.5×10^{-6}	2.8×10^{-7}
Pb-210	22.3 a	0.600	8.4×10^{-6}	0.200	3.6×10^{-6}	2.2×10^{-6}	1.9×10^{-6}	1.9×10^{-6}	6.9×10^{-7}
Po-210	138 d	1.000	2.6×10^{-5}	0.500	8.8×10^{-6}	4.4×10^{-6}	2.6×10^{-6}	1.6×10^{-6}	**1.2×10^{-6}**

Table 17: MEMBERS OF THE PUBLIC: COMMITTED EFFECTIVE DOSE PER UNIT INTAKE e(g) VIA INGESTION (Sv/Bq) - thorium decay series

Radionuclide	Physical half life		Age ≤ 1 a	f_1 for *g>1a*	Age 1–2 a	2–7 a	7–12 a	12–17 a	>17 a
		f_1	e(g)		e(g)	e(g)	e(g)	e(g)	e(g)
Th-232	1.40×10^{10} a	0.005	4.6×10^{-6}	5.0×10^{-4}	4.5×10^{-7}	3.5×10^{-7}	2.9×10^{-7}	2.5×10^{-7}	**2.3×10^{-7}**
Ra-228	5.75 a	0.600	3.0×10^{-5}	0.200	5.7×10^{-6}	3.4×10^{-6}	3.9×10^{-6}	5.3×10^{-6}	6.9×10^{-7}
Th-228	1.91 a	0.005	3.7×10^{-6}	5.0×10^{-4}	3.7×10^{-7}	2.2×10^{-7}	1.5×10^{-7}	9.4×10^{-8}	**7.2×10^{-8}**
Ra-224	3.66 d	0.600	2.7×10^{-6}	0.200	6.6×10^{-7}	3.5×10^{-7}	2.6×10^{-7}	2.0×10^{-7}	6.5×10^{-8}

Table 18: MEMBERS OF THE PUBLIC: COMMITTED EFFECTIVE DOSE PER UNIT INTAKE e(g) VIA INGESTION (Sv/Bq) - actinium decay series

Radionuclide	Physical half life		Age ≤ 1 a	f_1 for *g>1a*	Age 1–2 a	2–7 a	7–12 a	12–17 a	>17 a
		f_1	e(g)		e(g)	e(g)	e(g)	e(g)	e(g)
U-235	7.04×10^{8} a	0.040	3.5×10^{-7}	0.020	1.3×10^{-7}	8.5×10^{-8}	7.1×10^{-8}	7.0×10^{-8}	**4.7×10^{-8}**
Pa-231	3.27×10^{4} a	0.005	1.3×10^{-5}	5.0×10^{-4}	1.3×10^{-6}	1.1×10^{-6}	9.2×10^{-7}	8.0×10^{-7}	7.1×10^{-7}
Ac-227	21.8 a	0.005	3.3×10^{-5}	5.0×10^{-4}	3.1×10^{-6}	2.2×10^{-6}	1.5×10^{-6}	1.2×10^{-6}	**1.1×10^{-6}**
Ra-223	11.4 d	0.600	5.3×10^{-6}	0.200	1.1×10^{-6}	5.7×10^{-7}	4.5×10^{-7}	3.7×10^{-7}	1.0×10^{-7}

Table 19: WORKERS: COMMITTED EFFECTIVE DOSE PER UNIT INTAKE e(g)1 and e(g)2 via INHALATION and e(g) via INGESTION (Sv/Bq) - (uranium decay series)

radionuclide	half-life	Type	f1	e(g)1 µm	e(g)5 µm	f1	e(g)
U-238	4.47×10^{9} a	F	0.020	4.9×10^{-7}	5.8×10^{-7}	0.020	4.4×10^{-8}
		M	0.020	2.6×10^{-6}	1.6×10^{-6}	0.002	7.6×10^{-9}
		S	0.002	7.3×10^{-6}	5.7×10^{-6}		
U-234	2.44×10^{5} a	F	0.020	5.5×10^{-7}	6.4×10^{-7}	0.020	4.9×10^{-8}
		M	0.020	3.1×10^{-6}	2.1×10^{-6}	0.002	8.3×10^{-9}
		S	0.002	8.5×10^{-6}	6.8×10^{-6}		
Th-230	7.70×10^{4} a	M	5.0×10^{-4}	4.0×10^{-5}	2.8×10^{-5}	5.0×10^{-4}	2.1×10^{-7}
		S	2.0×10^{-4}	1.3×10^{-5}	7.2×10^{-6}	2.0×10^{-4}	8.7×10^{-8}
Ra-226	1.60×10^{3} a	M	0.200	3.2×10^{-6}	2.2×10^{-6}	0.200	2.8×10^{-7}
Pb-210	22.3 a	F	0.200	8.9×10^{-7}	1.1×10^{-6}	0.200	6.8×10^{-7}
Po-210	138 d	F	0.100	6.0×10^{-7}	7.1×10^{-7}	0.100	2.4×10^{-7}
		M	0.100	3.0×10^{-6}	2.2×10^{-6}		

Table 20: WORKERS: COMMITTED EFFECTIVE DOSE PER UNIT INTAKE e(g)1 and e(g)2 via INHALATION and e(g) via INGESTION (Sv/Bq) - (thorium decay series)

radionuclide	half-life	Type	f1	e(g)1 µm	e(g)5 µm	f1	e(g)
Th-232	1.40×10^{10} a	M	5.0×10^{-4}	4.2×10^{-5}	2.9×10^{-5}	5.0×10^{-4}	2.2×10^{-7}
		S	2.0×10^{-4}	2.3×10^{-5}	1.2×10^{-5}	2.0×10^{-4}	9.2×10^{-8}
Ra-228	5.75 a	M	0.200	2.6×10^{-6}	1.7×10^{-6}	0.200	6.7×10^{-7}
Th-228	1.91 a	M	5.0×10^{-4}	3.1×10^{-5}	2.3×10^{-5}	5.0×10^{-4}	7.0×10^{-8}
		S	2.0×10^{-4}	3.9×10^{-5}	3.2×10^{-5}	2.0×10^{-4}	3.5×10^{-8}
Ra-224	3.66 d	M	0.200	2.9×10^{-6}	2.4×10^{-6}	0.200	6.5×10^{-8}

Table 21: WORKERS: COMMITTED EFFECTIVE DOSE PER UNIT INTAKE e(g)1 and e(g)2 via INHALATION and e(g) via INGESTION (Sv/Bq) - (actinium decay series)

radionuclide	half-life	Type	f1	e(g)1 µm	e(g)5 µm	f1	e(g)
U-235	7.04×10^{8} a	F	0.020	5.1×10^{-7}	6.0×10^{-7}	0.020	4.6×10^{-8}
		M	0.020	2.8×10^{-6}	1.8×10^{-6}	0.002	8.3×10^{-9}
		S	0.002	7.7×10^{-6}	6.1×10^{-6}		
Pa-231	3.27×10^{4} a	M	5.0×10^{-4}	1.3×10^{-4}	8.9×10^{-5}	5.0×10^{-4}	7.1×10^{-7}
		S	5.0×10^{-4}	3.2×10^{-5}	1.7×10^{-5}		
Ac-227	21.8 a	F	5.0×10^{-4}	5.4×10^{-4}	6.3×10^{-4}	5.0×10^{-4}	1.1×10^{-6}
		M	5.0×10^{-4}	2.1×10^{-4}	1.5×10^{-4}		
		S	5.0×10^{-4}	6.6×10^{-5}	4.7×10^{-5}		
Ra-223	11.4 d	M	0.200	6.9×10^{-6}	5.7×10^{-6}	0.200	1.0×10^{-7}

Calculations performed for entire decay series assuming secular equilibrium, as well as for some subseries, indicate that in the case of committed dose for workers caused by inhalation of NOR, activity concentration equal to the clearance or exemption levels significantly exceeds the dose of 1 mSv/year and the contribution of thorium isotopes is crucial. This underscores the importance of evaluating thorium isotopes in the source of exposure, as thorium isotopes are typically not measured directly. Instead, their activity concentration is extrapolated from the direct measurement of their decay product.

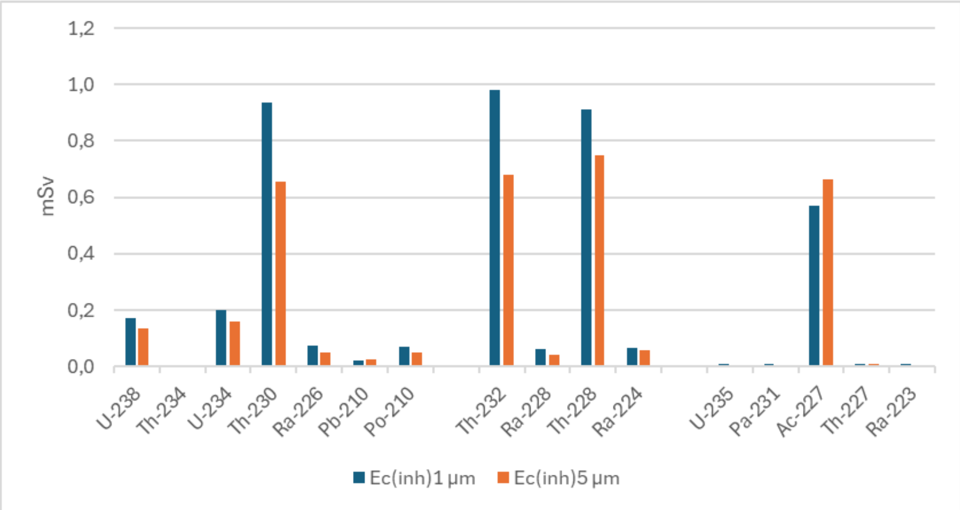

Figure 17: NOR contribution to the committed dose, workers, working time 1800 h, dust PEL 10 mg/m³ 1 Bq/g secular equilibrium

The simulations conducted, showed also that neglecting the contribution of the actinium decay series to committed dose is not justified. Assuming the natural ratio of U-238 to U-235, the contribution of U-235 and its decay products constitute about 45% of the dose caused by the uranium-238 decay series (*Figure 18*). The most contributing radionuclide from the actinium decay series is Ac-227 (see the *Figure 16*), rarely considered in the routine monitoring.

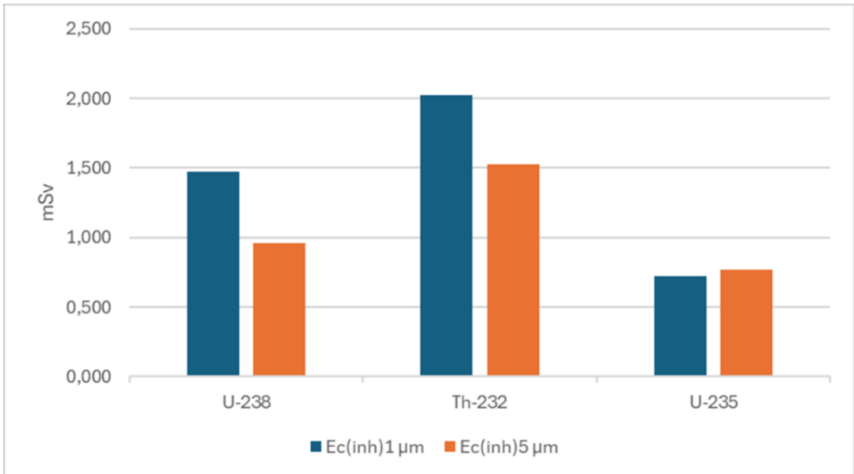

Figure 18: Decay series contribution to the committed dose, workers, working time 1800 h, dust PEL 10 mg/m³, 1 Bq/g, secular equilibrium

As dust concentration is crucial for the committed dose, the integration of OSH standards establishing permissible exposure limits (PELs) for aerosols and dust, which define the maximum concentrations that workers can be exposed to over a specified period, with RP in NORM-involving industries is suggested. The examples were calculated for PEL (Permissible Exposure Limit) applied in titanium dioxide industry.

