NUCLEAR CONTROL & CONSULTING GmbH

Report

Regulation of NORM-industries regarding the Norwegians Pollution Control Act's application on radioactive pollution

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Summary and proposals

In this report, Norwegian radiation protection regulations that affect NORM industries are analyzed and compared with regulations implemented in several European countries as well as international standards. A focus is laid on comparing limit values used for establishing an authorization system by licensees.

Comparison of the Norwegian legislation to international standards and other EU legislation

As a central result, the authors of this report state that the Norwegian radiation protection legislation refers to international standards and is similar to many European legislative systems. However, in some essential parts, the provisions on radiation protection in NORM-affected industries deviate significantly from most other European systems.

The most significant features of the Norwegian regulations regarding their impact on NORM-industry are:

1. The IAEA approach regarding the exemption of moderate quantities of radioactive substances is applied to the bulk amounts of NORM in industry.
2. Consequently, the summation rule for naturally occurring radionuclides from industrial processes is applied for the calculation of exemption values and classification limits for radioactive waste.
3. The annual activities for exemption of discharges from requiring a permit are extremely low. Any sufficiently large effluent amount will exceed the limits due to the background load of natural radionuclides.

Although the international standards set by IAEA BSS [29] also contain limit values of total activities for naturally occurring radionuclides, these values should be applied only for moderate amounts of radioactive material. For that reason, IAEA stated that NORM industries with bulk amounts of materials need other regulatory approaches. Consequently, the IAEA has set exemption and clearance values for NORM only for specific activities, not total activities. Moreover, the IAEA approach[1] does not require the application of a summation formula. This reflects the practical difficulties in determining the complete set of all decay series radionuclides (e. g. U-234, Th-232, Th-230, and Po-210 at the ordinary level occurring in NORM cannot be determined by common gamma-spectrometry).

According to para I1.4 in IAEA BSS [29], for radionuclides of natural origin, the exemption of bulk amounts of NORM should be derived on a case-by-case basis by using a dose criterion of the order of 1 mSv y^{-1}. As far as persons of the public can be affected, this value may be split up into dose limits per exposure pathway of 0.25 mSv or 0.3mSv y^{-1}. Such approach is applied in several European countries.

Generally, the application of the de-minimis-dose of 10 µSv per year is considered to be impracticable for NORM.

[1] The same approach is used in the EU Directive 2013/59/Euratom

In Norway, the Radiation Protection Act [5], and the Radioactive Pollution and Radioactive Waste Regulation (FOR-2010-11-01-1394) [6] contain different criteria for classifying NORM regarding its regulatory requirements.

Although the use of the summation formula results in low specific activity exemption limits and also raises issues of uniqueness, the exemption of NORM from the regulations of the Radiation Protection Act is workable to the extent that it generally exempts large quantities of substances with sufficiently low specific activity from the regulations. Similar holds for the classification of radioactive waste and radioactive waste requiring disposal in the Radioactive Pollution and Radioactive Waste Regulation.

Four case studies with data from three Norwegian companies analyzed in this report showed:

- Elkem Bremanger produces silica and silica dust from a feedstock with low natural radioactivity. Due to the high temperatures in the melting process, Pb-210 and Po-210 are enriched in dust in relation to the other radionuclides of the U-238 decay series. However, the specific activities in dust remain significantly below the exemption values for radioactive substances according to the Radiation Protection Act and the limits for classifying dust as a radioactive waste according to the Radioactive Pollution and Radioactive Waste Regulation.
- The anode production in the Hydro Karbon plant in Årdalstangen also operates with a feedstock with low natural radioactivity. However, the high temperatures in the anode baking process, results in an evaporation of Po-210 (partly also Pb-210). Therefore, these radionuclides are enriched in dust in relation to the other radionuclides of the U-238 decay series. The specific activities reach a level far above the exemption values. Regulatory control is justified from a radiological point of view.
- The aluminum melting unit in the Hydro Aluminum plant in Øvre Årdal operates with a feedstock with low natural radioactivity. Due to the moderately high temperatures in the melting process, mainly Po-210 is somewhat enriched in dust in relation to the other radionuclides of the U-238 decay series. The specific activities in dust remain significantly below the exemption values for radioactive waste. Compared with background values, the specific activities in dust from Hydro Aluminum are lower or in the same range as the natural background.
- The fertilizer production by Yara processes phosphate ores that can possess a somewhat enhanced natural radioactivity. The phosphate sand generated as waste is classified as radioactive waste due to a slightly increased specific activity of Pb-210 and the accounting of all radionuclides with specific activities in the background range.

In summary, the case studies analyzed in this report showed (cf. Table A) that in two of the four plants the specific activity in the collected dust is so low that it is neither classified as radioactive substance according to Radiation Protection Act nor as radioactive waste according to Radioactive Pollution and Radioactive Waste Regulation. But Table A also demonstrates that in industrial process NORM may occur that's regulatory control is justified and necessary. This hold in particular for dust generated in the anode production of Hydro Karbon.

Table A: Results of the case studies: Assessments of solid materials regarding legal terms

	Radioactive substance	**Radioactive waste**	**Radioactive waste requiring disposal**	**Material**
Elkem	No	No	No	Dust
Hydro Karbon	Yes	Yes	Yes	Dust
Hydro Aluminium plant	No	No	No	Dust
Yara	No	Yes	No	Phosphate sand

A fundamentally different approach to international and other national standards is the permit requirement of discharges in the Radioactive Pollution and Radioactive Waste Regulation. Since this permit requirement is based on the requirements that apply in international radiation protection for moderate quantities of radioactive substances (up to about 1 Mg), discharges from NORM industries are subject to requirements that do not show any radiation protection justification. In practice, the annual amounts of activity discharge are crucial. Because these amounts are calculated using the summation formula and no subtraction of natural background is considered, the thresholds for discharges that require a permit are so low that large quantities of masses contaminated on a natural background level require a permit.

Consequently, in all four case studies analyzed in this report, the data resulted in the assessment of “discharge requiring a permit”. Although, e. g., the specific activities in dust and water from Elkem are lower or in the same range as the natural background the annual discharge amounts exceed the limits requiring a permit established in the Norwegian regulations.

The dose modeling of discharges from Yara (see Ch. 7.1.3) has shown that the effective dose (including the background!) due to the emission of dust for adults, for children, and for infants are lower than 0.01 mSv y^{-1}, and consequently orders magnitude lower than 1 mSv y^{-1}. Similarly, the radiation risk to the marine environment due to discharges into the Frierfjord can be disregarded from the radiation protection point of view. Both results are obtained despite the emissions being in the order of MBq per year, i. e. 4 orders of magnitude higher than the exemption values of the Pollution Control Act [7]. Analog results were obtained in a German study that estimated exposure dues to discharges of dust from NORM facilities [54]. In accordance with this fact, NORM discharges are not an issue in the radiation protection regulation in most EU countries.

The deterioration prohibition frequently seems to be an easy approach to avoiding each environmental contamination. The regulatory basis for the application of this principle is § 2 FOR-2016-12 [5]. This article restricts the scope of this law to natural radiation that is not elevated due to human activity (cf. Ch. 5.1.2). As mentioned in Ch. 5.1.2 we interpret the term “*elevated due to human activity*” in a way, that a measurable distinctiveness of elevated and ordinary radioactivity levels occurs. A minor change that cannot be (statistically significant) distinct from the background should not be considered “*elevated*”. Monitoring that does only record natural background does not correspond to the principle of proportionality. Moreover, the determination of natural background data should not be a task of the NORM industries.

Although the authors of this report are not lawyers, they see a problem in applying the principle of equality to all processes in Norway because of this approach. For instance, all wastewater treatment plants that discharge more than 100 m^3 y^{-1} with typical background concentrations of 5 Bq m^{-3} Ra-226 and 5 Bq m^{-3} U-238 will also exceed the permit-values[2]. Similarly, in large ventilation or air conditioning systems, Pb-210 bound to dust can exceed the discharge of 1,000 Bq Pb-210 y^{-1}.

It can implicitly be concluded that the, in essence, impractical inclusion of emissions in the regulatory scope define in view of the legislator a lower threshold for a harmful effect. If we consider the permit-values of total activity set in the Radioactive Pollution and Radioactive Waste Regulation, we have to state that they are lower by a factor of 10 compared to the exemption values for moderate amounts derived referring to the dose level of 10 μSv y^{-1} according to the IAEA BSS that is primarily applied in the national radiation protection legislation for utilization of artificial radionuclides [29]. Following the underlying dose model, the Radioactive Pollution and Waste Regulation sets a level of about 1 μSv y^{-1} or less as a level of “harmful effects”.

We see these very restrictive limits of unauthorized discharges as the implementation of a positive intention to limit discharges to the environment and, in particular, to comply with the obligations of the OSPAR Convention. However, this report shows that the formal application of the criteria results in monitoring discharges that are “close to background” and consequently broadly in line with the target of the OSPAR Convention regarding radioactive discharges. Moreover, the regulatory approach leads to unequal legal treatment, as it is hardly possible to monitor all emitters of discharges in Norway in the way that has so far been required for the companies examined here.

Comparing different European regulations (see Ch. 5) revealed that all countries that explicitly define limits for discharges in their national regulations have values that are several orders of magnitude higher than those in Norway. This holds for Austria, Sweden, the UK, and the Netherlands. Furthermore, in these countries function of defined limits is more the generic demonstration of compliance with dose limits than a decision on authorization needs.

With these settings, the Norwegian regulations deviate from international radiation protection standards and established regulatory approaches in many European countries. Consequently, companies in the NORM industry are required to implement extensive monitoring programs of environmental media. The risk assessments, executed e. g. by Yara (cf. Ch. 7), yielded no significant radiation risks to any environmental protection good. Despite this fact, it must be stated that such monitoring causes significant administrative and economic costs at the company level. Moreover, it generates (at a low level) negative side-effects like CO_2 emissions.

[2] We would like to point out, that any large wastewater treatment plant is expected to exceed the limit value for I-131 ($1 \cdot 10^5$ Bq/y) of Annex II FOR-2010-11-01-1394) [6] because treated patients release I-131 and the population averaged annual mean is in the order of several kBq per capita!

Alternative ways to regulate NORM-industries

According to the scope of this report, alternative ways to regulate NORM industries should be discussed.

To get a broad basis for this discussion, the authors of this report state that despite the use of the sum formula and the associated difficulties of uniform application for NORM industries (see below), the exemption of substances with low specific activity from the requirements of the Radiation Protection Act is a reasonable regulation. It draws the attention of responsible managers and employees to naturally occurring radioactivity in operational processes and is frequently to be limited with ordinary occupational safety to a level that is tolerable according to radiation protection standards. The classification of residual materials as radioactive waste leads to lower limits than in many other European countries due to the application of the summation formula, but is basically justifiable, since waste classified in this way can be recovered or disposed of in a similar way to other hazardous waste under waste legislation. A special category of radiation protection monitoring for waste with high specific activity and an associated restriction on disposal routes is also the practice in several European countries.

All the aforementioned cases refer to operational processes and can be controlled with operational measures. For all these cases, it is important in our view to design the enforcement of the regulations in such a way that it can be implemented in a practicable manner. The graded approach based on a realistic assessment of doses and considering the proportionality of risks and restrictions should be taken into account.

A completely different assessment must be given for discharges. Despite these regulations must be understood as part of an overarching approach to environmental policy, the regulations for discharges lead to permit requirements even for small discharge quantities. If applied consistently and formally to all emitters in Norway, even small companies and institutions would be subject to an authorized surveillance of discharges. Therefore, a discussion on alternatives to this part of the regulation seems justified to us. In this regard we point out that reduction of emissions is a general target of environmental protection and control of emissions a tool for reaching it. But the proportionality of the end and the means should be considered, too.

Even though Norway is not a member of the European Union, some basic principles as defined in the Treaty on the Functioning of the European Union [1] will be used here as a general guideline. According to Art. 191 policy on the environment shall aim at a high level of protection considering the diversity of situations in the various regions of the Union. It shall be based on the

- precautionary principle,
- the principle that preventive action should be taken,
- the principle that environmental damage should, as a priority, be rectified at the source and
- the principle that the polluter should pay.

From these principles, prevention refers mainly to avoiding or reducing discharges or waste generation in the operational processes of a facility. The rectification at the source is done by cleaning unavoidable emissions, and the polluter pay principle describes the responsibilities in the case of occurred contamination.

Related to emissions (of naturally occurring radionuclides from industrial processes) to the environment, the precautionary principle can be applied as guidance. This principle should be applied, and it aims to avoid or reduce as best as possible environmental threats of harm by an early and anticipating behavior. A prohibition of deterioration is often derived from this principle and means that any relevant contamination from controllable sources should be forbidden.

While the term “harm” in the case of radioactivity can be related to doses, the term “contamination” refers to measurable specific activities in environmental media.

In principle, it is left to the discretion of the legislator how to regulate the basic principles of environmental protection in a particular field, such as radiation protection. However, both the legislation and its application in practice should comply with the principle of proportionality, i.e., the action should not exceed what is necessary to achieve the objectives (cf. Art. 5 in [2]). For radiation protection, standards of necessity can be referred to the principle of justification.

The justification principle is the key argument for the determination of acceptable requirements concerning e. g. dose assessments. These requirements should be commensurate with the magnitude and likelihood of exposures resulting from the industrial processes.

According to the ICRP [26], the justification principle is applied when deciding whether to take action to reduce exposure and avert further additional exposures. Any decision will always have some disadvantages and should be justified in the sense that the benefit should be greater than the harm. As explained in the ICRP Publication No. 103 [10], the input to the justification decision may include many aspects that could be informed by the NORM industries, workers, public, and organizations other than the government or national authority. The need for a protection strategy controlling NORM exposure is better understood after a radiological characterization of the exposure situation. Furthermore, the ICRP suggests the establishment at a national level of a list of industries involving NORM for which a radiological risk assessment should be undertaken to determine whether a protection strategy is justified. The level of control may then be determined through the implementation of the optimization principle [26]. That means an optimized (graded) approach should be applied to NORM industries so that efforts and resources expended on protection are commensurate with the radiological hazards and risks and that this should be taken into account when a decision is taken on control of the exposure. The burden imposed by the regulatory system should be balanced with the outcomes to be achieved. Requirements that do not contribute meaningfully to achieving radiological and non-radiological protection should be avoided [26].

Overall, we find that an alternative regulation for the approval of discharges from NORM industries would be desirable. The specific activity of the emissions should be given greater weight and the total activities, which are currently very narrowly defined, should only be limited to the extent that it is actually radiologically relevant.

As a consultant we have to acknowledge that any change of a legal requirement is a political decision and can be influenced only by political forces. For that reason, we suggest developing common interpretations of the regulatory requirements with the competent authorities that help in practical cases together. Such possibilities could be:

1. Definition of generic background values in water and air which can be disregarded in any assessments of measured specific activities. Such a definition would agree with the Radiation Protection Act, that restricts the scope of the law to radiation “elevated due to human activity” (cf. Ch. 5.1.2). If the values are set at a level representing the upper range of natural variability the remaining cases should be focused on the actually relevant cases.
2. Determination of radionuclides whose measurement is usually sufficient to assess a material regarding the regulatory requirements in cases with NORM. The standard set of such radionuclides could be: U-238, Ra-226, Pb-210, Ra-228, Th-228. Po-210 have to be added in cases that high temperature processes are applied.
3. K-40 plays a specific role in radiation protection because it does not contribute to an inner exposure. Therefore, it can be disregarded in any radioactive emission control.
4. Artificial radionuclides, in particular Cs-137 from bomb and Chernobyl fallout should not be a part of NORM assessments.
5. For practical reasons the summation formulars could be reduced to Th_{nat}, U_{nat} where the values of the parameter are taken from the radionuclide that´s specific activity is the maximum in the corresponding decay series. This would reduce the different assessments depending on the number of analyzed radionuclides.

Regarding the monitoring requirements a graded approach should be aimed with an exclusive monitoring of emissions as a basic case. Immission monitoring should be established only if measurable trends can be expected. An expert estimation should be the basis for decision making.

Conclusions

In summary, the authors of this report state:

1. It is obviously the intention of the legislator to monitor industrial plants with regard to radioactive discharges. For this reason, the legislator has set extremely low exemption limits to release the activities from the permit. On the other hand, since the scope of the regulations is not limited to certain industries, the question must be asked whether the previous regulation complies with the overriding principle of equality. That means that there are exposure situations due to that radionuclides are discharged into the air from exhaust systems or waste water into water bodies, which are not regulated by radiation protection legislation (e. g. discharge from sewage treatment plants of radionuclides from medical application).
2. In contrast to many European countries, the “graded approach” is not developed in a similar level of detail in Norway. Any exceeding of the very low annual discharge amounts of total activity results in the licensing requirement and is not comparable to any other European country.

3. As a consequence of this legal framework, monitoring programs have been required by the competent authorities and carried out by the companies, which so far have not shown any discernible radiological impact of discharges on the environment.

In conclusion, it is estimated that the regulations are too strongly determined by the precautionary principle, and the proportionality of the means is questionable. Further development of the regulatory framework and/or the design of its measures should be sought. In this context, however, it should be noted that the legislation itself cannot be amended. Rather, it is a matter of determining how the legal requirements can be designed, taking into account the aspect of proportionality in terms of expenditure on the industries. In the short term, the possibility of removing the requirement for permit in the case of discharges may not be realistic. The requirement of a permit can, in principle, be judged as reasonable. The permit is an appropriate instrument for the competent authorities to be informed about the activities in the NORM industries and for the obligation to perceive the possibility of supervisory control. Therefore, efforts should focus on the appropriate design of regulatory surveillance. In this context, the authors of this report propose:

a. The surveillance of companies by the authorities should be more oriented towards the graded approach to comply with the proportionality principle.

b. Related to this graded approach, an adequate assessment should be established with respect to the natural background of the natural occurring as a reference (the determination of background values should be set independently of operators under the responsibility of the competent authorities); as a basis for the evaluation of industry specific emissions the additional effective doses above background should be considered relevant.

c. For applying the following steps for a graded approach could be conceivable, it could be managed in the frame of existing Norwegian radiation protection legislation:

    - Notification
        - for discharges of radioactivity into the air or into the water should be required if the exemption limits of Annex 1 in [5] is exceeded, and
        - for disposal of radioactive contaminated waste should be required if the additional effective dose for worker and/or members of the public is exceeded above 1 mSv y^{-1}.
    - The disposal process could additionally be controlled by a written clearance from the authority in that obligations could be issued for a verification management (e. g. the documentation of data of the disposed masses and total activities)
    - Permit for discharges of radioactivity into the air or into the water should be necessary if the additional effective dose for workers and/or members of the public due to emissions is exceeded above 0.3 mSv per year. An environmental monitoring should be established individually, and the real effort should be based on the expected extent of dose exceedance.

d. Unless estimates and experience indicate expected changes in environmental media, monitoring programs should not generally be required.

e. Since the authorities have the possibility to detect even minor changes within the framework of general environmental monitoring, demands for environmental monitoring based purely on formal values are not proportionate.

f. An independent expert could be involved to assess discharges regarding the need for monitoring. This expert could also be involved in developing an appropriate monitoring program if it is necessary.

Content

Figures

Tables

1 Introduction

Mining and industry are crucial sectors of the Norwegian economy. The production of crude oil and natural gas strongly dominates the Norwegian economy. But in the ranking of trade values exported from Norway [3], metals stand with a share of 9.8 % in third place. Among the ten top exports of Norway are raw aluminum, raw nickel, and ferroalloys [3]. The production of metals, fertilizers, and minerals other than mineral oil or gas is an important sector of the Norwegian economy that has to compete internationally in world markets.

The Federation of Norwegian Industries represents over 3,100 member companies with approx. 130,000 employees and works for framing conditions for businesses in the Norwegian industry. One challenge that has arisen in the last few years concerns the Norwegian Regulation of Radioactive Pollution and Radioactive Waste [6] and its application to handling radioactive waste and radioactive pollution in industries of the raw material sector [4]. Large volumes of materials (ores, minerals) are typically processed in this industry sector. The processed materials contain radionuclides of natural origin and may form naturally occurring radioactive material (acronym: NORM). Since the volumes of raw materials processed are large, the limit values of Annex II in the Regulation of Radioactive Pollution and Radioactive Waste for the total radioactive activity (Bq y^{-1}) are often exceeded. However, the radiological risk is primarily related to the specific activity[3], which is frequently very low. If, when the total discharged activity is large, the specific activity is low, measures may be required under regulatory requirements, and expenditures may be necessary that have no radiation protection benefit and whose proportionality is unclear. In order to be able to seek ways of risk-adequate surveillance of radioactivity in the NORM-affected industries together with the competent authorities, the Federation of Norwegian Industries has commissioned Nuclear Control & Consulting GmbH (NCC) to compare the Norwegian regulation for NORM to other European legislations and international standards of the IAEA.

[3] In this report we use (in agreement with the Norwegian regulations) the term "specific activity“ for the mass-related activity concentration (Bq g^{-1}).

2 Scope of the report

The primary scope of this report is to compare the Norwegian regulation for NORM industries to EU legislation and international recommendations from the IAEA (see above). According to the terms of reference set out in the project description [4], the report shall provide information on the following topics:

1. Comparison of limit values for when a permit is required and/or recommended in the Norwegian regulation compared to European legislation (Directive 2013/59/Euratom) and International Basic Safety Standards from IAEA. Any differences between the Norwegian limit values and internationally recommended limit values should be described. Cases where scientific reasons may explain any differences should be described.
2. In addition, the Norwegian regulation, including limit values, should be compared to legislation in
    a. Sweden,
    b. Denmark and Finland, as well as
    c. other selected European countries that can be relevant in this regard.
3. It should also be described whether limit values in national or international legislations or recommendations differ between naturally occurring radionuclides and artificial radionuclides.
4. The environmental benefits of regulating NORM industries, which process ores with naturally occurring radionuclides on a background level, should be described. Any environmental benefits should be weighed against administrative and economic costs at the company level. Costs could be related to, for instance, implementing surveillance programs and reporting on the radioactive emissions from processing NORM.
5. The Federation of Norwegian Industries should provide cases from three companies that may serve as a basis for this assessment. The assessment should also take into account any risks of radioactive pollution being concentrated in the environment in recipients and organisms as a result of emissions from the NORM-industries.
6. Finally, the report should consider whether there are alternative ways of regulating radioactive emissions from NORM industries in Norway. The advantages and disadvantages of alternative ways of regulation should be described and compared to the current Norwegian regulation. It is a condition that alternative regulations considered should not increase risks to the environment or human health.

3 Basics and terms

Radiation protection is based worldwide on the International Commission on Radiological Protection (ICRP) recommendations and the standards derived from these recommendations by the International Atomic Energy Agency (IAEA). In Europe, Directive 2013/59/EURAOM [23] is binding for the EU member states and is used for orientation by non-member states. Despite this unique basis, national implementations differ in many details. In particular, some terms are defined and applied with different meanings. For that reason, in this chapter, some relevant terms of the Norwegian radiation protection regulation that are important for this report are compared with those of other countries or with international standards e. g., from the European Union (EU) or the International Atomic Energy Agency (IAEA).

The following documents of the Norwegian legislation are considered:

- Strålevernforskriften - Radiation Protection Regulation; short name in this report: FOR-2016-12 [5]
- Forskrift om forurensningslovens anvendelse på radioaktiv forurensning og radioaktivt avfall - Radioactive Pollution and Waste Regulation; short name in this report: FOR-2010-11 [6]
- Forurensningsloven - Pollution Control Act; short name in this report: LOV-1981-03-13-6 [7]
- Forskrift om gjenvinning og behandling av avfall (avfallsforskriften) (engl.: Waste Ordinance). Kapittel 16. Radioaktivt avfall. Short name in this report: FOR-2004-06-01-930 [8.
- Internkontrollforskriften - Internal Control Regulation for Systematic HSE Work; short name in this report: FOR-1996-12 [9]

Some relevant terms are compiled in Table 3-1.

Generally, the radiation protection system (for ionizing radiation) aims to protect people and the environment against the detrimental effects of radiation exposure without unduly limiting the desirable human actions associated with such exposure (ICRP [10] para 26).

To implement this aim in a practicable concept, it is first necessary to demarcate the radiation protection system from the areas not covered by radiation protection. This demarcation is made by the terms “exclusion” and “exemption”.

By **exclusion**, exposures that cannot be regulated are excluded from radiological protection legislation. Exclusion is usually implemented in the scope of the legislative systems by defining what is not regulated. Typical exposures not amenable to control 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 (cf. IAEA [11]).

As a consequence of the exclusion of uncontrollable radiation, background radiation must be separated from the dose considered in radiation protection.

By **exemption,** exposures that need not be regulated are exempted from some or all radiological protection regulatory requirements. This is the case if controls are regarded as unwarranted, often because the effort to control is considered inappropriate compared to the associated risk (ICRP [10] para 52).

Unlike exclusion, which makes very general qualitative statements, exemption depends on quantitative values of the effective dose, the activity, or the specific activity of radionuclides. While effective dose (which cannot be measured directly) always refers to radiation from controllable sources (without background!), activity or specific activity is a quantity that can be measured directly on materials. Depending on the origin of analyzed materials, measured activity may characterize the background or controllable materials.

Any substances that are not excluded or contain radionuclides that are not exempted can be considered radioactive in a regulatory context. For that reason, the definition of a radioactive substance or a radioactive material is a crucial element in any legal radiation protection system.

The ICRP 103 [10] and the IAEA Standards Series/Safety Guide No. RS-G-1.7 [11] defines the term radioactive material as a material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity, often taking into account of both activity and activity concentration. An example of such a definition is that of the UK, where "*any substance which contains one or more radionuclides whose activity cannot be disregarded for the purposes of radiation protection*" is defined as a radioactive substance (see Table 3-1).

The Norwegian *Strålevernforskriften* (FOR-2016-12 [5]) describes in § 1 the scope of the regulation in general terms. In § 4 q., any source containing radioactive material, i.e., material emitting alpha, beta, gamma, or neutron radiation, is defined as a "radiation source" (*Radioaktiv strålekilde*). A similar definition is used in the Radioactive Pollution and Waste Regulation (FOR-2010-11 [6]), where § 2 a defines a "**radioactive substance**" (*radioaktivt stoff*) as everything that emits alpha-, beta- or gamma-radiation. This pure physical definition is general and includes any substance that contains radionuclides, i.e. in practice, all substances. In its Safety Standards [12], the IAEA points out that this "scientific" meaning of radioactive should not be confused with the "regulatory" meaning of radioactive. However, the Swedish and Finnish legislations contain similar, pure physical definitions (see Table 3-1).

For distinguishing between the general environmental radioactivity (which generally does not fall within the scope of the regulation) and radioactive substances covered by the regulations, the Norwegian regulations contain provisions on the **exemption**. In particular, the Radioactive Pollution and Waste Regulation [6] gives exemption values in Annex I a) to exempt practices, substances, or waste from regulatory surveillance. The design of the requirements for exemption and the special features concerning natural radionuclides are dealt with in Chapter 5.1.

In contrast to exposures that need not be regulated and can be exempted, the term **clearance** describes the possibility that materials under regulatory control with very low levels of radioactivity do not longer need to be regulated. In such a case, radioactive materials can be released from the control of the radiation protection authority. The prerequisite for the release is a permit from the radiation protection authority. In everyday communication, however, the terms exemption and release are often used synonymously.

Another basic term used in this report is **NORM.** NORM stands for Naturally Occurring Radioactive Material and is defined in the IAEA Glossary [15] as "*material containing no significant amounts of radionuclides other than naturally occurring radionuclides*". For clarification, IAEA explains that

- *the exact definition of 'significant amounts' would be a regulatory decision, and*
- *material in which the activity concentrations of the naturally occurring radionuclides have been changed by a process is included in naturally occurring radioactive material (NORM)*.

In radiation protection systems, NORM is considered a source of exposure to workers or persons of the public. To ensure that any radiation protection measures that refer to exposure from NORM are commensurate with the actual radiological risk, the international Standards set by the IAEA recommend applying a graded approach to regulation [12]. The graded approach includes as a regulatory core the following three elements:

- Exemption (and clearance),
- Notification (and registration),
- Licensing[4].

For NORM, the international standards set by IAEA [11] specify an exemption value of 1 Bq g^{-1} for each radionuclide in the uranium decay chain or the thorium decay chain and 10 Bq g^{-1} for K-40. Unlike artificial radionuclides, the IAEA has not set exemption values for the total activity. The omission of the specification of absolute activity limits results from the assumption that large masses of material always occur or may occur in NORM industries. More detailed explanations of the IAEA-Standards are described in Chapter 4.2.

A particular challenge is the application of exemption and clearance values for liquids in various national legislations. As we will show later, this application is not consistent in Europe.

The question of how regulatory control is implemented in national laws can be resolved in very different ways. In connection with the questions to be answered regarding Norwegian legislation and its implementation in practice, the terms waste and discharge play an essential role.

Waste is defined in the EU Directive 2008/98/EC [13] (see Table 3-1), and this definition is generally applied in many European countries. The definition excludes (among others) radioactive waste and effluents making them subject to separate regulations. The interface between the regulatory fields inside and outside radiation protection opens different approaches for the regulators and various interpretations of the regulations in practice. For instance, there are several national regulations in Europe that consider NORM as a separate category of waste that is distinct from radioactive waste (e.g. Austria, Czech Republic, Finland, Germany, Hungary, Ireland, Italy, Luxembourg, Romania, and Switzerland). To better distinguish from waste, the term **residue** that was introduced in the former EC Directive 29/96/EURATOM [32, is further used. Other countries like Norway (and Denmark, France, Lithuania, the Netherlands, Poland, Slovenia, Sweden, and the UK [14]) consider NORM waste as part of radioactive waste. A third way is performed in Belgium and Spain. NORM waste is regulated as radioactive waste in these countries when management

[4] The terms "registration" and "licensing" (or permit) are partly summarized as "authorization". This agrees with a definition given by the IAEA in [12]. However, the terms are sometimes used synonymously and, for example, "authorization" is understood only as licensing.

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.

The consequences of these different concepts will be discussed in the later chapters of this report.

In the Norwegian Pollution Control Act (LOV-2021-05 [7]), the term **pollution** is defined to be the introduction of solids, liquids, or gases to air, water, or ground. While the introduction of solids can be considered part of waste management, liquid and gaseous effluents are named **discharge**. Discharges of radioactive effluents are, e.g., considered in the EU Directive 2013/59/EURATOM as a part of the regulatory system regarding the protection of members of the public and long-term health protection in normal circumstances. The typical benchmark for limitation of discharges is the dose limit for persons of the public of 1 mSv y^{-1}.

In their national legislation, many countries refrain from introducing specific regulations on discharges from NORM industries. A German study [54] has supported this approach by showing that doses higher than 1 mSv y^{-1} caused by discharges from NORM industries are unlikely.

As part of this report, arrangements for handling radioactive wastes and discharges in other countries have been reviewed. The different approaches will be outlined in the following chapters. First, the international framework set by ICRP, IAEA, and the European Commission (EC) is considered, then the Norwegian legislation. Finally, the radiation protection legislation of selected European countries is described.

Table 3-1: Relevant terms in the radiation protection legislation of Norway and of other countries as well as in international safety standards.

Term	Norwegian regulation	International documents and regulation
Radioactive material or radioactive substance	Radiation Protection Regulation FOR-2016-12 [5] § 4 q. **Radioaktiv strålekilde**: strålekilde inneholdende radioaktivt stoff, dvs. stoff som sender ut alfa-, beta-, gamma- eller nøytronstråling (Radioactive source: radiation source containing radioactive material, i.e. material emitting alpha, beta, gamma or neutron radiation) Radioactive Pollution and Waste Regulation FOR-2010-11 [6] § 2 a. **radioaktivt stoff:** stoff som sender ut alfa-, beta- eller gammastråling (radioactive substance: substance emitting alpha, beta or gamma radiation)	**ICRP 103** [10] (Glossary): **Radioactive material:** Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity, often taking account of both activity and activity concentration. **IAEA (2022)** [15] (Glossary): **Radioactive material:** Material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity**.** In regulatory terminology in some States, radioactive material ceases to be radioactive material when it becomes radioactive waste; the term radioactive substance is used to cover both, that is radioactive substance includes radioactive material and radioactive waste. **Sweden (Strålskyddslag (2018:396))** [64] Glossary of terms 5 § **Radioactive material** means a radioactive substance or a material that contains a radioactive substance or is contaminated with a radioactive substance. **Finland (Säteilylaki – 2018)** [47] § 4 Definitions: 14) **radioactive substance** means a substance that decays spontaneously and emits ionizing radiation. **Austrian Radiation Protection Act** [16]: Section 3 (55): **Radioactive substance**: any substance that contains one or more radionuclides, the activity or activity concentration of which cannot be disregarded in terms of radiation protection. **German RP Act** [17]**:** Section 3 The term **'radioactive substances'**

Term	Norwegian regulation	International documents and regulation
		(1) For the purposes of this Act, '**radioactive substances'** (nuclear fuels and other radioactive materials) means all substances containing one or more radionuclides, the activity or specific activity of which precludes their being disregarded under the provisions contained in this Act or in a statutory ordinance issued by the Federal Government with the consent of the Bundesrat on the basis of this Act**. …** (2) The activity or specific activity of a substance may be disregarded in accordance with subsection (1), first sentence, above insofar as, in accordance with this Act or a statutory ordinance issued by the Federal Government on the basis of this Act with the consent of the Bundesrat 1. it falls below specified exemption values 2. if the substance concerned occurs within the context of a practice subject to licensing in accordance with this Act, with the Atomic Energy Act or with ***the German RP Ordinance*** **[18]**, it falls below specified clearance values, and clearance has been given for the substance in question, 3. if the substance concerned is of natural origin, is not used as a nuclear fuel or to generate nuclear fuel because of its radioactivity and is not subject to monitoring under the provisions of the Atomic Energy Act, this Act or *the German RP Ordinance*. **Swiss RP Ordinance** [19]: **Art. 3 p. radioactive material** (synonymous q. radioactive substance): Material that contains, is activated, or contaminated with radionuclides and that fulfilled the following requirements: 1. the handling is subject to licensing requirements and to the monitoring according to the RP legislation, 2. the handling is not exempted from any requirements or monitoring according to the RP legislation. **UK Ionising Radiations Regulations** [20]**:** **Art. 2 "radioactive substance"** means any substance which contains one or more radionuclides whose activity cannot be disregarded for the purposes of radiation protection

Term	Norwegian regulation	International documents and regulation
		“**radioactive material**” means material incorporating radioactive substances.
Exclusion	Radiation Protection Regulation FOR-2016-12 [5] § 2 - Saklig virkeområde / Material scope Forskriften gjelder også for naturlig ioniserende stråling når denne er forhøyet på grunn av menneskelig aktivitet. Dette omfatter blant annet radon i eksisterende bygninger og lokaler hvor mennesker kan oppholde seg. … The regulations also apply to natural ionizing radiation when human activity enhances exposure. This includes radon in existing buildings and premises where people may reside.	**ICRP 103** [10]: **Exclusion**: The deliberate exclusion of a particular category of exposure from the scope of an instrument of regulatory control.
Exemption (level)	Radiation Protection Regulation FOR-2016-12 [5] § 2 - Saklig virkeområde **/** Material scope Andre radioaktive strålekilder er unntatt fra kravene i § 9 første ledd bokstav r, § 13, § 17, § 18 og § 27 dersom total aktivitet (Bq) eller aktivitetskonsentrasjon (Bq^{g-1}) er lavere eller lik unntaksgrensene i forskriftens vedlegg. For strålekilder som inneholder flere radionuklider skal summen av forholdet mellom aktivitet eller aktivitetskonsentrasjon for hver radionuklide og unntaksgrensen for respektive radionuklide, være mindre eller lik 1. … Other radioactive sources are exempted from the requirements in Section 9 first paragraph litera r, Section 13, Section 17, Section 18 and Section 27 if the total activity (Bq) or activity concentration ($Bq\ g^{-1}$) is lower than or equal to the exemption limits in the Annex to the Regulations. For radiation sources containing several radionuclides, the sum of the ratio between the activity or activity concentration for each radionuclide and the exemption limit for the respective radionuclide shall be less than or equal to 1.	**IAEA (2022) [15] and IAEA (2004) [11]:** **Exemption:** 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 and the potential exposure due to the source or practice are too small to warrant the application of those aspects or that this is the optimum option for protection irrespective of the actual level of the doses or risks. Exemption means exemption from the requirements for practices. Any exposure whose magnitude or likelihood is essentially unamenable to control through the requirements of the Standards is deemed to be excluded from the Standards. **Exemption**: The determination by a regulatory body that a source or practice activity involving radiation need not be subject to some or all aspects of regulatory control. **EU-BSS [23]:** Art. 4 (34): "exemption level" means a value established by a competent authority or in legislation and expressed in terms of activity concentration or total activity at or below which a radiation source is not subject to notification or authorization Art. 26 (1) (a)/(b) Exemption from notification: radioactive

Term	Norwegian regulation	International documents and regulation
	Radioactive Pollution and Waste Regulation FOR-2010-11 [6]: § 6. Unntak / Exceptions: Departementet, eller den departementet bemyndiger, kan i særskilte tilfeller gjøre unntak fra bestemmelsene i denne forskriften. The Ministry, or the person authorized by the Ministry, may in special cases make exceptions to the provisions in these regulations.	materials where the quantities of the activity involved do not exceed in total the exemption values set out in Table B, column 3/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. Austrian Radiation Protection Act[16]: Art. 111 (1): Radioactive materials that contain 1. artificial radionuclides or 2. natural occurring radionuclides that are not used as a nuclear fuel or to generate nuclear fuel because of its radioactivity are allowed to be exempted if the exposition of members of the public does not extend an effective dose of 10 µSv per year. German RP Act [17]: Section 5 (15) ‘Exemption values’ means values for the activity and specific activity of radioactive substances as laid down in a statutory ordinance in accordance with section 24, first sentence, no. 10, and for practices in connection with such radioactive substances as a measure of the need for monitoring in accordance with this Act and with the statutory ordinances issued on the basis hereof. UK Ionising Radiations Regulations [20]: Schedule 1 No. 1: Work with ionizing radiation is not required to be notified in accordance with regulation 5 when the only such work being carried out is in one or more of the following categories … c) where the concentration of activity per unit mass or quantity of a radioactive substance does not exceed values which may be approved by the appropriate authority for specific types of work and where such work satisfies the exemption criteria set out in paragraphs 2 and 3 below

Term	Norwegian regulation	International documents and regulation
Clearance		**IAEA (2022)** [15] and **IAEA (2004)** [11] Glossary: **Clearance:** Removal of regulatory control by the regulatory body from radioactive material or radioactive objects within notified or authorized facilities and activities. Conceptually: freeing certain materials or objects in authorized facilities and activities from further control - is closely linked to, but distinct from, and not to be confused with, exemption. **Clearance** is similar to exemption but relates specifically to the removal of radioactive material within authorized practices from any further control by the regulatory body. Bulk amounts of material may be involved in clearance, and for this reason, regulatory bodies may wish to adopt more stringent values of activity concentration. **German RP Ordinance** [21]: § 31 'Clearance of radioactive substances; dose criterion' (1) The following may only be used, recovered, disposed of, possessed or transferred to a third party as non-radioactive substances after issuance of clearance: 1. radioactive substances originating from activities …, and 2. movable articles, buildings, rooms or parts thereof and components, floor areas, installations or parts thereof (articles), which originated from, were contaminated by or were activated by activities specified … Substances and articles shall in particular require clearance that originated from controlled areas in which 1. unsealed radioactive substances are or have been handled, 2. unsealed radioactive substances are or have been present, or 3. there was a possibility of activation. (2) The dose criterion for clearance shall be that only an **effective dose in the range of 10 µSv per calendar** may occur to members of the public caused by the substances and articles to be cleared.

