DCE RECOMMENDATIONS FOR GUIDELINES FOR THE SAFE MANAGEMENT OF RADIOACTIVE WASTE GENERATED FROM THE MINERAL AND HYDROCARBONS INDUSTRIES IN GREENLAND

Technical Report from DCE – Danish Centre for Environment and Energy No. 243 2022

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Data sheet

Series title and no.:	Technical Report from DCE – Danish Centre for Environment and Energy No. 243
Category:	Scientific advisory report
Title:	DCE recommendations for Guidelines for the Safe Management of Radioactive Waste generated from the mineral and hydrocarbons industries in Greenland
Author(selqq):	Violeta Hansen, Gert Asmund, and Jens Søndergaard
Institution:	Department for Ecoscience
Publisher:	Aarhus University, DCE – Danish Centre for Environment and Energy ©
URL:	http://dce.au.dk/en
Year of publication:	June 2022
Editing completed	May 2020
Referee:	Anders Mosbech
Quality assurance, DCE:	Vibeke Vestergaard Nielsen
External comments:	Environmental Agency for Mineral Resource Activities, Nuuk, http://dce2.au.dk/pub/komm/TR243_komm.pdf. Tim Moulding, and Kevin Scissons. comments can be found in workzone.
Financial support:	Environmental Agency for Mineral Resource Activities, Nuuk
Please cite as:	Hansen, V., Asmund, G. & Søndergaard, J., 2022. DCE recommendations for Guidelines for the Safe Management of Radioactive Waste generated from the mineral and hydrocarbons industries in Greenland. Aarhus University, DCE – Danish Centre for Environment and Energy, 48 pp. Technical Report No. 243 http://dce2.au.dk/pub/TR243.pdf

Abstract: These recommendations for guidelines provide safety requirements and guidance to ensure the safe management of waste containing naturally occurring radioactive materials (NORM) and technologically enhanced naturally occurring radioactive material (TENORM) generated from Greenland's mineral and hydrocarbons industries. The recommendations for guidelines include requirements for all phases of the waste facility, e.g., site selection, site assessment, site design and preparation, construction, operation (e.g., treatment, disposal), closure, site release from licensing, and long-term stewardship. Herein recommendations for guidelines are based on the most recent international standards recommended by the International Commission on Radiological Protection, European Union, International Atomic Energy Agency, and International Council on Mining and Metals. The recommended herein waste management practice is a graduated approach. This means that the greater the risk, the more stringent the mitigation measures should be. The policy, practice, regulation, and supervision should (shall) be continuously improved to comply with the existing best available technologies (BAT), best environmental practices (BEP), and changing levels of understanding within the management of radioactive waste. The Environmental Agency for Mineral Resources Activities (EAMRA) requested in 2018 recommendations for "Guidelines for the safe management of radioactive waste generated from the mineral activities in Greenland." In 2020, EAMRA requested that the DCE also include the safe management of radioactive waste generated from Greenland's hydrocarbons activities in the recommendations. As requested, the recommendations are provided in the format of draft guidelines. However, the Greenland administration's administrative setup is only tentatively indicated and should be further addressed by EAMRA.

Keywords:	Radioactive waste, safe management, mining, oil and gas, Arctic
Layout:	Karin Balle Madsen
Front page photo:	Violeta Hansen
ISBN:	978-87-7156-689-5
ISSN (electronic):	2244-999X
Number of pages:	48
Internet version:	The report is available in electronic format (pdf) at http://dce2.au.dk/pub/TR243.pdf

Contents

Preface

The Environmental Agency for Mineral Resources Activities (EAMRA) requested in 2018 recommendations for "Guidelines for the safe management of radioactive waste generated from the mineral activities in Greenland." In 2020, EAMRA requested that the DCE also include the safe management of radioactive waste generated from Greenland's hydrocarbons activities in the recommendations. As requested, the recommendations are provided in the format of draft guidelines. However, the Greenland administration's administrative setup is only tentatively indicated and should be further addressed by EAMRA.

The Kingdom of Denmark includes the islands of Greenland and the Faroe Islands. These territories are linked within the 'Commonwealth of the Realm', where both island territories enjoy autonomous authority in most domestic affairs, while Denmark remains constitutionally responsible for foreign, defense, and security policies. This division of responsibility is important to appreciate the following fully.