20.2 Exposure to external radiation

Compared to internal exposure which always is subject calculation, external exposure is usually directly measured therefore there is no need-to-know radionuclides suite enclosed in the source. On other hand, from the perspective of exemption/clearance levels it is important that in the decay series there are very few gamma emitters. The dose conversions are provided for each radionuclide individually. Most contributing are short-lived radionuclides (Figure 19). That is why in any kind of modelling the mutual relationship with their parent radionuclides must be carefully examined. It is significant, that again the total contribution of thorium decay series is about 2.5 times bigger than uranium one (Figure 20).

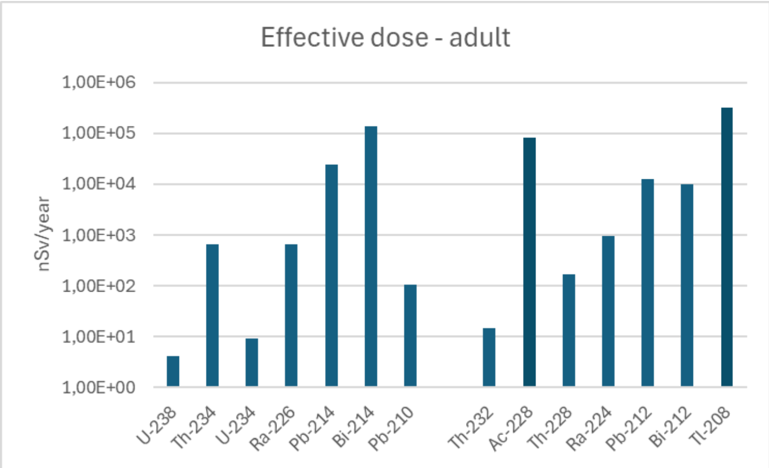

Figure 19: NOR contribution to the external dose, member of the public, exposure time 8760 h, 0.5 g/cm2,1 Bq/g, secular equilibrium

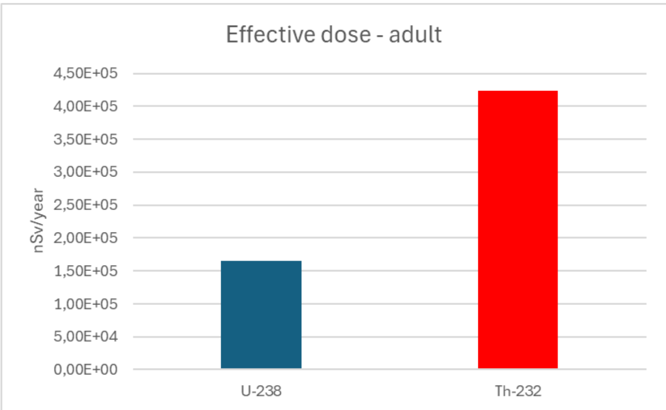

Figure 20: Uranium and thorium decay series contribution to the effective dose from external exposure, member of the public, exposure time 8760 h, 0.5 g/cm^2,1 Bq/g, secular equilibrium

The examples present different contribution decay series into effective dose that can result in dose overestimation or underestimation and emphasise the necessity of proper NORM characterization, necessary measurement scope identification, considering the mutual relationships either of NOR within a decay series or isotopes of the same element between decay series.

21. Part 3 – Suggestions for consideration to the current system of characterisation of NORM

Current knowledge and experience make it possible, and even necessary, to modify existing system on NORM management with listed below aspects:

- Define clearance and exemption levels expressed in a parent radionuclide activity concentration for sub-series or single radionuclide that cannot get equilibrium in a reasonable period, listed in the Table 22.

Table 22: Subseries and individual radionuclides that should be considered individually for exemption and clearance

Main Isotope	Decay Products
U-238	Th-234, Pa-234m
Th-230	
U-234	
Ra-226	Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
Pb-210	Bi-210, Po-210
Rn-222	Po-218, Pb-214, Bi-214, Po-214
Th-232	Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36)
Ra-228	Ac-228
Th-228	Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)
Ra-224	Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)
Rn-220	Po-216
Pb-212	Bi-212
U-235	Th-231
Pa-231	
Ac-227	Fr-223 (0.0138) Th-227
Ra-223	Rn-219, Po-215, Pb-211, Bi-211, Tl-207

- Apply the summation rule of above required exemption and clearance values for subseries' parent radionuclides, regardless the decay series they are coming from, when they are simultaneously present.

- Add actinium decay series (include its contribution to U-238 series when exemption or clearance levels are calculated, require being included in dose evaluation)

- Establish absolute clearance levels for NORM activity concentrations that ensure the resulting dose remains within acceptable limits under all currently identified exposure scenarios. These levels should, at minimum, be more conservative than those currently applied to NORM in building materials. Possible suggestions are included in the Table 23.

Table 23: Recommended exemption levels by activity concentration

	RP 112[9]	EU BSSD	International BSS	RP 122	0.3 mSv dose constraint[10]	TENORMHARM group [11]
	Bq/kg					
^{238}U	50	1000	1000	500	25 (33)	200
^{232}Th	33	1000	1000	500	25 (33)	200
^{40}K	600	10000	10000	5000	200 (0)	(not considered)

- Further development the approach for specific clearance levels or exemption levels based on exposure possible scenarios seems therefore very important, for example as the revision of RP 65 and RP 122 part II including implementation of up-to-date data for exposure scenarios and new ICRP dose conversion coefficients.

[9] Calculated on base of criteria: f_1<0.5
[10] Air kerma rate 1 m above ground, basing on recommendation of ICRU 53 for the radionuclides distributed homogeneously in the ground. In brackets, calculated not taking into account the potassium forty presence.
[11] Level assumed for the ranking of TENORM industry, not exactly treat as exemption level.

Part 4. Integration of NORM oriented radiation safety measures into existing OSH system

22. Introduction

In most, nearly all, NORM involving industries there are already existing prevention and mitigation measures determined by occurrence of other stressors than radioactivity – chemical and physical stressors. Considering the nature of hazard caused by NOR and typical exposure scenarios at NORM workplaces, some existing protective measures used within the occupational health and safety (OSH) systems can also be considered effective in reducing radiological risks. For example, dust mitigation not only reduces overall particle exposure but also limits the intake of radionuclides via inhalation and, to some extent, ingestion – such as the unintentional ingestion of dust particles through contact with the lips. Activities aimed at unifying—or more precisely, integrating—radiation protection mitigation and prevention into existing occupational health and safety OSH systems, based on scientifically justified rationales, are expected.

22.1 Sources of exposure in NORM-involving industries

Exposure scenarios in NORM-involving industries should be defined based on the specific industrial sector and are usually determined by technological processes applied. Further in the text, an example from the mining industry and raw material processing is described. In mining, the primary concern is occupational exposure resulting from elevated concentrations of radionuclides in the ore, as well as the potential for increased exposure due to the nature of the mining process involved. The mining method (surface or underground) and the minerals comminution method determines external exposure geometry. In underground mines, when walls of underground galleries are considered as a source of radiation, exposure geometry can be assumed as ISO (isotropic geometry) defined as radiation field in which the particle fluence per unit of solid angle is independent of directions. In other cases, LAT (lateral geometry) can be assumed, where the incident of radiation is from either side of the body in the direction orthogonal to the long axis of the body or ROT (rotational geometry), same as LET, assuming the body is rotating around its long axis [107]. The assumed geometry depends on the worker's position relative to the identified source and the nature of the work being performed. In general, doses from external exposure received by workers depend on their proximity to bulk quantities of material rather than on the mobilization of radionuclides. However, to identify sources of gamma radiation, it is important to understand the processes leading to NOR accumulation – unless NOR considered are an inherent part of the ore body or the surrounding rock strata. Regardless of the specific characteristics of NORM present in a workplace, inhalation of dust should be considered the primary contributor to the committed effective dose from internal exposure. Particular attention should be given to the presence of formation waters, where applicable, as they may lead to the accumulation of sediments or scales containing enhanced concentrations of NOR. These deposits can contribute to localised external exposure due to increased gamma dose rates, as well as to internal exposure via inadvertent ingestion. Furthermore, radon exhalation may lead to significant accumulation in the mine atmosphere—especially in underground mining environments—regardless of the type of mineral being extracted. This can result in notable exposure via inhalation of radon and its short-lived decay products, particularly under conditions of underground mines.

Comminution of ores and physical separation processes of minerals include gravity concentration, magnetic and electrostatic separation, and even flotation. Such processes are carried out in an environment that is not chemically active. Therefore, there are no changes of processed material, and the exposure is determined by NOR activity concentration in the raw materials used, taking into account any fractionation that may result from the processing steps.

Gamma doses received by workers involved depend on their proximity to bulk quantities of material and exposure geometry – both of which are, in turn, determined by the specifics of the production process (that includes transport, storage technology and, at least preliminary, waste treatment). Dust (particulate matter) inhalation is the crucial source of intake, while ingestion can be considered only as inadvertent and often can be neglected. Radon exhalation to workplace atmosphere must be considered, especially when dry, loose materials are processed, unless a process is carried out in open air.

Wet chemical extraction processes and thermal processes used for extraction, processing and combustion result in formation of precipitates, scales and resins as well as combustion products which typically exhibit the highest enhancement in radionuclide activity concentration. Changes in aggregate state, as well as reduction of feedstock material mass (volume), are common, and result in radionuclide speciation and in an increase in activity concentration. NOR accumulation depends more on chemical conditions than on the original ore (e.g. fossil fuel) grade.

For dose evaluation, decay series disequilibrium should almost always be taken into account. Due to the nature of the above-mentioned processes, direct contact between workers and potential NORM is limited; therefore, occupational exposure is typically associated with parts of a production process related to transport, storage and waste treatment. Supporting materials as, for example refractories or abrasives, can contribute to the exposure regardless the processed material, as they constitute permanent features of the workplace. There is no general rule allowing for identification of an universal exposure scenario, however external exposure must always be considered, as it is determined by the exposure geometry and the distance from the source. Although dust is rarely present during the main processing steps, it cannot be excluded during feedstock pre-treatment and subsequent waste handling. Inadvertent ingestion can typically be considered negligible under these conditions.

According to EU BSSD, as well as International BSS, exposure to radon in workplaces is considered separately, as existing exposure. However, both the documents require to include radon exposure in the total occupational exposure when an activity is accounted as practice due to exposure to NORM or radon activity concentration permanently exceeds a reference level. Considering the characteristics of such workplaces, radon in underground workplaces should almost always be considered as a significant contributor to occupational exposure [108]. In case of above-ground workplaces, occupational exposure in NORM-involving industry is primarily determined by external exposure to gamma radiation and dust inhalation.

In general, the total effective dose used for occupational exposure assessment consists of three main components: external exposure to gamma radiation, committed effective dose primarily from inhalation and exposure to radon, which should be preferably assessed through measurement of the radon progeny concentration (potential alpha energy concentration, PAEC):

$$E_c = E_\gamma + E_{int} + E_\alpha$$

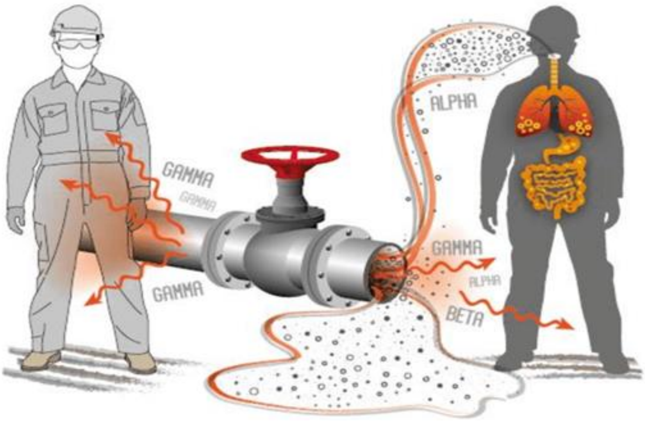

Figure 21. Occupational exposure in NORM involving industries, Source: IOGP Report 412, Managing Naturally Occurring Radioactive Material (NORM) in the oil and gas industry [109].