Term	Norwegian regulation	International documents and regulation
Waste	Pollution Control Act LOV-2021-05 [7] § 27. Definitions: Med **avfall** menes løsøregjenstander eller stoffer som noen har kassert, har til hensikt å kassere eller er forpliktet til å kassere. Som avfall regnes ikke avløpsvann og avgasser. **Waste** means loose objects or substances that someone has discarded, intends to discard or is obliged to discard. Waste does not include waste water and waste gases.	**EU Waste Directive** [13] Article 3. Definitions: waste' means any substance or object which the holder discards or intends or is required to discard; 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; (d) radioactive waste; 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;
Radioactive waste	Radioactive Pollution and Waste Regulation FOR-2010-11 [6]: **§ 2 c. radioaktivt avfall / radioactive waste:** løsøregjenstander eller stoffer som regnes som avfall etter forurensingsloven § 27 første ledd, og inneholder eller er forurenset med radioaktive stoffer med spesifikk aktivitet som er større eller lik verdiene angitt i vedlegg **I** bokstav a, movable objects or substances that are considered waste pursuant to section 27, first para**.**, of the Pollution Control Act, and contain or are contaminated with radioactive substances with specific activity greater than or equal to the values specified in Annex **I**, point a	**IAEA (2022)** [15] Glossary**:** **Radioactive waste:** For legal and regulatory purposes, material for which no further use is foreseen that contains, or is contaminated with, radionuclides at activity concentrations greater than clearance values as established by the regulatory body. **ICRP 104 (2007)** [22]: **Radioactive waste:** Radioactive material in gaseous, liquid, or solid form for which no further use is foreseen. Controls for radioactive waste are needed when radionuclides are present in quantities or activity concentrations greater than the exemption or clearance values, as established by the regulatory body, are present. **EU-BSS** [23]: Art. 4 (79): **"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

Term	Norwegian regulation	International documents and regulation
		regulatory authority under the legislative and regulatory framework of the Member State. **Sweden (Strålskyddslag (2018:396))** [64]: **radioactive waste**: radioactive material that is waste under Chapter 15, section 1 of the Environmental Code or for which there is no planned and acceptable use. **Finland Säteilylaki (2018)** [47]: § 4 Definitions (15) **radioactive waste** means a radioactive substance, or a device, article or object contaminated with it which has no use or for which no owner can be found and which must be disposed of because of to render its radioactivity harmless; **Austrian Radiation Protection Act** [16]: Art. 3 (54): **Radioactive waste**: radioactive material for which no further use is foreseen, and that is subject to regulatory control as radioactive waste. **German RP Act** [17]: § 5 (1) **'Waste'** (*not radioactive waste*) means all substances and articles that constitute waste within the meaning of § 3 (1) of the Circular Economy Act (Kreislaufwirtschaftsgesetz), including waste that is excepted from the scope of the Circular Economy Act in accordance with § 2 (2) Nos. 1-4 or 7-15 of the Circular Economy Act. Residual material and installation components that must be rendered harmless through recovery, or disposed of in a controlled manner in accordance with § 9a (1) of the Atomic Energy Act, as well as other radioactive waste, residues, and other radioactive substances that are subject to the provisions of the Repository Site Selection Act (Standortauswahlgesetz) or of the Atomic Energy Act, shall not be regarded as waste within the meaning of this Act.

Term	Norwegian regulation	International documents and regulation
Radioactive waste subject to mandatory disposal	Radioactive Pollution and Waste Regulation FOR-2010-11 [6]: **§ 2 d. deponeringspliktig radioaktivt avfall / radioactive waste subject to disposal:** radioaktivt avfall med større eller lik verdier for total aktivitet og spesifikk aktivitet enn angitt i vedlegg I bokstav b radioactive waste with values for total activity and specific activity greater or equal than those specified in point (b) of Annex I (contained in this regulation).	There is no comparable definition, neither by the IAEA, ICRP nor by the EU member states. In Finland Säteilylaki – 2018) [47], there is a much broader definition. § 4 Definitions 16) rendering radioactive waste harmless means the measures necessary to render radioactive waste harmless, i.e., the treatment, containment, disposal or limitation of the use of radioactive waste in such a way that the waste does not cause damage to health or the environment;
Notification/Declaration/ Registration	Radiation Protection Regulation FOR-2016-12 [5] **§ 13. Meldeplikt / :** Virksomheter som anskaffer, leier ut, bruker … og radioaktive kilder over unntaksgrensene i forskriftens vedlegg og som ikke er godkjenningspliktige etter § 9 eller § 10, skal **gi melding** til Direktoratet for strålevern og atomsikkerhet. Strålekildene skal ikke tas i bruk før virksomheten har fått bekreftelse på at meldingen er mottatt. Meldingen skal gis i elektronisk form, og inneholde de opplysninger som er nødvendige for at Direktoratet for strålevern og atomsikkerhet skal kunne vurdere om aktiviteten omfattes av meldeplikten. Companies that acquire, lease, use or handle … radiation sources above the exemption limits in the Annex to the Ordinance and that are not subject to approval under § 9 or § 10 must **notify** the Directorate for Radiation Protection and Nuclear Safety. ... Radiation sources may not be put into operation until the authority has confirmed receipt of the notification. The **notification** must be in electronic form and contain the information that the Directorate for Radiation Protection and	**IAEA (2022)** [11]: **Notification:** 1. A document submitted to the regulatory body by a person or organization to notify an intention to carry out a practice or other use of a source. **EU Directive 2013/59/EURAOM [22]** (57) "notification" means submission of information to the competent authority to notify the intention to carry out a practice within the scope of this Directive; (86) "registration" means permission granted in a document by the competent authority, or granted by national legislation, through a simplified procedure, to carry out a practice in accordance with conditions laid down in national legislation or specified by a competent authority for this type or class of practice; *Comment: Registration is part of authorization, while notification is a level below or a step before (depending on the specific case).* **German RP Act** [17]: Section 62 (1) (→ *NORM*) Release of residues from monitoring: The obligated party … must **declare** the intended recovery or disposal of the residues to the competent authority without

Term	Norwegian regulation	International documents and regulation
	Nuclear Safety needs to assess whether the activity is subject to the **notification** requirement. The Directorate for Radiation Protection and Nuclear Safety may require an adapted reporting system for radiation sources.	undue delay, stating their nature, mass, and specific activity, as soon as he or she has established that said residues require monitoring ... **UK Ionising Radiations Regulations [20, 24]:** **Notification** applies to any work with ionizing radiation that does not require registration (regulation 6) or consent (regulation 7), as long as the work is not listed in Schedule 1. Part 2 No. 6 (2): The following practices are **not registrable practices** - (e) any practice involving radioactive material where the amount of the radioactive material does not exceed 1,000 kg and the activity concentration value of the radioactive substance in that material does not exceed the value specified in … column 4 of Part 2 of Schedule 7 (for naturally occurring radionuclides which are not processed for their radioactive, fissile or fertile properties); (f) any practice involving radioactive material where the amount of the radioactive material exceeds 1,000 kg and the activity concentration value of the radioactive substance in that material does not exceed the value in … column 2 of Part 2 of Schedule 7 (for naturally occurring radionuclides which are not processed for their radioactive, fissile or fertile properties).

4 International standards

4.1 ICRP

The ICRP Publication 103 (published in 2007 and abbreviated in the following ICRP-BSS) [10] replaced the ICRP Publication 60 [25] and is the basis of the current radiation protection worldwide. As a basis for any radiation protection (against ionizing radiation), ICRP analyses and assess the biological effects of radiation and the risks resulting from it. In para 87 ICRP-BSS, the Commission states that "*the approximated overall fatal risk coefficient of 5% per Sv on which current international radiation safety standards are based continues to be appropriate for the purposes of radiological protection."* This risk coefficient stands behind the dose limits and reference values recommended by ICRP for the protection of workers and persons of the public.

In ICRP-BSS, the Commission introduced the concept of exposure situations as a new basis for radiation protection. This new concept defines three types of exposure situations, planned, existing, and emergency, as the starting points for the radiation protection system. For activities involving NORM, the ICRP recommends that the regulatory approach should be based on the existing exposure situation. Such exposure situations are defined by ICRP as "*exposure situations that already exist when a decision on control has to be taken, including prolonged exposure situations after emergencies*" ([10] para. 176).

Guidance on how radiological protection in industrial processes involving NORM should be carried out is described in Publication 142 of ICRP [26]. In this publication, the Commission states that NORM presents no real prospect of a radiological emergency. Therefore, actions to protect workers and the public should consider only long-term external exposure, intake of radioactive material, and radon or thoron inhalation. A summary of dose assessments for members of the public (excluding exposure to radon) demonstrates that the distribution of exposures is generally less than a few mSv annual effective dose. Because exposures due to industrial activities involving NORM are "*controllable, with protection achieved through justification of taking protective actions and optimization of protection*," ICRP recommends (already in Publication 104 [22] and continuing in Publication 142 [26]) using an integrated and graded approach to protect workers, the public, and the environment. Such an approach has to include characterizing the exposure situation and optimizing radiological protective actions. However, ICRP emphasizes that workers in industries involving NORM are exposed to other hazards, too. *The radiological risk is often not the dominant hazard and may historically not even have been a consideration* ([26] para 71). For that reason, the radiation protection strategy should complement measures established to manage other hazards. It has to be taken into account that existing industrial hygiene controls already limit the potential for radiation exposure (e. g., control of airborne dust) ([26] para 9).

Even though the ICRP recommends in its Publication 103 [10] dose limits for occupational and public exposure in planned exposure situations, the ICRP does not set activity or activity concentration values as exemption and clearance values.

In its Publication 104 [27], the ICRP clarifies: Exclusion and exemption of industries involving NORM and activities using numerical criteria may be useful but lack the qualitative judgment that is also often necessary. Industries involving NORM can give rise to both occupational and public exposure. Occupational exposure is radiation exposure of workers incurred as a result of their work. Public exposure encompasses all exposures to humans other than occupational exposures. It is addressed by controlling NORM discharges and wastes (or residues), including recycling and reuse.

Industries involving NORM may also generate exposure to the environment through extraction, transportation, storage, processing, effluents, and discharges [26]. The optimization process should consider the protection of the environment. The aim is to avoid deleterious effects on non-human species, too (cf. [28]). Such an approach should be commensurate with the overall level of risk and compatible with common standards of environmental protection, notably the optimization of discharges in the environment.

According to ICRP 142 [26] para. 75-77, reference levels could be about a few mSv per year, below 10 mSv per /year, and these doses could take into account several pathways: external exposure due to gamma radiation and internal exposure due to inhalation and, to a much lesser extent, ingestion of radioactive dust, but not the dose due to radon.

For the dose assessment, the pathways need to be considered in industrial processes with respect to NORM discharges and wastes or residues. Liquid and gaseous radioactive and/or non-radioactive effluents may be discharged deliberately from the normal operation of industries involving NORM. In certain cases, such as oil and gas extraction, the phosphate processing industry, and the combustion of coal, NORM discharges have been an issue for the protection of both people and the environment. The ICRP recommends in Publication 142 a site-specific control of discharges that should include, from a radiological protection point of view,

- radiological characterization of discharges,
- identification of potential exposure pathways, taking into account the environmental distribution of radionuclides in space and time, as well as radionuclide mobility under ambient conditions,
- dose assessments and risk estimation,
- justification of measures to control discharges,
- selection of a reference level and
- selection and implementation of measures within a protection strategy through an optimization process (as low as reasonably achievable).

The ICRP points out that, in practice, optimization can be complex because some processes, such as effluent treatment, may lead to additional waste production in which increased concentrations of radionuclides occur or an increase in the overall volume of waste results. In these complex situations, the radiological characterization of NORM released in the environment may be performed by analyzing radionuclides with respect to their physical and chemical forms and activity concentrations both to the source and in the environmental media concern (air, water, sediment, soil). For assessing the exposure of non-human species, it may be further relevant to identify the mobility of radionuclides, spatial and temporal variation, environmental pathways to plants and animals, and bioavailability. When dealing with NORM discharges in the environment, special requisites concerning radionuclides, time intervals for analysis, samples to be analyzed, organisms of concern, record keeping, and monitoring plan should be specified as necessary. Long-term environmental monitoring should be performed regularly to check if the protection criteria are still being met [26].

In Publication 103 [10], para 261, ICRP refers to planned discharges of long-lived radionuclides to the environment and the problem of a possible build-up of contaminations in the environment. ICRP recommends *that planning assessments should consider whether build-up in the environment would result in the constraint being exceeded, taking account of any reasonable combination and build-up of exposures. Where such verification considerations are not possible or are too uncertain, it would be prudent to apply a dose constraint of the order of 0.1 mSv in a year to the prolonged component of the dose attributable to the long-lived artificial radionuclides.* But regarding discharges from NORM-affected industries, ICRP states: *In planned exposure situations involving natural radioactive material, this limitation is not feasible and not required* ([10] para 261).

4.2 IAEA

In order to support national legislators in implementing the ICRP recommendations in national laws and to achieve internationally harmonized radiation protection in principle, the IAEA transforms the recommendations of ICRP into international standards. In 2004, the IAEA published its Safety Guide No. RS-G-1.7 on Application of the Concepts of Exclusion, Exemption, and Clearance [11]. In this document, the IAEA describes the general criteria for the exemption of a practice or a source within a practice from the requirements of radiation protection. These criteria were further developed after 2004.

In the General Safety Requirements Part 3 published in 2014 (IAEA-BSS) [29], the IAEA adapted its Standards to the new system of ICRP and stated that exposure due to natural sources should be considered an existing exposure situation. However, the regulatory approaches for planned exposure situations should be applied to (cf. [29] para 3.4):

- Exposures in specified practices if the specific activity (IAEA: “activity concentration”) exceeds the (clearance) values given in Table 4-2;
- Public exposure due to discharges or due to the management of radioactive waste involving material that exceeds the values of Table 4-2.

It is worth noting that NORM with specific activity less than 1 Bq g^{-1} in the U-238 and Th-232 series is not exempted from regulatory control. Instead, it is considered an existing exposure situation (cf. [29] footnote 60).

For exemption, IAEA specifies two fundamental prerequisites:

a. Radiation risks arising from the practice or from a source have to be sufficiently low.
b. Regulatory control of the practice or the source would yield no net benefit (reducing individual doses or health risks).

These conditions are also applied for the removal of regulatory control by the regulatory body from radioactive material within notified or authorized activities (“clearance” – see [15]). However, in the case of clearance, they refer to the radiation risks arising from cleared material and the benefits of continued regulatory control.

Based on these prerequisites, the IAEA considers artificial radionuclides and radionuclides of natural origin that are part of specified practices using their radioactivity or nuclear fuel properties and recommends exemption values for two types of material:

- Material in a moderate amount, i.e., material where the quantities involved are at the most in the range up until one ton.
- Material in bulk amount.

In case of moderate amounts, practices or sources can be exempted if either the total activity of an individual radionuclide or the activity concentration does not exceed the exemption level. For naturally occurring radionuclides and some artificial ones, the exemption values are compiled in Table 4-1. These values were derived based on models and a limitation of the effective doses to individuals in the order of 10 µSv y^{-1} or less. Foodstuff and drinking water pathways of intake were taken into account to consider the radiological consequences as appropriate.

Because of their derivation for moderate amounts and referred to the de minimis dose of 10 µSv y^{-1}, the values are inappropriate for large quantities of material typically present in NORM industries.

Table 4-1: Exemption/clearance values of activity concentration for selected radionuclides of artificial and/or natural origin of moderate and bulk amount (from [29])

Radionuclide i	Exemption values X_i for moderate amounts		Exemption values X_i for bulk amounts
	Activity concentration [Bq g^{-1}]	Activity [Bq]	Activity concentration [Bq g^{-1}]
Co-60	10	$1 \cdot 10^5$	0.1
Cs-137 [1]	10	$1 \cdot 10^4$	0.1
Pb-210 [1]	10	$1 \cdot 10^4$	-
Po-210	10	$1 \cdot 10^4$	-
Ra-226 [1]	10	$1 \cdot 10^4$	-
Ra-228 [1]	10	$1 \cdot 10^5$	-
Th-228 [1]	1	$1 \cdot 10^4$	-
Th-230	1	$1 \cdot 10^4$	-
Th-232	10	$1 \cdot 10^4$	-
U-235 [1]	10	$1 \cdot 10^4$	-
U-238 [1]	10	$1 \cdot 10^4$	-
Am-241	1	$1 \cdot 10^4$	0.1

[1] Parent radionuclides and their progenies

For bulk amounts, the IAEA also lists exemption limits based on the 10 µSv criterion. However, the corresponding table in [29] does not list values for radionuclides of natural origin. According to para I1.4 in [29], for radionuclides of natural origin, the exemption of bulk amounts of material should be derived on a case-by-case basis by using a dose criterion of the order of 1 mSv in a year.

For radioactive material (in moderate amounts) containing more than one radionuclide, the sum of the measured activity concentrations for individual radionuclides has to be less than the derived value for the mixture (X_m), determined as follows ("Summation rule"):

$$X_m = \frac{1}{\sum_{i=1}^{n} \frac{f(i)}{X(i)}} \quad (1)$$

where

f(i) the fraction of activity concentration of radionuclide i in the mixture,

X(i) the applicable level for radionuclide i as given in Table 4-1 and

n number of present radionuclides.

For NORM, the IAEA assumes that it always occurs in bulk amounts. The exposure from NORM is considered an existing exposure situation if the specific activity is sufficiently low. However, exposure from NORM whose specific activity exceeds the (clearance) values of Table 4-2 is considered a planned exposure situation. Therefore, any release of material for which no further use is foreseen (residue or NORM-waste) that exceeds the values of Table 4-2 from regulatory control requires clearance by the competent authority.

According to [29] para I12, radioactive material within a notified or authorized practice may be cleared without further consideration, provided that activity concentrations of radionuclides of natural origin do not exceed the relevant level given in Table 4-2. The values of specific activity (termed as "activity concentration" by the IAEA) for radionuclides of natural origin set out in Table 4-2 have been determined based on the worldwide distribution of activity concentrations in soil provided by UNSCEAR [30]. They are valid for the U-238, Th-232, and U-235 decay chains in secular equilibrium. The values can also be used individually for each decay product in the chains or the head of subsets of the chains, such as the subset with Ra-226 as its parent [11]. **There is no summation rule to apply. Moreover, the total activity does not play any role in the clearance of NORM.**

Table 4-2: Clearance values for NORM from IAEA (from [29])

Each radionuclide in the uranium and thorium decay chains	1 Bq g^{-1}
K-40	10 Bq g^{-1}

For radionuclides of natural origin in residues that might be recycled or the disposal of which is liable to cause the contamination of drinking water supplies, the activity concentrations must be limited to meet a dose criterion of the order of 1 mSv y^{-1} ([29] para I12).

Suppose natural sources are subject to planned exposure situations. In that case, "*relevant parties shall ensure that radioactive waste and discharges of radioactive material to the environment are managed in accordance with the authorization" (*[29] Requirement 31). Therefore, operational limits and conditions relating to public exposure should be established or approved, including authorized limits for discharges ([29] para 3.126c). These limits should involve the possible buildup and accumulation in the environment of radionuclides from discharges ([29] para 3.123). In this regard, all significant exposure pathways by which discharged radionuclides could give rise to exposure of members of the public should be determined by an appropriate (pre-operational) study ([29] para 3.132b). A program with discharge control measures should be implemented or reviewed as appropriate and in agreement with the competent authorities ([29] para 3.134).

The IAEA does not establish specific dose limits for discharges from industrial processes associated with naturally occurring radionuclides. But generally, the effective dose for persons of the public should be limited to 1 mSv y^{-1} ([29] Schedule III.3)

4.3 EC/EU

The radiation protection system in many European countries is based on the standards specified in Directive 2013/59/Euratom (EU-BSS) [23]. In this Directive, the European Commission (EC) lays down a system in which protection against natural radiation sources should be fully integrated within the overall requirements. In particular, industries processing NORM should be managed within the same regulatory framework as other practices. Unlike the recommendation in the ICRP-BSS [10], where NORM activities are categorized into existing exposure situations, the EC classifies the handling of NORM in industrial processes as a planned exposure situation.

According to EU-BSS Art. 23, the EU member states shall identify classes or types of practice involving NORM that lead to exposure of workers or members of the public, which cannot be disregarded from a radiation protection point of view. Therefore, the EC points out specific industrial sectors that should be taken into account. These industrial sectors are listed in Annex VI of the EU-BSS [23]. Oil and gas production, production of phosphate fertilizers, mining of ores other than uranium ore, or processing of niobium/tantalum ore are some of the mentioned sectors.

In Art. 24 to Art. 29 EU-BSS, the EC describes the regulatory framework for implementing the graded approach to regulatory control in national legislation. *Member States shall require practices to be subject to regulatory control for the purpose of radiation protection, by way of notification, authorisation and appropriate inspections, commensurate with the magnitude and likelihood of exposures resulting from the practice, and commensurate with the impact that regulatory control may have in reducing such exposures or improving radiological safety.*

Provisions regarding the release of materials from regulatory control are given in Art. 30 EU-BSS. *Member States shall ensure that the disposal, recycling or reuse of radioactive materials arising from any authorised practice is subject to authorisation*. As a prerequisite for disposal, recycling or reuse the EU-BSS requires that *the activity concentrations for solid material do not exceed the clearance levels set out in Table A of Annex VII; or comply with specific clearance levels and associated requirements for specific materials or for materials originating from specific types of practices*.

The criteria are differentiated for the regulatory control between materials containing naturally occurring radionuclides, where these result from authorized practices in which natural radionuclides are processed for their radioactive, fissile or fertile properties and NORM resulting from industrial processes. In Annex VII Table A, Part 2 of EU-BSS [23], the exemption or clearance values for naturally occurring radionuclides in solid materials are listed. These values also apply to the clearance of solid materials for reuse, recycling, conventional disposal, or incineration. For NORM, they are the same as defined by the IAEA with 1 Bq g^{-1} for natural radionuclides from the U-238 and the Th-232 series as well as 10 Bq g^{-1} for K-40 (cf. Table 4-2). According to the remarks in Annex VII No. 2 (b) EU-BSS these values apply to all radionuclides in the decay chain of U-238 or Th-232. **A summation rule does not have to be applied**. For segments of the decay chain, which are not in equilibrium with the parent radionuclide, e. g. Pb-210 – Bi-210 – Po-210, higher values may be applied.

Additionally, to the exemption or clearance values for materials, the EC points out in Annex VII No. 3 (e) that 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, the general exemption and clearance criteria can be applied. For clearance of NORM, the exposure of members of the public have to meet the following criterium in all feasible circumstances: *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 $\leq$ 1 mSv y^{-1}*. The *assessment of doses to members of the public shall take into account the pathways of exposure through airborne or liquid effluent as well as the pathways resulting from the disposal or recycling of solid residues*. *The member states may specify dose criteria lower than 1 mSv per year for specific types of practices or specific pathways of exposure.*

According to Art. 12 (2) EU-BSS, the member states should set the limit on the effective dose for public exposure at 1 mSv y^{-1}.

Where applicable, national legislation or a license shall include conditions on the discharge of radioactive effluents (Art. 29 (4)). The operational protection of members of the public in normal circumstances from practices subject to licensing shall include appropriate limits as part of the discharge authorization. According to Art. 65 (2), these discharge authorizations shall take into account, where appropriate, the results of a generic screening assessment for demonstrating that environmental criteria for long-term human health protection are met. The radioactive airborne or liquid discharges into the environment in normal operation should be monitored appropriately or, where appropriate, evaluated. The results should be reported to the competent authority. The EC does not require specific dose limits for the discharge of radioactive airborne or liquid discharges into the environment. And also, no values are set for the activity concentration of radionuclides in discharges.

In the (elder) document “Practical Use to the Concepts of Clearance and Exemption” (RP 122) [31], EC gives some explanation and clarification of general clearance for the release of materials resulting from practices according to Title III of Directive 96/29/Euratom [32]. The clearance values in RP-122 Part II are based on dose calculations with a dose limit of 0.3 mSv y^{-1}. They can be applied to any solid, dry material but not to liquids or gases (in general considered as effluents). For raw material in secular equilibrium for the U-238 and Th-232 decay chains, there is a rough agreement between the 1 Bq g^{-1} criterion and the values in RP 122, Part II, when adjusting for the different dose criteria applied (1 mSv y^{-1} in the EU-BSS vs. 0.3 mSv y^{-1} in RP-122 Part II).

Independently of the regulations on radiation protection, the EU has set standards for the permissible radioactive contamination of drinking-water in the Directive [33]. The values refer to an indicative dose of 0.1 mSv y^{-1} and contain the values compiled in Table 4-3 with regard to naturally occurring radionuclides.

Table 4-3: Guidance levels for radionuclides in drinking-water (from [33]

Radio nuclide	Guidance level (Bq l^{-1})	Radio nuclide	Guidance level (Bql^{-1})	Radio nuclide	Guidance level (Bq l^{-1})
Pb-210	0.2	Ra-226	0.5	U-234	1
Po-210	0.1	Ra-228	0.2	U-238	1

Because natural radionuclides always occur as a mixture, assessing drinking-water has to be based on a summation formula:

$$\sum_k \frac{C_{(obs)k}}{C(der)_k} \leq 1 \qquad (1)$$

With

$C_{(obs)}$ = observed concentration of radionuclide i

$C_{(der)}$ = derived concentration of radionuclide i

4.4 World Health Organization (WHO)

WHO does not normally deal with radiation protection issues in a strict sense. However, in its “Guidelines for Drinking-Water Quality” [34], WHO has published screening and guidance levels. Screening levels are set to 0.5 Bq/l gross alpha activity and 1 Bq/l gross beta activity. For assessing drinking-water if screening levels are exceeded, guidance levels are given. These levels refer to an adult drinking 2 Liters of water per day and an ingestion dose limit of 0.1 mSv per year. Table 4-4 shows the values for natural radionuclides. K-40 does not contribute to the ingestion dose and is not listed. Analog to the EU Drinking Water Directive, the mixture of radionuclides has to be taken into account via a summation formula (see Eq. 1).

In its additional explanations, WHO states that *screening levels and guidance levels are conservative and should not be interpreted as mandatory limits. Exceeding a guidance level should be taken as a trigger for further investigation, but not necessarily as an indication that the drinking-water is unsafe.*

Table 4-4: Guidance levels for radionuclides in drinking-water (from [34]

Radio nuclide	Guidance level (Bq l^{-1})	Radio nuclide	Guidance level (Bq l^{-1})	Radio nuclide	Guidance level (Bq l^{-1})	Radio nuclide	Guidance level (Bq l^{-1})
Pb-210	0.1	Ra-226	1	Th-228	1	U-234	1
Po-210	0.1	Ra-228	0.1	Th-230	1	U-235	1
				Th-232	1	U-238	1

4.5 OSPAR Convention

Norway is one of the European countries bordering the North Atlantic. The country has been a party to the "Convention for the Protection of the Marine Environment of the North-East Atlantic" (the 'OSPAR Convention') [35] since its first signing. Within this convention, the contracting parties are obliged to take all possible steps to prevent and eliminate pollution and to take the necessary measures to protect the maritime area against the adverse effects of human activities so as to safeguard human health and conserve marine ecosystems and, when practicable, restore marine areas which have been adversely affected (cf. [35] Article 2). One of the strategic objectives requires the contracting parties to *prevent pollution by radioactive substances in order to safeguard human health and to protect the marine environment with the ultimate aim of achieving and maintaining concentrations in the marine environment at near background values for naturally occurring radioactive substances and close to zero for human made radioactive substances* [36].

One of the principles that the Convention provides for application is the precautionary principle. According to Article 2, the contracting parties shall apply *the precautionary principle, by virtue of which preventive measures are to be taken when there are reasonable grounds for concern that substances or energy introduced, directly or indirectly, into the marine environment may bring about hazards to human health, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea, even when there is no conclusive evidence of a causal relationship between the inputs and the effects.*

The Convention formulates a policy framework that national legislators must fill out. As the objectives of the Convention are only described in qualitative terms, there is considerable scope for discretionary decisions. In this context, it should be noted that the application of the precautionary principle according to the OSPAR Convention cited above should be based on *"reasonable grounds for concern".*

5 Comparison of exemption/clearance concepts between the Norwegian legislation and the legislation of other countries

5.1 Norwegian Regulations

5.1.1 Introductory remarks

In the following chapters, we consider parts of the Norwegian radiation protection legislation related to this report's scope. The authors point out that they are trained natural scientists with many years of radiation protection experience but no legal education. Our assessments are based on experience from practical work with radiation protection regulations, which not only refer to Germany but also include various other European countries.

We have taken note that Norwegian law differs from its civil law continental counterparts by assigning a very high value to jurisprudence and is not codified in systematic codes [37]. These facts must also be kept in mind if regulations implemented in many EU member states are compared with Norwegian ones, particularly regarding the recommendations and proposals described in chapter “Summary and proposals”.

The main regulation on radiation protection considered in this report is the *Forskrift om strålevern og bruk av stråling (strålevernforskriften)* (Radiation Protection Act) [5]. As a short-term, we use the following abbreviated legal code number FOR-2016-12). In § 1 the purpose of this Act is defined as: *to ensure the safe use of radiation, to prevent harmful effects of radiation on human health, and to contribute to the protection of the environment.* The focus of this Act is protecting persons exposed during their work (or as patients) to ionizing radiation. The Act also covers provisions regarding (FOR-2016-12 § 2) *natural ionizing radiation when it is elevated due to human activity. This includes radon in existing buildings and premises where people may reside.*

The general regulation on environmental protection is the *Lov om vern mot forurensninger og om avfall (Forurensningsloven*) [7] (Act Concerning Protection against Pollution and Concerning Waste). As short-term, we use: “Pollution Control Act”, abbreviated legal code number LOV-2021-5. For the purpose of this Act, pollution means:

1. the introduction of solids, liquids or gases to air, water or ground,
2. noise and vibrations,
3. light and other radiation to the extent decided by the pollution control authority,
4. effects on temperature

which cause or may cause damage or nuisance to the environment.

Further, this Act contains general regulations regarding wastewater and waste disposal. It gives neither provisions on radioactively contaminated wastewater nor radioactive waste.

The Pollution Control Act and all regulations relating thereto are intended to protect the environment and, in this way, also persons of the public. Exposures of employees at workplaces are not part of this regulation. Since the disposal of waste can lead to exposure of persons who are not employees of the waste producer and who, in the case of radioactive waste, are to be protected from radiation as members of the public, the basic framework for waste disposal is also regulated in the Pollution Control Act.

The *Forskrift om forurensningslovens anvendelse på radioaktiv forurensning og radioaktivt avfall* [6] (Regulation on the Pollution Control Act's Application on Radioactive Pollution and Radioactive Waste), short term in the following: "Regulation on Rad-Pollution and Rad-Waste", abbreviated legal code number FOR-2010-11), therefore refers to the Pollution Control Act. This Regulation contains the essential provisions regarding radioactive waste and discharges.

5.1.2 Exclusion

The concept of exclusion, with its distinction of controllable and non-controllable exposures, is not explicitly defined in Norwegian legislation, neither in the Regulation on Rad-Pollution and Rad-Waste FOR-2010-11 nor in the Act against Pollution LOV-2021-5. FOR-2010-11 applies to radiation from radioactive substances that are or may be harmful or disadvantageous to the environment. However, a definition of what harmful or disadvantageous means is not directly given. Similarly vague is the Radiation Protection Act FOR-2016-12. According to its § 2, it applies to natural ionizing radiation if this is elevated due to human activity.