22.2 Mitigation and prevention recommended from the perspective of radiation protection

From the perspective of radiation protection there are no well-defined requirements concerning protection means (radiation safety) applied against ionizing radiation in the workplace. The EU BSSD sets requirement and criteria how to achieve a proper radiation safety level however there are neither details of practical nor technical solutions provided. The protection system is set on limits, constraints or reference values expressed in terms of either radionuclide activity concentration or the effective dose, while decisions on how to meet these criteria are left to the decision of the industry owner or operator.

General rules of radiation safety are defined based on physical properties of ionizing radiation and summarised as: time, distance, and shielding. Therefore, reducing (minimizing) the duration of exposure to radiation (time), increasing the distance from radiation sources, and using appropriate shielding are essential strategies for effective radiation protection. In cases where well-identified sources of radiation are used, the application of these principles and subsequent evaluation of exposure reduction are relatively straightforward. However, in case of NORM-involving industries, special considerations are necessary due to the nature of the sources and the specific characteristics of the workplace and the tasks – work performed. IAEA GSG-7 [110] provides some suggestions on radiation safety measures, distinguishing among engineered controls, administrative controls and personal protective equipment. In line with this document, but not limited to it, such practical solutions – measures – can be applied to radiation exposure resulting from NORM associated with production processes, in general:

- Before a practice is put into operation, preliminary data concerning NORM should be used to implement preventive control measures to the maximum extent possible. These include quality in design, installation, maintenance, and operation, as well as administrative arrangements and personnel training. Such measures should be prioritised to minimise potential exposure, before resorting to personal protective equipment as the primary means of worker protection.
- In ongoing practices, direct shielding in NORM-related industries is typically impractical, apart from the use of basic protective gear such as work clothing and gloves. Therefore, other measures that achieve a similar protective effect may be considered, such as effective workplace ventilation, removal of unnecessary radioactive sources from the work area, and the use of containment devices. According to IAEA classification, all of these are considered engineered controls, which are often permanent features of the workplace or the production process.

- Maintaining a greater distance from the source is often limited by the nature of the production process. Therefore, control of working time—such as limiting shift duration, rotating workers, and restricting access to areas with the highest exposure—can be effective. In addition to organizational and administrative controls, training workers to recognise potential sources of radiation and to avoid unnecessary time spent in high-exposure areas is also recommended.
- Ensuring good work hygiene practices to prevent skin contamination and inadvertent ingestion.

Considering sources of exposure and exposure scenario described in the previous section, dust and radon (radon progeny) are of crucial importance for workplace in underground mines and in confined spaces in which dry processing of NORM is carried out. Dust control and adequately designed and properly controlled ventilation systems are effective means of minimizing exposure in workplaces prone to airborne contamination and particulate matter. IAEA GSG-7 provides detailed requirements set for a ventilating system under such conditions. Most important among them are:

- an adequate or prescribed number of air changes in the workplace must be ensured, in detail, every workplace should be supplied with air in quantity and quality sufficient to ensure that exposure due to airborne contaminants, such as dust, radon and other radioactive gases, is minimised,
- air velocities should be high enough to dilute the airborne contaminants but not so high as to cause settled dust to be resuspended,
- the auxiliary ventilation should be supplied to the affected parts of the workplace, the fresh air supplied by the primary ventilation system might not be adequate. Examples of such workplaces include development ends in underground mine tunnelling operations and product bagging areas in facilities processing radioactive minerals,
- the primary systems for ventilation and dust control should preferably be operated continuously; if the continuous operation of these systems is not practicable, access to workplaces should only be possible after the ventilation system has been restarted and appropriate monitoring has been performed to ensure that the concentrations of airborne contaminants have been reduced to acceptable levels,
- an industry operator is obliged to employ an appropriately qualified ventilation officer who is responsible for maintaining a ventilation system and reports its conditions directly to senior levels of the mine/plant management.

Considering the dust control IAEA GSG-7 first underline that:

"In most operations involving the potential for high dust generation, for example mining and mineral processing, the adoption of dust control measures is usually a legal requirement because of the necessity of protecting workers against non-radiological hazards such as inhalation of silica particles. These measures generally provide sufficient restrictions on airborne dust concentrations to ensure adequate protection of workers against the inhalation of any radionuclides of natural origin that may be present in the dust"

However, some specific requirements are explicitly defined, such as:

- *The generation of dust in operations should be reduced to the extent practicable by the use of appropriate techniques for mining and mineral processing, such as the use of proper blasting patterns and timing, the use of water and other means of suppressing dust, and the use of appropriate equipment.*
- *where dust is generated, it should be suppressed at source. Where necessary and practicable, the source should be enclosed under negative air pressure. Air might have to be filtered before being discharged to the environment.*

- *dust that has not been suppressed at source may be diluted to acceptable levels by means of frequent changes of air in the working area. Again, the exhaust air might have to be filtered before being discharged to the environment.*
- *care should be taken to avoid the resuspension of dust as a result of high air velocities.*
- *where methods of dust control do not achieve acceptable air quality in working areas, enclosed operating booths with filtered air supplies should be provided for the workers.*

22.3 EU legislation on OSH

22.3.1 Structure

National Occupational Safety and Health systems (OSH) in EU Member States are developed based on Article 153 of the Treaty on the Functioning of the European Union that gives the EU the authority to adopt directives in the field of safety and health at work. The Framework Directive, with its wide scope of application, and further directives focusing on specific aspects of safety and health at work are the fundamentals of European safety and health legislation.

Directive 89/391 – OSH of 12 June 1989 *on the introduction of measures to encourage improvements in the safety and health of workers at work* - hereinafter called „Framework Directive" was enforced in 1989 [111]. The aim of this Directive was to introduce measures to encourage improvements in the safety and health of workers at work. It applies to all sectors of activity, both public and private, except for specific public service activities, such as the armed forces, the police or certain civil protection services. Some provisions of the Framework Directive brought general, widely applicable obligations including, among others, the following:

- The Directive obliges employers to take appropriate preventive measures to make work safer and healthier.
- The Directive introduces as a key element the principle of risk assessment and defines its main elements – hazard identification, worker participation, introduction of adequate measures with the priority of eliminating risk at source, documentation and periodical re-assessment of workplace hazards.

On the basis of this Framework Directive a series of individual directives were adopted dealing with different risks/hazards as well as different activities and workplaces. The content of these directives is consulted with Member States via collaboration with The Advisory Committee for Safety and Health at Work. The Committee is a tripartite body set up in 2003 by a Council Decision (2003/C 218/01) [112]. It took on the tasks of the former Advisory Committee on Safety, Hygiene and Health Protection at Work as well as the Safety and Health Commission for the Mining and Other Extractive Industries [113]. It is obliged to collaborate with competent authorities for safety and health at work, inter alia with the Senior Labour Inspectors Committee and the Scientific Committee for Occupational Exposure Limits to Chemical Agents, mainly by exchanging information.

The Framework Directive had to be transposed into national law by the end of 1992. Member States are free to adopt stricter rules for the protection of workers when transposing EU directives into national law. Therefore, legislative requirements in the field of safety and health at work can vary across EU Member States.

All directives applicable to OSH in the EU are available on the European Agency for Safety and Health at Work web site [114].

22.3.2 Scope of application

The Framework Directive defines the general scope of its application in terms of the risk/hazard and workplaces where such risk/hazards may occur. In the preamble defines the general scope of its application as:

- *Whereas the provisions of this Directive apply, without prejudice to more stringent present or future Community provisions, to all risks, and in particular to those arising from the use at work of chemical, physical and biological agents covered by Directive 80/1107/EEC (1), as last amended by Directive 88/642/EEC (2);*

Subsequently the cited Council Directive 80/1107/EEC repealed by the Council Directive 98/24/EC [115] defining its scope of application excludes occupational exposure to ionizing radiation, declares the following:

Article 1

1. This Directive, which is the fourteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC, lays down minimum requirements for the protection of workers from risks to their safety and health arising, or likely to arise, from the effects of chemical agents that are present at the workplace or as a result of any work activity involving chemical agents.

— *2. The requirements of this Directive apply where hazardous chemical agents are present or may be present at the workplace, without prejudice to the provisions for chemical agents to which measures for radiation protection apply pursuant to Directives adopted under the Treaty establishing the European Atomic Energy Community.*

Main text of the Framework Directive [111] the workplaces of interest defines as:

Article 2 ***Scope***

1*. This Directive shall apply to all sectors of activity, both public and private (industrial, agricultural, commercial, administrative, service, educational, cultural, leisure, etc.)*

2. This Directive shall not be applicable where characteristics peculiar to certain specific public service activities, such as the armed forces or the police, or to certain specific activities in the civil protection services inevitably conflict with it.

In that event, the safety and health of workers must be ensured as far as possible in the light of the objectives of this Directive.

Article 16: ***Individual Directives — Amendments — General scope of this Directive***

1. The Council, acting on a proposal from the Commission based on Article 118a of the Treaty, shall adopt individual Directives, inter alia, in the areas listed in the Annex.

2. This Directive and, without prejudice to the procedure referred to in Article 17 concerning technical adjustments, the individual Directives may be amended in accordance with the procedure provided for in Article 118a of the Treaty.

3. The provisions of this Directive shall apply in full to all the areas covered by the individual Directives, without prejudice to more stringent and/or specific provisions contained in these individual Directives.

Areas referred to in Article 16 (1) are listed in the Annex such as:

— *Work places*

— *Work equipment*
— *Personal protective equipment*
— *Work with visual display units*
— *Handling of heavy loads involving risk of back injury*
— *Temporary or mobile work sites*
— *Fisheries and agriculture*

Based on amendment of the Framework Directive from 2007, in which the list of the individual directives is explicitly provided can be concluded that the Framework Directive with its general principles continues to apply in full to all the areas covered by the individual directives, but where individual directives contain more stringent and/or specific provisions, these special provisions of individual directives prevail. Moreover, the list of hazards or risk already identified is not closed and industry operators are obliged to pay attention to new ones may appear due to technological process development as it was already declared in the original preamble of the Framework Directive:

- ***Whereas employers shall be obliged to keep themselves informed of the latest advances in technology and scientific findings concerning workplace design, account being taken of the inherent dangers in their undertaking, and to inform accordingly the workers' representatives exercising participation rights under this Directive, so as to be able to guarantee a better level of protection of workers' health and safety****;*

As there is no explicit exclusion of radiation risk, particularly in the context of NORM, the following directives may be considered for potential applicability to workplaces where exposure to ionizing radiation can occur:

The Directive on safety and health requirements for the workplace [116] - provides definition of workplace for the purposes of this Directive is:

'workplace' means the place intended to house workstations on the premises of the undertaking and/or establishment and any other place within the area of the undertaking and/or establishment to which the worker has access in the course of his employment.

Workplaces where exposure to radiation occur are not explicitly excluded from the scope of this directive; however, it does not apply to the extractive industry, as this is excluded under Article 1. Among the requirements potentially relevant to radiation protection, beyond the general obligation of employer to inform workers and/or their representatives about all safety and health measures (to be) taken at the workplace, specific provisions concerning ventilation of enclosed workplaces are outlined in Annex I, paragraph 6:

(6.1) Steps shall be taken to see to it that there is sufficient fresh air in enclosed workplaces, having regard to the working methods used and the physical demands placed on the workers. If a forced ventilation system is used, it shall be maintained in working order. Any breakdown must be indicated by a control system where this is necessary for workers' health.

6.2. If air-conditioning or mechanical ventilation installations are used, they must operate in such a way that workers are not exposed to draughts which cause discomfort. Any deposit or dirt likely to create an immediate danger to the health of workers by polluting the atmosphere must be removed without delay.