From our practitioner's point of view, the term "*elevated due to human activity*" requires measurable distinctiveness of elevated and ordinary radioactivity levels. A minor change that cannot be distinct from the background or any assumed but not detectable contamination should not be considered "*elevated*".

Any harmful effects of radiation on "the environment" can only be judged with doses and dose limits for both humans and non-human species. Measured activity concentrations are not suitable for the assessment of effects. Harmful effects can be excluded if doses remain lower than established dose limits.

In our understanding, the term "*disadvantageous effects*" ("*ulempe*") means effects that have adverse consequences for other parties/stakeholders. Such disadvantageous effects can result from any contamination, independently of harmful effects. A typical example from Germany (but other counties, too) is radioactively contaminated scrap that is not accepted by melting facilities independently from exemption levels.

5.1.3 Dose limits

§ 6 of the Radiation Protection Act (FOR-2016-12) [5] sets dose limits and action limits that apply to members of the public and persons not occupationally exposed to radiation. The effective dose to the members of the public and the non-occupationally exposed workers shall not exceed 1 mSv y^{-1}. Radiation and shielding measures shall be planned so that non-occupationally exposed workers and members of the public are not exposed to an effective dose > 0.25 mSv y^{-1}. In the comments to the individual provisions of FOR-2016-12, the legislator explains that the public exposure limit of 1 mSv y^{-1} applies to any planned use or activity involving ionizing radiation. The requirement that each individual undertaking shall limit exposure of the members of the public and non-occupational exposed persons to 0.25 mSv y^{-1} is since the probability of exposure of individuals from more than 4 different radiation sources per year is very small.

Even though the Regulation on Rad-Pollution and Rad-Waste regulates radiation from radioactive substances that are or may be harmful or disadvantageous to the environment, it does not specify any dose limits for radiation effects. Instead, it uses limit values of total activity and specific activity.

5.1.4 Exemption from the Radiation Protection Act

According to the Radiation Protection Act (FOR-2016-12) Annex I [5], radioactive sources can be exempted from regulatory control, and notification is not required if the total activity (Bq) or specific activity (Bq g^{-1}) is less than or equal to the exemption values given in Table 5-1. For sources containing a mixture of radionuclides, the sum of the ratio of activity or activity concentration for each radionuclide to the exemption limit for that radionuclide must be less than or equal to 1 (see Eq. 2).

$$\sum_k \frac{A}{A_{e,k}} \leq 1 \text{ or ("eller") } \sum_k \frac{C_k}{C_{e,k}} \leq 1 \qquad (2)$$

with

A_k: activity of radionuclide k

$A_{e,k}$: limit value for the activity of radionuclide k (see Table 5-1)

C_k: specific activity of radionuclide k

$C_{e,k}$: limit value for the specific activity of radionuclide k (see Table 5-1)

The “or” (“eller”) between both criteria means that one criterion is sufficient for the exemption. Radioactive sources with sufficiently low specific activity are exempted independently from their total activity, and vice versa; “small” sources with low total activity are exempted in cases they have high specific activity.

In Table 5-1, exemption values for naturally occurring radionuclides are listed. Similar to the international approaches, Norwegian exemption values of individual radionuclides include daughter nuclides in decay chains (see

Table 5-2). As stated in the heading of Annex II [5], radionuclides marked with “a” in the table are parent nuclides in equilibrium with their daughter products. Working with a radionuclide that is specified as a parent nuclide, implies that one is also working with its daughter products. The radiation contribution from these daughter products is taken into account when setting the exemption limits for the parent nuclides in question.

In the Radiation Protection Act Annex I, the abbreviations “Th-nat” and “U-nat” are listed, and the exemption values of specific activities for the whole U-238- or Th-232 decay chain (U-nat, Th-nat) are 1 Bq g^{-1} and correspond to the international ones. However, the terms “Th-nat” and “U-nat are not explained in Annex II. We assume that according to the Regulation on Rad-Pollution and Rad-Waste [6], the terms are specified as follows:

- Th-nat: Ra-228, Ac-228, Th-228, Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Tl-208 (0.36), Po-212 (0.64)
- U-nat: Th-234, Pa-234m, U-234, Th-230, Ra-226, Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210

Using this specification, all mixtures with specific activities of all daughter nuclides below 1 Bq g^{-1} should comply with the requirements for exemption or clearance.

Table 5-1: Exemption values for naturally occurring radionuclides (excerpt from Annex I in [5])

	Radiation Protection Act [5]	
Radionuclide	Total activity [Bq]	Specific Activity [Bq g^{-1}]
K-40	1×10^6	100
Pb-210[a]	1×10^4	10
Po-210	1×10^4	10
Ra-226[a]	1×10^4	10
Ra-228[a]	1×10^5	10
Th-228[a]	1×10^4	1
Th-230	1×10^4	1
Th-232	1×10^4	10
U-234	1×10^4	10
U-235[a]	1×10^4	10
U-238[a]	1×10^4	10
Th-nat	1×10^3	1
U-nat	1×10^3	1

[a] Radionuclides in equilibrium with daughter products (seen Table 5-2). The activity values in the table refer to the parent nuclide alone, but the radiation contribution from the daughter products is taken into account in determining the activity limit for the parent nuclide.

Table 5-2: Naturally occurring radionuclides in equilibrium with daughter products (excerpt from Annex II in [5])

Radionuclide	**Daughter products**
Pb-210	Bi-210, Po-210
Ra-226	Rn-222, Po-218, Pb 214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
Ra-228	Ac-228
Th-228	Ra-224, Rn-220, Po-216, Bi-210, Pb-212, Tl-208 (0.36), Po-212 (0.64)
U-235	Th-231
U-238	Th-234, Pa-234m

In the international radiation protection system, the term NORM is not applied to radionuclides of natural origin that are used for their radioactivity or nuclear fuel properties. In such a case, the radionuclides are treated in the same way as artificial radionuclides. This holds, e.g., for U-238 and U-235 in nuclear facilities. The Norwegian regulations do not implement this separate treatment of radionuclides of natural origin whose radioactive or fissile properties are utilized and naturally occurring radionuclides not utilized for their radioactivity in industrial processes.

In consequence, this results in two significant deviations from the international system:

1. The summation rule is applied to radionuclides in NORM, too.
2. The total activity is considered to be a part of the exemption regulations for NORM.

The summation rule reduces the exemption value for NORM in two ways:

1. In an actual material, the exemption value for each U-nat and Th-nat is lower than 1 Bq g^{-1} because both shares must be considered part of the summation formula.
2. If the summation rule is exemplarily applied to a material where uranium is partly removed by processing, the exemption value according to the Radiation Protection Act [5] is lower than 0.84 Bq g^{-1}, i.e., significantly less than 1 Bq g^{-1} (see Table 5-3).

Table 5-3: Application of the summation rule to a material with a disturbed equilibrium of the U-238-decay series (arbitrary example for demonstration). Exemption values according to [5]

Radionuclide k	**Exemption value $C_{e,k}$ (Table 5-1)**	**Specific Activity C_k (example)**	**$C_k / C_{e,k}$**
	Bq g^{-1}	Bq g^{-1}	
Ra-226+	10	0,84	0,084
Th-230	1	0,84	0,84
U-234	10	0,42	0,042
U-238	10	0,42	0,042
Sum			**1,008**

5.1.5 Permit requirements according to Regulation on Rad-Pollution and Rad-Waste

5.1.5.1 Radioactive waste

The Regulation on Rad-Pollution and Rad-Waste [6] contains provisions regarding the waste and discharge permit requirements.

The term “Waste” is defined in the Pollution Control Act [7] section 27, first para.: “*Waste” means discarded objects of personal property or substances. Surplus objects and substances from service industries, manufacturing industries, treatment plants, etc., are also considered to be waste.*

“Radioactive waste” (*radioaktivt avfall*) is defined in the Regulation on Rad-Pollution and Rad-Waste (§ 2 b. in [6]). If the waste contains or is contaminated with radioactive substances with specific activity greater than or equal to specific exemption values, it is termed “radioactive waste”. This specification is comparable to the legislation of other countries or in the Safety Standards of the IAEA, the ICRP, and the EU. Referring to a criterion that asks whether an activity is “greater than or equal to”, the corresponding values should be interpreted as threshold values, not as exemption values.

Regulation on Rad-Pollution and Rad-Waste Annex I a) lists values for specific activities (Bq g^{-1}) for radionuclides, above which waste is classified as radioactive waste. If the waste contains more than one radionuclide, the sum of the ratio between the specific activity for each radionuclide and the corresponding value in the table shall be checked to be greater than or equal to 1 (see Eq. 3).

$$\sum_k \frac{C_k}{C_{e,k}} \geq 1 \quad (3)$$

with

C_k: specific activity of radionuclide k

$C_{e,k}$: limit value for the specific activity of radionuclide k from

Table 5-4: Limit values for naturally occurring radionuclides to classify materials as radioactive waste (excerpt from Annex I a) in Regulation on Rad-Pollution and Rad-Waste [6])

Radionuclide	**Specific Activity $C_{e,k}$ [Bq g^{-1}]**
K-40	10
Pb-210[a]	1
Po-210	1
Ra-226[a]	1
Ra-228[a]	1
Th-228[a]	1
Th-230	1
U-234	1
U-235[a]	1
U-238[a]	1
Th-nat (incl. Th-232)[a]	1
U-nat [a]	1

[a] Radionuclides in equilibrium with daughter products (see Table 5-2), Th-nat and U-nat see explanation in Chapter 5.1.4). The activity limits in the table refer to the parent nuclide alone, but the dose contribution from the daughter products is taken into account in determining the activity limit for the parent nuclide.

In the legal sense, the property of waste to be radioactive depends exclusively on its specific activity. The specific activity values in the Regulation on Rad-Pollution and Rad-Waste Annex I (Table 5-4) agree formally with the exemption values of the IAEA and EU. However, due to the required application of the summation formula Eq. 3 in any case of radioactive disequilibria, the effective limit is much lower than 1 Bq g^{-1}. As demonstrated in the exemplary calculation in Table 5-5, the limits for classifying waste as radioactive are a factor 3 lower than the international exemption values of the IAEA and EU that do not apply a summation formula in the case of NORM.

Table 5-5: Application of the summation rule to a waste material with a disturbed equilibrium of the U-238-decay series (arbitrary example for demonstration).

Radionuclide k	**Exemption value $C_{e,k}$ (Table 5-4)**	**Specific activity C_k (example)**	C_k / $C_{e,k}$
	Bq g^{-1}	Bq g^{-1}	
Ra-226+	1	0,33	0,33
Th-230	1	0,33	0,33
U-234	1	0,16	0,16
U-238	1	0,16	0,16
Sum			**0,99**

5.1.5.2 Radioactive waste requiring disposal

The Regulation on Rad-Pollution and Rad-Waste [6] defines in § 2 d) the term “Radioactive waste subject to disposal” (*deponeringspliktig radioaktivt avfall)* as: *radioactive waste with greater or equal values for total activity and specific activity than stated in Annex I letter b*.

Annex I b) contains the values for the specific activities and for the total activity (Bq) per year (see Table 5-6) applied for the classification of waste requiring disposal within the meaning of § 2 d).

If the waste contains several radionuclides, the waste is subject to mandatory disposal if the sum of the ratio between specific activity for each radionuclide and the corresponding value in the table and the sum of the ratio between activity for each radionuclide and the corresponding value in the table is greater than or equal to 1 (see Eq. 3).

$$\sum_k \frac{C_k}{C_{e,k}} \geq 1 \text{ and (“og”) } \sum_k \frac{A_k}{A_{e,k}} \geq 1 \qquad (4)$$

with

C_k: specific activity of radionuclide k

$C_{e,k}$: limit value for the specific activity of radionuclide k from Table 5-6

A_k: activity of radionuclide k

$A_{e,k}$: limit value for the activity of radionuclide k from Table 5-6

It is important to note that both criteria are connected on Eq. 4 with the word “and/“og”! This means small amounts of waste are generally exempted from the requirements, and large amounts of total activity remain out of consideration if they occur with a sufficiently low specific activity. Regarding the total activity “A_k” the expected quantity during a year shall be used to assess the obligation to dispose of the waste.

The Regulation on Rad-Pollution and Rad-Waste [6] does not differentiate the disposal route, e. g. a surface landfill or underground storage. Provisions regarding the disposal of radioactive waste are contained in the *Forskrift om gjenvinning og behandling av avfall (avfallsforskriften)* (Waste Ordinance), Chapter 16) [8].

The Waste Ordinance regulates the requirements for the reception, interim storage, treatment and other disposal of radioactive waste (§ 16-3 d). According to § 16-3 Waste Ordinance, the term "disposal" means the final disposition of radioactive waste, e.g. by incineration, recycling or controlled disposal. Therefore, the provisions are primarily related to facility operators, where a waste holder or collector can deliver radioactive waste (§ 16-3 e).

Regarding the permit need, the Waste Ordinance distinct three cases (§ 16-5):

(a) Anyone who handles radioactive waste requiring disposal shall have a permit from the Norwegian Radiation and Nuclear Safety Authority.
(b) Anyone who has a permit to handle hazardous waste pursuant to Section 11-6 of the Waste Ordinance may handle radioactive waste not requiring disposal.
(c) Anyone who does not have a permit to handle hazardous waste pursuant to Section 11-6 of the Waste Ordinance, but who nevertheless handles radioactive waste not requiring disposal shall have a permit from the Norwegian Radiation and Nuclear Safety Authority.

According to this regulation, any operator who will accept and dispose of radioactive waste requiring disposal, needs a permit of the Radiation and Nuclear Safety Authority. In contrast to that, landfills approved for the disposal of hazardous waste can accept and dispose of radioactive waste not requiring disposal.

Waste holders that have a permit to handle (chemically contaminated) hazardous waste can handle radioactive waste not requiring disposal without a permit of the Radiation and Nuclear Safety Authority. Otherwise, they need a permit.

Table 5-6: Limit values for naturally occurring radionuclides classified as radioactive waste requiring disposal (excerpt from Annex I b) in Regulation on Rad-Pollution and Rad-Waste [6])

Radionuclide	**Total Activity $A_{e,k}$ [Bq y^{-1}]**	**Specific Activity $C_{e,k}$ [Bq g^{-1}]**
K-40	10^6	100
Pb-210[a]	10^4	10
Po-210	10^4	10
Ra-226[a]	10^4	10
Ra-228[a]	10^5	10
Th-228[a]	10^4	1
Th-230	10^4	1
U-234	10^4	10
U-235[a]	10^4	10
U-238[a]	10^4	10
Th-nat (incl. Th-232)[a]	10^3	1
U-nat[a]	10^3	1

[a] Radionuclides in equilibrium with daughter products (see Table 5-2). The activity limits in the table refer to the parent nuclide alone, but the radiation contribution from the daughter products is taken into account in determining the activity limit for the parent nuclide.

5.1.5.3 Radioactive discharges requiring a permit

In § 4, the Regulation on Rad-Pollution and Rad-Waste [6] enables the Norwegian Radiation and Nuclear Safety Authority to grant permits for activities that cause or may cause radioactive contamination and lay down more detailed conditions to prevent radioactive contamination from causing damage or inconvenience. Further, § 4 defines that *activities that result or may result in the supply of radioactive substances with a total activity or specific activity that is greater than or equal to the values specified in Appendix II shall … always be considered to cause significant damage or inconvenience and cannot take place without a permit (tillatelse*).

This approach differs significantly from the concept of exemption. While the exemption's approach is to establish values below which control is not deemed necessary, the Regulation on Rad-Pollution and Rad-Waste establishes thresholds above which regulatory control occurs.

Although the formula that has to be applied for radionuclide mixtures

$$\sum_k \frac{C_k}{C_{e,k}} \geq 1 \text{ or ("eller") } \sum_k \frac{A}{A_{e,k}} \geq 1 \qquad (5)$$

with

C_k: specific activity of radionuclide k
$C_{e,k}$: limit value for the specific activity of radionuclide k from Table 5-7
A_k: activity of radionuclide k
$A_{e,k}$: limit value for the activity of radionuclide k from Table 5-7

looks very similar to Eq. 2, the differences are substantial. While a material that complies with one criterion in Eq.2 can be exempted, Eq. 5 means that any material which does not comply with both criteria needs a permit for discharge.

The values for naturally occurring radionuclides in Annex II of [6] are listed in Table 5-7. The data show that discharges are exempted from regulatory control only if they are lower by a factor of 10 compared to the values in the Radiation Protection Act. Because the values of the Radiation Protection Act correspond to the exemption values of moderate amounts according to IAEA (cf. Table 4-1) that were derived referring to the dose level of 10 µSv per year, the Regulation on Rad-Pollution and Rad-Waste implicitly sets a level of about 1 µSv per year or less as a level of harmful effects. This is significantly below international standards.

Table 5-7: Limit values for naturally occurring radionuclides in radioactive materials requiring a permit (excerpt from Annex II in Regulation on Rad-Pollution and Rad-Waste [6])

Radionuclide	Total Activity $A_{e,k}$ [Bq y^{-1}]	Specific Activity $C_{e,k}$ [Bq g^{-1}]
K-40	10^5	10
Pb-210[a]	10^3	1
Po-210	10^3	1
Ra-226[a]	10^3	1
Ra-228[a]	10^4	1
Th-228[a]	10^3	0,1
Th-230	10^3	0,1
U-234	10^3	1
U-235[a]	10^3	1
U-238[a]	10^3	1
Th-nat (incl. Th-232)[a]	10^2	0,1
U-nat [a]	10^2	0,1

[a] Radionuclides in equilibrium with daughter products (see Table 5-2). The activity limits in the table refer to the parent nuclide alone, but the radiation contribution from the daughter products is taken into account in determining the activity limit for the parent nuclide.

5.1.6 System

Figure 5-1 shows a simplified flow scheme of the Norwegian radiation protection system. The system has two different parts. The Radiation Protection Act (RPA) regulates operational radiation protection measures to ensure the safe use of radiation, to prevent adverse effects of radiation on human health and to contribute to the protection of the environment. It can be seen as a supplement to occupational health and safety with regard to radiological hazards.

The Regulation on Rad-Pollution and Rad-Waste (RPW) serves the purpose of protecting the outdoor environment against pollution and promoting better waste management. Its focus is clearly environmental protection.

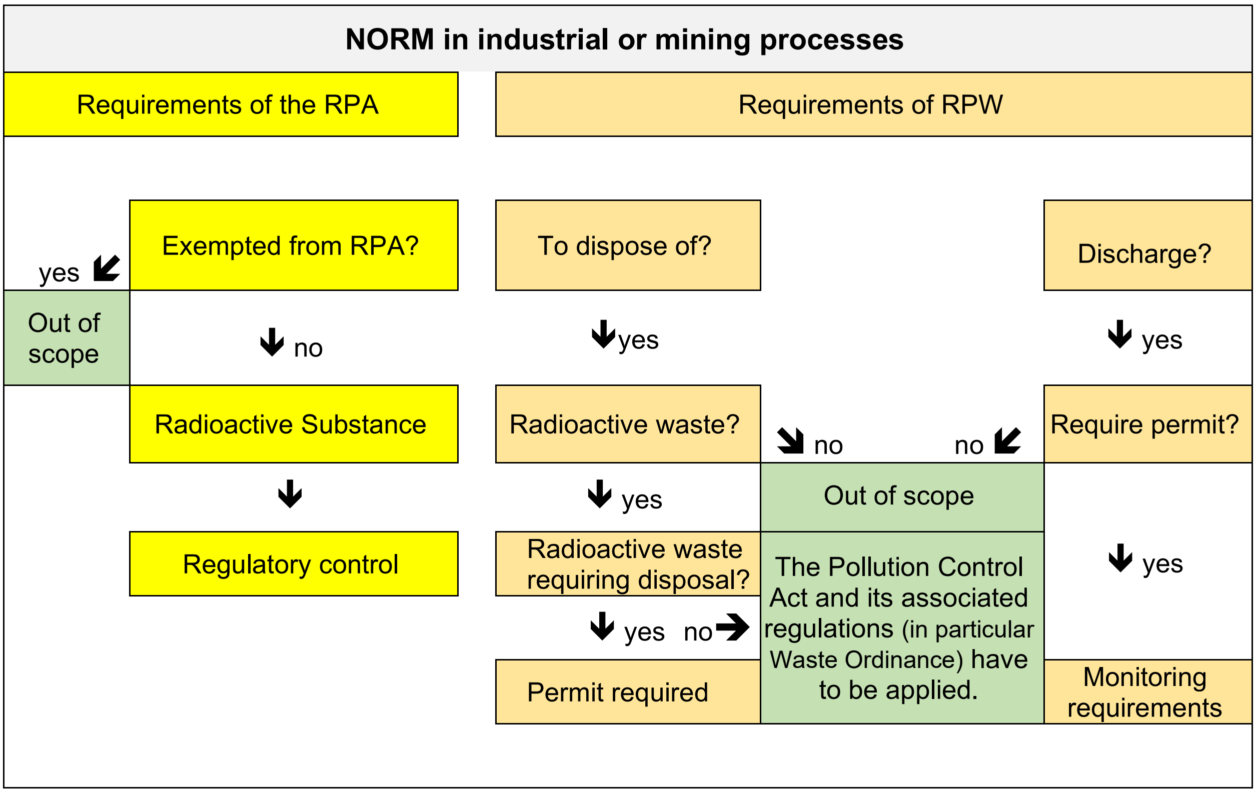

Figure 5-1: Simplified flow scheme of the regulatory radiation protection system in Norway

For both parts of the regulatory framework, the first thing to clarify is whether or not an activity or radiation source falls within the regulatory scope. Only when this question is answered with "yes" do the legal requirements apply. A graduated level of regulatory control is implemented internationally and also in Norway.

5.2 Austria

The current RP regulations are laid down in the Austrian Radiation Protection Act ("Strahlenschutzgesetz", StrSchG) [16] associated with the Austrian Radiation Protection Ordinance ("Strahlenschutzverordnung" AllgStrSchV [38]).

5.2.1 Disposal and recovery of NORM

The dose criteria for public exposure for exempting notified practices from authorization is defined as 1 mSv y^{-1}. Annex 1 part D in the General Radiation Protection Ordinance (AllgStrSchV (2020) [38]) sets the general clearance/exemption values for naturally occurring radionuclides according to the standards in the EU-BSS [23]. Individual values are applied for specific clearance for disposal in landfills or incineration, especially for Pb-210, Po-210 (Annex 1 part D Table 3; see Table 5-8).

Table 5-8: Clearance/exemption values for naturally occurring radionuclides from practices (Annex 1 Part D Table3 in the AllgStrSchV)

Radionuclide	**General clearance, exemption values [Bq g^{-1}]**	**Specific clearance/exemption values for disposal in landfills or incineration [Bq g^{-1}]**
U-238 series	1	10
Th-232 series	1	10
Pb-210/Po-210	-	50
K-40	10	-

Residues with naturally occurring radionuclides from industrial processes are excluded from the obligations of licensees according to Art. 15 para. 1 in the Austrian Radiation Protection Act (StrSchG (2020) [16]) and Art. 7 para 2 in the AllgStrSchV [38] if these exemption values in Table 5-8 are not exceeded.

The Austrian Standard ÖNORM S5252 [39] addresses the estimation of effective dose for individual persons of the public by NORM in case of discharge and landfilling of residues. Liquid discharges are also addressed there, for example, by spreading the activity in water, by different exposition paths, and the resulting exposure for members of the public.

5.2.2 Discharge of NORM

Art. 77 of the AllgStrSchV [38] addresses discharges. Radioactive substances may be discharged with wastewater or exhaust air only if the exposure of members of the public due to the discharges does not exceed an effective dose of 0.3 mSv y^{-1}. This requirement can be assumed to be fulfilled if the activity concentration of the discharges does not exceed the values of Annex 2 Part C Table 3 (see Table 5-9).

Table 5-9: Discharge values for mixtures of naturally occurring radionuclides (Annex 2 C Table 3 in the Austrian AllgStrSchV [38])

Mixture of radionuclides	**Activity concentration into the exhaust air [Bq/m^3]**	**Activity concentration into the wastewater [Bq/m^3]**
Mixture of naturally occurring radionuclides of the U-238- and U-235-series in their natural relationship	$9 \cdot 10^{-3}$	-
Mixture of naturally occurring radionuclides of the U-238- and U-235-series in their natural relationship and of the Th-232 series	$6 \cdot 10^{-3}$	$1,5 \cdot 10^{5}$

The conditions for the application of the activity concentration values are specified in Annex 2 Part C as follows:

a. Values shall apply as an annual average for discharge in the form of aerosols with exhaust air for exhaust air flows of $1 \cdot 10^5$ to $1 \cdot 10^6$ m³ per hour (five times these values shall apply for lower exhaust air flows).
b. The activity concentration values for exhaust air are applicable only if the stack height and exhaust air flows are in defined ranges.
c. Buildings in the immediate vicinity of the emission point of the discharge are overhung by a factor of 2.5.

The annual activity that complies with the requirements can be estimated from the amounts mentioned under a. in the range of 5 MBq to 50 MBq per year. The authority may permit higher values under case-specific conditions.

5.3 Belgium

The current Belgian RP legislation is the amended Royal Decree 2001 (“Koninklijk besluit van 20 juli 2001 houdende algemeen reglement op de bescherming van de bevolking, van de werknemers en het leefmilieu tegen het gevaar van de ioniserende stralingen” 2001 [40]). The amendments due to adapting the Directive 2013/59/Euratom have been summarized by the Federaal Agentschap voor Nucleaire Controle (FANC) (in french: Agence fédérale de Contrôle nucléaire (AFCN)) in [41].

5.3.1 Disposal and recovery of NORM

The occupational activities that pose a risk of external exposure, ingestion, or inhalation of natural radioactive substances in existing or future premises, under normal working conditions or normal occupancy rates, or during maintenance, including those occupational activities related to associated residue or waste streams that are considered planned exposure situations and are listed in Article 1, paragraph 2, are those occupational activities involving natural radiation sources, of which:

1° the total amount exceeds 1 ton;

2° for stationary sources, the activity concentration exceeds the levels defined in Annex VIII;

3° for liquid sources, the activity concentration exceeds the levels defined in Annex IX.

They must be declared to the Agency in accordance with Article 9.1.

The competent Agency shall determine in which industrial sectors these levels may be exceeded. Raw materials, products, by-products or residues from an activity, including parts of installations, may be considered natural sources.

When the activity concentration exceeds the exemption values applicable to the transport of natural radiation sources, which were determined in Article 4 of the Royal Decree of 22 October 2017 on the transport of dangerous goods of class 7, the restriction regarding quantities exceeding 1 ton does not apply.

The regulations relating to NORM processing, disposal, and recovery are mentioned in articles 4, 9, and 20.3 of the Royal Decree. Notification is only compulsory for NORM industries belonging to the "positive list" given in Article 4 of the Decree. During the licensing process, specific conditions related to disposal or discharge can be specified. Art. 4 lists the sectors subject to regulation as part of the "professional activities in that natural radiation sources are used". This list of professional activities has been updated in the publication of a decree in the Belgian Official Gazette of 30 March 2012 (FANC/AFCN 2012) [42].The processing, upgrading, and recycling of NORM residues are also subject to this decree.

The current dose criterion for exempting notified practices from authorization is defined as 0.3 mSv y^{-1}. But as stated by St. Pepin in [43], the implementation of the EU-BSS [23] will introduce clearance values for moderate quantities (defined as < 1 Mg y^{-1}) of non-aqueous waste. A clearance license may be issued for larger quantities or activity concentrations above clearance values if an impact study shows that doses are below 10 µSv y^{-1}.

If the specific activities of the naturally occurring radionuclides do not exceed the clearance/exemption values in Table 5-10 (from [43]), no further restrictions according to the Belgian RP legislation are imposed. If these values are exceeded, the industries must notify the practices, including reuse or recycling, at the competent authority FANC/AFCN.

For mono-landfills disposal, exemption/clearance values of 0.1 Bq g^{-1} for Ra-226+ and Ra-228+ apply in Belgium [42].

Licenses can be issued for the disposal of liquid radioactive waste according to Article 23 para 1 of the Royal Decree (2001) [40]. The disposal, removal in view of recycling, and recovery of radioactive waste originating from work activities involving NORM are also subject to a permit issued by the competent authority [44].

Table 5-10: Clearance/exemption values for naturally occurring radionuclides in the Belgian RP legislation

Radionuclide	General Clearance/ exemption values [Bq g^{-1}]	Clearance/ exemption values for mono-landfills [Bq g^{-1}]
K-40	5	-
Pb-210+	5	-
Po-210	5	-
Ra-226+	0.5	0.1
Ra-228+	1	-
Th-228+	0.5	-
Th-230	10	-
Th-232sec [1)]	5	-
U-238sec [1)]	0.5	0.1
U-nat.	5	-

[1)] Th-232+ = Th-232sec; U-238+ = U-238sec

5.3.2 Discharge of NORM

The current Belgian Radiation Protection Decree [40] has only generic clearance values for solids but not for liquids or gases.

A registration for NORM discharges is required if the activity concentration is below the activity values in RP 122, part II [31], and licensing if this concentration is above the values mentioned in [45] up to a dose limit of 0.3 mSv y^{-1}. Moderate quantities (< 1 Mg) are exempted from notification if the activity concentration does not exceed the defined exemption values for the transportation of radioactive substances in Belgium (i.e. 10 times the exemption/clearance values). This graded approach is illustrated in Figure 5-2.

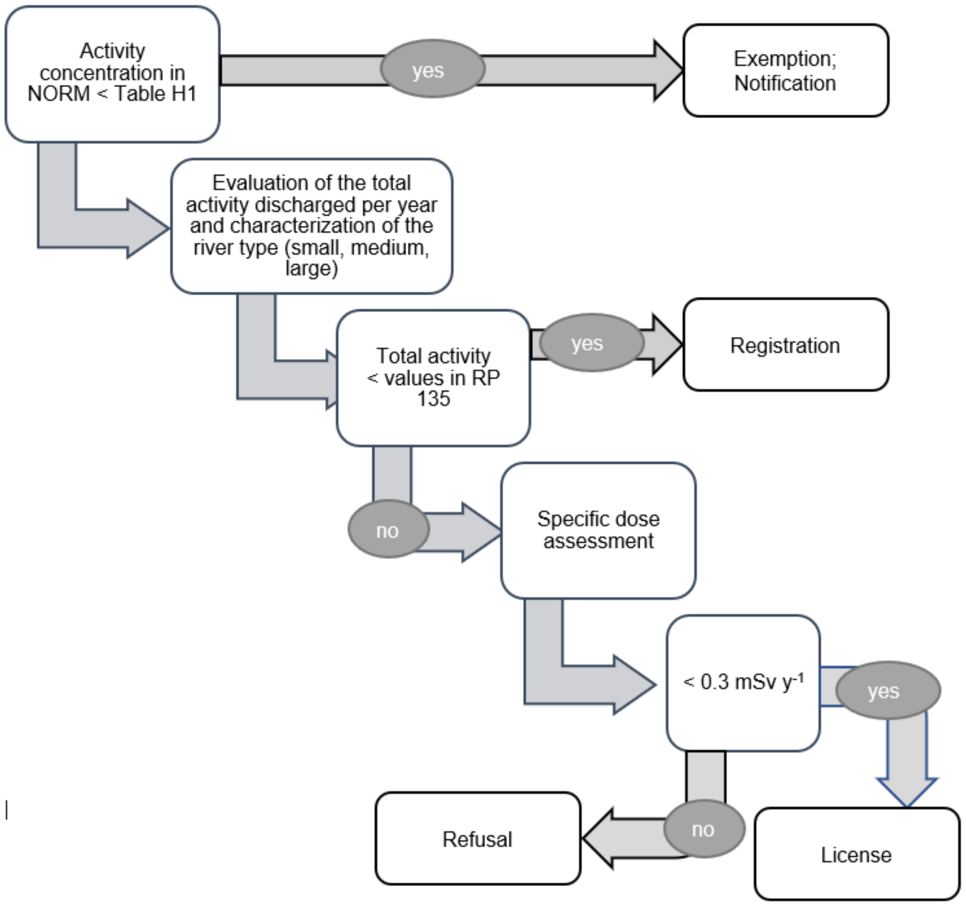

Figure 5-2: Flow diagram for the tiered assessment in Belgium. Adopted from [44]

The maximum concentrations in liquid discharges from Table C of the Royal Decree (2001) [40] should not be directly applied to "work activities involving natural radiation sources" (see Table 5-11). In practice, however, they are used as reference values in the assessment of the declarations from these work activities [44]. For discharges of NORM, in case the concentration in the liquid discharges exceeds the exemption value, a second tier of assessment will be made using the screening values on the basis of the dose criteria of 0.3 mSv y^{-1} derived from RP 135 [45].

In the project of the new Royal Decree implementing the EU-BSS [23], the values from Table 5-11 will be used as exemption values for liquids containing naturally occurring nuclides. But these clearance values have not been derived from a proper dose assessment. Rather they are pragmatic values based on a rule of thumb that any discharge of liquid waste with this activity concentration would be diluted before reaching any human receptor [42].

Table 5-11: Exemption values for liquid natural radiation sources according to Table C of the Belgian Royal Decree (2001) [40]

Radionuclide	Activity concentration [Bq l^{-1}]
K-40	160
Pb-210	1.4
Po-210	0.83
Ra-226	3.6
Ra-228	1.4
Th-228	14
Th-230	4.8
Th-232	4.3
U-234	20
U-238	22

5.4 Czech Republic

The current RP regulations are laid down in Czech Atomic Act (ZÁKON ze dne 14. července 2016 [46]).

5.4.1 Disposal or recovery of NORM

The dose criteria for public exposure for exempting notified practices from authorization is defined as 1 mSv y^{-1}. The Czech Republic sets the general clearance/exemption values to 1 Bq g^{-1} for natural radionuclides from the U-238 series and from the Th-232 series as well as 10 Bq g^{-1} for K-40 according to the EU-BSS [23]. The clearance values are binding for operators of NORM sectors listed in a "positive list".

5.4.2 Discharge of NORM

The clearance values for the discharge of wastewater into surface water and into the wastewater treatment plant for the public are summarized in Table 5-12. If the clearance values are not exceeded, NORM is exempted from any further RP restrictions. These values were derived from clearance values for liquids containing artificial radionuclides. They should ensure that the effective dose will not exceed 0.3 mSv y^{-1} in case of consumption of surface water.

Table 5-12: Clearance values for discharge of wastewater according to the Czech Republic Legislation

Discharge of wastewater into	Average total alpha activity volume concentration [Bq/l]	Average total beta activity volume concentration [a] [Bq/l]
surface water	0.5	1
the wastewater disposal system for public	50	100

[a] without the contribution of K-40

The radioactive liquids from NORM industries may be discharged without a license of the competent authority (State Office for Nuclear Safety, Czech abbreviation SÚJB] if

a) the clearance values are not exceeded or
b) the effective dose of each member of the public during a calendar year caused by a discharge is lower than 0.3 resp. 0.1 mSv.

5.5 Finland

The current Finish RP regulations are laid down in Finish Radiation Act (Säteilylaki, lait tulivat voimaan 15.12.2018 (859/2018) [47]).

5.5.1 Disposal and recovery of NORM

The Finish Radiation and Nuclear Safety Authority (Säteilyturvakeskus, abbreviated: STUK) has issued more detailed regulations [48] on release limits in accordance with the EU-BSS [15] and sets the general clearance/exemption values to 1 Bq g^{-1} for natural radionuclides from the U-238 and Th-232 series. These limits must be applied for the treatment, use, and storage of NORM and NORM waste according to section 145 para 3) of [47]. The limits are given for NORM-related industries as effective dose levels. They are defined with 1 mSv y^{-1} for workers and 0.1 mSv y^{-1} for members of the public.