The Directive on use of personal protective equipment [117] - defines the personal protective equipment (PPE) as *equipment designed to be worn or held by the worker to protect him against one or more hazards likely to endanger his safety and health at work, and any addition or accessory designed to meet this objectiv*e. The Directive does not apply to ordinary working clothes and uniforms, equipment used by emergency and rescue services, PPE used by the military or the police, PPE for means of road transport, sports equipment, self-defence equipment and portable devices for detecting and signalling risks and nuisances. However, it is underlined that Framework Directive are fully applicable without prejudice to more restrictive and/or specific provisions contained in this Directive. Important from the radiation protection perspective is that:

> *Article 4 – General provisions, Employers' obligations*
>
> *2. Where the presence of more than one risk makes it necessary for a worker to wear simultaneously more than one item of personal protective equipment, such equipment must be compatible and continue to be effective against the risk or risks in question.*
>
> *7. The employer shall first inform the worker of the risks against which the wearing of the personal protective equipment protects him.*
>
> *8. The employer shall arrange for training and shall, if appropriate, organise demonstrations in the wearing of personal protective equipment.*
>
> *Article 6 – Rules of use*
>
> *1. Without prejudice to Articles 3, 4 and 5, Member States shall ensure that general rules are established for the use of personal protective equipment and/or rules covering cases and situations where the employer must provide the personal protective equipment. taking account of Community legislation on the free movement of such equipment.*
>
> *These rules shall indicate in particular the circumstances or the risk situations in which, without prejudice to the priority to be given to collective means of protection, the use of personal protective equipment is necessary.*
>
> *Annexes I, II and III, which constitute a guide, contain useful information for establishing such rules.*
>
> *2. When Member States adapt the rules referred to in paragraph 1, they shall take account of any significant changes to the risk, collective means of protection and personal protective equipment brought about by technological developments.*
>
> *3. Member States shall consult the employers' and workers' organization on the rules referred to in paragraphs 1 and 2.*
>
> *Article 7 – Information for workers*
>
> *Without prejudice to Article 10 of Directive 89/391/EEC, workers and/or their representatives shall be informed of all measures to be taken with regard to the health and safety of workers when personal protective equipment is used by workers at work.*

Annexes I, II and III, which constitute a guide, contain useful information for establishing such rules including these ones concerning radiation safety (e.g. Equipment for EYE AND FACE PROTECTION, for HAND AND ARM PROTECTION, for BODY PROTECTION/OTHER SKIN PROTECTION). Annex III provides "*non-exhaustive list of activities and sectors of activity which may require the provision of personal protective equipment*". The main categorizations are based on the type of general risk (chemical, physical, biological, other); subcategories specify the particular risk – for example direct contact with biological agent, solid aerosols, or electric shock. Protective measures are organised according to the part of the human body. Examples of relevant activities and industry sectors are listed alongside the corresponding body parts affected by the identified risk. Mainly healthcare sectors associated with the use of ionizing radiation are listed in this Annex III.

The Directive on the protection of workers from the risks related to exposure to carcinogens, mutagens or reprotoxic substances (CMR) at work [118] addresses the health and safety risks associated with occupational exposure to CMR substances. However, it explicitly does not apply to " *workers exposed only to radiation covered by the Treaty establishing the European Atomic Energy Community*". The directive covers requirements concerning risk assessment, detailed prescription of prevention measures, needs on training and information and health surveillance of exposed workers. Binding limit values for 41 carcinogenic, mutagenic or reprotoxic agents are listed in Annex III to this directive. Most of these binding limit values were introduced or made more stringent by the four amendments to the Directive published between 2017 and 2024.

The Directive laying down minimum requirements for the safety and health protection of workers in the surface and underground mineral-extracting industries [119] - defines for the purpose of this Directive:

> *(a) surface and underground mineral-extracting industries shall mean all industries practicing: — surface or underground extraction, in the strict sense of the word, of minerals, and/or — prospecting with a view to such extraction, and/or — preparation of extracted materials for sale, excluding the activities of processing the materials extracted, excluding the mineral-extracting industries through drilling defined in Article 2 (a) of Directive 92/91/EEC;*
>
> *(b) workplace shall mean the whole area intended to house workstations, relating to the immediate and ancillary activities and installations of the surface or underground mineral-extracting industries, including overburden dumps and other tips and accommodation, where provided, to which workers have access in the context of their work.*

There is no explicit exclusion from the scope of this directive. Among general obligations in Article 3 there is one specific which can be considered as somehow related to radiation safety:

> *2. The employer shall ensure that a document concerning safety and health, hereinafter referred to as 'safety and health document', covering the relevant requirements laid down in Articles 6, 9 and 10 of Directive 89/391/EEC (Framework Directive), is drawn up and kept up to date.*
>
> *The safety and health document shall demonstrate in particular that:*
>
> — ***the risks to which workers at the workplace are exposed have been determined and assessed****,*
>
> — *adequate measures will be taken to attain the aims of this Directive,*
>
> — *the design, use and maintenance of the workplace and of the equipment are safe.*
>
> *The safety and health document must be drawn up before work starts and be revised if the workplace has undergone major changes, extensions or conversions.*

One of the provisions of the Article 4 is also applicable to radiation protection.

Article 4. Protection from fire, explosions and health-endangering atmospheres

> *The employer shall take measures and precautions appropriate to the nature of the operation:*
>
> *— to avoid, detect and combat the starting and spread of fires and explosions, and*
>
> *— to prevent the occurrence of explosive and/or* ***health-endangering atmospheres****.*

The Directive 92/91/EEC - concerning the minimum requirements for improving the safety and health protection of workers in the mineral-extracting industries through drilling (eleventh individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC) [120] - lays down the minimum requirements for improving the safety and health protection of workers in the mineral-extracting industries through drilling i.e. extraction of minerals (onshore and offshore), preparation of extracted materials for sale, etc. The scope of applicability of this directive is declared on basis of definitions provided as:

Article 2 Definitions

(a) mineral-extracting industries through drilling shall mean all the industries practising:

- *extraction, in the strict sense of the word, of minerals through drilling by boreholes, and/or*
- *prospection with a view to such extraction, and/or*
- *preparation of extracted materials for sale, excluding the activities of processing the materials extracted;*

(b) workplace shall mean the whole area intended to house workstations, relating to the immediate and ancillary activities and installations of the mineral-extracting industries through drilling, including accommodation, where provided, to which workers have access in the context of their work.

Similarly, to the directive on the surface and underground mineral-extracting industries, the industry operator is obliged to demonstrate in the safety and health documentation that the risks to the workers at the workplace have been identified and assessed, including consideration of health-endangering atmospheres. Since exposure to NOR is not explicitly excluded, the directive could be considered as addressing aspects of radiation safety, particularly given that issues related to NOR in the oil and gas industry are now very well recognised. Moreover, the directive provides specific minimum requirements applicable to the off-shore and on-shore sectors separately, leaving no doubt that these requirements-provisions must be considered from the perspective of radiation safety, even though this is not explicitly stated.

22.3.3 Commentary to the section 22.3.2

The scope of the framework directive, covers, as declared*, all sectors of activity, both public and private (industrial, agricultural, commercial, administrative, service, educational, cultural, leisure, etc.).* There is no clear and unambiguous provision that excludes radiation hazards from the scope of its application. Based on this, it can be assumed that the requirements established by the directive itself, as well as by all subsequent individual directives, may be applied to radiation safety. In fact, the EU BSSD [4] is listed on the European Agency for Safety and Health at Work web site [114] alongside other individual OSH directives addressing physical risks, such as those related to noise, vibration, electromagnetic fields, and artificial optical radiation. Therefore, it could also be argued that ionising radiation is treated as a separate issue under this directive. This interpretation may be valid, to some extent, in the context of artificial radioactivity and the nuclear industry. However, the challenges associated with NORM have a slightly different character. In particular, given the specific characteristics of radiation sources in NORM-involving industries, as discussed in the section 22.1, application of various obligations, requirements and control measures from individual OSH directives to optimise hazard and risk management appears to be very well justified. For example, considering the Framework Directive, the Article 6 providing general obligations on employer require:

2. The employer shall implement the measures referred to in the first subparagraph of paragraph 1 on the basis of the following general principles of prevention:

(a) avoiding risks;
(b) evaluating the risks which cannot be avoided:

- *(c) combating the risks at source;*
- *(d) adapting the work to the individual, especially as regards the design of work places, the choice of work equipment and the choice of working and production methods, with a view, in particular, to alleviating monotonous work and work at a predetermined work-rate and to reducing their effect on health.*
- *(e) adapting to technical progress;*
- *(f) replacing the dangerous by the non-dangerous or the less dangerous;*
- *(g) developing a coherent overall prevention policy which covers technology, organization of work, working conditions, social relationships and the influence of factors related to the working environment;*
- *(h) giving collective protective measures priority over individual protective measures;*
- *(i) giving appropriate instructions to the workers.*

Moreover, the individual OSH directives are providing opportunities to include exposure to NOR almost directly into existing system of risk management and control. For example, looking into Directive on the protection of workers from the risks related to exposure to carcinogens, mutagens or reprotoxic substances at work [118] the required method of CMR substances allows directly include typical NORM (which, by the way, are CRM), see the Figure 22.

There is also an opportunity to develop a radiation protection system tailored to specific exposure scenarios by drawing on the provisions of individual OSH directives. In Poland, based on investigations and first legislative implementation at the eighties of twentieth century, regardless that in those times Poland was not yet a member of the EU, the system of radiation protection in underground mines have been developed based on EU OSH system. Considering requirements of the EU Directive 92/104/EEC on mineral-extracting industries, exposure to NOR, including radon progeny was identified as one, among other natural hazards in underground mines environment, such as methane, coal dust explosions, rock bursts, cave-ins, fires, water, gas and rock outbursts and climatic risk. All together were listed in Geological and Mining Law Act of 9 June 2011 [121] Official publication: *Dziennik Ustaw* ; Number: *2011/163/981*; Publication date: *2011-08-05*. In subsequent regulations*:*

- Regulation of the Minister for Energy of 23 November 2016 laying down detailed requirements for the operation of underground mining plants [122] Official publication: *Dziennik Ustaw* ; Number: *2017/1118* ; Publication date: *2017-06-09,*
- Regulation of the Minister for the Environment of 8 December 2017 on operating plans for mining plants [123] Official publication: *Dziennik Ustaw* ; Number: *2017/2293* ; Publication date: *2017-12-11,*

requirements concerning the control system of hazard caused by natural radioactivity in underground mines were specified as engineered controls, working procedures, personal protective equipment, delineation of areas, information, instruction, training and health surveillance. It is worth being underlined that first this system was developed outside radiation protection legislative system as there NOR were not considered at all. Later, after EU BSSD were introduced into Polish legislative system, some unifications were done. The details and history of this system is described in the dedicated article [124].

ANNEX III

LIMIT VALUES AND OTHER DIRECTLY RELATED PROVISIONS (ARTICLE 16)

A. LIMIT VALUES FOR OCCUPATIONAL EXPOSURE

Name of agent	EC No (1)	CAS No (2)	Limit values						Notation	Transitional measures
			8 hours (3)			Short-term (4)				
			mg/m^3 (5)	ppm (6)	f/ml (7)	mg/m^3 (5)	ppm (6)	f/ml (7)		
Hardwood dusts	—	—	2 (8)	—	—	—	—	—	—	Limit value 3 mg/m^3 until 17 January 2023
Chromium (VI) compounds which are carcinogens within the meaning of point (i) of Article 2(a) (as chromium)	—	—	0,005	—	—	—	—	—	—	Limit value 0,010 mg/m^3 until 17 January 2025 Limit value: 0,025 mg/m^3 for welding or plasma cutting processes or similar work processes that generate fume until 17 January 2025
Refractory ceramic fibres which are carcinogens within the meaning of point (i) of Article 2(a)	—	—	—	—	0,3	—	—	—	—	
Respirable crystalline silica dust	—	—	0,1 (9)	—	—	—	—	—	—	
Benzene	200-753-7	71-43-2	0,66	0,2	–	–	–	–	Skin (15)	Limit value 1 ppm (3,25 mg/m^3) until 5 April 2024. Limit value 0,5 ppm (1,65 mg/m^3) from 5 April 2024 until 5 April 2026.

Figure 22 CRM identification and characterisation according to the OSH directive on Directive 2004/37/EC [118]

In summary, when considered from the perspective of radiation protection in NORM-involving occupational exposure scenarios, the existing European OSH legislative framework may be regarded as complementary to the EU BSSD. It establishes a robust structure of obligations and preventive measures that, in many cases, can be effectively applied to workplaces involving NORM, without requiring substantial legislative revision.

The application of standard OSH measures – such as ventilation, dust control, and personal protective equipment – can often contribute to a reduction in exposure to ionising radiation in NORM-involving industries.

Maintaining radiation protection as a distinct discipline with its own regulation remains essential. System of radiation protection is based on integration of multiple exposure pathways – both internal and external – within the concept of effective dose. As defined by the ICRP, effective dose provides a risk-adjusted measure of total body exposure, enabling consistent application of dose limits, constraints, and reference levels across diverse exposure situations.

This integrated approach supports the graded regulatory control advocated by both the EU and international standards, allowing for proportionate measures based on the magnitude and nature of the exposure. In this context, NORM-related activities are typically treated as planned exposure situations, and the existing OSH framework can serve as a practical foundation for implementing radiation protection requirements in alignment with the broader system of radiological protection.

The EU BSSD supports the radiation protection system through the involvement of educated and trained professionals, such as Radiation Protection Experts (as defined in Article 82 of the EU BSSD), who are responsible for ensuring a high standard of radiation protection in the workplace. Radiation protection measures should be implemented in addition to the existing occupational health and safety provisions already in place at the workplace.

22.4 ICRP Publication 142

The ICRP report on radiological protection from naturally occurring radioactive material (NORM) in industrial processes [64], raises the problem of occupational exposure in NORM-involving industries. General recommendations are providing in terms of principles of radiation protection dealing with applicable criteria and approaches to exposure situation controls. From the perspective of this report, it is important that it directly requires the integration of radiation safety measures into existing OSH systems. Considering optimization, first it should be underlined that:

(63) Optimisation of the protection of human health and the environment in industries involving NORM is implemented through a process that involves:

> *(a) assessment of the exposure situation;*
>
> *(b**) identification of possible protective options to maintain or reduce exposure to as low as reasonably achievable, taking into account economic and societal factors;***
>
> *(c) selection and implementation of the most appropriate protective options under the prevailing circumstances; and*
>
> *(d) regular review of the Radiological protection from naturally occurring radioactive material (NORM) in industrial processes exposure situation to evaluate if there is a need for corrective actions, or if new opportunities for improving protection have emerged.*

And then it is underlined that:

(71) 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 workplace hazards, such as airborne dust, will also restrict radiation exposures, and an integrated approach to worker protection is recommended.

(79) 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, and may, in fact, be adequate for radiological protection without further addition. Where additional radiological protection controls are considered necessary, these should be integrated into the wider safety strategy as far as practicable.

Given the stringency of this requirement, its implementation—if a decision is made to adopt it—will likely require a gradual and coordinated approach.

22.5 Part 4 - Suggestions for further considerations

The review of existing European OSH system provides evidence that this is suitable framework to include radiation safety measures oriented towards hazard related to NORM. The structure of OSH system based on individual directives covering different risk and hazards as well as different type of workplaces is providing wide possibility of such integration depending on the specific NORM involving activities.

First step to be considered worth of implementation should be based on the ICRP 142 recommendation as such:

4.1.3.1. Characterization of the situation

(82) This characterization, determining who is exposed, when, where, and how, is an important starting point for the protection of workers. It includes characterization of the source, with the aim of identifying the distribution of NORM radionuclides and their activity concentrations throughout the industrial process, Radiological protection from naturally occurring radioactive material (NORM) in industrial processes including mode of exposure, chemical and physical characteristics of particulates, NORM distribution, and activity concentrations at all stages of the industrial process in both operational and maintenance conditions. Feed materials, intermediates, residues, wastes (including contamination of the plant), and discharges to the environment should be considered, as well as radon and thoron.

(83) Characterising the source will help to identify the main exposure pathways to workers, the public, and the environment. In terms of exposure of 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 through inhalation) received from work with NORM.

- Once such data are collected, the most relevant individual OSH directive can be identified and considered applicable to NORM in each specific case. Without the need for significant modifications, it is highly likely that all subsequent requirements outlined in ICRP Publication 142—such as:
  - *4.1.3.4. Delineation of areas*
  - *4.1.3.5. Engineered controls*
  - *4.1.3.6. Working procedures*

- *4.1.3.7. Information, instruction, and training*
- *4.1.3.8. Personal protective equipment*
- *4.1.3.11. Health surveillance*

It may be worth considering a general modification to the Occupational Safety and Health (OSH) system. One possible approach could involve adding a clarification to the preamble of the OSH Framework Directive, stating that:

> "This directive may apply to situations where exposure caused by Naturally Occurring Radioactive Material (NORM) is non-negligible from a radiation protection perspective."

As a broader solution, it might also be of consideration to:

- Expand the existing list of 41 substances covered under the directive on carcinogens, mutagens, and reprotoxic substances (CMR) to include typical NORM-related substances, or
- Develop an additional individual OSH directive that specifically addresses NORM exposure scenarios in non-nuclear industries.

The idea of raising this issue could potentially fall within the remit of the Advisory Committee on Safety and Health at Work, established by the Council Decision of 22 July 2003 [112]. Among its responsibilities, the Committee may be expected to identify emerging risks and consider appropriate legislative or policy responses:

> *Article 2 1. The Committee **shall** have the task of assisting the Commission in the preparation, implementation and evaluation of activities in the fields of safety and health at work. This task shall cover the public and the private sectors of the economy.*
>
> *(c) draw the Commission's attention to areas in which there is an apparent need for new knowledge and for suitable training and research measures;*

Strengthening the role of radiation protection professionals in the implementation of occupational safety and health measures to ensure the proper application of radiation protection principles and the reduction of workers' effective dose is crucial.

23. Additional aspects remain to be addressed in future

As part of the work carried out under WP 5.5, in addition to the topics already discussed in detail, several issues were identified that go beyond the scope of this document and the work package itself, but which should nonetheless be addressed in the future. These topics include, in particular, the following:

I. Legal and economic support of NORM waste recovery - NORM waste often possesses useful physical properties, which—given the current limited availability of natural raw materials—makes it a potential substitute in various applications. In addition to reuse within the original industrial process, there is growing interest in utilizing NORM waste in construction (including non-residential buildings) and in environmental remediation activities. Some potential, though more limited, uses are also emerging in agriculture. However, the reuse of NORM waste in these sectors is currently hindered by the absence of clear legislative criteria. In particular, permissible levels of naturally occurring radionuclides (NOR) for such products have not yet been established. Considering the scarcity of critical raw materials, the use of certain types of NORM waste for the recovery of valuable elements—including radionuclides—appears promising. There are frequent initiatives to extract such elements from disposed mining waste. For example, the recovery of critical elements or barite from black coal mining sediments has been tested. Deliverable 5.11 [125] of this project discusses a case study involving plans to recover uranium from bioheap leachate solutions at a Ni-Cu-Zn-Co mine. However, all of these cases have demonstrated that the current legal framework poses significant obstacles to the practical implementation of such recovery activities and is not yet equipped to support the use of NORM waste for extracting valuable elements. Therefore, the development of a dedicated legal framework to authorize and regulate such activities is urgently needed.

II. Protection against exposure to radon and radon progeny – At a many of NORM-involving workplaces, radon and its progeny, and in some cases also thoron and its progeny, are significant sources of workers‘ exposure to radiation. At certain types of workplaces – particularly those located underground – radon and its progeny can be the main source of exposure. Occupational safety and health (OSH) measures, such as workplace ventilation, can also effectively reduce exposure to both radon, thoron and their decay products. In addition to identifying and implementing optimal targeted measures to reduce exposure, the measurement of input values for estimating exposure itself also presents a challenge. The RadoNorm project addresses this issue in detail, particularly in Deliverables 2.7 [126] and 5.9 [127] whose conclusions we refer to here as well.

III. Considerations of environment/ecosystem/non-human biota – There is an international consensus on the need to consider also exposure of non-human biota to radiation. In practice, sufficient data are not yet available, so the approach remains to be anthropocentric. Environmental radiation assessments are sometimes conducted using specialized models, even though they’re not required by regulation. Radiation effects on ecosystems can be difficult to detect—not because they’re insignificant, but because they’re often masked by other stressors like chemical pollution or habitat degradation. These overlapping factors make it challenging to isolate radiation’s impact, yet considering it remains essential for comprehensive environmental protection.

24. Concluding remarks

A key challenge across the issues discussed in this report is that the materials and terms involved are often poorly defined. For instance, NORM (Naturally Occurring Radioactive Material), recommended by the IAEA, refers only to materials containing natural radionuclides, without specifying their source or chemical form. The definition relies on strict criterion, “no significant amounts of artificial radionuclides” while exact definition of “significant amounts” would be a regulatory decision. Similarly, radioactive material is a material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity.

The EU Basic Safety Standards avoid the abbreviation altogether, instead using more descriptive phrases such as "naturally occurring radioactive materials" or "natural radiation sources." To provide clarity, the EU BSSD identifies specific industries where such materials are typically encountered and could present exposure concerns.

Such materials originate from or are generated at workplaces identified based on binding positive lists defined in national legislation taking into account list of industrial sectors specified in Annex VI of the EU BSSD. The requirements of the EU BSSD and the respective national legislation implementing the Directive apply to such identified workplaces. The positive lists may differ, as their definition is the responsibility of individual Member States. A positive list should be a result of a national survey, and it is, of course, a legitimate question to ask how complete these positive lists actually are. To address this, a more precise definition of NORM could be introduced on the EU level. This revised definition would help identify a coherent category of materials requiring specific treatment under radiation protection, OSH, and waste management frameworks.

The criteria for decision-making in waste management are firstly set in terms of radionuclides activity concentration. The second set of criteria is expressed in terms of effective dose, which should account for all 30 radionuclides present in the natural decay series and potassium, as well as various exposure pathways and exposure scenarios. Such an assessment is usually very complex and requires evaluation by a qualified specialist, e.g. radiation protection expert as suggested by the EU BSSD.

Regulatory framing, while sufficient for establishing legal obligations, poses challenges for industrial operators unfamiliar with radiation protection. From their perspective, seemingly ordinary materials suddenly become subject to complex compliance requirements. Furthermore, societal associations of "radioactivity" with nuclear weapons or reactor accidents lead to reluctance in acknowledging its presence, often resulting in avoidance or denial. The same issue can be observed in the area of conventional waste treatment and management.

25. References

[1] International Atomic Energy Agency, IAEA nuclear safety and security glossary: terminology used in nuclear safety, nuclear security, radiation protection and emergency preparedness and response, 2022 (Interim) Edition. Vienna: International Atomic Energy Agency, 2022.

[2] European Parliament, Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste. 2011. Accessed: May 26, 2025. [Online]. Available: http://data.europa.eu/eli/dir/2011/70/oj/eng

[3] GEMET, 'inert waste'. Accessed: July 13, 2025. [Online]. Available: https://www.eionet.europa.eu/gemet/en/concept/4283

[4] European Parliament, Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. 2014. Accessed: Aug. 12, 2024. [Online]. Available: http://data.europa.eu/eli/dir/2013/59/2014-01-17/eng

[5] INTERNATIONAL ATOMIC ENERGY AGENCY et al., Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. INTERNATIONAL ATOMIC ENERGY AGENCY, 2014. doi: 10.61092/iaea.u2pu-60vm.