If the quantity of radioactive substance exceeds the release limit, the quantity referred to the practice requires the license of the Radiation and Nuclear Safety Authority. NORM waste is legally not radioactive waste, but assessment and licensing for recycling and disposal are needed.

5.5.2 Discharge of NORM

For discharges, there is a dose level in the range of 0.1 mSv y^{-1} for members of the public based on a generic exemption/clearance criterion [49].

5.6 France

The current radiation protection legislation in France is laid down in the Public Health Law (Code de la santé publique [50]) amended in February 2022 ("Décret n° 2022-174 [51]), as well as in the Environmental Law (Code de l'environnement [52]), latter in particular for waste regulations.

Naturally occurring radioactive substances ("Substance radioactive d'origine naturelle") are defined in Annex 13-7 of the Public Health Law as any substance containing one or more naturally-occurring radionuclides not used for their radioactive, fissile or fertile properties whose mass activity concentration(s) exceed(s) one or more exemption limit values defined in Table 1 of Annex 13-8 of Part I of this Code. The corresponding values in Annex 13-8 Table 1 are 1 Bq g^{-1} for natural radionuclides from the U-238- and Th-232-series and 10 Bq g^{-1} for K-40 according to the EU-BSS [23]. In a comment to this table, all radionuclides in the U-238 and Th-232 series are considered to be in radioactive equilibrium with their parent. In case of radioactive disequilibria due to industrial processing, the parent radionuclides shall be taken as the head of the chain in relation to their progeny, and the same exemption value has to be applied.

5.6.1 Disposal or recovery of NORM

Waste that complies with the exemption values given above can be disposed of in a landfill for inert waste, a landfill for non-hazardous waste, or a landfill for hazardous waste, depending on its chemical characteristics. If, for at least, the specific activity of one decay-series radionuclide is higher than 1 Bq g^{-1} but lower than 20 Bq g^{-1}, then the waste can be stored in a landfill for non-hazardous waste or a landfill for hazardous waste, depending on its chemical characteristics [53]. If some activity concentrations exceed 20 Bq g^{-1}, then waste must be stored in a radioactive waste disposal facility.

5.6.2 Discharge of NORM

The French decision n°2008-DC-0095 [53] contains specific regulations for discharges of radioactively contaminated wastewater from authorized practices. The regulation does not differentiate between artificial and naturally occurring radionuclides but between short- and long-lived radionuclides. Liquid effluents from such practices have to be collected in tanks or containers for storing and decay. They can be rejected in sewer systems, having made sure that the activity concentration for radionuclides with a half-life of less than 100 days is lower than 10 Bq l^{-1}. The discharge of wastewater contaminated with radionuclides with half-lives longer than 100 days from industrial processes in public sewer systems must be authorized beforehand on a case-by-case basis, including the definition of discharge limits by the competent authority.

France has not implemented any other exemption values for the discharge of effluents or air [44].

Within the framework of authorization, the French nuclear safety authority sets the conditions for discharges into the environment, which may require in particular ([53] Article 23):

1. Continuous monitoring of the activity and/or concentration of effluents discharged;
2. Spot sampling;
3. Implementation of an environmental radiological monitoring plan;
4. Periodic information of local residents or the municipalities concerned.

5.7 Germany

Germany has brought the Radiation Protection Act (abbreviated in German as StrlSchG) [17] and the Radiation Protection Ordinance (abbreviated in German as StrlSchV) [18] into force to comply with the requirements of the EU-BSS.

The limit for the effective dose for occupationally exposed persons is 20 mSv y^{-1} (§ 78 para. 1 StrlSchG). As the result of exposure from practices requiring a license or notification under the StrlSchG, the limit for the sum of effective doses for members of the public is 1 mSv y^{-1} (§ 80 para 1 StrlSchG).

5.7.1 Disposal and recovery of NORM

Materials from industrial or mining processes specified in a “positive list” in Annex 1 StrlSchG are classified as “residues”. Residues require surveillance if the surveillance limits specified in Annex 5 StrlSchV are exceeded. These surveillance limits depend on the intended ways of recovery or disposal, also given in

Annex 5 StrlSchV. A general surveillance limit is defined as C = 1 Bq g^{-1} in Annex 5 No. 1. Alternative surveillance limits are shown in Table 5-13.

Whether a residue exceeds the surveillance limit has to be checked with a sum formula:

$$C_{U238max} + C_{Th232max} \leq C \quad (6)$$

Here $C_{U238max}$ and $C_{U238max}$ are the highest specific activities of the radionuclides of the U-238- and of the Th-232 series, each related to dry mass.

Anyone engaged or permitting engagement on his responsibility where residues requiring surveillance accumulate and where the utilization or disposal thereof cause an effective dose for persons of the public that may exceed 1 mSv per calendar year has to take measures for the protection of the general public. In particular, the recovery or disposal of residues requiring surveillance is only permitted if these residues (= NORM waste) are released from surveillance by the competent authority according to § 62 para. 2 StrlSchG.

Table 5-13: Individual monitoring values for residues depending on its intended recovery or disposal

Annex 5 No.	Intended recovery or disposal	Surveillance limit [Bq g^{-1}]
2	a) more than 5,000 tons of residues are deposited in the catchment area of a usable aquifer per calendar year, or b) more than 50% residues are incorporated in construction materials in the case of recovery in road(1), path, landscape or hydraulic construction, in sports and play areas, or in other areas.	0.5
3	Underground recovery or landfilling of residues.	5
5	When an area > 1 hectare will be covered with leftover rock for landfilling or recovery in road, path or landscape construction, including in sport and play areas, in the catchment area of a usable aquifer.	$C_{U238max}$: 0.2 $C_{Th232max}$: 0,2

(1) to the disposal of slags in road, path, landscape or hydraulic construction in other areas: C = 1 Bq g^{-1}

And, especially for residues, where the greatest specific activity of Pb-210+ radionuclides exceeds the greatest specific activity of the other radionuclides of the U-238series by a factor A larger than 5, in derogation from No's. 1 to 3, a factor R is implemented pursuant to

$$R \cdot C_{U238max} + C_{Th232max} \leq C \quad (7)$$

The factor R shall have the value 0.5 with above-ground recovery or disposal. The factor R shall be taken from Table 5-14 for underground recovery or disposal.

Table 5-14: Factor R that shall be taken for underground recovery or disposal

Factor A	Factor R
5 < A ≤ 10	0.3
10 < A ≤ 20	0.2
20 < A	0.1

All these factors were derived from dose assessments for corresponding scenarios.

Related to the dose criteria of 1 mSv y^{-1}, it can be taken into account that external gamma radiation becomes less important in materials with only Pb-210+. Higher specific activities for Pb-210+ with the determined factors arise from these dose assessments to achieve a comparable dose as for the other radionuclides of the U-238 or Th-232 series.

In Germany, it is forbidden to landfill or dispose of liquid wastes or liquid residues from any sources independent of the NORM content. After solidification (via evaporation, in geopolymer, or other techniques) of possible liquid residues, the regulations for solid NORM residues are applied.

5.7.2 Discharge of NORM

For the discharge of radionuclides from installations or facilities operating under a radiation protection regime into the air or water, the effective dose for members of the public has to comply with the dose limit of 0.3 mSv y^{-1} (§ 99 para. 1 StrlSchG). In Annex 11, the StrlSchV contains values for simplified checking discharges via air and water regarding their compliance with the dose limit of 0.3 mSv per year. These values were derived from enormously simplified models. For discharges via air, it was assumed that the emitted air is inhaled undiluted and for discharges with water, the water is directly used as drinking water. Consequently, the values obtained are highly conservative and are applied only to discharges from radiation protection areas with artificial radionuclides. In the case of NORM, the StrlSchV is oriented towards realistic scenarios for dose assessments. Moreover, the German RP legislation does not define any specific limits for discharges of NORM. The general constraint of 1 mSv per calendar (§ 61 para. 1) year applies here, too.

Water discharged from NORM industries was investigated as a part of a research project [54]. A result of dose assessments in this project, executed for the German Federal Office for Radiation Protection (BfS), has demonstrated that taking into account the average production capacity of a facility under typical meteorological conditions prevailing in Germany, effective doses did not significantly exceed 0.1 mSv y^{-1} for any of the sectors considered. This assertion bases on the results of generic approaches in [54] to estimate radiological impact for NORM industrial sectors with significant dust emissions (cement production, primary iron production, lead smelters, and coal-fired power plants) operating in Germany. Only discharges of mine effluents from closed hard coal mines (as part of the perpetual mine management obligations) were identified to potentially lead to effective doses for members of the public exceeding 0.1 mSv y^{-1}. The main reason for the absence of relevant doses to the public was the high level of environmental standards for discharges in general. In the case of mine effluents, long-lasting sedimentations can lead to a significant dose for the public, at least in rare and almost unpredictable situations.

As a consequence, the NORM industries have no further obligations for notification of discharges due to their production processes.

5.8 Ireland

The risk from industrial processes with NORM are covered by Ireland's Ionising Radiation Regulations (IRR19 [55]).

5.8.1 Disposal or recovery of NORM

Sector-specific surveys of the non-nuclear sector demonstrated that worker doses were below 1 mSv y^{-1} and public doses considerably lower. The assessments carried out to date indicate that no worker is likely to receive a dose > 1 mSv y^{-1} and that doses likely to be received by members of the public are considerably lower than those received by workers and are well within limits set in national legislation.

Therefore, Ireland perceives any need for detailed regulation. The dose criteria for public exposure for exempting notified practices from authorization is defined as 1 mSv y^{-1}. IRR19 sets the general clearance/exemption values to 1 Bq g^{-1} for natural radionuclides from the U-238 series and from the Th-232 series as well as 10 Bq g^{-1} for K-40 according to the EU-BSS [23]. The use or disposal of NORM is subject to regulation if they are liable to give rise to a radiation dose of > 1 mSv y^{-1}.

The Irish Environmental Protection Agency (EPA) has found it necessary to adopt a sector-specific approach to the risk assessment methodologies it has adopted. EPA has carried out an extensive survey of such industries and the materials they handle and dispose of, including those involving discrete sources (for example, thoriated products) and diffuse sources (mainly those arising from extractive industries, especially oil, and gas but also peat burning and bauxite and cement production) [44].

Ireland has additional conditions that the sum rule must be applied for mixtures of radionuclides. The disposal method must not concentrate activity [44].

5.8.2 Discharge of NORM

There is not any regulation concerning the discharge of NORM in the Irish legislation. The Irish EPA will consider the need for separate guidance to be provided on this topic [56].

5.9 Italy

The current Italian RP legislation is laid down in the Legislative Decree (Decreto Legislativo 31 luglio 2020 no 101, abbreviated D. lgs 101/2020) that was brought into force on 12 August 2020 [57].

5.9.1 Disposal or recovery of NORM

Section II Table II-1 D. lgs 101/2020 defines a list of industrial sectors ("positive list") and their classes or types of practices involving the use of NORM, including research and secondary processes. D. lgs 101/2020 Table II-2 sets general clearance/exemption values according to the EU-BSS [23]. For Pb-210, Po-210 and oil sludges, modified values can be applied (Section II No. 2 - 5 in [57]; see Table 5-15).

Table 5-15: Exemption values for naturally occurring radionuclides in Italy (D. lgs 101/2020)

Radionuclides	**General exemption values [Bq g^{-1}]**	**Exemption values for landfills or recovery for road construction [Bq g^{-1}]**	**Exemption values for oil sludge [Bq g^{-1}]**
K-40	10	-	-
Pb-210, Po-210	5	0.5	100
Ra-228	-	-	10
Th-230	-	-	100
Th-232	-	-	100
Th-232 series	1	0.5	5
U-238 series (without Pb-210/Po-210)	1	0.5	5
U-nat	-	-	100

Section II No. 5 D. lgs 101/2020 specifies that where the residues are destined for incineration, for exemption, the operator must demonstrate that the dose for a representative person complies with the dose exemption level, even if the specific activity of the residues to be disposed of is lower than the values shown in Table II-2 in D. lgs 101/2020 [57].

5.9.2 Discharge of NORM

Discharges from NORM-affected industries are not regulated in D. lgs 101/2020 in a specific way. According to Annex I No. 8.8 D. lgs 101/2020, the competent authorities shall require for the release of liquid or aeriform effluents into the environment that the criteria of no radiological relevance are met. These criteria are set in Annex II No. 3 for workers to 1 mSv effective dose per year and for (representative) persons of the public 0.3 mSv y^{-1}. In the case of disposal to the environment of residues and effluents potentially impacting drinking water sources, it shall be demonstrated that the effective dose to persons of the public is less than 0.1 mSv y^{-1}.

5.10 Latvia

The current Latvian RP legislation is laid down in the “Law on Radiation Safety and Nuclear Safety” (Par radiācijas drošību un kodoldrošību) that was brought into force on 23 December 2020 [58].

Licensing Regulation sets exclusion for natural radioactive material, the specific radioactivity of which exceeds the exemption values specified in the Annex of this Regulation; if such material is not used for its radioactive, fertile or fissile properties, the total effective dose of ionizing radiation received by members of the public does not exceed 1 mSv y^{-1}. The value of 1 Bq g^{-1} is set for the natural decay chains [76].

5.11 Lithuania

The current Latvian RP legislation is laid down in the “Law on Radiation Protection” (Radiacinės Saugos įstatymo), that has been brought into force on 21 June 2018 [59].

5.11.1 Disposal and recovery of NORM

The dose criteria for public exposure for exempting notified practices from authorization is defined to 1 mSv y^{-1}. Lithuania sets the general clearance/exemption values to 1 Bq g^{-1} for natural radionuclides from the U-238 series and from the Th-232 series as well as 10 Bq g^{-1} for K-40 according to the EU-BSS [23].

5.11.2 Discharge of NORM

Art. 10 No. 6 specifies that practices must be notified if they are related to the use or production of NORM that may enter the water and consequently cause radioactive contamination of drinking water or unjustified public exposure due to food. But there are not any known NORM industries with discharges containing natural radioactivity [76].

Liquid discharges from authorized practices at that type of institution (non-nuclear sector without NORM industries) are regulated with a dose constraint as well, and the total dose due to liquid and gaseous discharges to the public is less than 0.2 mSv y^{-1}.

5.12 The Netherlands

The current RP legislation is the “Besluit van 23 oktober 2017, houdende vaststelling van regels ter bescherming van personen tegen de gevaren van blootstelling aan ioniserende straling (Besluit basisveiligheidsnormen stralingsbescherming)” (Royal Decree 2017) [60].

5.12.1 Disposal and recovery of NORM

The Royal Decree (2017) includes limit values for generic, i.e., unconditional, exemption, and release. The general dose (on-site) criteria for both a member of the public and for a worker for exempting notified practices from authorization is defined as 0.3 mSv y^{-1}.

The general clearance/exemption values are set in Annex 3 Table A Part 2 Royal Decree 2017 to 1 Bq g^{-1} for natural radionuclides of the U-238, U-235, and Th-232 series as well as 10 Bq g^{-1} for K-40 according to the EU-BSS [23]. The highest activity concentration from each decay series is decisive [61]. For potassium quantities < 1 Mg, the clearance and exemption level for K-40 is set to 100 Bq g^{-1}, i.e., because the highest specific activity in pure metallic potassium is about 32 Bq g^{-1} K-40, natural materials up to masses of 1 Mg are generally exempted.

These clearance/exemption values can be applied for unlimited amounts of solid material. The Royal Decree (2017) includes the possibility of specific, i.e., conditional, exemption, and release. This means that for certain operations involving NORM, higher values for an exemption or clearance can be set. The starting point is that the radiological risks are demonstrably limited and are verified by a dose assessment.

For the oil and gas production and geothermal industry, higher specific clearance values are applied in the Netherlands. This is justified due to the arguments that landfill sites are constructed such that they can safely store hazardous waste [14]. That means at least,

- a water treatment system is operating that ensures that leaching into the groundwater does not occur,
- a monitoring system is in place to ensure that this requirement is met and,
- when the landfill has reached its maximum capacity, it will be sealed by a protective multi-layer system.

Based on a dose assessment, specific clearance values for wet sludges from oil and gas production and geothermal facilities are applied (see Table 5-16).

5.12.2 Discharge of NORM

Article 10.4 Royal Decree (2017) regulates the exemption from the ban on discharges and states that the prohibition referred to in Article 10.3 does not apply if:

- it concerns a discharge of radioactive substances released as a result of operations with naturally occurring radionuclides, and
- the activity of the total radionuclides to be discharged in a calendar year upon leaving the site is lower than the release value listed in Annex 3, Part B, Table C.

The release values of Annex 3, Part B, Table C Royal Decree (2017) are compiled in Table 5-17.

Table 5-16: Specific clearance level for wet sludges from oil and gas production and geothermal facilities in the legislation of the Netherlands.

Radionuclide	Clearance values to water [Bq l^{-1}]
K-40	100
Pb-210+	100
Po-210	100
Ra-226+	5
Ra-228+	10
Th-228+	5
Th-232+	5
U-238+	5

Table 5-17: Annual discharge activities (release values) of naturally occurring radionuclides exempted from the ban of discharges in the Netherlands

Radionuclide	Annual discharge activity into water [GBq y^{-1}]	Annual discharge activity into air [GBq y^{-1}]
Pb-210+	10	10
Po-210	10	10
Rn-222+	–	10,000
Ra-223+	1,000	–
Ra-224+	1,000	–
Ra-226+	10	10
Ra-228+	100	1
Ac-227+	100	10
Th-227	1,000	–
Th-228+	1,000	1
Th-230	100	1
Th-232sec	100	1
Th-234+	10,000	-
Pa-231	10,000	0.1
U-234	1,000	10
U-235+	1,000	10
U-238sec	1,000	10

The Royal Decree (2017) also contains notes on the values explaining the conceptual background. Since these notes are informative for the task to be dealt with here, a translation (of a part) of the notes to Article 10.4 is given in the following.

“As described in the notes to Article 10.3, the Directive requires a permit for all operations involving significant discharges to the environment. In doing so, the Directive does not distinguish between artificial radionuclides and radionuclides of natural origin. This is also expressed in Recital 16 of the Directive: "Protection against natural sources should be fully included in the general requirements rather than being dealt with separately in a specific title. In particular, industry branches handling materials containing natural radionuclides should be managed within the same regulatory framework as other operations". However, this consideration does not mean that the clearance values for radioactive substances or waste from practices involving naturally occurring radionuclides should be the same as for radioactive substances of artificial origin. Therefore, the decree does not distinguish between authorisation requirements for discharges of naturally occurring radioactive substances and artificial radionuclides but sets different clearance values.

The clearance values for discharges of radioactive substances from operations with naturally occurring radionuclides, in Giga Becquerels per calendar year are listed in Annex 3 (section B, table C) of the Decree. These values, like the release values for discharges of radionuclides of artificial origin, are calculated on the basis of realistically conservative scenarios and assumptions, with the dose criterion being the value of 10 Microsieverts in a calendar year for a member of the public. As for discharges of radioactive substances resulting from practices involving artificial radionuclides, this is a factor of 100 lower than the dose criterion for release values for other practices. This dose value differs from the dose criterion for discharges from artificial sources, which, because of its good manageability and optimisability, is set at the relatively low value of 0.1 Microsieverts in a year. The air dispersion scenario for the discharge of radioactive substances from operations with naturally occurring radionuclides assumes a relatively low discharge height of 10 metres, with a heat content of 1 MW and an average particle size. This scenario is conservative because air discharges generally involve process industries with higher temperatures and chimneys. For the dispersion of radioactive substances from operations with naturally occurring radionuclides into water, the scenario "discharge directly into surface water in the form of a river, with discharge to the sea" was chosen because water discharges from the process industry generally take place in this way. Incidentally, the results based on the different water dispersion scenarios do not differ much. In those exceptional cases where the real situation may give doses significantly higher than the dose criteria, the Authority may, if necessary, intervene by regulation […]. Examples, where this could be possible, include the transfer of mineral sands (upwelling) with relatively high activity or discharges to canals or rivers with a small volume, which could result in a relatively high concentration in the water. These scenarios have not been used in the calculation of the release values because they are exceptional cases. This approach was chosen because these exceptional cases would unnecessarily limit the many other cases.”

5.13 Romania

Industrial processes with NORM are under the control of the Romanian RP legislation [62] [63. Based on the EU-BSS [23], the exemption values are the same as defined by the IAEA with 1 Bq g^{-1} for natural radionuclides from the U-238 series and the Th-232 series as well as 10 Bq g^{-1} for K-40.

For workers involved in activities with NORM, a graded approach of regulation is applied:

- If the activities involve materials with activities of any radionuclide of the U-238 or Th-232 series higher than 1 Bq g^{-1}, then a notification is required.
- If the dose for the workers is between 1 mSv y^{-1} and 6 mSv y^{-1}, registration is required.
- If the dose for the workers is higher than 6 mSv y^{-1}, authorization is required.

Public exposure from all authorized practices is limited to 1 mSv y^{-1}. There are no particular criteria for discharges of liquids or air from NORM industries.

For discharge in air or water, there is a general dose constraint for the population of 0.3 mSv y^{-1} (Art. 38-40, Art. 50 in [62].)

5.14 Sweden

The current Swedish RP legislation is laid down in the “Radiation Protection Act (2018:396)” (Strålskyddslag (2018:396)), which was brought into force on 1 June 2018 [64] and the Radiation Protection Ordinance (Strålskyddsförordning (2018:506) [65]. Both regulations contain only general requirements, which are specified in several provisions of the Swedish Radiation Safety Authority. The basic provisions for ionizing radiation activities subject to authorization are contained in the separate document of the Swedish Radiation Safety Authority “Strålsäkerhetsmyndighetens föreskrifter om grundläggande bestämmelser för tillståndspliktig verksamhet med joniserande strålning”, SSMFS (2018:1) [66]). Regulations on exemptions from the Radiation Protection Act and on clearance of materials, building structures and areas is the content of “Strålsäkerhetsmyndighetens föreskrifter om undantag från strålskyddslagen och om friklassning av material, byggnadsstrukturer och områden“; SSMFS (2018:3) [67]. Specific regulations regarding NORM are made in “Strålsäkerhetsmyndighetens föreskrifter”, SSMFS (2018:4) [68].

5.14.1 Disposal and recovery of NORM

According to Section 4 SSMFS (2018:4), the provisions of the Radiation Protection Act (2018:396) and the Radiation Protection Ordinance (2018:506) do not apply to anyone who handles naturally occurring radioactive material with a specific activity lower than 1 Bq g^{-1} for natural radionuclides from the U-238 series and the Th-232 series, as well as 10 Bq g^{-1} for K-40. These values comply with the values of EU-BSS [23]. For building materials, other values hold and only for assessing building materials, a summation formula (Index-formula) is mentioned in the Annex of SSMFS (2018:4).

Moreover, in Section 6 SSMFS (2018), anyone is exempted from radiation protection requirements who

1. handles alum shale-based lightweight concrete,
2. handles soil or rock masses,
3. possesses, stores or in any way non-physically handles red pyrites or phosphate gypsum,
4. handles unprocessed mineral samples that are part of a geological collection,
5. handles ceramic utensils intended for household purposes or ceramic ornaments; or
6. handles water filters in an individual household.

Handling of NORM with a specific activity that exceeds 1 kBq kg^{-1} of dry substance per radionuclide in the uranium or thorium series or 10 kBq kg^{-1} of dry matter for K-40, and which are not exempted from the license requirement under Section 6, has to be notified to the Swedish Radiation Safety Authority. The notification must be renewed within five years if the handling is ongoing and nothing else has been communicated to the Swedish Radiation Safety Authority.

NORM, which was handled under the provisions of the Radiation Protection Act (2018:396), may be cleared by the person handling the material if

1. the activity concentration is not more than 1 kBq kg^{-1} of dry matter per radionuclide in the uranium and thorium series, and not more than 10 kBq kg^{-1} of dry matter for K-40[5], or
2. the material originates in Sweden and is disposed of or recycled in the manner specified in Sections 11-13 SSMFS (2018) (see below).

It is prohibited to dilute NORM if the purpose of this is to enable the material to be cleared. However, the Swedish Radiation Safety Authority may authorize the mixing of NORM with non-radioactive material for reuse or recycling purposes or for disposal or other management if this can be done without entailing an unacceptable risk of exposure of people or the environment to harmful effects of radiation (Section 10 SSMFS (2018)).

NORM with a specific activity of no more than 10 kBq kg^{-1} of dry matter per radionuclide in the uranium and thorium series and no more than 100 kBq kg^{-1} of dry matter for K-40, may be deposited in a landfill without having to take into account the radioactive properties of the material (Section 11 SSMFS (2018)).

Furthermore, NORM, which has been generated as waste during exploration, may be deposited in a landfill or re-deposited in cavities created during exploration without considering the material's radioactive properties. The same holds for water filters from individual households that may be disposed of as household waste without considering the radioactive properties of the water filter.

Any landfill used for NORM-waste disposal has to provide at least the same protection level as a landfill for non-hazardous waste according to the Swedish waste law (Section 12 SSMFS (2018)). Additionally, for the clearance of radioactively contaminated land areas for future use without any restrictions, a dose constraint of 0.1 mSv y^{-1} is defined [69].

5.14.2 Discharge of NORM

In the regulations regarding NORM (SSMFS (2018:4)) do not contain any specific provisions on discharges. Discharges are regulated in Chapter 5 of the basic provisions for ionizing radiation activities, SSMFS (2018:1). In § 4 of this chapter, a dose constraint regarding effective dose to members of the public is set at 0.1 mSv per year and activity. This constraint has to be applied only to (ongoing human) activities during which radiation protection is to be optimized.

In § 7 SSMFS (2018:1) [67], the requirements for the exemption of discharges of water to sewers are given. A facility where open radiation sources are manufactured or used, and which is not a nuclear facility (i.e. could be NORM) or a facility that receives radioactive waste for disposal may release such radionuclides if

1. the activity content at each individual discharge event does not exceed the values specified in the third column of Annex 1 SSMFS (2018:3),
2. the total activity content of the discharge in a calendar month does not exceed ten times the values set out in the third column of Annex 1 SSMFS (2018:3).

[5] does not apply to materials to be used as building materials

The activity from the discharge of urine and feces containing radionuclides from medical or veterinary examinations or treatments is excluded from the requirements. If the discharge contains more than one radionuclide, the maximum permitted activity has to be calculated with a summation formula (Annex 5 SSMFS (2018:3).

The activity values of the third column of Annex 1 SSMFS (2018:3) and the total annual activity amounts derived from these values are compiled in Table 5-18. However, according to Chapter 3 SSMFS (2018:3) the provisions do not apply to

1. gaseous or liquid material released to the environment,
2. naturally occurring radioactive substances that are not covered by a license or notification,
3. activities involving only naturally occurring radioactive substances and substances and which are carried out without the aim of using their radioactive, fissile, or fertile properties thereof.

Therefore, the application is restricted to activities with up to 3 tons of material quantities. Despite these limitations, the values may indicate the assessment of discharges with water according to Swedish law and its dose constraint of 0.1 mSv per year [76].

Table 5-18: Activity values of the third column of Annex 1 SSMFS (2018:3) and total annual activity amounts derived from these values for naturally occurring radionuclides

	Activity values [Bq]	**Total annual activity amounts [Bq y^{-1}]**
Pb-210+	$1 \cdot 10^4$	$1{,}2 \cdot 10^6$
Bi-210	$1 \cdot 10^6$	$1{,}2 \cdot 10^8$
Po-210	$1 \cdot 10^4$	$1{,}2 \cdot 10^6$
Rn-220+	$1 \cdot 10^7$	$1{,}2 \cdot 10^9$
Rn-222+	$1 \cdot 10^8$	$1{,}2 \cdot 10^{10}$
Ra-223+	$1 \cdot 10^5$	$1{,}2 \cdot 10^7$
Ra-224+	$1 \cdot 10^5$	$1{,}2 \cdot 10^7$
Ra-226+	$1 \cdot 10^4$	$1{,}2 \cdot 10^6$
Ra-228+	$1 \cdot 10^5$	$1{,}2 \cdot 10^7$
Ac-227+	$1 \cdot 10^3$	$1{,}2 \cdot 10^5$
Th-227+	$1 \cdot 10^4$	$1{,}2 \cdot 10^6$
Th-228+	$1 \cdot 10^4$	$1{,}2 \cdot 10^6$
Th-230+	$1 \cdot 10^4$	$1{,}2 \cdot 10^6$
Th-231+	$1 \cdot 10^7$	$1{,}2 \cdot 10^9$
Th-232+	$1 \cdot 10^3$	$1{,}2 \cdot 10^5$
Th-234+	$1 \cdot 10^5$	$1{,}2 \cdot 10^7$
Pa-231+	$1 \cdot 10^3$	$1{,}2 \cdot 10^5$
U-234+	$1 \cdot 10^4$	$1{,}2 \cdot 10^6$
U-235+	$1 \cdot 10^4$	$1{,}2 \cdot 10^6$
U-238+	$1 \cdot 10^4$	$1{,}2 \cdot 10^6$

5.15 Switzerland

The current RP legislation of Switzerland is laid down in the Radiation Protection Ordinance (RPO, "Strahlenschutzverordnung, StSV (2017), which was brought into force on 26 April 2017 [70].

5.15.1 Disposal and recovery of NORM

In Art. 168 para. 1 in [70], a list of industrial sectors ("positive list") and their classes or types of practices involving the use of NORM is defined. Materials from NORM industries must be analyzed to check if the specific activity exceeds the exemption values as specified in Annex 2 of [70] that are equal to those in Annex VII Table B column 3 EU-BSS with 1 Bq g^{-1} for natural radionuclides from the U-238 series and the Th-232 series as well as 10 Bq g^{-1} for K-40 [23].

5.15.2 Discharge of NORM

According to Art. 169 para. 1 in [70], NORM whose specific activity is higher than the exemption limits in Annex 2 of [70] may be released into the environment with the approval of the competent authority if

a. disposal via the usual disposal channels would not be possible or would only be possible with disproportionate expense; and
b. by appropriate measures, the effective dose for persons from members of the public does not exceed the value of 0.3 mSv y^{-1}.

Discharges above this rate require authorization on a case-by-case basis, with limits fixed by the regulatory authority based on a drinking water dose criterion of 0.3 mSv y^{-1}.

5.16 United Kingdom (UK)

The UK countries England, Wales, Scotland, and Northern Ireland have individually their own legislative framework governing radioactive waste. The so-called "Environmental Permitting" in England and Wales [71] introduces a common permitting framework for all pollution regulation regimes, including radioactive waste and especially exemption provisions for aqueous liquids and the concept of relevant liquids.

"The Ionising Radiations Regulations 2017" [20] regulates the requirements of radiation protection in the UK. The graded approach in the UK regulation from an exemption to registration for artificial and naturally occurring radionuclides (processed for their radioactive, fissile or fertile properties) is illustrated in Figure 5-3. The UK regulation differences also between practices, where radioactive material containing naturally occurring radionuclides are or are not processed for their radioactive, fissile or fertile properties.

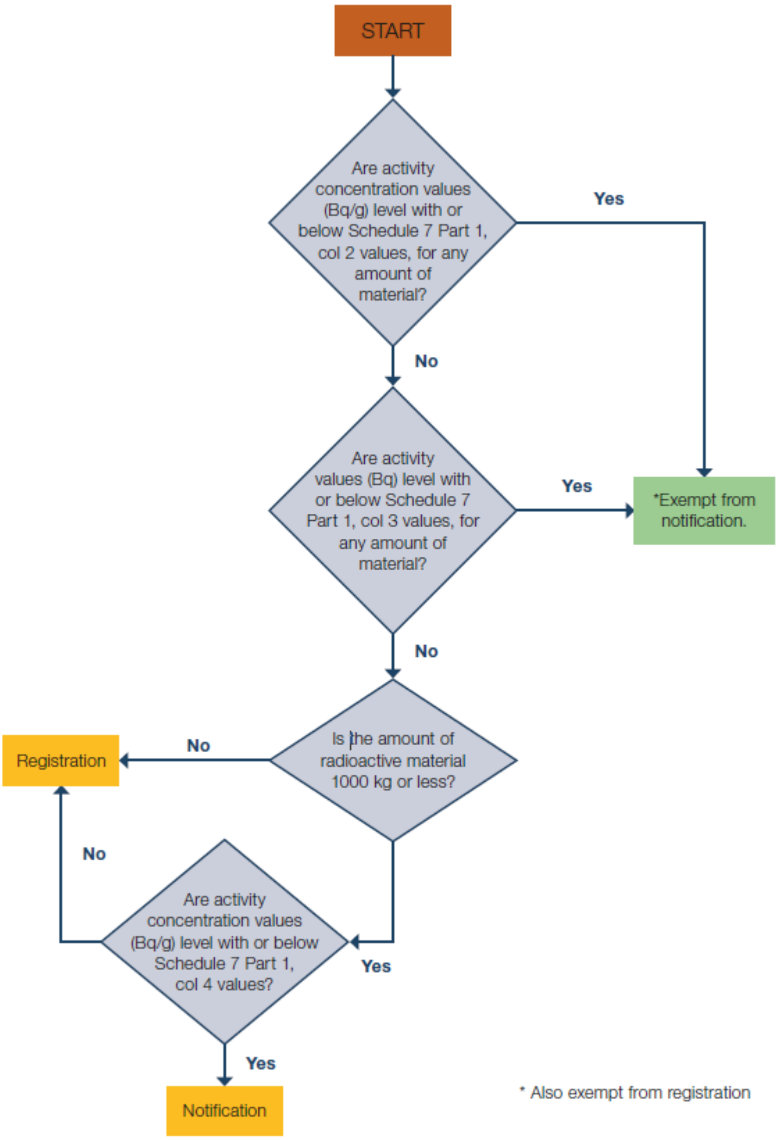

Figure 5-3: Exemption flowchart – Schedule 7 Part 1. Artificial and naturally occurring radionuclides (processed for their radioactive, fissile or fertile properties) from [24]

According to Regulation 5 para. 1 and 6 para. 2, work with ionizing radiation (radioactive material ≤ 1,000 kg) requires

- registration for naturally occurring radionuclides (which are processed for their radioactive, fissile or fertile properties) that are listed in Schedule 7, Part 1 (see Table 5-19),
- notification for naturally occurring radionuclides (which are not processed for their radioactive, fissile or fertile properties) that are listed in Schedule 7, Part 2 (see Table 5-20).

5.16.1 Disposal and recovery of NORM

Naturally occurring radionuclides that are not processed for their radioactive, fissile or fertile properties belong not to any registrable practices. The activity concentration values in Table 5-20 are specified for radioactive materials that exceed 1,000 kg (Schedule 7, Part 2 column 2) or do not exceed these masses (Schedule 7, Part 2 column 4). Whereas the concentration values of K-40, Pb-210+, Po-210, Ra-226+, and Ra-228+ are 10 times higher for masses below 1000 kg (1 Mg), the values for Th-228+, Th-232sec, and U-238sec are the same, independently if the materials exceed 1 Mg or not.