[6] B. Michalik et al., 'Report on available solutions and technologies applicable for legacy site remediation, NORM involving industries and treatment of radioactivity in water', RadoNorm Deliverable D5.11, 2024. [Online]. Available: https://www.radonorm.eu/wp-content/uploads/file_exchange/D5.11_Report-on-available-solutions-and-technologies-applicable-for-legacy-site-remediation-NORM-involving-industries-and-treatment-of-radioactivity-in-water.pdf

[7] J. M. Popic, L. Urso, and B. Michalik, 'Assessing the exposure situations with naturally occurring radioactive materials across European countries by means of the e-NORM survey', Science of The Total Environment, vol. 905, p. 167065, Dec. 2023, doi: 10.1016/j.scitotenv.2023.167065.

[8] B. Michalik, 'Is it necessary to raise awareness about technologically enhanced naturally occurring radioactive materials?', J. Environ. Monit., vol. 11, no. 10, p. 1825, 2009, doi: 10.1039/b904911h.

[9] European Parliament, Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC. 2009. Accessed: May 27, 2025. [Online]. Available: http://data.europa.eu/eli/dir/2006/21/2009-08-07/eng

[10] European Parliament, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance). 2008. Accessed: May 25, 2025. [Online]. Available: http://data.europa.eu/eli/dir/2008/98/oj/eng

[11] Council of the European Union, Ed., The Euratom Treaty: consolidated version 2016. Luxembourg: Publications Office, 2016. doi: 10.2860/45054.

[12] European Commission, '99/669/EC, Euratom: Commission Recommendation of 15 September 1999 on a classification system for solid radioactive waste'. Accessed: May 26, 2025. [Online]. Available: https://eur-lex.europa.eu/eli/reco/1999/669/oj/eng

[13] European Commission. Directorate General for Energy., Benchmarking analysis of member states approaches to definition of national inventories radioactive waste and spent fuel. LU: Publications Office, 2020. Accessed: May 29, 2025. [Online]. Available: https://data.europa.eu/doi/10.2833/460048

[14] International Atomic Energy Agency, Ed., Classification of radioactive waste: general safety guide. in Safety standards series, no. GSG 1. Vienna: International Atomic Energy Agency, 2009.

[15] European Commission. Directorate General for Energy., IDOM Consulting, Engineering, Architecture SAU., and BGE Technology GmbH., Study on radioactive waste classification

schemes in the European Union: final report. LU: Publications Office, 2023. Accessed: May 29, 2025. [Online]. Available: https://data.europa.eu/doi/10.2833/987498

[16] D. Theobald, 'What is ultrafiltration and what are ultrafiltration processes in wastewater?', Water Technology. Accessed: May 29, 2025. [Online]. Available: https://www.watertechonline.com/wastewater/article/15547515/what-is-ultrafiltration-and-what-are-ultrafiltration-processes-in-wastewater

[17] REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT on progress of implementation of Council Directive 2011/70/EURATOM and an inventory of radioactive waste and spent fuel present in the Community's territory and the future prospects THIRD REPORT. 2024. Accessed: May 29, 2025. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52024DC0197

[18] M. Wysocka, S. Chałupnik, I. Chmielewska, E. Janson, W. Radziejowski, and K. Samolej, 'Natural Radioactivity in Polish Coal Mines: An Attempt to Assess the Trend of Radium Release into the Environment', Mine Water Environ, vol. 38, no. 3, pp. 581–589, Sept. 2019, doi: 10.1007/s10230-019-00626-0.

[19] S. Schmid and J. Wiegand, 'Radionuclide Contamination of Surface Waters, Sediments, and Soil Caused by Coal Mining Activities in the Ruhr District (Germany)', Mine Water and the Environment, vol. 22, no. 3, pp. 130–140, Nov. 2003, doi: 10.1007/s10230-003-0013-z.

[20] D. Bednář, E. Geršlová, P. Otáhal, and D. Vöröš, 'Effects of mine water discharge on river sediments: metal fate and behaviour, Upper Silesian Coal Basin', Environ Earth Sci, vol. 83, no. 2, p. 71, Jan. 2024, doi: 10.1007/s12665-023-11356-6.

[21] S. Chalupnik, B. Michalik, M. Wysocka, K. Skubacz, and A. Mielnikow, 'Contamination of settling ponds and rivers as a result of discharge of radium-bearing waters from Polish coal mines', Journal of Environmental Radioactivity, vol. 54, no. 1, pp. 85–98, Jan. 2001, doi: 10.1016/S0265-931X(00)00168-5.

[22] International Atomic Energy Agency, Application of the Concept of Exemption. in General Safety Guide, no. GSG-17. Vienna: INTERNATIONAL ATOMIC ENERGY AGENCY, 2023. [Online]. Available: https://www.iaea.org/publications/15293/application-of-the-concept-of-exemption

[23] International Atomic Energy Agency, Application of the Concept of Clearance. in General Safety Guide, no. GSG-18. Vienna: INTERNATIONAL ATOMIC ENERGY AGENCY, 2023. [Online]. Available: https://www.iaea.org/publications/15291/application-of-the-concept-of-clearance

[24] International Atomic Energy Agency, Policies and strategies for radioactive waste management. in IAEA nuclear energy series, no. NW-G-1.1. Vienna: International Atomic Energy Agency, 2009. [Online]. Available: https://www.iaea.org/publications/8116/policies-and-strategies-for-radioactive-waste-management

[25] International Atomic Energy Agency, Policies and Strategies for the Management of NORM Residues and Wastes. in IAEA Nuclear Energy Series. International Atomic Energy Agency, 2024. doi: 10.61092/iaea.zg6m-a7fl.

[26] 'Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management: —Third Review Meeting of the Contracting Parties—', atomos, vol. 51, no. 8, pp. 640–640, 2009, doi: 10.3327/jaesjb.51.8_640.

[27] 'Radioactive waste and spent fuel - European Commission'. Accessed: May 31, 2025. [Online]. Available: https://energy.ec.europa.eu/topics/nuclear-energy/radioactive-waste-and-spent-fuel_en

[28] State Office for Nuclear Safety, '4th National Report from the Czech Republic - Implementation of Council Directive 2011/70/EURATOM of 19 July 2011 Establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste', 2024. [Online]. Available: http://sujb.gov.cz/en/reports/

[29] Danish Health Authority, Radiation Protection, '4th National Report from Denmark - Implementation of Council Directive 2011/70/EURATOM of 19 July 2011 Establishing a

Community framework for the responsible and safe management of spent fuel and radioactive waste', 2024.

[30] Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection, '4th National Report from Germany - Implementation of Council Directive 2011/70/EURATOM of 19 July 2011 Establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste', Aug. 2024. [Online]. Available: https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Nukleare_Sicherheit/durchfuehrungsbericht_2011_70_euratom_en_bf.pdf

[31] National Inspectorate for Nuclear Safety and Radiation Protection (ISIN) and Government of Italy, '4th National Report from Italy - Implementation of Council Directive 2011/70/EURATOM of 19 July 2011 Establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste', 2024. [Online]. Available: https://energy.ec.europa.eu/topics/nuclear-energy/radioactive-waste-and-spent-fuel_en#national-programmes-and-reports

[32] Ministry of Infractructure and the Environment of the Netherlands and The Authority for Nuclear Safety and Radiation Protection (ANVS), 'The national programme for the management of radioactive waste and spent fuel.', The Hague, 09-08–2016, 2016. [Online]. Available: https://english.autoriteitnvs.nl/documents/report/2016/08/09/the-national-programme-for-the-management-of-radioactive-waste-and-spent-fuel

[33] Ministerstwo Przemysłu, '4th National Report from Poland - Implementation of Council Directive 2011/70/EURATOM of 19 July 2011 Establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste', Warsaw, 2024. [Online]. Available: https://energy.ec.europa.eu/topics/nuclear-energy/radioactive-waste-and-spent-fuel_en#national-programmes-and-reports

[34] ENRESA, '7th GENERAL RADIOACTIVE WASTE PLAN', Madrid, Dec. 2023. [Online]. Available: https://www.enresa.es/documentos/EN_7-plan-general-residuos-radiactivos.pdf

[35] '3rd National Report from Spain - Implementation of Council Directive 2011/70/EURATOM of 19 July 2011 Establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste', 2021. [Online]. Available: https://energy.ec.europa.eu/topics/nuclear-energy/radioactive-waste-and-spent-fuel_en#national-programmes-and-reports

[36] M. García-Talavera, J. Mrdakovic Popic, P. Gorts, S. Pepin, and K. Jones, 'Application of the concepts of exemption and clearance to the regulation of naturally occurring radioactive material (NORM) across HERCA countries', HERCA, HERCA WG NAT Report 2021, 2021.

[37] Publications Office of the European Union, 'Waste hierarchy - EUR-Lex'. Accessed: May 25, 2025. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum:waste_hierarchy

[38] European Commission, Directorate-General for Environment, 'Waste Framework Directive - European Commission'. Accessed: May 25, 2025. [Online]. Available: https://environment.ec.europa.eu/topics/waste-and-recycling/waste-framework-directive_en

[39] Commission Decision of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste (notified under document number C(2000) 1147) (Text with EEA relevance) (2000/532/EC)Text with EEA relevance. 2023. Accessed: May 30, 2025. [Online]. Available: http://data.europa.eu/eli/dec/2000/532/2023-12-06/eng

[40] 'Regulation - 1272/2008 - EN - clp regulation - EUR-Lex'. Accessed: May 27, 2025. [Online]. Available: https://eur-lex.europa.eu/eli/reg/2008/1272/oj/eng

[41] European Parliament, Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste, consolidated version. 2018. Accessed: July 23, 2025. [Online]. Available: http://data.europa.eu/eli/dir/1999/31/2018-07-04/eng

[42] European Commission, 2003/33/EC: Council Decision of 19 December 2002 establishing criteria and procedures for the acceptance of waste at landfills pursuant to Article 16 of and Annex II to

Directive 1999/31/EC, vol. 011. 2002. Accessed: July 23, 2025. [Online]. Available: http://data.europa.eu/eli/dec/2003/33(1)/oj/eng

[43] European Parliament, Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial and livestock rearing emissions (integrated pollution prevention and control) (Recast) (Text with EEA relevance). 2024. Accessed: July 23, 2025. [Online]. Available: http://data.europa.eu/eli/dir/2010/75/2024-08-04/eng

[44] European Environment Agency, 'European Industrial Emissions Portal'. Accessed: July 23, 2025. [Online]. Available: https://industry.eea.europa.eu

[45] European Commission. Directorate-General for Environment, 'Publication of new EU environmental standards for the waste incineration sector - European Commission'. Accessed: July 23, 2025. [Online]. Available: https://commission.europa.eu/news-and-media/news/publication-new-eu-environmental-standards-waste-incineration-sector-2019-12-18_en

[46] European Commission: Directorate-General for Environment, Radiation Protection No. 122 II: Practical Use of the Concepts of Clearance and Exemption – Part II: Application of the Concepts of Exemption and Clearance to Natural Radiation Sources. in Radiation protection series. Luxembourg: European Commission, 2002.

[47] International Atomic Energy Agency, Ed., Management of NORM residues. in TECDOC, no. 1712. Vienna: Internat. Atomic Energy Agency, 2013. [Online]. Available: https://www-pub.iaea.org/MTCD/Publications/PDF/TE-1712_web.pdf

[48] T. Doksanská and A. Kelnarová, 'Disequilibrium in natural decay series in samples from Czech water treatment plants: Uranium, radium and thorium isotopes determination', Journal of Environmental Radioactivity, vol. 281, p. 107580, Jan. 2025, doi: 10.1016/j.jenvrad.2024.107580.