Table 5-19: Data in Column 4 with exemption values of naturally occurring radionuclides (which are processed for their radioactive, fissile or fertile properties); Schedule 7, Part 1

Radionuclide	Column 4 Concentration for Registration (amounts of radioactive material that do not exceed 1 Mg) Regulation 6 (2) (e) [Bq g^{-1}]
Pb-210+	10
Ra-226+	10
Ra-228+	10
Ac-227	-
Th-227	10
Th-228+	1
Th-230	1
Th-232	10
Pa-231	1
U-235+	10
U-238+	10

Table 5-20: Data for of naturally occurring radionuclides (which are not processed for their radioactive, fissile or fertile properties); Schedule 7, Part 2

Radionuclide	**Column 2** **Concentration for: Notification (any amount of radioactive material); Registration (amounts of radioactive material that exceed 1 Mg)** **Regulation 5 (1) & 6 (2) (e) [Bq g^{-1}]**	**Column 3** **Quantity for Notification** **Regulation 5 (1) [Bq]**	**Column 4** **Concentration for Registration (amounts of radioactive material that do not exceed 1 Mg)** **Regulation 6 (2) (e) [Bq g^{-1}]**
K-40 (1)	10	$1 \cdot 10^6$	$1 \cdot 10^2$
Pb-210+	1	$1 \cdot 10^4$	$1 \cdot 10$
Po-210	1	$1 \cdot 10^4$	$1 \cdot 10$
Ra-226+	1	$1 \cdot 10^4$	$1 \cdot 10$
Ra-228+	1	$1 \cdot 10^5$	$1 \cdot 10$
Th-228+	1	$1 \cdot 10^4$	1
Th-232sec	1	$1 \cdot 10^3$	1
U-238sec	1	$1 \cdot 10^3$	1

(1) Potassium salts in quantities less than 1,000 kg are exempt.

Provisions are in place to exempt NORM waste

- with high volume low-level radioactive waste comprising NORM arising from NORM industrial activities or land remediation (“Type 1”), and
- with higher activity high volume low-level radioactive waste (“Type 2”).

Therefore, specific exemptions for land disposal or incineration are specified, as there are conditions attached, such as keeping adequate waste disposal records and that the waste must be transferred to a person for burial or incineration of the waste or a person defined as being waste permitted. The dose criteria selected in order to demonstrate exemption as a Type 1 or 2 NORM waste are 1 mSv y^{-1} for any landfill worker and 0.3 mSv y^{-1} for any member of the public.

A generic radiological impact assessment has been carried out by (Anderson & Mobbs, 2010 [72]). The results show that for NORM waste concentrations up to the values given in Table 5-21 these criteria will be met. For Type 2 NORM waste, it is the responsibility of the waste producer to demonstrate that these criteria have been met by doing a site-specific assessment.

Table 5-21: NORM waste concentrations and maximum disposal quantities

Radionuclide	Type 1 NORM concentration [Bq g^{-1}]	Type 1 NORM total activity for landfill [GBq y^{-1}]	Type 1 NORM total activity for incineration [MBq y^{-1}]	Type 2 NORM concentration [Bq g-1]
Pb-210+	100	1,000	100	200
Po-210	100	1,000	100	200
Ra-226+	5	50	100	10
Ra-228+	5	50	100	10
Th-230	5	50	100	10
Th-232sec	5	50	100	10
U-234	5	50	100	10
U-238+	5	50	100	10

From a review (Benson et al., 2016 [73]) of the original calculations used to derive exemption values, it was determined that there was scope for safely increasing the exemption/clearance values for Pb-210+ and Po-210 [14]. The steel industry and the gas exploration/production sector produce NORM wastes containing Pb-210 and Po-210 that currently require disposal under the UK Radioactive Substances Regulations [74], permitting requirements at a significant cost. Based on the results of the review [73], the UK legislation was updated to increase the exemption/clearance values for Pb-210+ and Po-210.

5.16.2 Discharge of NORM

In the UK, liquids (aqueous and non-aqueous liquids) that cannot be discharged to the water environment and remain "in scope" of the RP regulations are considered waste.

Three industry sectors were identified that generate liquid NORM wastes in England and Wales [75]. The most significant of these is the oil and gas industry. This industry generates in excess of $2 \cdot 10^8$ m^3 of produced water every year. The majority of this waste arises on offshore installations. These industries have permits to discharge their produced water directly to sea or re-inject it back into the seabed or hydrocarbon-bearing formation where suitable facilities exist [76]. Titanium dioxide manufacturing is the second sector with permits to dispose of significant quantities of liquid waste. The third industry discharging NORM liquid wastes includes facilities using small quantities of uranium and thorium compounds. The quantities being disposed of are small enough that they may be disposed to a sewer under the exemption provisions.

These liquid NORM wastes (aqueous and non-aqueous liquids) do not contain artificial radionuclides or naturally occurring radionuclides used for their radioactive, fertile or fissile properties (except for relevant liquids) that are considered to be radioactive waste for the purposes of the UK legislation, irrespective of activity concentration. For liquid NORM wastes, a generic assessment of the annual activities of NORM discharged from facilities should be applied. This assessment is based on a dose criterion of public doses being less than 0.3 mSv y^{-1}. Especially the Scottish Environment Protection Agency has undertaken work related to the assessment of doses from NORM discharges into a marine environment, and this work could be used to support the development of exemption values [76].

Whether a substance is in or out of scope of the UK regulatory framework depends on whether or not it falls within the definition of radioactive material or radioactive waste. There is a common definition of radioactive material and radioactive waste with descriptive and numerical criteria. These criteria are summarized and illustrated in Figure 5-4

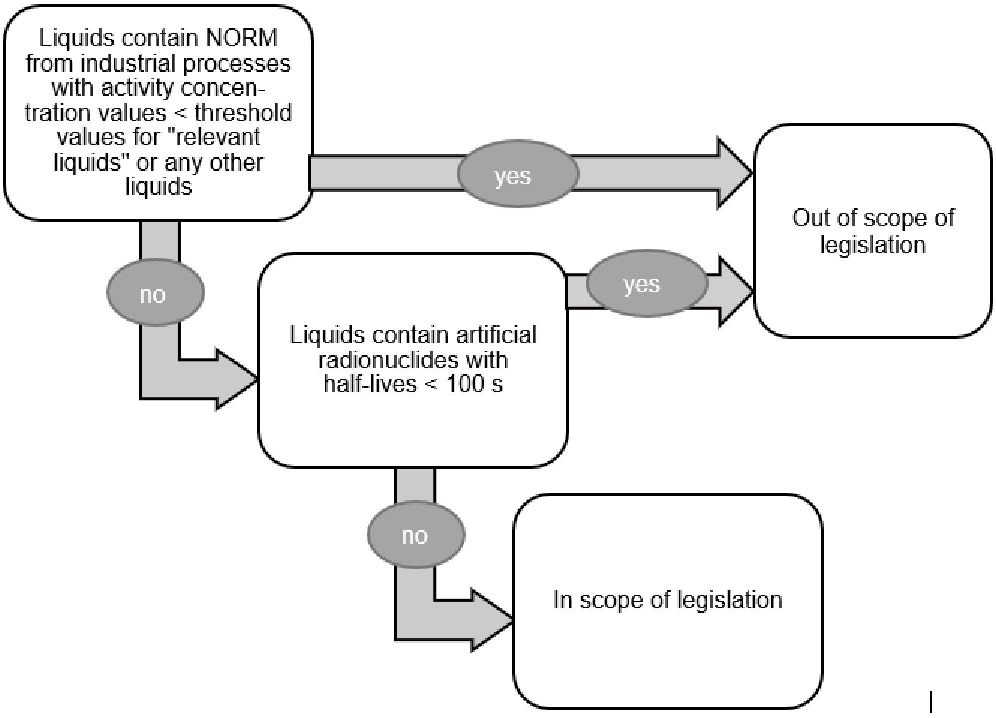

Figure 5-4: Flow diagram to determine whether a liquid is in or out of the scope of the UK regulatory framework

Ewers and Mobbs propose “Out of scope values” for liquid wastes classed as any other liquid as criteria for exemption [77]. These values are based on the Generalized Derived Limits (GDLs) in [78] for freshwater using a dose criterion of 10 µSv y^{-1} and were assessed for the exposure pathways for ingestion of river water and freshwater fish and external exposure from shoreline sediment. The screening values alongside the UK exemption values for disposal of aqueous wastes to a sewer or to a relevant river or the sea and any other liquid activity concentration are listed in Table 5-22 (from [76]).

There are a few conditional exemptions that allow NORM liquids to be disposed of without authorization. For example, small quantities of aqueous effluent (uranium/thorium aqueous liquid, wastes up to $1 \cdot 10^5$ Bq l^{-1}) to be discharged to a sewer (capacity > 100 m^3 of effluent per day at the sewerage plant) or to a person (by tanker) who is permitted to receive such waste [76].

Table 5-22: Exemption values for discharge of naturally occurring radionuclides to a relevant sewer, river or sea and any other liquid activity concentration in the UK legislation

Radionuclide	Exemption values to relevant sewer [Bq y^{-1}]	Exemption values to relevant river or sea [Bq y^{-1}]	Any other liquid activity concentration [Bq l^{-1}]
Pb-210+	$1 \cdot 10^4$	$1 \cdot 10^4$	0.1
Po-210	$1 \cdot 10^4$	$1 \cdot 10^4$	0.1
Ra-226+	$1 \cdot 10^5$	$1 \cdot 10^5$	1
Ra-228+	$1 \cdot 10^5$	$1 \cdot 10^5$	0.1
Th-228+	$1 \cdot 10^7$	$1 \cdot 10^7$	1
Th-230	$1 \cdot 10^7$	$1 \cdot 10^7$	10
Th-232+	$1 \cdot 10^6$	$1 \cdot 10^7$	0.1
U-234	$1 \cdot 10^6$	$1 \cdot 10^6$	10
U-238+	$1 \cdot 10^6$	$1 \cdot 10^6$	10

Based on the proposed values in [78], the annual discharge limits arising from decontamination or cleaning operations from industrial processes are given as a standard condition in the Scottish Environment Protection Agency's Offshore Installation Registrations (see Table 5-23 [76]). The agency has assessed the doses for humans and biota for typical exposure pathways resulting from the discharges from offshore installations to demonstrate that the doses are below the level of regulatory concern. An assessment of the impact due to discharges of NORM to water from an onshore installation would be required for radioactive discharges to water from any other facility.

Table 5-23: Annual discharge limits for NORM containing waste given as a standard condition in the Scottish Environment Protection Agency's Offshore Installation Registrations

Radionuclide	Annual limit [Bq y^{-1}]
Ra-226	$2 \cdot 10^9$
Ra-228	$2 \cdot 10^9$
Pb-210	$2 \cdot 10^9$
Po-210	$2 \cdot 10^9$

6 Assessment of national or international legislation/recommendations concerning the release of naturally occurring radionuclides and artificial radionuclides

Regarding NORM waste, two very different approaches are implemented in the legislation of different European countries. In some countries, NORM waste is defined as radioactive waste, and Directive 2011/70/Euratom is fully applicable. In some other countries, NORM waste is either

- not considered radioactive waste,
- defined as such only when the activity concentration of the relevant radionuclides is above certain values, or
- when a dose criterion related to waste management is exceeded.

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.

In some EU countries (e.g. Belgium or Spain), the clearance and exemption values given in Part I of the previous guidance from the EC, “Practical Use to the Concepts of Clearance and Exemption” (RP 122) [79] are implemented in their national radiation protection legislation. The EC gives some explanation and clarification of general clearance for the release of materials resulting from practices according to Title III of the 96/29/Euratom [80] from regulatory control for any possible application. The term "general clearance" also implies that there are no restrictions on the origin and type of material to be cleared. RP also clarifies the difference between exemption and clearance and explains the distinction between general clearance and specific clearance. The clearance values given in this document apply to any solid, dry material, not to liquids or gases (in general considered as effluents).

In view of the activity concentration values which exempted NORM practices or cleared NORM might produce in the different environmental compartments, given the current environmental standards for industrial pollution control in Europe, consideration of potential doses to biota is not deemed to be necessary for an exemption or clearance purposes.

The European countries acknowledge that, internationally, there is an increasing awareness that protection standards aimed uniquely at humans do not necessarily ensure adequate protection of non-human biota and related ecosystems. According to the comments at HERCA [14], Norway is the only known country where legislation requires considering potential environmental risks per se, including non-human biota, when assessing the impact of approved practices.

As mentioned in [23], for the purpose of exemption from notification or for the purpose of clearance, the amounts of radioactive substances or activity concentrations are usually assessed in the way that

- 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 and

- 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 dose criteria are the base for the definition of exemption values for activity concentrations of the artificial and naturally occurring radionuclides. And, for the purpose of exemption from authorization, less restrictive dose criteria for NORM may be applied according to [23]. But there are different values defined in the countries, although default values are implemented, for instance, in [23] for the EU countries. The distinction between several countries will be analyzed in this WP 2. The IAEA recommendations will be included in the treatment of this issue, too.

Table 6-1: Exemption values for discharges of naturally occurring radionuclides according to different regulations of European countries

	Norway [6]	**UK [76]**	**Sweden [67]**	**The Netherlands [60]**	
Radionuclide	[MBq y^{-1}]	to relevant river or sea [MBq y^{-1}]	[MBq y^{-1}]	Into water [MBq y^{-1}]	Into Air [MBq y^{-1}]
K-40	0.1	-	-	-	-
Pb-210[a]	0.001	0.01	1.2	10,000	10,000
Po-210	0.001	0.01	1.2	10,000	10,000
Ra-226[a]	0.001	0.1	1.2	10,000	10,000
Ra-228[a]	0.01	0.1	12	100,000	1,000
Th-228[a]	0.001	10	1.2	1,000,000	1,000
Th-230	0.001	10	1.2	100,000	1,000
U-234	0.001	1	1.2	1,000,000	10,000
U-238[a]	0.001	1	1.2	-	-
Th-nat	0.0001	10	0.12	100,000	1,000
U-nat	0.0001	-	-	1,000,000	10,000

Table 6-2: Summary of the exemption values for NORM-related practices in European countries

Country	**NORM disposal or recovery**		**NORM discharges**		**Remarks**
	Dose criterion	Exemption values for naturally occurring radionuclides	Dose criterion for NORM discharge	Exemption values for naturally occurring radionuclides	
	mSv y^{-1}	Bq g^{-1}	mSv y^{-1}	-	
EU/EC	1	U-238, Th-232 = 1 K-40 = 10	-	-	EU-BSS [23]
Austria	1	adopted from [23]	0.3	Up to 50 MBq (see Table 5-9)	Discharge values are set for mixtures of naturally occurring radionuclides
Belgium	1	not adopted from [23]; see Table 5-10	0.3	-	Dose assessment is required if discharge exceeds limits
Czech Republic	1	adopted from [23]	0.3	see Table 5-12	-
Finland	1	adopted from [23]	0.1	-	Dose assessment is required for discharge
France	1	see [52]	-	10 Bq l^{-1}	Discharge of wastewater for radionuclides with a half-life < 100 days
Germany	1	not adopted from [23]; sum formula; see Table 5-13	-	-	Individual exemption values, depending on intended recovery or disposal
Ireland	1	adopted from [23]	-	-	-
Italy	1	see Table 5-15	0.1	-	Dose assessment is required for discharge
Latvia	1	adopted from [23]	-	-	-
Lithuania	1	adopted from [23]	-	-	-
The Netherlands	1	not adopted from [23]; see Table 5-16	0.01	see Table 5-17	-
Romania	1	adopted from [23]	-	-	-
Sweden	1	adopted from [23]	0.1	-	Dose assessment is required for discharge
Switzerland	1	adopted from [23]	0.3	-	Dose assessment is required for discharge
United Kingdom	1	not adopted from [23]; see Table 5-19 - Table 5-21	0.3	see Table 5-22	Specific discharge limits for NORM in Scotland, see Table 5-23

7 Environmental risks due to releases from NORM-affected industries – three case studies

7.1 Introduction

As mentioned in Chapter 2, the Federation of Norwegian Industries has provided data on case studies from the three companies:

- Elkem,
- Hydro Aluminum AS, Årdal Karbon (Hydro Karbon) and Hydro Aluminum AS, Årdal metallverk (Hydro metallverk) and
- Yara Porsgrunn Norway AS.

These case studies are summarized in the following to analyze the environmental risks due to discharges and to weigh them against administrative and economic costs at the company level.

As described in Chapter 5.1, exemption from the requirements of the Norwegian provisions depends strongly on discharge amounts. The relevant benchmark for the assessment of emissions is derived from the Regulation on Rad-Pollution and Rad-Waste [6] para. 4 and the limit values in Annex II of this regulation. These limits refer to both the total activity (Bq y^{-1}) and the mass-related specific activity (Bq g^{-1}).

In the industries that process ores or minerals at high temperatures (greater 800°C - 1000°C), data in the literature (e.g., [81], [82]) show that the release of Pb-210 in dust via the chimney can be in the range of several MBq (10^6 Bq) even though GBq (10^9 Bq) per year. These emissions are much higher than the corresponding values defined in Annex II of the Pollution Control Act.

A rough orientation about the meaning of the values in Annex II of Regulation on Rad-Pollution and Rad-Waste [6], the total activity (Total aktivitet) for Pb-210 shall be considered. The discharge value is 10^3 Bq per year, and the activity concentration (Spesifikk aktivitet) is 1 Bq g^{-1}. Because the activity concentration of Pb-210 in (uncontaminated) ambient air is about 0.3 Bq per 1000 m^3 [83] and the mass-related activity concentration of Pb-210 in the dust is in the order of 10 Bq $g^{-1,}$ any high-volume discharge (e.g., from ventilation of underground shafts in cities) will result in exceeding the limits.

Discharges will result in environmental contamination only if the specific activity exceeds the background activities in natural environmental media. Therefore, in Table 7-1, background values of specific activities in dust and seawater are compiled. The specific activities of dust particles correspond, with the exception of Pb-210 and Po-210, to the specific activities of the soil the dust comes from. With a dust load of 50 µg m^{-3} and 25–50 Bq kg^{-1} U-238 and Th-232 in the soil (UNSCEAR 2008 [84]), the concentrations in air are expected to be 1 – 2 µBq m^{-3}. This is, generally, what is observed. Due to the decay of Rn-222 in the atmosphere, much higher concentrations occur for Pb-210 (500 µBq m^{-3}) and Po-210 (50 µBq m^{-3}). With a mass concentration of dust of 50 µgm^{-3}, the specific activities of the dust particles given in Table 7-1 results.

Table 7-1: Background values of radionuclides in dust and seawater

Radionuclide	Dust particles	Seawater (near German coast) [85]	Seawater [86]
	[Bq/kg]	[mBq/l]	[mBq/l]
K-40	-	-	12 000
Pb-210	10,000	-	2.0 – 5.0
Po-210	1,000	-	2.0 – 3.7
Ra-226	25 – 50	1.4 - 2.0	3.4 – 3.6
Ra-228	25 – 50	3.8 - 4.7	10
Th-228	25 – 50	-	0.12
Th-230	25 – 50	-	0.052
Th-232	25 – 50	-	0.0005
U-234	25 – 50	-	46.7*
U-235	1 - 2	-	1.9*
U-238	25 – 50	-	41.0

* calculated from U-238

In the following chapters 7.2 to 7.4 the regulation of NORM-industries regarding the Norwegians Pollution Control Act's application on radioactive pollution data is analyzed and assessed for four different plants. As far as not otherwise specified, all data used were obtained from the companies.

7.2 Elkem

7.2.1 Processes and licensing requirements

Elkem is one of the world's leading providers of advanced silicon-based materials. An overview of the technology for manufacturing silica and ferrosilicon is contained in [87]. Elkem offers microsilica, silicon powders, and complementary products for the production of advanced refractory and ceramic products. One refractory product is Silica fume, also known as condensed silica fume or microsilica. Silica fume is a co-product of silicon or ferrosilicon production, consisting of ultrafine (sub-micron), amorphous, non-porous, perfectly spherical silicon dioxide (SiO_2) particles, with purity levels of 85 to 99 % [88].

For this study, Elkem has provided radionuclide data from several plants (Bremanger, Bjølve, Carbon, Rana, Salten, and Thamshavn). Apart from minor exceptions, the radioactivity of the other sites, such as Bremanger is less significant, so there was no need for a permit/license from the Norwegian Radiation Protection Agency.

Elkem Bremanger AS (Elkem) is a plant located in the village of Svelgen, on the west coast of Norway (Figure 7-1), that produces inoculants, microsilica, and silicon powder used, e.g., in the iron foundry industry. For the manufacturing of inoculants and special FeSi, Elkem operates two reduction furnaces, and for silicon and microsilica, an additional reduction furnace. Figure 7-2 shows a flow scheme of the silica fume production.

Figure 7-1: View of Elekem Bremanger plant.
From https://www.elkem.com/about-elkem/worldwide-presence/norway/elkem-bremanger/

Via the chimneys, dust may be released into the air. Discharges to the sea with the result from:

- process water from the Silgrain plant,
- seepage water from the Elkem landfill (Sande) and
- seepage water from the lower filling in the Sætrevika landfill [89].

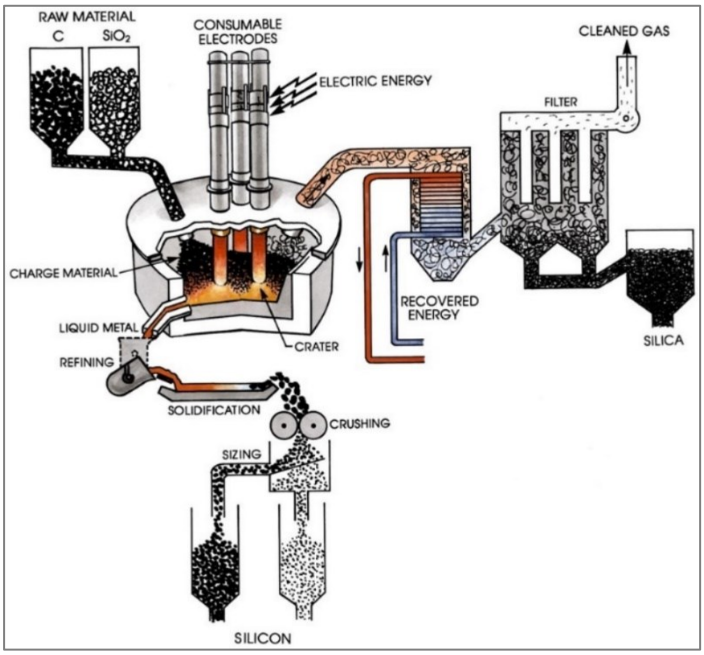

Figure 7-2: Silica fume production process at the “Elkem Bremanger Smelteverk” (from [90])

The discharges from Elkem Bermanger Smelteverk are limited by an official permit concerning its NORM-contaminated emission at the “Elkem Bremanger Smelteverk” plant. Table 7-2 shows the limits for annual dust and water emissions of naturally occurring radionuclides defined in the permit.

Table 7-2: Limits for the annual discharge of radioactivity via dust and water [89] specified in the permit for the “Elkem Bremanger Smelteverk” (from [91])

Radionuclide	Maximal annual discharge of water [MBq y^{-1}]	Maximal annual discharge of dust [MBq y^{-1}]
Pb-210	50	100
Po-210	150	50
Ra-226	250	10
Ra-228	400	5
Th-228	150	10
Th-230	250	3
Th-232	150	0,5
U-234	150	0,5
U-235	10	0,05
U-238	150	0,5

In 2021, the total discharge of microsilica dust from the ovens via the chimney into the air was about 82.8 Mg (82,800 kg). The annual discharge amounts of process water from the Silgrain plant and seepage water from landfills in 2021 are listed in Table 7-3.

Table 7-3: Annual discharges from Elkem Bremanger into the sea in 2021, from [89]

Discharge source	Discharge volume [10^6 m^3 y^{-1}] ([l y^{-1}])
process water of the Silgrain plant	1.575 (1,574,996,000)
seepage water from the Elkem landfill (Sande)	2.601 (2,600,844,000)
seepage water from the lower filling in Sætrevika landfill	0.010 (9,785,000)

7.2.2 Radiological situation at the “Elkem Bremanger Smelteverk” plant

The feedstock for manufacturing silica consists of (cf. [91])

- SiO_2 (quartz)
- carbon in the form of coal and coke.

These materials and the products manufactured from them have very low natural radioactivity and are usually not considered NORM (see Table 7-4).

The central step of the silica production process in Bremanger is melting in an electric melting furnace. The high temperatures in the melting process result in a redistribution of heavy metals and naturally occurring radionuclides in the process output with enrichment of elements that evaporate at the high temperatures in minor mass streams of the process output (here: dust) [92]).

Table 7-4: Specific activities of feedstock material (quartz) and products from the “Elkem Bremanger Smelteverk” plant (data obtained from Elkem). Background values from UNSCEAR 2008

Radionuclide	Quartz	Micro Dense	Microlite P	Micromax	Background (soil, Norway)
	[Bq kg^{-1}]	[Bq kg^{-1}]	[Bq kg^{-1}]	[Bq kg^{-1}]	[Bq kg^{-1}]
Cs-134	<0.14	< 0.18	8.5	< 0.15	—
K-40	2.0	6.9	94	5.0	850
Pb-210	<2.8	<3.5	18	26	—
Ra-226	0.48	1.21	3.3	0.34	50
Ra-228	<0.49	1.31	2.2	<0.65	45*
Th-228	< 0.18	1.31	< 0.59	0.28	45*
U-238	< 1.6	< 2.4	< 5.3	< 2.2	50

´* values transferred from Th-232 value in UNSCEAR 2008

Table 7-5 gives specific activities of dust generated in the oven processes of the “Elkem Bremanger Smelteverk” via the chimney into the air. The data were obtained from Elkem. The datasets also include results for K-40 and Cs-137. Cs-137 is a residue of historical events (nuclear weapon tests, Tschernobyl fallout) and is not considered a part of NORM. Because K-40 and Cs-137 radionuclides are not specified in the official emission permit, they are disregarded in the following assessments.

For comparison, background values, given in Table 7-1, are listed, too.

Table 7-5: Specific activities of dust generated in the oven process at the “Elkem Bremanger Smelteverk” plant and natural background values derived from UNSCEAR

Radio-nuclide	Filterdust oven 2, Chamber 7, E1, 5 år	Filterdust oven 4, Chamber 5, H10, 6 år	Microsilica dust 2020	Microsilica dust 2021 (a)	Microsilica dust 2021 (b)	Natural background (dust)
	[Bq kg^{-1}]	[Bq kg^{-1}]	[Bq kg^{-1}]	[Bq kg^{-1}]	[Bq kg^{-1}]	[Bq kg^{-1}]
Pb-210	63	96	11	250	340	10,000
Po-210	-	-	40	95	200	1,000
Ra-226	34	37	24,7	27,8	91	25 – 50
Ra-228	26,3	30	11,4	10,3	25	25 – 50
Th-228	25,4	5,7	5	2,4	8.3	25 – 50
Th-230	-	-	8,2	5	< 5	25 – 50
Th-232	-	-	4,8	5	< 5.0	25 – 50
U-234	-	-	10	5	< 10	25 – 50
U-235	5,4	-	0,47	0,23	< 0.4	1 - 2
U-238	39	29	-	-	< 10	25 – 50

The highest values of the specific activity were measured for Pb-210 and Po-210. Such enrichment is typically for high-temperature processes. The boiling point of Pb-210 is at 1,740°C, and that of Po-210 is at 962°C. The highest flue gas temperature in the oven is around 1,800 - 2,000 °C in the oven process [90] and, due to these conditions, Po-210 and Pb-210 evaporate from the molten silica and are nearly entirely transferred to the microsilica dust. Despite this effect, the data in Table 7-5 demonstrate that the measured values in filterdust and microsilica, with a single exception of 91 Bq kg^{-1} Ra-226, are in the same range or lower than the corresponding background values. Therefore, any deposition of dust particles emitted from the "Elkem Bremanger Smelteverk" will not result in enhanced specific activities in soil.

Compared to the exemption values compiled in Table 5-1, all measured values of the specific activity (given in Bq kg^{-1} = 0.001 Bq g^{-1}) comply with the stronger exemption criterium as it is given in the Regulation on Rad-Pollution and Rad-Waste [6]. (Only the Pb-210-background values of natural dust do not do so.)

Table 7-6 gives the discharged process water and seepage water activity concentrations from the "Elkem Bremanger Smelteverk". The uranium concentrations are on the same level as the seawater and can be classified as corresponding to the natural background. The other radionuclides in Table 7-6 have somewhat higher concentrations than seawater. The highest values are measured for Ra-226 with 0.106 Bq l^{-1} and Ra-228 with 0.183 Bq l^{-1} in the seepage water from the Sætrevika landfill. Because thorium is very less soluble in (chemically neutral) water, the measured concentrations of thorium isotopes indicate a certain amount of particulate matter in the analyzed samples.

All concentration values measured in water samples are negligible compared to the exemption values compiled in Table 5-1 (0.1 Bq l^{-1} corresponds to 0.0001 Bq g^{-1}). The process water and the seepage water from the Elkem landfill also comply[6] with the EU and WHO drinking-water standards (see Ch. 4.3, 4.4). Only the seepage water of the lower filling in Sætrevika landfill exceeds the drinking-water standards due to its contamination with Po-210 and Ra-228. Both radionuclides have rather short half-lives, and their migration range is limited.

Nevertheless, the authorities can use the exceedance of drinking-water standards to justify licensing requirements, and the discharged activities can be used as the formal criterium for justifying conditions.

The naturally occurring radionuclide activities discharged in 2021 with the microsilica dust via the chimneys have been calculated with the specific activities in the column "Micorosilica dust 2021 (b)" in Table 7-5 and 82.8 Mg of emitted dust to the air. The loads obtained are given in Table 7-7. Compared to the exemption values compiled in Table 5-1, values (given in MBq/y = 1,000 x 10^3 Bq) exceed those given in the Regulation on Rad-Pollution and Rad-Waste [6] by orders of magnitude. However, the values comply with the limits in the permit for the Elkem Bremanger Smelteverk" site (see Table 7-7).

[6] For better demonstration of compliance a lower detection limit for Po-210 is desirable.

Table 7-6: Activity concentration of the discharged process and seepage water at the “Elkem Bremanger Smelteverk” site; from [89]

Radionuclide	Process water	seepage water from		Seawater (cf. Table 7-1)
	Silgrain plant	Elkem landfill (Sande)	lower filling in Sætrevika landfill	
	[Bq l^{-1}]	[Bq l^{-1}]	[Bq l^{-1}]	[Bq l^{-1}]
Pb-210	< 0.01	0.014	< 0.010	0.002 – 0.005
Po-210	< 0.28	< 0.38	0.31	0.002 – 0.004
Ra-226	0.034	0.073	0.106	0,001 – 0.004
Ra-228	0.035	< 0.025	0.183	0.010
Th-228	0.034	0.026	0.067	0.0002
Th-230	0.032	< 0.005	< 0.005	$5 \cdot 10^{-5}$
Th-232	0.024	< 0.005	< 0.005	$5 \cdot 10^{-7}$
U-234	0.045	0.0098	0.022	0.047
U-235	0.00212	0.00032	0.00085	0.002
U-238	0.046	0.0098	0.067	0.041

Table 7-7: Airborne radionuclide activities emitted via dust from the “Elkem Bremanger Smelteverk” in 2021; [89]

Radionuclide	Microsilica dust load 2021 [MBq y^{-1}]	Permitted annual discharge via dust [MBq y^{-1}]	Share: actual/permit
Pb-210	28.2	100	28,2%
Po-210	16.6	50	33,2 %
Ra-226	7.53	10	75.3 %
Ra-228	2.07	5	41,4 %
Th-228	0.69	10	6,9 %
Th-230	- 1)	3	-
Th-232	- 1)	0,5	-
U-234	- 1)	0,5	-
U-235	- 1)	0,05	-
U-238	- 1)	0,5	-

1) The specific activities are below the detection limit

The activity loads of the naturally occurring radionuclides in 2021 that are discharged as process water of the Silgrain plant, as seepage water from the Elkem landfill (Sande), and from the Sætrevika landfill calculated with the discharge amounts in Table 7-3 are compiled in Table 7-8. Similar to the dust, values exceed those given in the Regulation on Rad-Pollution and Rad-Waste [6] by orders of magnitude.

Summed up over the three pathways, all radionuclides meet the specified limits provided in the permit for the Elkem Bremanger Smelteverk" site (see Table 7-8). The highest permit limit share is caused by the high discharge volume from the Elkem landfill (Sande) and its Ra-226 load. A part of this load can be attributed with high certainty to the natural background. Po-210 and Ra-228 from Sætrevika landfill that exceed the background level substantially deliver minor contributions to the total discharged activities.

Table 7-8: Activity loads discharged via water from the "Elkem Bremanger Smelteverk" in 2021; [89]

	process water	**seepage water**		**Permitted annual discharge**	**Share: actual/permit**
Radionuclide	**Silgrain plant**	**Elkem landfill (Sande)**	**Sætrevika landfill**		
	[MBq y^{-1}]	[MBq y^{-1}]	[MBq y^{-1}]	[MBq y^{-1}]	-
Pb-210	- 1)	36.4	- 1)	50	72,8%
Po-210	- 1)	- 1)	3.03	150	2,0%
Ra-226	53.5	189.9	1.04	250	97,8%
Ra-228	55.1	- 1)	1.79	400	14,2%
Th-228	53.5	67.6	0.66	150	81,2%
Th-230	50.4	- 1)	- 1)	250	20,2%
Th-232	37.8	- 1)	- 1)	150	25,2%
U-234	70.9	25.5	0.22	150	64,4%
U-235	3.34	0.83	0.01	10	41,8%
U-238	72.4	25.5	0.66	150	65,7%

1) The specific activities are below the detection limit

7.2.3 Assessment of materials and emissions

As described in the previous chapter, dust considered radioactive is generated in the production processes of Elkem Bremanger, and discharges of water into the sea occur. This chapter examines which materials or discharges may result in the highest requirements for regulatory monitoring according to the Norwegian Radiation Protection Act [5] as well as the Regulation on Rad-Pollution and Rad-Waste [6]. This is done by calculation the ratios of measured values and limit values according to the regulations described in Ch. 5.1.4 and 5.1.5.

According to Table 7-5 the sample "Microsilica dust 2021 (b)" represents the highest measured specific activities of dust samples. In Table 7-9 the measuring results are evaluated regarding the exemption criteria of the Radiation Protection Act [5]. For microsilica dust (and consequently all dust amounts at Elkem Bremanger) the sum of specific activity ratios is lower than 1, the sum of and total activity ratios is considerably higher than 1. The final assessment of this result is given in the next chapter.

Table 7-9: Evaluation of the summation formula for sample "Microsilica dust 2021 (b)" related to the exemption from Radiation Protection Act requirements

Radionuclide	Specific activity		Total annual discharge	
k	$C_{max,k}$	$C_{max,k}/C_{e,k}$	$A_{max,k}$	$A_{max,k}/A_{e,k}$
	[Bq g^{-1}]		[MBq (y^{-1})]	
Pb-210a	0.34	0.034	28.2	2,820
Po-210	[0.2]	-	16.6	1,660
Ra-226a	0.091	0.0091	7.53	753
Ra-228a	0.025	0.0025	2.07	20.7
Th-228a	0.0083	0.0083	0.69	69
Th-230	0.005	0.005	0.41	41.4
Th-232	0.005	0.0005	0.41	41.4
U-234	0.01	0.001	0.83	82.8
U-235a	0.0004	0.00004	0.03	3,312
U-238a	0.01	0.001	0.83	82.8
Sum		**0.061**		**5,574**

Because the Regulation on Rad-Pollution and Rad-Waste [6] has to be applied independently from the classifications of the Radiation Protection Act, the question whether the dust produced at Elkem in the case of intended disposal has to be classified as radioactive waste, needs an independent check. Therefore, the summation formula of Eq. 3 (see Ch. 5.1.5.1).

$$\sum_k \frac{C_k}{C_{e,k}} \geq 1$$

was applied to the measured specific activities in Table 7-5. The limit activities $C_{e,k}$ were taken from Table 5-4. The different units – Bq/kg vs. Bq g^{-1} – were considered. The values were taken as measured, i.e., background concentrations were not subtracted.

Because the limit values of several radionuclides include their decay products in a radioactive equilibrium (see Table 5-2), the daughter products according to Table 5-2 (here: Po-210) were only considered if their activity concentration was higher than that of the corresponding parent nuclide.