[49] International Atomic Energy Agency, Radiation Protection and NORM Residue Management in the Titanium Dioxide and Related Industries. in Safety Reports Series, no. 76. Vienna: INTERNATIONAL ATOMIC ENERGY AGENCY, 2012. [Online]. Available: https://www.iaea.org/publications/8884/radiation-protection-and-norm-residue-management-in-the-titanium-dioxide-and-related-industries

[50] K. Karfopoulos et al., 'Results of the joint IAEA/EEAE Intercomparison exercise on radioanalytical characterization of NORM samples in the European region', Radiation Protection Dosimetry, vol. 201, no. 3, pp. 223–246, Mar. 2025, doi: 10.1093/rpd/ncaf003.

[51] International Atomic Energy Agency, Ed., Radiation protection and the management of radioactive waste in the oil and gas industry. in Safety reports series, no. 34. Vienna: IAEA, 2003. [Online]. Available: https://www-pub.iaea.org/mtcd/publications/pdf/pub1171_web.pdf

[52] D. J. Karangelos, N. P. Petropoulos, M. J. Anagnostakis, E. P. Hinis, and S. E. Simopoulos, 'Radiological characteristics and investigation of the radioactive equilibrium in the ashes produced in lignite-fired power plants', Journal of Environmental Radioactivity, vol. 77, no. 3, pp. 233–246, Jan. 2004, doi: 10.1016/j.jenvrad.2004.03.009.

[53] W. Schroeyers, Ed., Naturally occurring radioactive materials in construction: intergrating radiation protection in reuse (cost action Tu1301 Norm4Building). in Woodhead Publishing Series in Civil and Structural Engineeing. Duxford, United Kingdom: Woodhead Publishing, An Imprint of Elsevier, 2017.

[54] R. Virta, 'Implementing nuclear non-proliferation in Finland. Regulatory control, international cooperation and the Comprehensive Nuclear-Test-Ban Treaty', Vantaa, STUK-B 343, 2025. [Online]. Available: https://www.julkari.fi/bitstream/handle/10024/151627/stuk-b343.pdf

[55] OECD, More than Just Concrete Realities: The Symbolic Dimension of Radioactive Waste Management. in Radioactive Waste Management. OECD, 2010. doi: 10.1787/9789264097971-en.

[56] B. Michalik, S. Pépin, and N. Tsurikov, 'European Waste Catalogue – a platform for a common approach to norm and other industrial waste', in Naturally occurring radioactive material (NORM

VI): proceedings of the sixth International Symposium on Naturally Occurring Radioactive Material ... held in Marrakesh, Morocco, 22 - 26 March 2010, Vienna: Internat. Atomic Energy Agency, 2010, pp. 217–241. [Online]. Available: https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1497_web.pdf

[57] S. Keith et al., 'HEALTH EFFECTS', in Toxicological Profile for Uranium, Agency for Toxic Substances and Disease Registry (US), 2013. Accessed: May 30, 2025. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK158798/

[58] H. Ishimori, K. Endo, T. Ishigaki, K. Yamada, and M. Yamada, 'Multiphysics of seismic analysis and reactive chemical transport analysis for long-term environmental safety evaluation of RC-built hazardous waste landfill', JGS Special Publication, vol. 9, no. 4, pp. 136–141, Oct. 2021, doi: 10.3208/jgssp.v09.cpeg114.

[59] European Environment Agency, 'Land use'. Accessed: July 23, 2025. [Online]. Available: https://www.eea.europa.eu/en/topics/in-depth/land-use

[60] J. A. Goldstone, 'The Rise of the West—or Not? A Revision to Socio-economic History', Sociological Theory, vol. 18, no. 2, pp. 175–194, July 2000, doi: 10.1111/0735-2751.00094.

[61] ERIH - European Route of Industrial Heritage e.V., 'Industrial History of European Countries – ERIH'. Accessed: July 24, 2025. [Online]. Available: https://www.erih.net/how-it-started/industrial-history-of-european-countries

[62] J. H. L. Voncken, 'Introduction—History of Coal Mining in South Limburg/Aachen Area/Campine Coalfield', in SpringerBriefs in Earth Sciences, Cham: Springer International Publishing, 2020, pp. 1–24. doi: 10.1007/978-3-030-18286-1_1.

[63] European Association for Coal and Lignite aisbl, 'EURACOAL statistics', powering transition in Europe. Accessed: July 24, 2025. [Online]. Available: https://euracoal.eu/info/euracoal-eu-statistics/

[64] International Commission on Radiological Protection, ICRP Publication 142: Radiological protection from naturally occurring radioactive material (NORM) in industrial processes P. in Annals of the ICRP, no. volume 48, no. 4 (2019). London: SAGE, 2019.

[65] O. Sykes, 'Looking back to look forward: Reflecting on the legacy and future of the European spatial development perspective', TrAESOP, vol. 4, no. 2, pp. 95–98, Dec. 2020, doi: 10.24306/traesop.2020.02.001.

[66] H. Haanes, S. Dahlgren, and A. L. Rudjord, 'Cold season dose rate contributions from gamma, radon, thoron or progeny in legacy mines with high natural background radiation', Radiation Protection Dosimetry, vol. 199, no. 12, pp. 1284–1294, July 2023, doi: 10.1093/rpd/ncad178.

[67] J. Mantero et al., 'Pit lakes from Southern Sweden: natural radioactivity and elementary characterization', Sci Rep, vol. 10, no. 1, Aug. 2020, doi: 10.1038/s41598-020-70521-0.

[68] B. Michalik, M. Wysocka, M. Bonczyk, K. Samolej, and I. Chmielewska, 'Long term behaviour of radium rich deposits in a lake ecosystem', Journal of Environmental Radioactivity, vol. 222, p. 106349, Oct. 2020, doi: 10.1016/j.jenvrad.2020.106349.

[69] B. Michalik et al., 'A methodology for the systematic identification of naturally occurring radioactive materials (NORM)', Science of The Total Environment, vol. 881, p. 163324, July 2023, doi: 10.1016/j.scitotenv.2023.163324.

[70] M. K. Sneve, J. M. Popic, and K. Siegien-Iwaniuk, 'Regulatory supervision of legacy sites: The process from recognition to resolution. Report of an international workshop, Lillehammer, 21-23 November 2017.', NRPA, Østerås: Statens strålevern, StrålevernRapport 2018:4, Apr. 2018. [Online]. Available: https://www.dsa.no/en/publications/stralevernrapport-4-2018-regulatory-supervision-of-legacy-sites/Str%25C3%25A5levernRapport%2520_04-2018_LegacyWS-Report_Lillehammer.pdf

[71] Nuclear Energy Agency, Challenges in Nuclear and Radiological Legacy Site Management: Towards a Common Regulatory Framework. in Radiological Protection, no. 7419. OECD, 2020. doi: 10.1787/ccb40709-en.

[72] M. K. Sneve and P. Strand, 'Regulatory supervision of legacy sites: The process from recognition to resolution. Report of an international workshop, Oslo, 17–19 November 2015.', NRPA, Østerås: Statens strålevern, StrålevernRapport 2016:5, Apr. 2016. [Online]. Available: https://www.dsa.no/publikasjoner/stralevernrapport-5-2016-regulatory-supervision-of-legacy-sites/StralevernRapport_05-2016.pdf

[73] M. K. Sneve, 'Regulatory Framework of Decommissioning, Legacy Sites and Wastes from Recognition to Resolution: Building Optimization into the Process. Report of an international workshop. Tromso, 29 October – 1 November 2019.', DSA, Oslo, Norway, DSA Report 5, 2020. [Online]. Available: https://www.dsa.no/publikasjoner/dsa-rapport-5-2020-regulatory-framework-of-decommissioning-legacy-sites-and-wastes-from-recognition-to-resolution/DSA-rapport%2005-2020%20Regulatory%20Framework%20komplett.pdf

[74] K. L. Kuhlman, J. Bartol, A. Carter, A. Lommerzheim, and J. Wolf, 'Scenario development for safety assessment in deep geologic disposal of high-level radioactive waste and spent nuclear fuel: A review', Risk Analysis, vol. 44, no. 8, pp. 1850–1864, Aug. 2024, doi: 10.1111/risa.14276.

[75] P. M. Chapman, 'Determining when contamination is pollution — Weight of evidence determinations for sediments and effluents', Environment International, vol. 33, no. 4, pp. 492–501, May 2007, doi: 10.1016/j.envint.2006.09.001.

[76] J. Brown et al., 'D9.61 – guidance to select level of complexity. Euratom CONCERT European Joint Programme TERRITORIES Project Deliverable Report.', European Joint Programme for the Integration of Radiation Protection Research H2020 – 662287, 2019. [Online]. Available: https://www.meenas.eu/wp-content/uploads/2023/05/D9.61_Guidance-to-select-level-of-complexity_30072019.pdf

[77] Argonne National Laboratory, Environmental Science Division, 'RESRAD Family of Codes'. Accessed: July 23, 2025. [Online]. Available: https://resrad.evs.anl.gov/

[78] European Parliament, Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds (codified version). 2019. Accessed: July 23, 2025. [Online]. Available: http://data.europa.eu/eli/dir/2009/147/2019-06-26/eng

[79] European Parliament, Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. 2013. Accessed: July 23, 2025. [Online]. Available: http://data.europa.eu/eli/dir/1992/43/2013-07-01/eng

[80] European Commission: Directorate-General for Environment, Radiation Protection No. 122: Practical use of the concepts of clearance and exemption. in Radiation protection series. Luxembourg: Office for Official Publications of the European Communities, 2000.

[81] European Commission, Directorate-General for Energy et al., Radiation Protection No. 135: Effluent and dose control from European Union NORM industries – Assessment of current situation and proposal for a harmonised Community approach – Volume 1, main report. in Radiation protection series. Publications Office, 2003. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/99c70673-26f1-11e6-86d0-01aa75ed71a1

[82] International Atomic Energy Agency, 'ENVIRONET - IAEA Network of Environmental Management and Remediation'. Accessed: July 23, 2025. [Online]. Available: https://nucleus.iaea.org/sites/connect/ENVIRONETpublic/SitePages/Home.aspx

[83] International Commission on Radiological Protection, ICRP Publication 39: Principles for limiting exposure of the public to natural sources of radiation. in Annals of the ICRP, no. 14,1. Oxford Frankfurt a.M.: Pergamon Pr, 1984. [Online]. Available: https://www.icrp.org/publication.asp?id=ICRP%20Publication%2039

[84] International Commission on Radiological Protection, ICRP Publication 60: 1990 recommendations of the International Commission on Radiological Protection, 1. ed. in ICRP publication Radiation protection, no. 60. Oxford: Pergamon Press, 1991. [Online]. Available: https://www.icrp.org/publication.asp?id=icrp%20publication%2060

[85] International Atomic Energy Agency, INTERNATIONAL BASIC SAFETY STANDARDS FOR PROTECTION AGAINST IONIZING RADIATION AND FOR THE SAFETY OF RADIATION

SOURCES. in Safety Series, no. 115. Vienna: International Atomic Energy Agency, 1996. [Online]. Available: https://gnssn.iaea.org/Superseded%20Safety%20Standards/Safety_Series_115_1996_Pub996_EN.pdf

[86] European Commission, Directorate-General Environment, Nuclear Safety and Civil Protection Radiation Protection Division, Radiation Protection No. 65: Principles and methods for establishing concentrations and quantities (exemption values) below which reporting is not required in the European directive, vol. 65. in Radiation protection series, vol. 65. Luxembourg: European Commission, 1993. [Online]. Available: https://circabc.europa.eu/ui/group/8f5f9424-a7ef-4dbf-b914-1af1d12ff5d2/library/b41db14e-c68f-4473-b4d1-5ed185fd0fbf/details?download=true

[87] European Parliament, Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation. 1996.

[88] C. Nuccetelli et al., 'Legislative aspects', in Naturally Occurring Radioactive Materials in Construction, Elsevier, 2017, pp. 37–60. doi: 10.1016/b978-0-08-102009-8.00004-9.