The ratios obtained and the calculated sums compiled in Table 7-10 demonstrate that all data are in a range below the limits. This even holds for a conservative calculation as it is made in column "Microsilica dust 2021 (b)" where values for K-40 and Cs-137 were taken from the dataset "Microsilica 2021 (a), and additionally, detection limits were applied for corresponding radionuclides.

Consequently, the dust of the Elkem Bremanger melting processes should not be classified as radioactive waste according to the Regulation on Rad-Pollution and Rad-Waste [6]. According to our interpretation of the waste classification hierarchy (Ch. 5.1.6), the waste is "out of scope" of the Regulation on Rad-Pollution and Rad-Waste. Collected filter dust or microsilica dust can be classified as non-radioactive waste. However, the disposal of waste must comply with the requirements of waste legislation.

Table 7-10: Assessment of dust with regard to the classification Rad Waste. Ratios of measured specific activities in dust referred to limit activities $C_{e,k}$ (Rad Waste) and sum calculated from them

Radionuclide	Filterdust oven 2, Chamber 7, E1, 5 år	Filterdust oven 4, Chamber 5, H10, 6 år	Microsilica dust 2020	Microsilica dust 2021 (a)	Microsilica dust 2021 (b)
Pb-210	0.063	0.096	0.011	0.25	0.34
Po-210	[0][c)]	[0][c)]	0.04	[0.095][c)]	[0.2][c)]
Ra-226	0.034	0.037	0.0247	0.0278	0.091
Ra-228	0.0263	0.03	0.0114	0.0103	0.025
Th-228	0.0254	0.0057	0.005	0.0024	0.0083
Th-230	0.039 [d)]	0.029 [d)]	0.0082	0.005	0.005 [b)]
Th-232	0.0254 [d)]	0.0057 [d)]	0.0048	0.005	0.005 [b)]
U-234	0.039 [d)]	0.029 [d)]	0.01	0.005	0.01 [b)]
U-235	0.0054	0.0015 [d)]	0.00047	0.00023	0.0004 [b)]
U-238	0.039	0.029	0.01 [d)]	0.005 [d)]	0.01 [b)]
Sum $C_k/C_{e,k}$	**0.30**	**0.26**	**0.13**	**0.31**	**0.49**

[a)] Values taken from column “Microsilica dust 2021 (a)”; [b)] Detection limit specified in Table 7-5 applied;
[c)] Covered by Pb-210; [d)] The data were supplemented based on the properties of decay series

The criterion for emissions requiring a permit is checked in Table 7-11. The activity amount of dust emission was calculated from the data set „Microsilica dust 2021 (b)“ in Table 7-10 and the annual dust quantity of 82.8 Mg (cf. Ch. 7.2.1). The total discharges of water are the sum of all activity loads discharged via water in 2021 (cf. Table 7-8).

Despite the very low specific activities, mostly of a natural background level, all activity amounts of discharges exceed the limits of Annex II in the Regulation on Rad-Pollution and Rad-Waste [6].

Table 7-11: Assessment of emissions with regard to the permit requirement. Ratios of discharge amounts referred to limit activities $A_{e,k}$ and sum calculated from them

	Dust emission	Discharges requiring a permit	Total discharges of water	Discharges requiring a permit
	$A_{max,k}$	$A_{max,k}/A_{e,k}$	$A_{max,k}$	$A_{max,k}/A_{e,k}$
	[MBq y^{-1}]	-	[MBq y^{-1}]	-
Pb-210a	28.2	28,200	36.4	36,400
Po-210	16.6	16,600	3.03	3,030
Ra-226a	7.53	7,530	244.44	244,440
Ra-228a	2.07	207	56.89	5,689
Th-228a	0.69	690	121.76	121,760
Th-230	0.41	414	50.4	50,400
Th-232	0.41	4,140	37.8	378,000
U-234	0.83	828	96.62	96,620
U-235a	0.03	33.12	4.18	4,180
U-238a	0.83	828	98.56	98,560
Sum $A_k/A_{e,k}$	-	**59,470**	-	**1,039,079**

7.2.4 Summarizing assessment

At Elkem's Bremanger plant, the production of silica and ferrosilicon produces dusts in which the radionuclide Pb-210 (and to a lesser extent Ra-226) are enriched as a result of thermal treatment. In addition, operational process waters and waters from operational landfills are discharged to the sea.

If the available measured values of the specific activity are evaluated with regard to the criteria of the Norwegian Radiation Protection Regulations described in chapter 5, then the results summarized in Table 7-12 for dust and in Table 7-13 for discharges with water are obtained.

All materials comply with the exemption requirements of the Radiation Protection Act. All waste amounts are **not** classified as radioactive waste and can be disposed of as common chemical waste.

The only criterion for which it is possible that the radiation protection regulations apply is the criterion of the permit requirement for discharges. Although this criterion is fulfilled "positively", a radiological hazard of the discharges is difficult to justify, because the specific activities of the discharges are in the range of the background values. Any conceivable enrichment of radionuclides in the environment would also involve the same radionuclides that occur in nature anyway. A need for environmental monitoring that can be derived for radiation protection reasons is not apparent from the measurement results of the Elkem plant in Bremanger.

Table 7-12: Summarizing assessment of microsilica dust 2021

Criterion	Requirement	Result
Material exempted from requirements of the RPA?	$\sum_k \frac{C_k}{C_{e,k}} \leq 1$ or $\sum_k \frac{A}{A_{e,k}} \leq 1$	Yes ("true" or "false" → "true") Sum C_{max} = 0.61 < 1? true Sum A_{max} = 5,320 < 1? false
Material to be classified as radioactive waste?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$	No Sum C_{max} = 0.49 > 1? false
Radioactive waste requiring disposal?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ and $\sum_k \frac{A}{A_{e,k}} \geq 1$	No ("true" and "false" → "false") Sum C_{max} = 0.066 > 1? true Sum A_{max} = 2,655 > 1? false
Radioactive discharges requiring a permit?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ or $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes ("true" or "false" → "true") Sum C_{max} = 0.66 > 1? false Sum A_{max} = 53,227> 1? true

Table 7-13: Summarizing assessment of discharges via water

Classi	Requirement	Result
Material exempted from requirements of the RPA?	$\sum_k \frac{C_k}{C_{e,k}} \leq 1$ or $\sum_k \frac{A}{A_{e,k}} \leq 1$	Yes ("true" or "true" → "true") Sum C_{max} = 0.0002 <1? true Sum A_{max} = 0.0020 < 1? true
Material to be classified as radioactive waste?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$	Not applicable
Radioactive waste requiring disposal?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ and $\sum_k \frac{A}{A_{e,k}} \geq 1$	Not applicable
Radioactive discharges requiring a permit?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ or $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes ("false" or "true" → "true") Sum C_{max} = 0.66 > 1? false Sum A_{max} = 1,039,079 > 1? true

7.3 Hydro

7.3.1 Processes and licensing requirements at Hydro Aluminium plant in Årdal

Hydro Aluminium operates two plants in the Årdal Municipality in Vestland County at the east end of the Sognefjord, Norway's longest and deepest Fjord. The Hydro Aluminium plant (Hydro metallverk) in Øvre Årdal (see Figure 7-3) produces primary aluminum by electric melting processes. Hydro Årdal Karbon (Hydro Karbon) in the community Årdalstangen (Figure 7-4) is a manufacturer of anodes [93]. Both plants produce

- 204,000 tons of primary aluminum,
- 220,000 tons cast house products (sheet ingot and foundry alloys) and
- 215.000 tons anodes.

Figure 7-3: Air view of the Hydro Aluminium plant (metallverk) in Øvre Årdal.
From https://www.hydro.com/en/about-hydro/hydro-worldwide/europe/norway/ardal/hydro-aluminium-as-ardal/

Figure 7-4: Site plan (left) and photo (above) of the Hydro Karbon plant in Årdal.

From: https://de.sognefjord.no/sognefjord-erkunden/aardal

The sole industrial method for the smelting of primary aluminum is the Hall-Héroult process. The process is described on the website of the International Aluminium Institute [94]. The following three paragraphs are taken from this website.

The main step of the Hall-Héroult process is the melting of a mixture of cryolite, alumina, and aluminum fluoride in large electrolytic cells connected in series (a “potline”). The cell contains an electrolytic bath of molten cryolite (Na_3AlF_6), maintained at a temperature of around 960 – 980°C, in which alumina powder (Al_2O_3) is dissolved. Aluminum fluoride (AlF_3) is added to the solution to maintain optimal chemistry and lower the electrolyte’s freezing point. Large carbon blocks serve as the positive electrode (anode). The molten metallic aluminum sinks to the bottom of the cell, while the gaseous by-products form at the top.

At Hydro Aluminium the prebake technology is applied. This technology uses multiple anodes in each cell, which are baked in a separate facility and attached to rods that suspend the anodes in the cell. New anodes are exchanged for spent anodes, with the remaining anode “butts” being recycled into new anodes.

Prebake anodes are made from petroleum coke, pitch, and recycled anode butts (the ends of the consumed anodes remaining at the end of their life) returned from the smelting process. These materials are mixed together in heated containers and poured into molds. Once formed, the anodes are transferred to a “bakehouse”. Here, the anodes are placed in a furnace at a temperature of 1120°C for a period of up to two weeks. This bakes the pitch in the mix, forming a solid block of carbon, able to withstand the extreme conditions inside the smelting pots but of a homogenous consistency that allows for efficient conduction of current and even consumption of the anode. The last stage of the anode production process takes place in the “rodding room”. Here the carbon blocks are fused to a steel rod (the means by which they will be lowered into the pot and through which the electrical current is passed) with molten cast iron. The rodded anodes are then transported to the smelter potroom to be placed in the reduction cells.

Hydro Karbon and Hydro metallverk have two separate licensees from the Norwegian Environmental Authority. The licensees include masses of emissions/discharges

- from aluminum production (metallverk) based on the electrolysis of aluminum oxide and subsequent casting and processing of the electrolysis metal [95] and
- from the production of anode pulp and burnt anodes for use in electrolysis furnaces for aluminum production (Hydro Karbon [96]).

In these licensees, the obligations related to emission are without any aspects concerning radioactivity.

The license for Hydro metallverk [95] concerns the production of approximately 225,000 tons of metal per year. The license covers a total production capacity for cast metal of 385,000 tons per year, including electrolysis metal, purchased cold metal, and alloying elements. It also applies to pollution from the reception, storage and/or treatment of hazardous waste and anode butts.

The emission components from the processes that are assumed to have the greatest environmental impact are expressly regulated in sections 3 to 14 of this license. Emissions that are not expressly regulated in this way are also covered by the license as long as information about such emissions had emerged in connection with the industrial processes or must be considered to have been known in some other way when the decision was made. However, this does not apply to emissions of priority hazardous substances.

The license for Hydro Karbon [96] applies to the production of anode pulp and burnt anodes for use in electrolysis furnaces for aluminum production. The license applies to emissions from

- the pulp mill with a production line for green anodes for subsequent burning in the anode factory, with a capacity of 270,000 tons per year,
- the anode factory with 2 ovens (ovens 3 and 4) for burning anodes for use in pre-bake ovens, with a capacity of 250,000 tons of burnt anodes per year and
- the handling and storage of raw materials and products.

Both licenses do not contain any specifications connected to radioactivity.

7.3.2 Radiological situation at the Hydro Karbon plant in Årdalstangen

A general scheme showing the flow of gas and water through the process line in the Hydro Karbon plant in Årdalstangen is given in Figure 7-5. In this sketch, numbers 1 to 7 indicate sampling points used to determine the activity concentration in water (seawater, freshwater, and wastewater) and the specific activities of dust from pipes and dust filters. Quantities of annual discharges are given in Table 7-14.

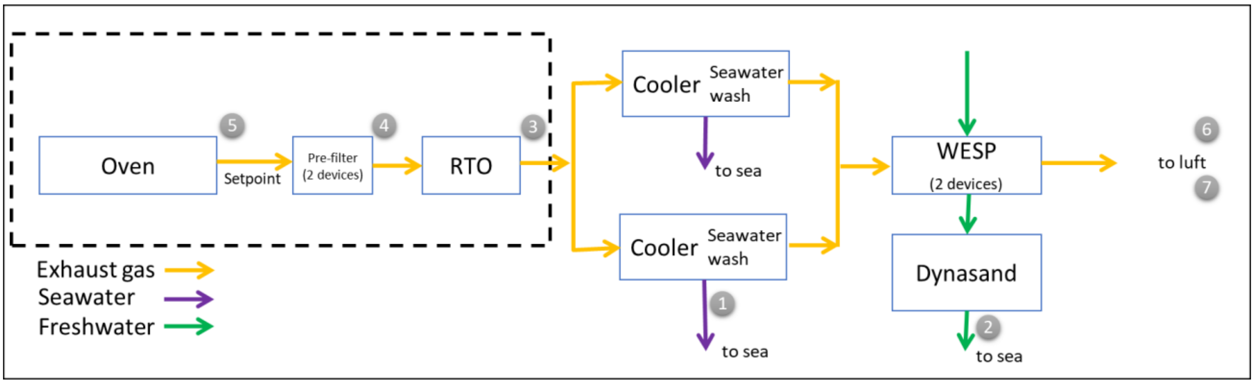

Figure 7-5: Sketch from the production process at the Hydro Karbon plant. Numbers indicate sampling sites.

Table 7-14: Annual discharges of Hydro Karbon plant in 2021

Water	**Air, sampling point 6**	**Air, sampling point 7**
Q [m^3 y^{-1}]	m [kg y^{-1}]	m [kg y^{-1}]
6,932,725	2,444	1,316

Specific activities in dust generated in the oven process (sampling points 5 – 4 – 3 in Figure 7-5) are compiled in Table 7-15. The samples were taken during pipe cleaning and in a combustion chamber. This dust remains in the facilities and is not released to the environment.

All three samples are characterized by very high Po-210 and high Pb-210 activity. The highest activities occur behind the combustion chamber (Sampling site “3”).

The activity ratio Po-210 : Pb-210 is nearly constant at about 45 : 1. This nearly constant ratio indicates that the data quality is consistent.

The strong enrichment of Po-210 is due to the temperature in the oven process. The boiling point of Pb-210 is at 1,740 °C, and of Po-210 is at 962 °C. The highest flue gas temperature in the oven is around 1,200-1,250°C, while the anode (the product) has a top temperature of around 1,100 °C. So, Po-210 escapes in the oven process with the gas nearly completely, Pb-210 to a much lower degree.

All other radionuclides have specific activities in or close to the background level.

Table 7-15: Specific activities in dust from the oven process in the Hydro Karbon plant. Sampling points No. 3 – 5 in Figure 7-5.

Radionuclide	**Pipe cleaning 4/3-20 ring line 5 [Bq kg^{-1}]**	**Pipe cleaning 4/3-20 damper surface 4 [Bq kg^{-1}]**	**Anode baking unit behind combustion chamber 3 [Bq kg^{-1}]**
Pb-210	2,500 ± 180	3,180 ± 210	9,900 ± 700
Po-210	119,100 ± 16.000	141,900 ± 18.200	419,500 ± 31,700
Ra-226	6 ± 2	5 ± 1	6.3 ± 2.2
Ra-228	≤ 6	≤ 1,1	11 ± 4
Th-228	≤ 2.2	3.5 ± 0.6	5.3 ± 1,0
Th-230	24 ± 12	16 ± 6	60 ± 12
Th-232	≤ 6	≤ 2	15 ± 5
U-234	7 ± 6	7.1 ± 2.8	62 ± 12
U-235	≤ 7	≤ 1,7	≤ 3
U-238	≤ 7	5.3 ± 2.4	57 ± 12

Specific activities from dust filters before discharge into the ambient air (sampling points 7 – 6) are given in Table 7-16. The values deviate significantly from the dust generated in the anode baking unit. Again, Po-210 has the highest activity concentration, but in particular, the isotopes of radium, thorium, and uranium occur in substantially higher values. Especially in dust from filter P1 collected at sampling point 6, the specific activities of radium, thorium, and uranium isotopes exceed the natural background by about one order of magnitude.

Table 7-16: Specific activities in dust filters. Sampling points 6 – 7 in Figure 7-5.

	Dust filter P1 11/3-20 Karbon, Anode factory 6	**Dust filter P2 11/3-20 Karbon, Anode factory 7**	**Natural background**
	[Bq kg^{-1}]	**[Bq kg^{-1}]**	**[Bq kg^{-1}]**
Pb-210	600 ± 400	500 ± 400	10,000
Po-210	40,900 ± 4,400	10,000 ± 1,700	1,000
Ra-226	438 ± 267	63 ± 25	25 – 50
Ra-228	≤ 700	≤ 200	25 – 50
Th-228	≤ 190	370 ± 50	25 – 50
Th-230	580 ± 100	67 ± 15	25 – 50
Th-232	200 ± 50	29 ± 9	25 – 50
U-234	190 ± 60	22 ± 9	25 – 50
U-235	≤ 40	3 ± 3	1 - 2
U-238	230 ± 60	27 ± 10	25 – 50

Because specific activities of Po-210 and Pb-210 in the filters are lower than a factor of 3 – 10 compared to the dust from the oven process, another source of dust must occur in the process line. Possibly this could be refractory material in the “rodding room”. In refractory material uranium, thorium and radium may occur in somewhat higher concentrations than the common natural background in soil. The measured specific activities of uranium, thorium and radium isotopes in the filtered dust can be interpreted as such a contribution.

Compared to the exemption values in Table 5-1, only Po-210 (10 Bq g^{-1} – 40.9 Bq g^{-1}), exceed exemption values of the Radiation Protection Act [5]. All other radionuclides listed in Table 7-16 have specific activities lower than the exemption values. However, Th-228 and Th-230 contribute with a share 0.58 (Th-230 in P1) and 0.37 (Th-228 in P2) significantly to the results of the summation formula (see Ch. 7.3.3).

Analyses results of water samples are compiled in Table 7-17. The results of incoming seawater are in excellent agreement with the values of seawater summarized in Table 7-1. The results from incoming freshwater are still lower and mostly below the detection limit.

The activity concentration of the water discharged into the sea after “Sea water wash” process (Sampling points 1 and 2 in Figure 7-5) is significantly enhanced only at Po-210 and slightly at Pb-210. All other radionuclides are in or close to the natural background level. This result is plausible because of the enhanced Po-210 in dust in the anode baking unit.

As already mentioned in the case of Elkem, radionuclide concentrations in water are negligible compared to exemption values for the specific activity. Therefore, the total discharged activities are the crucial criterium for regulatory requirements.

Table 7-17: Activity concentration of water samples.

	Incoming seawater to the treatment plant in Anode baking	**Incoming fresh water for cooling purposes from Årdals water**	**Water sample from the treatment plant in Anode baking; Sampling points 1 and 2**	**Seawater (for comparison, cf. Table 7-1)**
	[Bq/l]	**[Bq/l]**	**[Bq/l]**	**[Bq/l]**
Pb-210	≤ 0.005	≤ 0.005	0.014 ± 0.006	0.002 – 0.005
Po-210	0.0042 ± 0.0009	0.0011 ± 0.0008	0.36 ± 0.05	0.002 – 0.004
Ra-226	≤ 0.015	≤ 0.015	≤ 0.015	0.001 – 0.004
Ra-228	≤ 0.04	≤ 0.010	0.016 ± 0.006	0.010
Th-228	≤ 0.004	≤ 0.005	≤ 0.004	0.0002
Th-230	0.0010 ± 0.0004	0.0008 ± 0.0004	0.0010 ± 0.0004	$5 \cdot 10^{-5}$
Th-232	≤ 0.00015	≤ 0.00024	≤ 0.00016	$5 \cdot 10^{-7}$
U-234	0.040 ± 0.006	≤ 0.00025	0.043 ± 0.005	0.047
U-235	0.0012 ± 0.0006	≤ 0.00028	0.0012 ± 0.0005	0.002
U-238	0.037 ± 0.006	≤ 0.00028	0.037 ± 0.004	0.041

Using the total discharged quantities in Table 7-14 and the measured specific activities in Table 7-16 and Table 7-17, activities discharged via water and dust from the Hydro Karbon plant were calculated. The amounts obtained are compiled in Table 7-18.

Table 7-18: Activities discharged via water and dust from the Hydro Karbon plant in 2020

	Water from collection line from treatment plant Anode baking [MBq y^{-1}]	**Dust filter P 1 11/3-20 Karbon Anode factory** [MBq y^{-1}]	**Dust filter P 2 11/3-20 Karbon Anode factory** [MBq y^{-1}]
Pb-210	97.1 ± 41.6	1.47 ± 0.98	0.66 ± 0.53
Po-210	2,496 ± 347	100 ± 11	13.2 ± 2.22
Ra-226	< 104	1.07 ± 0.65	0.08 ± 0.03
Ra-228	110.9 ± 41.6	< 1.71	< 0.26
Th-228	< 27.7	< 0.46	0.49 ± 0.07
Th-230	6.9 ± 2.8	1.42 ± 0.24	0.09 ± 0.02
Th-232	< 1.1	0.49 ± 0.12	0.04 ± 0.01
U-234	298.1 ± 34.7	0.46 ± 0.15	0.03 ± 0.01
U-235	8.3 ± 3.5	0.1 ± 0.1	< 0.01
U-238	256.5 ± 27.7	0.56 ± 0.15	0.04 ± 0.01

7.3.3 Assessment of materials and emissions at Hydro Karbon

As described in the previous chapter, the “baking” of carbon anodes in a furnace results in dust particles that are strongly enriched in Po-210 (and somewhat lower in Pb-210). This dust is deposited at the inner surface of components and remains in the facility. It is not released.

Referring to the exemption values in Table 5-1, the specific activities of Po-210 exceed the exemption values of the Radiation Protection Act [5] by a factor 40. In Table 7-19 the measuring results compiled in Table 7-15 are evaluated regarding the exemption criteria of the Radiation Protection Act [5]. Because no total amount of dust from the anode baking unit is available, we estimated the total mass quantity that just complies with the exemption criteria. The amount of the mass is 24 grams!

If pipes or other parts of the facilities contaminated with the dust of the baking process are maintained, decommissioned, or repaired radiation protection is justified. Due to the limited time such measures require, the doses of the workers will be low if the common occupational protection measures are applied.

A rough estimation of the inhalation dose during a two-week working at a place with 1 mg/m³ dust concentration (AMAD 5 Micrometer), inhalation rate 1.2 m³/h and the Po-210 dose coefficient of 2.2E-06 Sv/Bq results in an inhalation dose of only 0.1 mSv. However, if the same workers make similar work at other facilities, the exposure may become significantly.

Table 7-19: Evaluation of sample "Anode baking unit behind combustion chamber" related to the exemption from Radiation Protection Act requirements

	$C_{max,k}$	$C_{max,k}/C_{e,k}$	$A_{max,k}$ (24 g)	$A_{max,k}/A_{e,k}$
	$Bq\ g^{-1}$	-	[Bq]	-
Pb-210a	9.9	0.99	237.6	$2.38 \cdot 10^{-2}$
Po-210	419.5	41.95	10068	$1.01 \cdot 10^{0}$
Ra-226a	0.0063	0.00063	0.15	$1.51 \cdot 10^{-5}$
Ra-228a	0.011	0.0011	0.26	$2.64 \cdot 10^{-6}$
Th-228a	0.0053	0.0053	0.13	$1.27 \cdot 10^{-5}$
Th-230	0.06	0.06	1.44	$1.44 \cdot 10^{-4}$
Th-232	0.015	0.0015	0.36	$3.60 \cdot 10^{-5}$
U-234	0.062	0.0062	1.49	$1.49 \cdot 10^{-4}$
U-235a	0.0027	0.000271429	0.07	$6.51 \cdot 10^{-6}$
U-238a	0.057	0.0057	1.37	$1.37 \cdot 10^{-4}$
Sum	-	**43.0**	-	**(1.0)**

Analogue to the procedure in Ch. 7.2.3 in the following we check whether the dust collected in filters (see Table 7-16) in the case of intended disposal has to be classified as

1. radioactive waste (see Ch. 5.1.5.1) or
2. radioactive waste requiring disposal (see Ch. 5.1.5.2)

Again, the summation formulas given in Ch. 5.1.5 were applied to the measured specific activities. The limit activities $C_{e,k}$ were taken from Table 5-4 (radioactive waste) and Table 5-6 (radioactive waste requiring disposal). The different units – Bq/kg vs. $Bq\ g^{-1}$ – were considered. The values were taken as measured, i.e., background concentrations were not subtracted.

Because the limit values for exemption from the requirements of the Radiation Protection Act (see Ch. 5.1.4) are the same as the limit values for waste requiring disposal, it was refrained from calculating and listing the values separately.

For checking the classification "waste requiring disposal" the total activity amounts of Table 7-18 were applied. It must be mentioned that these amounts are based on the total emitted dust mass (Table 7-14) and not on genuine waste amounts. For that reason, the evaluation of the data should be considered as indicative only. The amount would become reality if the total amount of emitted dust is retained in filter. Moreover, applying the total emitted mass to each analyzed dust sample results in an overestimation by a factor of about two. However, the sum value calculated in the last row in Table 7-21 is so high, that the uncertainties of the evaluations are irrelevant for the assessment.

In summary, the dust from Hydro Karbon plant is classified due to its very high Po-210 and Pb-210 as "radioactive waste requiring disposal". However, it should be noted that Po-210 activity is in excess of Pb-210, and its activity will decrease to the level of Pb-210 in about 2 years.

Table 7-20: Evaluation of dust filter samples regarding requirements of waste classification for specific activity C_k. Hydro Karbon plant

Radionuclide	**Dust filter P1 11/3-20 Karbon, Anode factory (6)**		**Dust filter P2 11/3-20 Karbon, Anode factory (7)**	
k	Rad waste	Rad waste requiring disposal	Rad waste	Rad waste requiring disposal
Pb-210	0.6	0.06	0.5	0.05
Po-210	40.9	4.09	10	1
Ra-226	0.438	0.0438	0.063	0.0063
Ra-228	0.7	0.07	0.2	0.02
Th-228	0.19	0.19	0.37	0.37
Th-230	0.58	0.58	0.067	0.067
Th-232	0.2	0.2	0.029	0.029
U-234	0.19	0.019	0.022	0.0022
U-235	0.04	0.004	0.01	0.001
U-238	0.23	0.023	0.027	0.0027
Sum $C_k/C_{e,k}$	**44.1**	**5.3**	**11.3**	**1.5**

Table 7-21: Evaluation of dust filter samples regarding the criterion “waste requiring disposal” for total activity. Hydro Karbon plant

	Dust filter P1 11/3-20 Karbon, Anode factory (6)	**Dust filter P2 11/3-20 Karbon, Anode factory (7)**
k	$A_k/A_{e,k}$	$A_k/A_{e,k}$
Pb-210	140	60
Po-210	9,500	1,250
Ra-226	110	8
Ra-228		
Th-228		49
Th-230	142	8.8
Th-232	490	38
U-234	47	2.8
U-235	2,3	1
U-238	57	3.5
Sum $A_k/A_{e,k}$	**$1{,}05 \cdot 10^4$**	**1,458**

In contrast to waste classification, which was based on waste masses corresponding to emitted dust masses, the question of the permit requirement for discharges can be examined directly with the available data. In Table 7-22 the specific activities of discharges via water and dust are evaluated regarding the criteria of radioactive discharge requiring a permit (Ch. 5.1.5.3). The sum $C_k/C_{e,k}$ demonstrates clearly that the concentration of water related to the limit values given in Annex II of the Regulation on Rad-Pollution and Rad-Waste [6] is close to zero. In contrast to this the specific activity of the emitted dust exceeds the limit values considerably.

Table 7-22: Evaluation of the summation formula for specific activity in water and dust filter samples regarding the criterion “radioactive discharge requiring a permit”. Hydro Karbon plant

Radionuclide	**Water from collection line from treatment plant Anode baking**	**Dust filter P1 11/3-20 Karbon, Anode factory (6)**	**Dust filter P2 11/3-20 Karbon, Anode factory (7)**
k	$C_k/C_{e,}$	$C_k/C_{e,}$	$C_k/C_{e,}$
Pb-210	0,000014	0.6	0.5
Po-210	0,000360	40.9	10
Ra-226	0,000000	0.438	0.063
Ra-228	0,000016	0.7	0.2
Th-228	0,000000	1.9	3.7
Th-230	0,000010	5.8	0.67
Th-232	0,000000	2	0.29
U-234	0,000043	0.19	0.022
U-235	0,000001	0.04	0.01
U-238	0,000037	0.23	0.027
Sum $C_k/C_{e,k}$	**0,0005**	**52.8**	**15.5**

In Table 7-23 the total (annual) activities of discharges are evaluated. The sum $A_k/A_{e,k}$ demonstrates clearly that the concentration of water related to the limit values given in Annex II of the Regulation on Rad-Pollution and Rad-Waste [6] exceeds in all three cases the limit values by order of magnitudes. This also holds for water with concentrations of radionuclides close to the natural background.

Table 7-23: Evaluation of the summation formula for total activity amounts emitted via water and dust regarding the criterion “radioactive discharge requiring a permit”. Hydro Karbon plant

Radionuclide	**Water from collection line from treatment plant Anode baking**	**Dust filter P1 11/3-20 Karbon, Anode factory (6)**	**Dust filter P2 11/3-20 Karbon, Anode factory (7)**
k	$A_k/A_{e,k}$	$A_k/A_{e,k}$	$A_k/A_{e,k}$
Pb-210	97,100	1,470	658
Po-210	2,495,781	100,000	13,160
Ra-226	0	1,070	82,908
Ra-228	11,092	171	0
Th-228	0	460	486,92
Th-230	6,933	1,420	88,172
Th-232	0	6,440	381,64
U-234	298,107	460	28,952
U-235	8,319	100	3,948
U-238	256,511	560	35,532
Sum $A_k/A_{e,k}$	**3,173,843**	**112,151**	**253,541**

7.3.4 Radiological situation at the Hydro Aluminium plant (metallverk) in Øvre Årdal

In the Hydro Aluminium plant (metallverk) in Øvre Årdal two different metallurgical processes are executed: the electrolytic melting and the following casting and processing of the electrolysis metal.

As described in Ch. 7.3.1, aluminum production by the Hall-Héroult process is based on a feedstock made from cryolite, alumina, and aluminum fluoride. The main mass component is alumina. The minerals that are mixed as the feedstock are treated and purified by different chemical procedures from natural ores. Thus, e.g., the alumina is much lower in its radioactivity than the bauxite it is manufactured from. Moreover, the temperature of the electrolytic bath of around 960 – 980°C is much lower than the temperature in many other metallurgical processes. At this temperature, only Po-210 evaporates effectively.

During the casting and processing of the electrolysis metal the temperatures are lower than in the melting process and therefore, significant redistributions and enrichments of radionuclides are not expected to occur.

The amounts of dust that is emitted or collected in bagfilters are compiled in Table 7-24. Additionally, water discharges of 56,940 m³ per year were registered in 2021.

Table 7-24: Annual amounts of dust at Hydro Aluminium plant (metallverk) in Øvre Årdal (ØÅ) in 2021

Facility	Site	[kg y^{-1}]
Elektrolyse (AAM) ØÅ	Diffuse source	2.204,0
	FTP (fume treatment plant)	3.468,8
	Separate bagfilters	26.802,8
	Roof	92.043,8
Foundry (AAM) ØÅ	Diffuse source	663,0
	Separate bagfilters	3.349,1

The data in Table 7-25 with specific activities of dust samples as waste from the emission filter confirm a slight enrichment for Po-210 of about 0.13 Bq g^{-1} (130 Bq kg^{-1}) in the fume treatment plant (FTP) pipe. The specific activities of Pb-210 are between ≤ 0.06 Bq g^{-1} (≤ 60 Bq kg^{-1}) at this pipe and about 0.06 Bq g^{-1} (63 Bq kg^{-1}) at the dust electrolysis above the roof (no data for Po-210).

All analysis results are lower than the common background and can be assessed as negligible. The specific activities of the other naturally occurring radionuclides than Po-210 are below 0.1 Bq g^{-1} and can be classified as insignificant, too.

Compared to the exemption values compiled in Table 5-1, all measured specific activities in Table 7-25 comply with the limits in the Regulation on Rad-Pollution and Rad-Waste [6]. This also holds for Po-210.

Table 7-25: Specific activities from dust in pipe FTP and from the dust electrolysis unit emitted above the roof at Hydro metallverk

	Dust in pipe FTP 05-06.06.2018	Dust, electrolyze unit above roof	Natural background
	[Bq kg^{-1}]	[Bq kg^{-1}]	[Bq kg^{-1}]
Pb-210	≤ 60	63 ± 12	10,000
Po-210	130 ± 40	-	1,000
Ra-226	≤ 71	8 ± 1	25 – 50
Ra-228	≤ 16	≤ 5	25 – 50
Th-228	≤ 90	3.5 ± 1.1	25 – 50
Th-230	29 ± 14	7 ± 3	25 – 50
Th-232	10 ± 8	≤ 2.7	25 – 50
U-234	7 ± 4	4.4 ± 2.2	25 – 50
U-235	≤ 4	≤ 1.5	1 - 2
U-238	4 ± 3	2.7 ± 1.8	25 – 50

The activity concentration of the water after wet wash electrolysis is at a low level. Po-210 has the highest concentration with 0.03 Bq l^{-1} (see Table 7-26). All other detected radionuclides are on a concentration level to assess as a natural one. There is also no information on whether the radionuclide analyses of the water sample are performed with the fluids and undissolved particles or just with the solved agents.

Table 7-26: Activity concentration of a water sample behind wet wash electrolysis at the Øvre Årdal site

	C [Bq l^{-1}]
Pb-210	0.00215 ± 0.0021
Po-210	0.030 ± 0.010
Ra-226	≤ 0.013
Ra-228	≤ 0.005
Th-228	0.0007 ± 0.0004
Th-230	≤ 0.00022
Th-232	0.012 ± 0.003
U-234	≤ 0.0006
U-235	0.0078 ± 0.0023 [a)]
U-238	0.00215 ± 0.0021

[a)] this value is assessed to be an artifact because otherwise, uranium would have to be classified as enriched uranium (nuclear material)

In Table 7-27 annual activity amounts collected in dust filters and activity amounts discharged via water are listed. The data refer to 2020 and were taken from the dataset obtained from Hydro. Using the measured specific activities listed in Table 7-25 and the (bold marked) mass amounts in Table 7-24 (referring to 2021) the data given in Table 7-27 are plausible.

Table 7-27: Activity amounts discharged by water and dust from the Hydro Aluminium plant in 2020

	Water sample behind wet wash electrolyze unit [MBq y^{-1}]	**Dust filter FTP [MBq y^{-1}]**	**Dust filter, electrolyze unit above roof [MBq y^{-1}]**
Pb-210	-	-	5.6 ± 1.0
Po-210	1.2 ± 0.11	1.1 ± 0.3	-
Ra-226	1.7 ± 0.6	-	0.70 ± 0.13
Ra-228	-	-	-
Th-228	-	-	0.31 ± 0.09
Th-230	0.039 ± 0.022	0.27 ± 0.13	0.59 ± 0.28
Th-232	-	0.09 ± 0.07	-
U-234	0.66 ± 0.17	0.06 ± 0.04	0.39 ± 0.20
U-235	0.033 ± 0.008	0.0032 ± 0.0018	0.02 ± 0.01
U-238	0.44 ± 0.13	0.040 ± 0.028	0.25 ± 0.16

7.3.5 Assessment of materials and emissions

According to Table 7-25 the sample “Dust in pipe FTP 05-06.06.2018” represents the highest measured specific activities of dust samples. In Table 7-28 the measuring results are evaluated regarding the exemption criteria of the Radiation Protection Act [5]. The sum of specific activity ratios is lower than 1, sum of total activity ratios is considerably higher than 1. The final assessment will be given in the next chapter.

Table 7-28: Evaluation of sample “Dust in pipe FTP; 05-06.06.2018” related to the exemption from Radiation Protection Act requirements

	C_k [Bq g^{-1}] = [MBq m^{-3}]	**$C_k/C_{e,k}$**	**A_k [MBq y^{-1}]**	**$A_k/A_{e,k}$**
Pb-210a	-	-	-	-
Po-210	0.13	0.013	1.1	110
Ra-226a	-	-	-	-
Ra-228a	-	-	-	-
Th-228a	-	-	-	-
Th-230	0.029	0.029	0.26	27
Th-232	0.01	0.001	0.09	9
U-234	0.007	0.0007	0.06	6
U-235a	0.004	0.0004	0.035	0,3
U-238a	0.004	0.0004	0.035	4
Sum	**-**	**0.045**	**-**	**156**

With the assumption that the investigated dust must be disposed of as waste, the classification of this waste according to the requirements of the Regulation on Rad-Pollution and Rad-Waste [6] is evaluated in Table 7-29 and Table 7-30.

Table 7-29: Waste classification with specific activity criterion. Hydro Aluminium plant

Radionuclide	**Dust in pipe FTP, 05-06.06.2018**		**Dust, electrolyze unit above roof**	
k	**Rad waste**	**Rad waste requiring disposal**	**Rad waste**	**Rad waste requiring disposal**
	$C_k/C_{e,k}$	$C_k/C_{e,k}$	$C_k/C_{e,k}$	$C_k/C_{e,k}$
Pb-210	-	-	0.063	0.0063
Po-210	0.13	0.013	-	-
Ra-226	-	-	0.008	0.0008
Ra-228	-	-	-	-
Th-228	-	-	0.0035	0.0035
Th-230	0.029	0.029	0.007	0.007
Th-232	0.01	0.01	-	-
U-234	0.007	0.0007	0.0044	0.00044
U-235	0.004	0.0004	0	0
U-238	0.004	0.0004	0.0027	0.00027
Sum $C_k/C_{e,k}$	**0.18**	**0.054**	**0.089**	**0.018**

Table 7-30: Evaluation of the total activity criterion for "Waste requiring disposal" classification. Dust from Hydro Aluminium plant

Radionuclide	**Dust in pipe FTP, 05-06.06.2018**	**Dust, electrolyze unit above roof**
k	**$A_k/A_{e,k}$**	**$A_k/A_{e,k}$**
Pb-210	0	6
Po-210	110	-
Ra-226	-	70
Ra-228	-	-
Th-228	-	3
Th-230	27	59
Th-232	90	-
U-234	6	39
U-235	0,3	-
U-238	4	25
Sum $A_k/A_{e,k}$	**237**	**202**

Table 7-31: Evaluation of discharged water related to the exemption from permit requirements

	C_k	$C_k/C_{e,k}$	A_k	$A_k/A_{e,k}$
	[Bq g^{-1}] = [MBq m^{-3}]	**-**	**[MBq y^{-1}]**	**-**
Pb-210a	$2.15 \cdot 10^{-6}$	$2.15 \cdot 10^{-6}$	0.12	122
Po-210	$3.00 \cdot 10^{-5}$	$3.00 \cdot 10^{-5}$	1.71	1708
Ra-226a	-	-	-	-
Ra-228a	-	-	-	-
Th-228a	$7.00 \cdot 10^{-7}$	$7.00 \cdot 10^{-6}$	0.04	40
Th-230	-	-	-	-
Th-232	$1.20 \cdot 10^{-5}$	$1.20 \cdot 10^{-4}$	0.68	6833
U-234	-	-	-	-
U-235a	-	-	-	-
U-238a	$2.15 \cdot 10^{-6}$	$2.15 \cdot 10^{-6}$	0.12	122
Sum	**-**	**$1.61 \cdot 10^{-4}$**	**-**	**8,826**

7.3.6 Summarizing assessment

In Table 7-32 to Table 7-35 a summarizing assessment of the Hydro Karbon plant materials is given. The following materials are considered:

- Dust from anode baking unit collected behind combustion chamber.
- Dust filter P2 11/3-20 Karbon, Anode factory. This sample was selected, because it represents less contaminated material and consequently the classification holds for all materials with higher radioactive contamination.
- Water from collection line from treatment plant.

The classification of the materials means:

- Dust from anode baking unit collected behind combustion chamber is classified due to its very high Po-210 activity as “radioactive substance” according to the Radiation protection Act. Its classification according to the radioactive waste requirements or requirements of discharges is only formally calculated and gives an orientation how this substance would be classified if necessary.
- If the dust represented by sample “dust filter P2” has to be disposed of, it must be classified as “radioactive substance” according to the Radiation protection Act, as “radioactive waste” and “radioactive waste requiring disposal“. The high specific Po-210 and Pb-210 activity results in the classification “radioactive waste”. The other two classification are additionally based on the total activity amounts.
- Emission of dust from Hydro Karbon plant clearly exceeds the limits for requiring a permit. This classification already results from the high specific activity.

- Although the specific activities in discharged waters are near to the natural background, the discharge is classified as “requires a permit”. This classification results only from the large amounts of water that pass through the facility.

If waste is stored before disposal Po-210 can be reduced to the level of Pb-210 in about 2 years. Whether such a decay storage is useful must be examined and evaluated in each individual case, if necessary.

Table 7-32: Summarizing assessment of dust from anode baking unit collected behind combustion chamber at Hydro Karbon plant in Årdalstangen

Criterion	Requirement	Result
Material exempted from requirements of the RPA?	$\sum_k \frac{C_k}{C_{e,k}} \leq 1$ or $\sum_k \frac{A}{A_{e,k}} \leq 1$	No (“false” or “false” → “false”) Sum C = 43 < 1? false Sum A < 1? false, if mass > 24 g
Material to be classified as radioactive waste?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$	Yes Sum C = 430 > 1? true
Radioactive waste requiring disposal?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ and $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes (“true” and “true” → “true”) Sum C = 43 > 1? true Sum A > 1? true, if mass > 24 g
Radioactive discharges requiring a permit?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ or $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes (“true” or “?” → “true”) Sum C = 4305 > 1? true Sum A > 1? Not defined, but not decisive

Table 7-33: Summarizing assessment of dust from dust filter P2 11/3-20 at Hydro Karbon plant in Årdalstangen

Criterion	Requirement	Result
Material exempted from requirements of the RPA?	$\sum_k \frac{C_k}{C_{e,k}} \leq 1$ or $\sum_k \frac{A}{A_{e,k}} \leq 1$	No (“false” or “false” → “false”) Sum C = 1.5 < 1? false Sum A = 1458 < 1? false
Material to be classified as radioactive waste?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$	Yes Sum C = 11.3 > 1? true
Radioactive waste requiring disposal?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ and $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes (“true” and “true” → “true”) Sum C = 1.5 > 1? true Sum A = 1458 > 1? true
Radioactive discharges requiring a permit?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ or $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes (“true” or “true” → “true”) Sum C = 15.3 > 1? true Sum A = 1.5E+04 > 1? true

Table 7-34: Summarizing assessment of discharges via water from Hydro Karbon plant in Årdalstangen

Classi	**Requirement**	**Result**
Material exempted from requirements of the RPA?	$\sum_k \frac{C_k}{C_{e,k}} \leq 1$ or $\sum_k \frac{A}{A_{e,k}} \leq 1$	Yes (“true” or “false” → “true”) Sum C = 4.8E-04 <1? true Sum A = 3.2E+05 < 1? false
Material to be classified as radioactive waste?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$	Not applicable
Radioactive waste requiring disposal?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ and $\sum_k \frac{A}{A_{e,k}} \geq 1$	Not applicable
Radioactive discharges requiring a permit?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ or $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes (“true” or “false” → “true”) Sum C = 4.8E-05 <1? true Sum A = 3.2E+06 < 1? false

The Hydro Karbon plant dust materials respectively discharges are assessed Table 7-35 and Table 7-36.

Dust from the fume treatment plant (FTP) is classified as

- “non-radioactive substance” related to the Radiation Protection Act requirements,
- a non-radioactive (ordinary) waste.

Despite the very low level of radioactive contamination, dust emissions are not exempt from the permit requirement. The cause is exclusively the annual amount of emitted dust.

An analogue assessment is obtained for the water discharge. Its permit requirements result only from the released total annual activity amount and do not consider the negligible potential of environmental contamination.

Table 7-35: Summarizing assessment of dust from the fume treatment plant (FTP). Hydro Aluminium plant

Criterion	**Requirement**	**Result**
Material exempted from requirements of the RPA?	$\sum_k \frac{C_k}{C_{e,k}} \leq 1$ or $\sum_k \frac{A}{A_{e,k}} \leq 1$	Yes ("true" or "false" → "true") Sum C = 0.045 < 1? true Sum A = 156 < 1? false
Material to be classified as radioactive waste?	$$\sum_k \frac{C_k}{C_{e,k}} \geq 1$$	No Sum C = 0.18 > 1? false
Radioactive waste requiring disposal?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ and $\sum_k \frac{A}{A_{e,k}} \geq 1$	No ("false" and "true" → "false") Sum C = 0.054 > 1? false Sum A = 237 > 1? true
Radioactive discharges requiring a permit?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ or $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes ("true" or "false" → "true") Sum C_{max} = 0.54 > 1? false Sum A_{max} = 2370 > 1? true

Table 7-36: Summarizing assessment of discharges via water from the Hydro Aluminium plant

Classi	**Requirement**	**Result**
Material exempted from requirements of the RPA?	$\sum_k \frac{C_k}{C_{e,k}} \leq 1$ or $\sum_k \frac{A}{A_{e,k}} \leq 1$	Yes ("true" or "false" → "true") Sum C = 5.3E-06 <1? true Sum A = 268 < 1? false
Material to be classified as radioactive waste?	$$\sum_k \frac{C_k}{C_{e,k}} \geq 1$$	Not applicable
Radioactive waste requiring disposal?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ and $\sum_k \frac{A}{A_{e,k}} \geq 1$	Not applicable
Radioactive discharges requiring a permit?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ or $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes ("false" or "true" → "true") Sum C_x = 1.61E-04. > 1? false Sum A = 8826 > 1? true

7.4 Yara

7.4.1 Processes and licensing requirements

Yara International ASA is a Norwegian company headquartered in Oslo that produces mineral fertilizers and related industrial products. Yara Norge AS (Yara) operates an integrated production site at Herøya near Porsgrunn, about 120 km southwest of Oslo. This site has an ammonia factory, four nitric acid factories, two NPK factories and a calcium nitrate factory (KS). The factories produce a wide range of NPK and KS.

Figure 7-6: Herøya industrial site near Porsgrunn (Photo from [97])

To manufacture nitrogen-phosphate-potassium (NPK) fertilizers, Yara processes phosphate rock, potassium chloride, and potassium sulfate. A flow scheme of the NPK process is shown in Figure 7-7.

The main feedstocks are

- Phosphate ore (Apatite = calcium phosphate)
- Potassium salts

Annually about 1.3 Mio. Mg raw materials are processed [98]. From these materials, phosphate ore from sedimentary deposits (e.g. Morocco, Jordania, …) is known for its slightly enhanced content of uranium. Another radioactive material is potassium salt which contains K-40.

In this report we focus on releases of radionuclides into the environment. Operational radiation protection due to radioactivity in raw materials and intermediate products is not considered.

In the nitrophosphate process, uranium follows the phosphate and is transferred into the ammonium phosphate fertilizers. In the literature (e. g. in [99, 100]) is generally described that due their similar chemical behavior, calcium and radium are able to exchange each other so that radium is omni present in apatite.

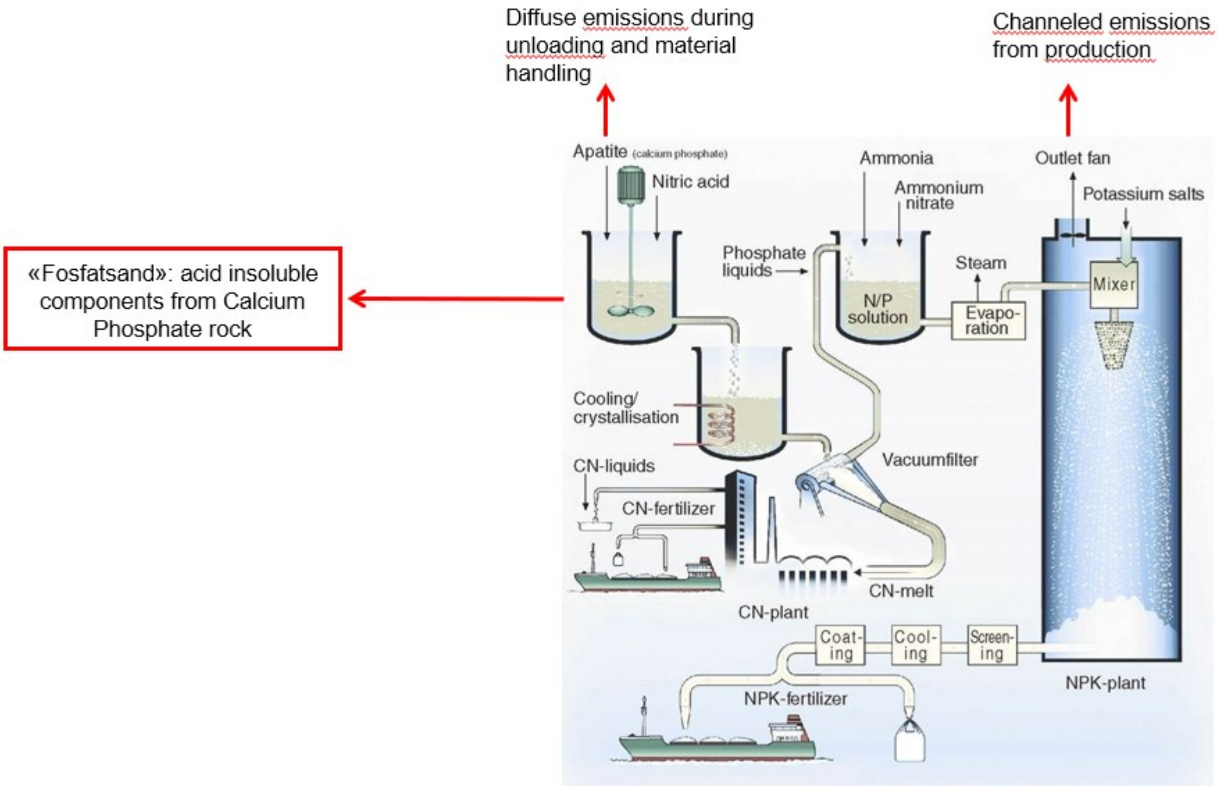

Figure 7-7: NPK process at Yara Porsgrunn (adapted from [97])

During the production processes, NORM is released to the environment in two situations:

- Unloading of raw materials.
- Production of NPK/KS.

Phosphates and K-salts are delivered by sea transport and are unloaded at two quays. During the unloading with a grabber, emissions into the air and water are possible. Production of mineral fertilizers (NPK) and calcium nitrate (KS) results in emissions of dust into the air from several stacks including the prill stacks [101].

In addition to the emissions to air and water a production waste; phosphate sand ("fosfatsand") is generated. This acid-insoluble part of the calcium phosphate rock is deposited in a local landfill. The annual amount of phosphate sand is typically more than 15,000 tons.

Yara Norway AS has a license for emissions granted in TU13-51-2 [102]. This license sets limits for annual dust emissions of Th-nat and U-nat as well as K-40 as indicated in Table 7-37. Of these limits, the one for K-40 in particular is difficult to justify radiologically. K-40 does not contribute to internal radiation exposure and occurs in seawater in amounts of about 13 kBq/m³, which is not significantly changed by the required limitation of discharges. By limiting the discharge of K-40, a non-existent radiological risk is associated. If, on the part of the authorities, there is a quite acceptable desire to control also discharges of salts into the environment and the ocean, then, in the opinion of the authors, it would be better to monitor the chemical parameter potassium and not to emphasize the radionuclide K-40.

Table 7-37: Licensed annual activity limits for emission of dust; License TU13-15-2. Data from [103]

Radionuclide	**Emission limit from unloading [MBq y^{-1}]**	**Emission limit from production [MBq y^{-1}]**
U-nat	16	-
Th-nat	5	-
K-40	125	805
Po-210	-	213
Pb-210	-	213
Ra-226	-	166
Ra-228	-	51
Th-228	-	52
Th-230	-	168
Th-232	-	52
U-234	-	186
U-235	-	9
U-238	-	186

7.4.2 Radiological situation

Table 7-38 and Table 7-39 show estimated emissions of radioactive substances in 2021 (from [97]). The calculated emission sums in Table 7-38 comply with the limits given in Table 7-37. As mentioned above, we consider the reporting of K-40 in the annual balances to be radiologically misleading since K-40 is to be considered here only as a general indicator, not as an indicator of radiation exposure. It would be better to monitor emissions of potassium salts via the chemical parameter potassium.

Table 7-38: YARA´s estimated emissions of radioactively contaminated dust to the sea and to the air from unloading of raw material.

	Phosphate rocks		**MOP**		**SOP**		**Sum**		**Sum**
	to sea	to air	to sea	to air	to sea	to air	to sea	to air	Total
	MBq y^{-1}								
U-nat	0.75	1.64	0	0	0	0	0.75	1.64	2.39
Th-nat	0.41	0.58	0	0	0	0	0.41	0.58	0.99
K-40	0.06	0.11	3.63	10.67	5.1	31.03	8.79	41.81	50.6

Table 7-39: YARA´s estimated radioactive emissions to the sea and to the air from production processes

Radionuclide	Emission to sea [MBq y^{-1}]	Emission to air [MBq y^{-1}]	Total emission [MBq y^{-1}]
K-40	40	451	491
Po-210	18	27	44
Pb-210	18	27	44
Ra-226	18	16	34
Ra-228	7	7	14
Th-228	7	7	14
Th-230	18	16	34
Th-232	7	7	14
U-234	18	20	38
U-235	1	1	2
U-238	18	16	34
Sum	**170**	**595**	**763**

In order to capture the effects of the releases in the Frierfjorden an environmental monitoring has been carried out by NIVA in 2015 [105] and by COWI in 2021 [113]. The monitoring program was approved by the Norwegian Radiation Protection Authority and prepared in accordance with Norwegian and international (IAEA) standards where available. The program design was based on the emissions of radionuclides to Frierfjorden. In 2015 the monitoring included an examination of the radioactive elements U-nat, Th-nat, and K-40 in seawater and sediment. In 2021 monitoring included radionuclides in the uranium and thorium decay chain in seawater and sediment.

The phosphate sands ("fosfatsand"), the acid-insoluble components from calcium phosphate rock processing, are with about 15,000 Mg per year the main waste stream generated [97]. Table 7-40 shows an example of radionuclide data performed by gamma-ray analysis and radiochemical separation followed by alpha spectrometry for uranium and thorium in 2017 [104]. Values for Th-232 have been added assuming an equilibrium with Th-228.

Pb-210 is the dominant radionuclide (0.87 Bq g^{-1}). The other naturally occurring radionuclides are in or close to the background level. However, it must be noted that the phosphate sand's analysis data partially fluctuate very significantly. In the four quarterly taken samples Q1 – Q4 2020 [97], the specific Pb-210 activities range from 0.33 Bq g^{-1} to 2.07 Bq g^{-1}.

Table 7-40: Example of analysis results from phosphate sands. Background values from UNSCEAR 2008

Radionuclide	C [Bq g^{-1}]	A [MBq y^{-1}]	Background (soil, Norway) [Bq g^{-1}]
K-40	0.13	1,950	0.85
Pb-210	0.870	13,050	
Ra-226	0.111	1665	0.050
Ra-228	0.027	405	0.045*
Th-228	0.024	356	0.045*
Th-230	0.012	176	0.050
Th-232	0.003	42	0.045*
U-234	0.032	474	0.050
U-235	0.001	21	
U-238	0.032	473	0.05

´* values transferred from Th-232 value in UNSCEAR 2008

The variation in measured specific activities may be caused by different raw material compositions and possibly process variations. However, the analytical results of sample Q4 demonstrate the challenges related to the exact determination of Pb-210 in solid materials. This sample was analyzed by three different laboratories, and the Pb-210 results are in a range between 0.95 Bq g^{-1} and 2.07 Bq g^{-1} [97]. The corresponding analyses have been executed by gamma-ray spectroscopy. Due to the low gamma energy of Pb-210 at 46.5 keV, the determination of the specific activity is strongly affected by the sample characteristics. Various absorption effects in the gamma spectrum arise depending on the mineralogical composition and on the average atomic number of the elements in the minerals. If the chemical elements with high atomic numbers have a high proportion in the samples, there are absorption effects in the gamma emissions. Due to this fact, the detector of the measurement systems cannot register the real emission that is correlated to the radionuclide activity in the sample. These absorption effects are even more pronounced in the energy range below 200 keV. The laboratories use different methods to determine the dimension of the effects for the correction of e. g. the specific activity of Pb-210. The application of the different strategies results in significantly different values, as it is demonstrated by the Q4 sample of the phosphate sands.

7.4.3 Assessment of materials and emissions at Yara

The only solid material that must be released into the environment from the processes at Yara is phosphate sand. Other emissions into air and sea occur dissipated and are characterized by their annual emission amounts (Table 7-39).

In Table 7-41 the measuring results of “Phosphate sand” (see Table 7-40) are evaluated regarding the exemption criteria of the Radiation Protection Act [5]. Po-210 was considered in equilibrium with Pb-210 and therefore covered by evaluation of Pb-210. Th-232 was estimated to have the same specific activity as Th-228. The sum of specific activity ratios is lower than 1, sum of total activity ratios is considerably higher than 1. The final assessment will be given in the next chapter.

Table 7-41: Evaluation of “Phosphate sand” related to the exemption from Radiation Protection Act requirements

	C_k [Bq g^{-1}] = [MBq m^{-3}]	$C_k/C_{e,k}$	A_k [MBq y^{-1}]	$A_k/A_{e,k}$
K-40	0.132	0.00132	1980	
Pb-210	0.870	0.08700	13050	1305000
Po-210				
Ra-226	0.111	0.01110	1665	166500
Ra-228	0.027	0.00270	405	4050
Th-228	0.024	0.02370	356	35550
Th-230	0.012	0.01170	176	17550
Th-232	0.003	0.00028	42	4200
U-234	0.032	0.00316	474	47400
U-235	0.001	0.00014	21	2100
U-238	0.032	0.00315	473	47250
Sum		**0.14**		**1.63E+06**

Analogue the criteria for classifying the phosphate sand as

1. radioactive waste (see Ch. 5.1.5.1) and
2. radioactive waste requiring disposal (see Ch. 5.1.5.2)

can be examined. Again, the limit activities $C_{e,k}$ were taken from Table 5-4 (radioactive waste) and Table 5-6 (radioactive waste requiring disposal). The values were taken as measured, i.e., background concentrations were not subtracted.

The ratios of specific activities to the limit values for radioactive waste and radioactive waste requiring disposal are given in Table 7-42 and the corresponding values for total activities for radioactive waste requiring disposal are given in Table 7-43.

The summarizing assessment of the sum-values is given in the next chapter.

Table 7-42: Examination of “Phosphate sand” regarding the specific activity radioactive waste criteria

Radionuclide	Phosphate sand	
K	**Rad waste**	**Rad waste requiring disposal**
	$C_k/C_{e,k}$	**$C_k/C_{e,k}$**
Pb-210	0.0132	0.0013
Po-210	0.8700	0.0870
Ra-226		
Ra-228	0.1110	0.0111
Th-228	0.0270	0.0027
Th-230	0.0237	0.0237
Th-232	0.0117	0.0117
U-234	0.0028	0.0028
U-235	0.0316	0.0032
U-238	0.0014	0.0001
Sum $C_k/C_{e,k}$	**0.0315**	**0.0032**

Table 7-43: Examination of “Phosphate sand” regarding the total activity radioactive waste criteria

Radionuclide	Phosphate sand
K	**A_k/A_e (· 10^6)**
Pb-210	0,0131
Po-210	
Ra-226	0,1665
Ra-228	0,0405
Th-228	0,0036
Th-230	0,0176
Th-232	0,0420
U-234	0,0474
U-235	0,0021
U-238	0,0473
Sum $A_k/A_{e,k}$	**0,380 (· 10^6)**

As mentioned in the beginning of this chapter, the emissions into air and sea occur dissipated and are characterized by their annual emission amounts (Table 7-39). For that reason, specific activities are of little significance. In Table 7-44 YARA´s estimated radioactive emissions are evaluated regarding the permit requirements.

Table 7-44: Examination of YARA´s estimated radioactive emissions to the sea and to the air regarding permit requirements

	Emission to sea	**Emission to air**	**Total emission**
	$A_k/A_{e,k}$ ($\cdot 10^6$)	$A_k/A_{e,k}$ ($\cdot 10^6$)	$A_k/A_{e,k}$ ($\cdot 10^6$)
Pb-210	0,018	0,027	0,044
Po-210	0,018	0,027	0,044
Ra-226	0,018	0,016	0,034
Ra-228	0,001	0,001	0,001
Th-228	0,007	0,007	0,014
Th-230	0,018	0,016	0,034
Th-232	0,070	0,070	0,140
U-234	0,018	0,020	0,038
U-235	0,001	0,001	0,002
U-238	0,018	0,016	0,034
Sum	**0,19 ($\cdot 10^6$)**	**0,20 ($\cdot 10^6$)**	**0,39 ($\cdot 10^6$)**

The data in Table 7-44 clearly show that the emitted activities exceed the permit exemption limits by orders of magnitude. The question therefore arises as to what radiological impact these activity releases can reveal in the environmental media. For examination this question the results of monitoring programs were checked.

In connection with the license TU13-51-2 [102], doses due to the dust emissions for members of the public and for the Yara-worker has been estimated (Report "Doser til befolkningen og ansatte fra virksomheten ved Yara Herøya" [103]). The dose modeling for the members of the public was based on the annual emission of the naturally occurring radionuclides from the U-238 and the Th-232 series as well as K-40 related to phosphate rocks and a dispersion calculation of the plume.

The effective dose for adults due to the emission of dust was estimated to 3.5 µSv y^{-1} (0.0035 mSv y^{-1}). For children, the result was 3.0 µSv y^{-1} (0.0030 mSv y^{-1}) and for infants 2.3 µSv y^{-1} (0.0023 mSv y^{-1}). The emission point was set in the model at the height of 100 m. However, the real height is 115 m. Due to this fact, the estimated effective doses are slightly overestimated.

The estimation for the Yara workers is based on the yearly emission of U-nat., Th-nat., and K-40. The effective dose due to the emission of dust is estimated to 0.002 µSv y^{-1} ($2.0 \cdot 10^{-6}$ mSv y^{-1}).

The dose assessment in report [103] also included the estimation of the effective dose due to the intake of fish. The nearest place where it might be natural to catch fish for human consumption is about 20 km south-southwest of the Yara discharge point. The calculation has been based on a generic model from the IAEA [105]. The effective dose was estimated to 0.00013 µSv y^{-1} ($1.3 \cdot 10^{-7}$ mSv y^{-1}) [103].

Another dose assessment has been carried out to biota from emissions of radioactivity to sea and to air in the stages of production. The results of this assessment show that emissions of radioactivity from Yara's plant at Herøya do not significantly impact the marine or terrestrial environment. The total risk coefficient for all scenarios for which calculations have been performed is below 1 and thus indicates a negligible effect on the marine or terrestrial environment. Emissions of fertilizer dust and “prill dust” are responsible for the largest single contribution with a total risk coefficient of 0.74 for the marine environment. It is stated in [101] that this value is overestimated since part of the dust is actually distributed between sales on land and in the sea. These results are documented in the report “Eksponering av miljøet fra utslipp til vann og luft av radioaktive stoffer fra Yara AS anlegg på Herøya” (“Exposure of the environment from discharges to water and air of radioactive substances from the Yara AS plant at Herøya”) from 6 Sep. 2018 [101].

7.4.4 Summarizing assessment

In Table 7-45 the assessment of the phosphate sands from Yara Porsgrunn is executed with the legal criteria according to chapters 5.1.3 to 5.1.5. The classifications obtained mean:

- Phosphate sand is exempted from the requirements of the Radiation protection Act.
- It is classified to be a radioactive waste.
- But it is not a radioactive waste requiring disposal.

The reason tor the latter classification is the low specific activity which makes the logical “and” relation “false”.

Table 7-45: Summarizing assessment of the phosphate sands from Yara Porsgrunn

Criterion	Requirement	Result
Material exempted from requirements of the RPA?	$\sum_k \frac{C_k}{C_{e,k}} \leq 1$ or $\sum_k \frac{A}{A_{e,k}} \leq 1$	Yes (“true” or “false” → “true”) Sum C = 0.14 < 1? true Sum A = 1.63 · 10^6 < 1? False
Material to be classified as radioactive waste?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$	Yes Sum C = 1.12 > 1? True
Radioactive waste requiring disposal?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ and $\sum_k \frac{A}{A_{e,k}} \geq 1$	No (“false” and “true” → “false”) Sum C = 0.14 > 1? false Sum A = 3.8 · 10^5 > 1? true
Radioactive discharges requiring a permit?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ or $\sum_k \frac{A}{A_{e,k}} \geq 1$	(not applicable)

In summary, the phosphate sand from Yara Porsgrunn is classified as “radioactive waste”, i.e. it can be handled and disposed off as hazardous waste pursuant to Section 11-6 of the Waste Ordinance.

The emissions from the Herøya industrial site can only be assessed with regard to the criterion "permit required". Here, too, the corresponding criterion is positive, as the total activities derived annually exceed the corresponding limits by orders of magnitude. This assessment is in clear contradiction to results of dose assessment for the dust emissions. The results show that the effective doses for members of the public are very small in the range of about 2 to 4 µSv y^{-1}. For workers, an effective dose of 0.002 µSv y^{-1} has been estimated.

Table 7-46: Summarizing assessment of the emissions from Yara Porsgrunn

Criterion	**Requirement**	**Result**
Material exempted from requirements of the RPA?	$\sum_k \frac{C_k}{C_{e,k}} \leq 1$ or $\sum_k \frac{A}{A_{e,k}} \leq 1$	(not applicable)
Material to be classified as radioactive waste?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$	(not applicable)
Radioactive waste requiring disposal?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ and $\sum_k \frac{A}{A_{e,k}} \geq 1$	(not applicable)
Radioactive discharges requiring a permit?	$\sum_k \frac{C_k}{C_{e,k}} \geq 1$ or $\sum_k \frac{A}{A_{e,k}} \geq 1$	Yes (“not applicable” or “true” → “true”) Sum C < 1? not applicable Sum A= 0,39 · 10^6 > 1? true

7.5 Classification regarding international and the other national legislation

In this chapter, we apply the national regulations described in Ch. 5.2 - 5.16 to the individual radiological situation of Elkem, Hydro, and Yara. The assessments obtained by this approach shall illustrate the ranges implemented in the different national regulations and demonstrate the special approach of the Norwegian regulations with regard to the surveillance of discharges.

7.5.1 Elkem

At the “Elkem Bremanger Smelteverk” site, the following discharges that are considered radioactive occur:

- In the electric furnace process, dust particles enriched with Pb-210, Po-210 are generated. The major part of the dust accumulates in filters, but a small amount is discharged into the air.
- Process waters from the Silgrain plant, seepage water from the Elkem landfill (Sande), and seepage water from the lower filling in Sætrevika landfill are discharged into the sea.

The Table 7-7 summarizes the estimated emissions of radioactively contaminated dust into the air and Table 7-8 . The recovery, recycling, conventional disposal, or incineration of NORM waste is not any issue at the “Elkem Bremanger Smelteverk” site.

Concerning the discharge processes, Elkem needs a license according to Norwegian legislation. The requirements in relation to the different national legislations are composed in Table 7-48. There are stated quite significant differences between these legislations. For example, according to the recommendation by the IAEA or the radiation protection law in Germany, no further issues are required due to the discharge of NORM as dust or water (liquids). In some other countries, the dose levels are specified to 0.1, 0.2, or 0.3 mSv per year e. g. in Belgium, Finland, or Lithuania. These values are partly defined without any differentiation between artificial or naturally occurring radionuclides concerning the discharge.

In Austria, the Netherlands, as another example, are activity concentration values are specified for the radionuclides of the U-238- and of the Th-232-series that must not be exceeded for exemption of liquid discharges. Elkem does not need to fulfill any further radiation protection legislation subsequently. But, on the other side, according to the radiation protection law in the United Kingdom, Elkem must apply for a license for the discharge of liquids.

The radiation protection legislation in the EU of dust discharges is diffuse and there are no further specific requirements associated with the NORM industries.

Table 7-47: The international radiation protection legislation in the matters of Elkem

	NORM	**Assessment scale**	**Relevant radionuclides**	**Requirement**
IAEA	dust to the air	C(U-238) or C(Th-232) > 1 Bq g^{-1}	-	no further requirement
	liquid discharges	no special standards for NORM	-	-
EU/EC	dust to the air and liquid discharges	dose criterion: 1 mSv y^{-1}	Pb-210 (Po-210 covered by Pb-210)	Dose assessment for workers and for members of the public, if > 1 mSv y^{-1} ⇒ Registration
Austria	dust to the air	U-238- and U-235-series in their natural relation-ship: $9 \cdot 10^{-3}$ Bq m^{-3} (9 Bq l^{-1})	Pb-210 (Po-210 covered by Pb-210)	Total activity according to Table 7-7 (without Po-210) < 50 MBq/y
	liquid discharges	U-238-, U-235- and Th-232 series in their natural relationship: $1.5 \cdot 10^{5}$ Bq m^{-3} (1.500 Bq l^{-1})		no excess ⇒ Exemption
Belgium	dust to the air	dose criterion: 0.3 mSv y^{-1}	U-238 & Th-232 series	must be checked in detail
Finland	dust to the air and liquid discharges	dose criterion: 0.1 mSv y^{-1}	U-238 & Th-232 series	must be checked in detail
Germany	dust to the air and liquid discharges	-	no restriction	-
Lithuania	liquid discharges	dose criterion: 0.2 mSv y^{-1}	-	must be checked in detail

	NORM	Assessment scale	Relevant radionuclides	Requirement
The Netherlands	liquid discharges	Screening values Pb-210+, Po-210, Ra-226+ > $1 \cdot 10^{10}$ Bq y^{-1} Ra-228+, Th-230, Th-232+ > $1 \cdot 10^{11}$ Bq y^{-1} Th-228, U-234, U-238+ > $1 \cdot 10^{12}$ Bq y^{-1}	U-238 & Th-232 series	no excess ⇒ Exemption
Sweden	liquid discharges	dose criterion: 0.1 mSv y^{-1}	U-238 & Th-232 series	must be checked in detail
United Kingdom	water into a relevant sewer, river or sea	Pb-210+, Po-210 > $1 \cdot 10^{4}$ Bq y^{-1} Ra-226+, Ra-228+ > $1 \cdot 10^{5}$ Bq y^{-1} Th-228+, Th-230 > $1 \cdot 10^{7}$ Bq y^{-1} Th-232+, U-234, U-238+ > $1 \cdot 10^{6}$ Bq y^{-1}	Pb-210+, Ra-226+, Ra-228+ Th-228+, U-234/U-238+	License required

7.5.2 Hydro Aluminium

From the two Hydro plants we considered in this report Hydro Aluminium (metallverk). This plant is characterized by NORM with low specific activities frequently close to the natural background. Nevertheless, Hydro Aliminium does not comply with the limit values that define the permit requirements for discharges. For that reason we focus in this chapter on the Hydro Aluminium plant.