[89] International Atomic Energy Agency, Application of the concepts of exclusion, exemption and clearance. IAEA Safety Standards Series No. RS-G-1.7. in General safety guide. Vienna: INTERNATIONAL ATOMIC ENERGY AGENCY, 2004. [Online]. Available: https://www.iaea.org/publications/7118/application-of-the-concepts-of-exclusion-exemption-and-clearance

[90] International Atomic Energy Agency, Derivation of activity concentration values for exclusion, exemption and clearance. Safety Reports Series No. 44. in Safety reports series. Vienna: INTERNATIONAL ATOMIC ENERGY AGENCY, 2005. [Online]. Available: https://www.iaea.org/publications/7131/derivation-of-activity-concentration-values-for-exclusion-exemption-and-clearance

[91] UNSCEAR, Sources and effects of ionizing radiation: United Nations Scientific Committee on the Effects of Atomic Radiation: UNSCEAR 2000 report to the General Assembly, with scientific annexes. New York: United Nations, 2000. [Online]. Available: https://www.unscear.org/unscear/en/publications/2000_1.html

[92] D. G. Wymer, 'Managing exposure to NORM — consensus or chaos? Keynote Address', in Naturally occurring radioactive material: (NORM V); proceedings of the Fifth International Symposium on Naturally Occurring Radioactive Material, International Atomic Energy Agency, Ed., in Publication / Division of Scientific and Technical Information, International Atomic Energy Agency. Seville: IAEA, 2008. [Online]. Available: https://www-pub.iaea.org/MTCD/Publications/PDF/Pub1326_web.pdf

[93] 'TENORMHARM Contract-No. FIGM-CT-2001-00174 "New approach to assessment and reduction of health risk and environmental impact originating from TENORM according to requirements of EU Directive 96/29/Euratom" - Final report on WP2 "Dose assessment, mitigation methods, remedial actions and monitoring strategies"'. [Online]. Available: https://cordis.europa.eu/project/id/FIGM-CT-2001-00174/results

[94] International Commission on Radiological Protection, ICRP 142: Radiological protection from naturally occurring radioactive material (NORM) in industrial processes. in Annals of the ICRP, no. volume 48, no. 4 (2019). London: SAGE, 2019.

[95] International Commission on Radiological Protection, ICRP Publication 103: The 2007 recommendations of the International Commission on Radiological Protection. in ICRP publication, no. 103. Oxford: Elsevier, 2007.

[96] H. Bateman, 'The solution of a system of differential equations occurring in the theory of radio-active transformations.', Proceedings of the Cambridge Philosophical Society, Mathematical and physical sciences., vol. 15, pp. 423–427, 1910 1908.

[97] N. Mitchell, D. Pérez-Sánchez, and M. C. Thorne, 'A review of the behaviour of U-238 series radionuclides in soils and plants', J. Radiol. Prot., vol. 33, no. 2, pp. R17–R48, June 2013, doi: 10.1088/0952-4746/33/2/r17.

[98] A. W. Nelson et al., 'Understanding the Radioactive Ingrowth and Decay of Naturally Occurring Radioactive Materials in the Environment: An Analysis of Produced Fluids from the Marcellus Shale', Environ Health Perspect, vol. 123, no. 7, pp. 689–696, July 2015, doi: 10.1289/ehp.1408855.

[99] International Commission on Radiological Protection, ICRP Publication 144: Dose Coefficients for External Exposures to Environmental Sources. in Annals of the ICRP, no. volume 49, no. 2 (2020). London: SAGE, 2020.

[100] International Commission on Radiological Protection, ICRP Publication 137: Occupational intakes of radionuclides. Part 3. in Annals of the ICRP, no. volume 46, no. 3/4 (2017). London: SAGE, 2018.

[101] B. Michalik, G. De With, and W. Schroeyers, 'Measurement of radioactivity in building materials – Problems encountered caused by possible disequilibrium in natural decay series', Construction and Building Materials, vol. 168, pp. 995–1002, Apr. 2018, doi: 10.1016/j.conbuildmat.2018.02.044.

[102] B. Michalik, J. Brown, and P. Krajewski, 'The fate and behaviour of enhanced natural radioactivity with respect to environmental protection', Environmental Impact Assessment Review, vol. 38, pp. 163–171, Jan. 2013, doi: 10.1016/j.eiar.2012.09.001.

[103] B. Michalik, 'NORM contaminated area identification using radionuclides activity concentration pattern in a soil profile', Journal of Environmental Radioactivity, vol. 173, pp. 102–111, July 2017, doi: 10.1016/j.jenvrad.2016.11.035.

[104] S. Chałupnik, M. Wysocka, E. Janson, I. Chmielewska, and M. Wiesner, 'Long term changes in the concentration of radium in discharge waters of coal mines and Upper Silesian rivers', Journal of Environmental Radioactivity, vol. 171, pp. 117–123, May 2017, doi: 10.1016/j.jenvrad.2017.02.007.

[105] J. C. Lozano, F. V. Tomé, and P. B. Rodríguez, 'Thorium isotope fractionation in the dissolution of inorganic samples by a microwave method', Radiochimica Acta, vol. 89, no. 10, pp. 633–638, Oct. 2001, doi: 10.1524/ract.2001.89.10.633.

[106] J. S. Morrell and M. J. Jackson, Eds, Uranium Processing and Properties. New York, NY: Springer New York, 2013. doi: 10.1007/978-1-4614-7591-0.

[107] International Commission on Radiation Units and Measurements, 'Report 57: Conversion Coefficients for use in Radiological Protection against External Radiation', Journal of the International Commission on Radiation Units and Measurements, vol. os29, no. 2, p. NP-NP, Aug. 1998, doi: 10.1093/jicru/os29.2.report57.

[108] K. Skubacz, A. Grygier, and B. Michalik, 'Report and comprehensive database containing information to radon progeny activity concentration and aerosols characteristic at selected workplaces.', RadoNorm Deliverable D2.3, 2024. [Online]. Available: https://www.radonorm.eu/wp-content/uploads/file_exchange/D2.3_Report-and-comprehensive-database-containing-information-related-to-radon-progeny-activity-concentration-and-aerosol-characteristics.pdf

[109] International Association of Oil & Gas Producers, 'Managing Naturally Occurring Radioactive Material (NORM) in the oil and gas industry', 412, 2016. [Online]. Available: https://www.plmedical.com/wp-content/uploads/NORM_Oil_Gas.pdf

[110] International Atomic Energy Agency, Occupational Radiation Protection: General Safety Guide. in IAEA Safety Standards Series No. GSG-7, no. v. GSG-7. Vienna: IAEA, 2018.

[111] European Parliament, Council Directive of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (89/391/EEC). 2008.

Accessed: July 28, 2025. [Online]. Available: http://data.europa.eu/eli/dir/1989/391/2008-12-11/eng

[112] European Council, Council Decision of 22 July 2003 setting up an Advisory Committee on Safety and Health at Work (Text with EEA relevance). 2003. Accessed: July 28, 2025. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32003D0913%2801%29

[113] Directorate-General for Employment, Social Affairs and Inclusion, 'Advisory Committee on Health and Safety at Work - European Commission'. Accessed: July 28, 2025. [Online]. Available: https://employment-social-affairs.ec.europa.eu/policies-and-activities/rights-work/health-and-safety-work/advisory-committee-health-and-safety-work-0_en

[114] European Agency for Safety and Health at Work, 'Safety and health legislation | Safety and health at work EU-OSHA'. Accessed: July 28, 2025. [Online]. Available: https://osha.europa.eu/en/safety-and-health-legislation

[115] European Parliament, Council Directive 98/24/EC of 7 April 1998 on the protection of the health and safety of workers from the risks related to chemical agents at work (fourteenth individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC). 2024. Accessed: July 28, 2025. [Online]. Available: http://data.europa.eu/eli/dir/1998/24/2024-04-08/eng

[116] European Parliament, Council Directive of 30 November 1989 concerning the minimum safety and health requirements for the workplace (first individual directive within the meaning of Article 16 (1) of Directive 89/391/EEC) (89/654/EEC). 1989. Accessed: July 28, 2025. [Online]. Available: https://eur-lex.europa.eu/eli/dir/1989/654/2019-07-26/eng

[117] European Parliament, Council Directive of 30 November 1989 on the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace (third individual directive within the meaning of Article 16 (1) of Directive 89/391/EEC) (89/656/EEC). 2019. Accessed: July 28, 2025. [Online]. Available: http://data.europa.eu/eli/dir/1989/656/2019-11-20/eng

[118] European Parliament, Directive 2004/37/EC of the European Parliament and of the Council of 29 April 2004 on the protection of workers from the risks related to exposure to carcinogens, mutagens or reprotoxic substances at work (Sixth individual Directive within the meaning of Article 16(1) of Council Directive 89/391/EEC) (codified version) (Text with EEA relevance)Text with EEA relevance. 2024. Accessed: July 28, 2025. [Online]. Available: http://data.europa.eu/eli/dir/2004/37/2024-04-08/eng

[119] European Parliament, Council Directive 92/104/EEC of 3 December 1992 on the minimum requirements for improving the safety and health protection of workers in surface and underground mineral-extracting industries (twelfth individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC). 2007. Accessed: July 28, 2025. [Online]. Available: http://data.europa.eu/eli/dir/1992/104/2007-06-27/eng

[120] European Parliament, Council Directive 92/91/EEC of 3 November 1992 concerning the minimum requirements for improving the safety and health protection of workers in the mineral-extracting industries through drilling (eleventh individual Directive within the meaning of Article 16 (1) of Directive 89/391/EEC). 2007. Accessed: July 28, 2025. [Online]. Available: http://data.europa.eu/eli/dir/1992/91/2007-06-27/eng

[121] Rządowe Centrum Legislacji, 'Dziennik Ustaw 2011 r. nr 163, poz. 981'. Accessed: July 28, 2025. [Online]. Available: https://dziennikustaw.gov.pl/DU/2011/s/163/981

[122] Internetowy System Aktów Prawnych, 'Rozporządzenie Ministra Energii z dnia 23 listopada 2016 r. w sprawie szczegółowych wymagań dotyczących prowadzenia ruchu podziemnych zakładów górniczych'. Accessed: July 28, 2025. [Online]. Available: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20170001118

[123] Internetowy System Aktów Prawnych, 'Rozporządzenie Ministra Środowiska z dnia 8 grudnia 2017 r. w sprawie planów ruchu zakładów górniczych'. Accessed: July 28, 2025. [Online]. Available: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20170002293

[124] M. Wysocka et al., ‘The system of monitoring and controlling natural radiation hazards in Polish coal mines’, IJMME, vol. 12, no. 3, p. 229, 2021, doi: 10.1504/IJMME.2021.119216.

[125] B. Michalik et al., ‘Report on available solutions and technologies applicable for legacy site remediation, NORM involving industries and treatment of radioactivity in water. Final version as of 30.06.2024 of deliverable D5.11 of project RadoNorm’, RadoNorm Deliverable D5.11, 2024. [Online]. Available: https://www.radonorm.eu/wp-content/uploads/file_exchange/D5.11_Report-on-available-solutions-and-technologies-applicable-for-legacy-site-remediation-NORM-involving-industries-and-treatment-of-radioactivity-in-water.pdf

[126] C. Vignaud et al., ‘Workplace-type specific methods to assess the exposure of workers to radon. Focus on underground workplaces and itinerant workers’, RadoNorm Deliverable D2.7, 2023. [Online]. Available: https://www.radonorm.eu/wp-content/uploads/2023/08/D2.7_Workplace-type-specific-methods-to-assess-the-exposure-of-workers-to-radon.pdf

[127] K. Navrátilová Rovenská et al., ‘Measurement protocol of radon progeny attached and unattached fraction. Focus on graded approach to measurement on underground and specific types of workplaces. Final version as of 26.8.2024 of deliverable D5.9 of project RadoNorm’, RadoNorm Deliverable D5.9, 2024. [Online]. Available: https://www.radonorm.eu/wp-content/uploads/file_exchange/D5.9_Measurement-protocol-of-radon-progeny-attached-and-unattached-fraction.pdf