The estimated emissions of radioactive contaminated dust into the sea and into the air are listed in Table 7-27. The recovery, recycling, conventional disposal, or incineration of NORM waste is not an issue at Hydro Aluminium (metallverk).

The requirements related to the emissions from the Hydro Aluminium plant (metallverk) in relation to international standards and different national legislations are composed in Table 7-48. The table demonstrates significant differences between these regulations. For example, according to the IAEA standards or the radiation protection law in Sweden, a dose assessment must be executed. If the effective dose for workers or for members of the public exceeds the value of 1 mSv per year, Hydro would have to register the discharge of the dust and of the water. In some other countries, the dose levels are specified to 0.1, 0.2 or 0.3 mSv per year e. g. in Belgium, Finland, or Lithuania. These values are partly defined without any differentiation between artificial or naturally occurring radionuclides concerning the discharge.

In Austria, the Netherlands, as another example, are activity concentration values are specified for the radionuclides of the U-238- and of the Th-232-series that must not be exceeded for exemption of liquid discharges. Hydro does not need to fulfill any further radiation protection legislation, subsequently. But, on the other side, according to the radiation protection law in the United Kingdom, Hydro must apply a license for the discharge of liquids. In Germany are no legal requirements for the discharge of liquids or dust from the NORM industries.

The radiation protection legislation in the EU of dust discharges is diffuse and there are no further specific requirements associated with the NORM industries.

Table 7-48: The international radiation protection legislation in the matters of Hydro Alumnium (metallverk)

	NORM	Assessment scale	Relevant radionuclides	Requirement
IAEA	dust to the air	C(U-238) or C(Th-232) > 1 Bq g^{-1}	Pb-210, Po-210	Dose assessment for workers and for members of the public, if > 1 mSv y^{-1} ⇒ Registration
	liquid discharges	no special recommendation for NORM	-	-
EU/EC	dust to the air and liquid discharges	dose criterion: 1 mSv y^{-1}	Pb-210, Po-210	Dose assessment for workers and for members of the public, if > 1 mSv y^{-1} ⇒ Registration
Austria	dust to the air	U-238- and U-235-series in their natural relationship: $9 \cdot 10^{-3}$ Bq m^{-3} (9 Bq l^{-1})	Pb-210, Po-210	must be checked in detail
	liquid discharges	U-238-, U-235- and Th-232 series in their natural relationship: $1.5 \cdot 10^{5}$ Bq m^{3} (1.500 Bq l^{-1})		no excess ⇒ Exemption
Belgium	dust to the air	dose criterion: 0.3 mSv y^{-1}	U-238 & Th-232 series	must be checked in detail
Finland	dust to the air and liquid discharges	dose criterion: 0.1 mSv y^{-1}	U-238 & Th-232 series	must be checked in detail
Germany	dust to the air and liquid discharges	-	no restriction	-
Lithuania	liquid discharges	dose criterion: 0.2 mSv y^{-1}		must be checked in detail
The Netherlands	liquid discharges	Screening values Pb-210+, Po-210, Ra-226+ > $1 \cdot 10^{10}$ Bq y^{-1} Ra-228+, Th-230, Th-232+ > $1 \cdot 10^{11}$ Bq y^{-1} Th-228, U-234, U-238+ > $1 \cdot 10^{12}$ Bq y^{-1}	U-238 & Th-232 series	no excess ⇒ Exemption

	NORM	Assessment scale	Relevant radionuclides	Requirement
Sweden	liquid discharges	dose criterion: 0.1 mSv y^{-1}	U-238 & Th-232 series	must be checked in detail
United Kingdom	water into a relevant sewer, river or sea	Pb-210+, Po-210 > $1 \cdot 10^4$ Bq y^{-1} Ra-226+, Ra-228+ > $1 \cdot 10^5$ Bq y^{-1} Th-228+, Th-230 > $1 \cdot 10^7$ Bq y^{-1} Th-232+, U-234, U-238+ > $1 \cdot 10^6$ Bq y^{-1}	Pb-210+, Ra-226+	License required

7.5.3 Yara

Due to material handling and processing of raw material containing NORM Yara has radioactive emissions to air and sea. Residues from the phosphate rock generated in the NPK process contain also NORM.

From the phosphate sands we considered in this report the date that are listed in Table 7-40. Yara should not have to notify the disposal of phosphate sands e. g. according to the recommendation of the IAEA, and according to the EU Council Directive, the phosphate sands are out of scope. The main criteria are the activity concentrations (specific activities) of 1 Bq g^{-1} for the radionuclides of the U-238- and of the Th-232-series. Although Yara also has analysis results for the phosphate sands in which the specific activity for lead is above 1 Bq g^{-1}, these data vary due to their different evaluation methods with regard to the absorption effects, so that these measured values are not specifically evaluated here (see Ch. 7.4.2).

Concerning the discharge processes, Yara needs licensees according to the Norwegian legislation. The requirements in relation to the international legislation are composed in Table 7-49. There are stated quite significant differences between these legislations. According to the recommendation by the IAEA or the radiation protection law in Sweden, a dose assessment must be executed. In some other countries, the dose levels are specified to 0.1, 0.2 or 0.3 mSv per year e. g. in Belgium, Finland, or Lithuania. These values are partly defined without any differentiation between artificial or naturally occurring radionuclides concerning the discharge. Yara has carried out a dose assessment. The maximum effective dose for members of the public has been estimated to 3,5 µSv y^{-1}. This is far below these dose values mentioned in these IAEA or national regulation.

In Austria, the Netherlands, as another example, are activity concentration values are specified for the radionuclides of the U-238- and of the Th-232-series that must not be exceeded for exemption of liquid discharges. Yara does not need to fulfill any further radiation protection legislations, subsequently. But, on the other side, according to the radiation protection law in the United Kingdom, Yara must apply a license for the discharge of liquids. The radiation protection legislation in the EU of dust discharges is diffuse and there are no further specific requirements such as environmental monitoring of the recipients associated with the NORM industries.

Table 7-49: The international radiation protection legislation in the matters of Yara

	NORM	Assessment scale	Relevant radionuclides	Requirements	Classification according to the data of Yara
IAEA	phosphate sands as waste	NORM > 1 Bq g^{-1} (for each radionuclide of the natural decay series)	Pb-210 (partially)	Notification, Dose assessment for workers and for members of the public, if > 1 mSv y^{-1} ⇒ Registration	The result of a dose assessment are far below 1 µSv y^{-1} for members of the public. ⇒ No registration needed relating to the data of Table 7-40.
	emissions to the sea and into the air	no special recommendation	-	-	
EU/EC	phosphate sands as waste	NORM > 1 Bq g^{-1} (for each radionuclide of the natural decay series)	Pb-210 (partially)	Notification, Dose assessment for workers and for members of the public, if > 1 mSv y^{-1} ⇒ Registration	Out of scope $C_{k,max}$ = C(Pb-210) < 1 Bq g^{-1}, relating to the data of Table 7-40
	emissions to the sea and into the air	dose criterion: 1 mSv y^{-1}	-	Dose assessment for workers and for members of the public, if > 1 mSv y^{-1} ⇒ Registration	The result of a dose assessment shows a maximum of 3.5 µSv y^{-1} for members of the public ⇒ No registration needed.
Austria	phosphate sands as waste	NORM > 1 Bq g^{-1}	Pb-210 (partially)	Notification, Dose assessment for workers and for members of the public, if > 1 mSv y^{-1} ⇒ Registration	Identical as for EU/EC
	dust into the air	U-238- and U-235-series in their natural relationship: $9 \cdot 10^{-3}$ Bq m^{-3} (9 Bq l^{-1})	-	The activity concentration must be determined by assumption of the specific activity and e. g. the grain density	Based on the existing data, more detailed calculations are required that are too complex in this context.

	NORM	Assessment scale	Relevant radionuclides	Requirements	Classification according to the data of Yara
Austria	emission to the sea	U-238-, U-235- and Th-232 series in their natural relationship: $1.5 \cdot 10^5$ Bq m^3 (1.500 Bq l^{-1})	U.-nat/Th-nat.	no excess ⇒ Exemption	
Belgium	phosphate sands as waste	K-40, Pb-210+, Po-210, Th-232sec, U-nat > 5 Bq g^{-1} Ra-228+ > 1 Bq g^{-1} Ra-226+, Th-228+, U-238sec > 0.5 Bq g^{-1}	Pb-210 (partially)	no excess ⇒ Exemption	K-40, Pb-210+, Po-210, Th-232sec, U-nat < 5 Bq g^{-1} Ra-228+ < 1 Bq g^{-1} Ra-226+, Th-228+, U-238sec < 0.5 Bq g^{-1} ⇒ Exemption
	dust to the air	dose criterion: 0.3 mSv y^{-1}	U-238 & Th-232 series	Dose assessment	Identical as for IAEA
Finland	phosphate sands as waste	NORM > 1 Bq g^{-1}	Pb-210 (partially)	authorization required	Identical as for EU/EC
	emission to the air and into the sea	dose criterion: 0.1 mSv y^{-1}	U-238 & Th-232 series	must be checked in detail	Identical as for IAEA
Germany	phosphate sands as waste	$C_{U238max} + C_{Th232max} \leq 1$ Bq g^{-1} For landfill disposal and if the disposal site is in the catchment area of a usable aquifer: > 5,000 Mg ⇒ ≤ 0.5 Bq g^{-1} For surface disposal of ≤ 5,000 Mg ⇒ ≤ 1 Bq g^{-1} individual valuation, if C(Pb-210) is exceeded > 5 times more than the other U-238 series nuclides	Pb-210 (partially)	Release of residues requiring surveillance from the monitoring obligation by the competent authority	$0.5 \cdot 0.87$ Bq g^{-1} + 0 Bq g^{-1} = 0.49 Bq g^{-1} ⇒ relating to the data of Table 7-40, above-ground or underground disposal is possible without any form of legal authorization.
	emissions to the air and into the sea	-	no restriction	-	-

	NORM	Assessment scale	Relevant radionuclides	Requirements	Classification according to the data of Yara
Lithuania	phosphate sands as waste	NORM > 1 Bq g^{-1}	Pb-210 (partially)	License required	Identical as for EU/EC
	liquid discharges, not dust	dose criterion: 0.2 mSv y^{-1}		Dose assessment	Identical as for EU/EC
The Netherlands	phosphate sands as waste	NORM > 1 Bq g^{-1}	Pb-210 (partially)	Dose assessment for workers and for members of the public, if > 0.3 mSv y^{-1} ⇒ Registration	Identical as for IAEA
	liquid discharges, not dust	Screening values Pb-210+, Po-210, Ra-226+ > $1 \cdot 10^{10}$ Bq y^{-1} Ra-228+, Th-230, Th-232+ > $1 \cdot 10^{11}$ Bq y^{-1} Th-228, U-234, U-238+ > $1 \cdot 10^{12}$ Bq y^{-1}	U-238 & Th-232 series	no excess ⇒ Exemption	U-nat and Th-nat to sea < $8 \cdot 10^{8}$ Bq y^{-1} ⇒ Exemption
Sweden	phosphate sands as waste	NORM > 1 Bq g^{-1}	Pb-210 (partially)	Dose assessment for workers and for members of the public, if > 0.1 mSv y^{-1} ⇒ Registration	Identical as for EU/EC
United Kingdom	phosphate sands as waste	NORM > 1 Bq g^{-1}	Pb-210 (partially)	Notification (not Registration); disposal in landfill possible	Identical as for EU/EC

	NORM	Assessment scale	Relevant radionuclides	Requirements	Classification according to the data of Yara
	water into a relevant sewer, river or sea	Pb-210+, Po-210 > 1 · 10^4 Bq y^{-1} Ra-226+, Ra-228+ > 1 · 10^5 Bq y^{-1} Th-228+, Th-230 > 1 · 10^7 Bq y^{-1} Th-232+, U-234, U-238+ > 1 · 10^6 Bq y^{-1}	Pb-210+, Ra-226+	License required	Yara has data for U-nat and Th-nat The activity concentration of the individual radionuclides have to be determined Probably a license would be required due to Pb-210+ > 1 · 10^4 Bq y^{-1} and Ra-226+, Ra-228+ > 1 · 10^5 Bq y^{-1}

7.6 Exposure to non-human biota

As described in Ch. 7.4 for the dose assessment performed to evaluate risk for non-human biota in the marine environment, a total risk coefficient of 0.74 for the largest single contribution due to the emissions of fertilizer dust and prill dust from Yara's plant at Herøya. The ERICA tool was used for this dose assessment.

The total risk coefficient of 0.74 corresponds to the “sum of the risk quotients” (RQ) in the ERICA tool [106]. If the sum of the risk quotients is < 1, then it can be assured that there is a very low probability that the assessment dose rate to any organism exceeds the incremental screening dose rate and therefore the risk to non-human biota can be considered as negligible.

Pb-210 and Po-210 are the relevant radionuclides in the dose assessment in the marine environment. Ra-226 can also be present with elevated activity concentration, but it will not be considered regarding the demonstrated case example further here. Pb-210 and Po-210 originate either from the radioactive decay of Ra-226 dissolved in the seawater, from the atmospheric deposition of Rn-222 daughters [107] or from the deposition of dust that were discharged via chimney from near coast-located industries. In contrast to terrestrial organisms, many marine species are highly enriched in these radionuclides.

Hansen et al. (2022) [108] published results that indicated spatial differences in Po-210 muscle concentrations between samples of the Arctic. Arctic charmuscle Po-210 activity concentrations ranged from 0.03 Bq kg^{-1} to 0.6 Bq kg^{-1} (referred to wet weight). Komperød et al. (2020) [109] reported a range of muscle Po-210 between 0.02 Bq kg^{-1} and 0.2 Bq kg^{-1} (referred to wet weight) in Atlantic salmon (Salmo salar) and farmed rainbow trout (Oncorhynchus mykiss) in the Baltic Sea (Bornholm) and the Norwegian Sea (Stokmarknes, Nordland) during 2018 and 2019, respectively.

In the IAEA Technical report series No. 484 [110], the Po-210 : Pb-210 activity ratio in salmon ranged from 0.09 to 0.69. In fish feed, the ratio is reversed, and it contains significantly more Po-210 than Pb-210, the salmon exhibits far more Pb-210 than Po-210. The Po-210 : Pb-210 activity ratio in fish feed ranges from 2.5 to 9.8.

The annual effective ingestion dose depends on the concentration of Po-210 in seafood and marine mammals and the annual consumption rate of these dietary products. Komperød et al. (2020) [109] estimated the committed effective adult dose from naturally occurring radionuclides Po-210, Pb-210 and Ra-226 via seafood ingestion to the Nordic population and demonstrated that Po-210 contributes about 80 - 90% to the estimated total dose. The mean committed effective Po-210 dose via seafood and marine mammals consumption was 771 ± 89 µSv y^{-1} (adult), and 1,410 ± 326 µSv y^{-1} (child, five years old), respectively.

Another dose assessment has been performed for the consumption of salmon or fish by applying the established models according to the German “Calculation Guide Mining” [111]. This guideline has been developed for the determination of radiation exposure due to environmental radioactivity resulting from mining in Germany. It can be adapted to industrial processes. This procedure is generally accepted by the German authorities. The relevant parameters (e. g. dose coefficients) will be applied from the publications of the International Commission on Radiation Protection (ICRP). Furthermore, the assessment will also consider any risks of radioactive pollution being concentrated in the environment in recipients and organisms because of emissions from the NORM-industries.

According to the data of the Global Change Data Lab [112] from the year 2020, the yearly fish consumption in Norway is about 51 kg fish per capita; 7 to 8 times more compared to the German population (6 kg y^{-1}).

The distribution of the age groups in Norway is similar to that in Germany (see Figure 7-8) [113]. Although in Germany live around 84 million inhabitants, and in Norway live around 5.4 million inhabitants.

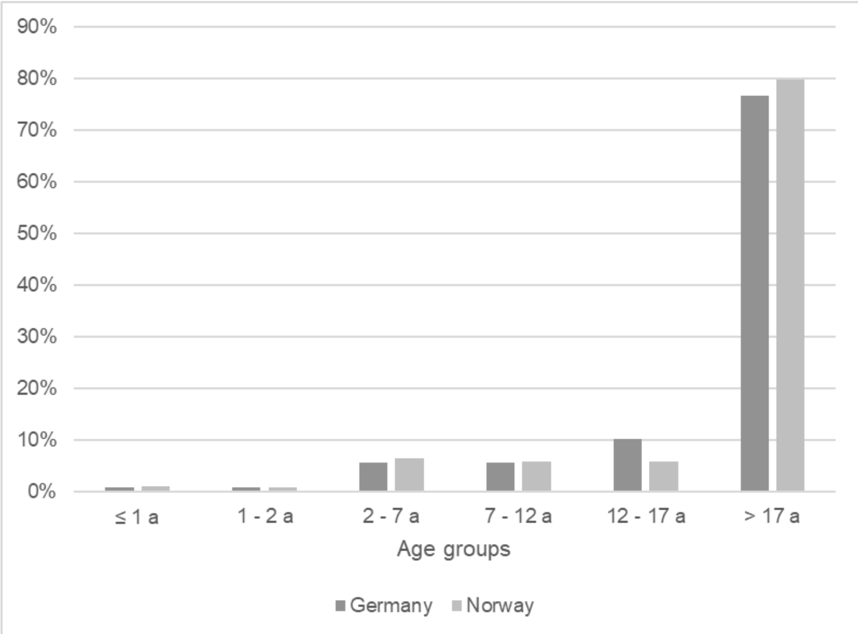

Figure 7-8: Distribution of the inhabitants in 6 age groups in Germany and Norway

Presuming that the distribution of the annual fish consumption in each age group is comparable between Norway and Germany, the annual consumption $U_{Fi,y}$ (see Eq. 7) can be assessed as it is illustrated in Figure 7-9. The data for Germany are from [111]. They can be assumed in a manner to be overestimated.

The calculation of the effective annual dose from locally produced food like salmon or fish bases on the above-mentioned values for relevant radionuclides Pb-210 and Po-210 from literature intended for human consumption. Other radionuclides are according to the existing information in the literature not relevant, furthermore. The effective annual dose is calculated as follows:

$$E_{Ing,y} = \sum_{Fi} p_{Fi} \cdot U_{Fi,y} \cdot \sum_{r}(C_{Fi,r}) \cdot g_{Ing,r,y} \qquad (8)$$

where:

$E_{Ing,y}$	Effective annual dose for reference person y from ingestion of the fish and salmon (Fi) [Sv]
$C_{Fi,r}$	Activity concentration of radionuclide r in fish and salmon Fi [Bq kg^{-1}]
p_{Fi}	Fraction of local production of fish and salmon (Fi) in the annual consumption, dimensionless,
$U_{Fi,y}$	Annual consumption of foodstuff n by reference person y [kg],
$g_{Ing,r,y}$	Ingestion dose coefficient for radionuclide r and reference person y [Sv Bq^{-1}].

Any background activity concentration is not taken into account in this equation, and the dose assessment is, even more, to be considered as overestimated.

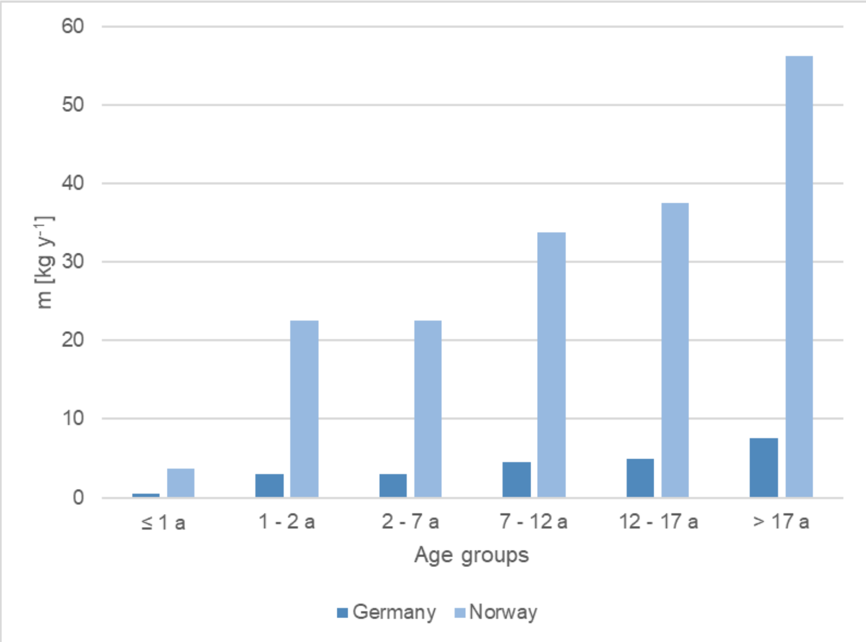

Figure 7-9: Fish consumption depending on the age groups in Germany and Norway

Regarding the proportion of regionally produced fish products or salmon, it is adopted that this food is manufactured and sold in the coast region from the nearby sea completely (p_n = 1). The applied Ingestion dose coefficient for Pb-210 and for Po-210 are listed in Table 7-50.

Table 7-50: Ingestion Dose Coefficient $g_{Ing,r,y}$ (from [111])

Age group	**≤ 1 y**	**1 - 2 y**	**2 - 7 y**	**7 - 12 y**	**12 - 17 y**	**> 17 y**
Nuclide	**[Sv Bq^{-1}]**	**[Sv Bq^{-1}]**	**[Sv Bq^{-1}]**	**[Sv Bq^{-1}]**	**[Sv Bq^{-1}]**	**[Sv Bq^{-1}]**
Pb-210	$8{,}4 \cdot 10^{-6}$	$3{,}6 \cdot 10^{-6}$	$2{,}2 \cdot 10^{-6}$	$1{,}9 \cdot 10^{-6}$	$1{,}9 \cdot 10^{-6}$	$6{,}9 \cdot 10^{-7}$
Po-210	$2{,}6 \cdot 10^{-5}$	$8{,}8 \cdot 10^{-6}$	$4{,}4 \cdot 10^{-6}$	$2{,}6 \cdot 10^{-6}$	$1{,}6 \cdot 10^{-6}$	$1{,}2 \cdot 10^{-6}$

The results of the dose assessment are shown in Figure 7-10. The highest annual effective dose $E_{Ing,y}$ is registered for children in the age group of 1 to 2 years for eating fish. The calculated value is about 130 µSv y^{-1} (0,13 mSv y^{-1}). It is adopted that one child consumes about 23 kg fish per year (daily consumption of around 60 g). All other calculated values of the annual effective dose are in the range of 60 µSv y^{-1} or below.

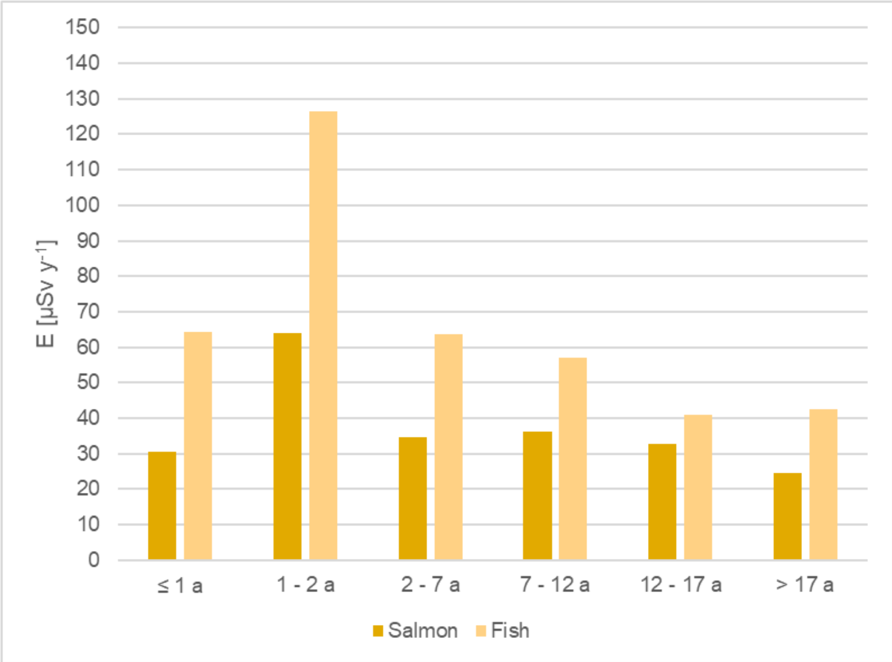

Figure 7-10: Effective annual dose E due to the consumption of salmon and/or fish for individual age groups

As it said before, especially because of the adopted annual consumption rates for each age group, the dose assessment is executed in a conservative manner. Due to this fact, the results of the calculation for the annual effective dose can be classified as low.

Related to the existing monitoring data from Yara [114], the dose assessment can also be performed by using the radionuclide data from sea water and factors for the transfer of radionuclides from water to fish. The Eq. 8 is applied according to the Calculation Guide Mining [111].

$$C_{Fi,r} = C_w \cdot T_{Fi,r} \qquad (9)$$

where:

$C_{Fi,r}$ Activity concentration of radionuclide r in fish Fi [Bq kg^{-1}]

$T_{Fi,r}$ Concentration factor for radionuclide r in fish Fi [l kg^{-1}]

Any background activity concentration is neglected in this equation, too. Accordingly, the dose assessment is even more to be considered as overestimated.

Table 7-51: Concentration factors $T_{Fi,r}$ for fish related to radionuclide r; from [111]

Radionuclide	**$T_{Fi,r}$ [l kg^{-1}]**
U-238	2
U-234	2
Th-230	30
Ra-226	10
Pb-210	60
Po-210	300
U-235	20
Pa-231	30
Ac-227	30
Th-232	30
Ra-228	10
Th-228	30
Ra-224	10

The report from COWI AS [114] contains data from seawater analyses in 2021. Table 7-52 summarizes the data from Table 5 of the COWI AS report for Stasjon 1S3 Frierfjorden sør. Only Pb-210, and the difficulty measurable thorium-isotopes exceed the background levels.

Table 7-52: Activity concentration of a water sample from Stasjon 1S3 Frierfjorden 2021

	Stasjon 1S3 Frierfjorden sør				Average	Stasjon Y2, 2015	Background
	14.01.21	20.04.21	06.07.21	11.10.21			
	[mBq l-1]	[mBq l-1]	[mBq l-1]	[mBq l-1]	[mBq l-1]	[mBq l-1]	[mBq l-1]
Pb-210	34	6	≤ 15	≤ 15	17.5	-	2- 5
Ra-226	≤ 2.6	≤ 2.6	≤ 7	≤ 2.7	≤ 3.7	-	1 - 4
Ra-228	≤ 12	≤ 6	≤ 12	≤ 6	≤ 9.0	-	10
Th-228	6.2	11	6.6	≤ 4	7	4	0.2
Th-230	≤ 1.3	1	0.6	2.8	1.4	1.6	$5 \cdot 10^{-2}$
Th-232	≤ 0.6	≤ 0.4	0.5	0.2	0.4	0.4	$5 \cdot 10^{-4}$
U-234	10.6	31	6.5	7.2	13.8	8.5	47
U-235	0.31	1	0.18	0.3	0.4	0.4	2
U-238	8.2	26	6	5.5	11.4	5.5	41

Using these data and the concentration factors, the activity concentration of fish can be calculated, as shown in Table 7-53.

Table 7-53: Activity concentration of fish on the base of a water sample from Stasjon 1S3 Frierfjorden; Sample date: 14.01.2021 and background values from [111]

Radionuclide	C [mBq kg-1]	Background [mBq kg-1]
U-238	16	4
U-234 a)	16	4
Th-230 b)	39	1
Ra-226 b)	26	7
Pb-210	2,040	30
Po-210 a)	10,200	150
U-235	6	0,2
Pa-231 a)	1	3
Ac-227 a)	1	3
Th-232 a)	57	1
Ra-228 b)	120	7
Th-228 a)	57	1
Ra-224 b)	120	

a) Data are assessed due to the relation of other radionuclides,
b) Measurement values are below the detection limit that is applied for the calculation

Figure 7-11 illustrates the results of this dose assessment. All calculated effective dose values are in the range of 0.1 to 1.2 µSv y^{-1}. These doses are very low. Compared with data from the literature concerning radioactivity in fish, as it is described before, the impact due to the emissions of the production process of Yara is lower than or in the range of the natural background. The calculated annual effective dose values are higher than those that were determined by the Institutt for energiteknikk (2020) [115]. It is not possible to determine a significant share that can be allocated to industrial processes from Yara.

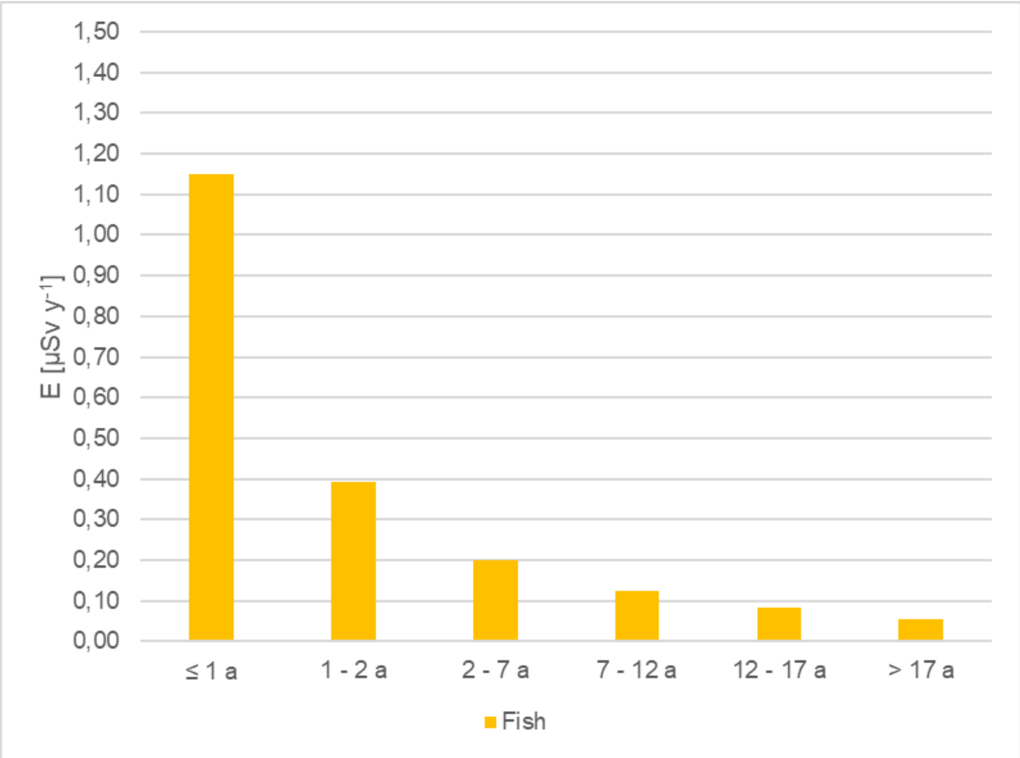

Figure 7-11: Results of the dose assessment by means of calculation of the activity concentration in fish using concentration factors for the transfer of radionuclides from seawater

7.7 Cost

The expenses of a required monitoring to control the effects of discharges or disposal of NORM and its benefits relating to the resulting exposures for human beings and non-human beings should be planned as an effective graded manner. This approach is like a cost-benefit assessment to appraise the desirability of surveillance of the relevant exposure pathways and define its detail level. The assessment can help predict whether the benefits of the planned measures within the monitoring program outweigh its expenses in relation to the resulting exposures due to the discharges or disposal of NORM.

Moreover, monitoring programs are generally intended for preserving ecosystems and maintaining biodiversity. Industries should actively protect the natural habitats of many species by reducing the release of radioactive emissions, which is crucial for the long-term health of the environment.

The costs implement the expenses for planning, execution and evaluation of all measures of the monitoring program. The benefits are the avoided damage due to monitoring of the exposure to human beings and non-human beings. Because almost no monitoring program can fully eliminate an impact and the associated risk from NORM discharges or NORM disposal, the costs of the residual risk (the remaining impacts after the implementation of the monitoring program) also need to be accounted for.

Assessing the costs and benefits of monitoring programs can be undertaken more narrowly, considering financial budgetary costs and benefits only or more comprehensively considering the wider costs and benefits, especially to the human beings and to the industry concerned. In addition, social costs and benefits may also be included in cost-benefit assessments. Usually, non-market costs and benefits must be included in the assessments of monitoring programs to realistically account for the full range of benefits and costs. Even though, non-market costs are more difficult to express in monetary terms.

In general, a cost-benefit assessment contains:

- the definition of the objective for the monitoring programs to be assessed,
- assessments comparing scenarios "with" and "without" the specific monitoring programs,
- the identification of all costs and benefits over a set timeline, e. g. 10 years or the time horizon of planned industrial processes that are responsible for the impact and the associated risk from NORM discharges or NORM disposal,
- the comparison of the costs and benefits for the analysis to the necessity for launching a monitoring program and if it is needed to derive an adequate and graded extent. As a result, it can be determined whether the benefits outweigh the costs. It is also important to consider the “payback time” - how long it will take to reach the break-even point at which the benefits have compensated the costs incurred.

The significant benefits of emissions monitoring must be evaluated with regard to its essential role,

- in driving corporate sustainability,
- improving public health,
- and promoting long-term environmental well-being.

It has to be assessed based on the calculated annual effective dose, how a monitoring program significant contributes the improvement of air, water, and soil quality. The decrease of radioactive emissions has a direct and positive impact on public health. The scale to evaluate the efforts for establishing monitoring programs can be the success of reducing the exposition to members of the public and to the environment.

Because of that monitoring programs are a critical aspect of adhering to local, national, and international environmental regulations. The industries must manage the challenge the accurately tracking and reporting of emissions data and the resulting impact to the environment. On this basis, a cost-benefit analysis allows the evaluation of the costs for the execution of monitoring programs and its effect to control potential long-term damages done by e. g. one Megagram of radioactive emissions. The benefits can be expressed in any other quantified measure that can be compared with the target value. This value can be the assessed dose to human beings and non-human beings: NOK per Sv.

From the radiation protection point of view, the decision to the extent of the monitoring programs as a protection strategy, the principle of optimization of protection becomes the driving principle to select the most effective actions for protecting the exposed public, workers, and the environment. The ICRP states in their Publication 142 [26] that the level of control may be determined by implementing the optimization principle. The magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures must be kept as low as reasonably achievable, guided by appropriate individual dose criteria, considering economic and societal factors. This is also understood as the ALARA principle.

There is a level of natural radiation exposure and certain sources that is unable to avoid in daily life. The impact due to the discharge or disposal of NORM is characterized as an additional natural exposure to the members of the public and to the environment. The optimization process should be commensurate with the overall level of risk and compatible with common standards of environmental protection, notably the optimization of discharges or disposal in the environment. In practice, the radiological impact should be included in the environmental impact assessment and monitored as necessary. The radiological risk is not necessarily dominant; the options to reduce doses may be more limited and/or may require different resources. As it is demonstrated in the exemplary dose assessment for the modeled discharges of fertilizer dust and prill dust from Yara's plant at Herøya, the total risk coefficient of 0.74 can be considered negligible (see Ch. 7.6), and there cannot be identified an impact that leads to a significant elevated impact compared to the natural background. And also, the effective dose for members of the public in the order of some µSv per year can be characterized as very low.

But, for a clear classification of the results presented, the natural background of the radiological exposure should be well-known for the dose assessments. The determination of these data cannot be imposed on the industries that have to evaluate their emissions. The industries themselves only should be obligated to a monitoring program if a significant impact due to their discharges or disposal can be adopted. As it can be assessed so far, there is no justification for establishing an expensive monitoring program if the first results do not indicate any reason that the effective dose for members of the public or the radiological risk to the non-human environment is significantly elevated above the natural background.

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