Denmark signed the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management on 29 September 1997, the day it opened for signature, and the Convention was accepted 3 September 1999 by a letter from the Foreign Ministry to the International Atomic Energy Agency (IAEA). Upon signature, the Kingdom of Denmark announced a territorial declaration concerning Greenland, stating that the Convention does not apply for the autonomous territories Greenland and the Faroe Islands. This territorial declaration could be withdrawn at any given time.

In 1985, the Danish Parliament decided that Denmark would not use nuclear energy. In 2010, pursuant to the newly adopted Act on Greenland Self-Government (Act no. 473 of 12 June 2009), Greenland was granted autonomous authority over natural resources within the territory. Additionally, by the decision of the Greenland Self-Government in October 2013, extraction of naturally occurring radioactive materials (NORM) in Greenland was accepted. Lastly, in August 2015, by the decision of the Greenland Self-Government, the reservation to this Convention was revoked. On 15 December 2016, the Kingdom of Denmark withdrew its territorial declaration concerning Greenland made upon acceptance of the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.

Waste that contains NORM is not radioactive waste within the purpose of the Convention. However, the decision to accept possible future extraction of NORM in Greenland has put some focus on Greenlandic management systems within the mineral resource administration regarding the safe management of radioactive waste and waste facilities in general. For transparency purposes, a description regarding the management related to NORM has been added to the first Greenlandic Report presented at the Sixth Review Meeting to the Convention, which took place 21 May – 1 June 2018, IAEA in Vienna.

The herein requested document by EAMRA is one outcome of the expert's recommendations for Greenland from the Sixth Review Meeting to the Convention, 21 May – 1 June 2018, IAEA in Vienna.

1 Introduction

These recommendations for guidelines provide safety requirements and guidance to ensure the safe management of waste containing naturally occurring radioactive materials (NORM) and technologically enhanced naturally occurring radioactive material (TENORM) generated from Greenland's mineral and hydrocarbons industries. The recommendations for guidelines include requirements for all phases of the waste facility, e.g., site selection, site assessment, site design and preparation, construction, operation (e.g., treatment, disposal), closure, site release from licensing, and long-term stewardship.

The herein recommendations for guidelines supplement the Greenland Parliament Act no. 7 of 7 December 2009 on mineral resources and mineral resource activities with later amendments (Mineral Resources Act (MRA)) (Ref. 1) and the Greenland Parliament Act no. 33 of 9 December 2015 on the Ionizing Radiation and Radiation Protection Act (Ref. 2) as regards the safe management of radioactive waste. According to the Mineral Resource Act, each licensee should (shall) prepare an Environmental Impact Assessment for new projects or when significant changes to an existing project occur. The herein recommendations for guidelines supplement the requirements for mineral resources activities, set up in the following documents: a) ''*Guidelines for preparing an Environmental Impact Assessment (EIA) report for mineral exploitation in Greenland, 2015*'', and b) ''*Geochemical test work in Environmental Impact Assessments for mining projects in Greenland, 2018*'' (Ref. 29 and 42). Furthermore, the herein recommendations supplement the requirements for hydrocarbon activities, set up in the following documents: a) ''*BMP Guidelines – for preparing an Environmental Impact Assessment (EIA) report for activities related to hydrocarbon exploration and exploitation off shore Greenland,* 2011'', b) ''*Greenland Bureau of Minerals and Petroleum Exploration Drilling Guidelines, 2011.'', c) ''BMP Stratigraphic Drilling Guidelines, April 2011'',* and d) ''*BMP Guidelines – for preparing an Environmental Impact Assessment (EIA) report related to stratigraphic drilling offshore Greenland, 2011''* (Ref. 43 - 46).

Herein recommendations for guidelines are based on the most recent international standards recommended by the International Commission on Radiological Protection (ICRP) (Ref. 3-12), European Union (EU) (Ref. 13-18), International Atomic Energy Agency (IAEA) (Ref.19-27, 51), and International Council on Mining and Metals (Ref. 52). The EU, ICRP, and IAEA recommendations represent an international consensus on radiation protection within the safe management of radioactive waste and provide the basis for regulatory control of radioactive materials in all countries of the world. The herein recommendations for guidelines may later be updated to reflect amendments to accepted national and international radiation protection practices.

EAMRA requested DCE to use the verbal form of ''should'' when developing this document. However, to assist EAMRA, in this document, the following verbal forms are used:

- Should (shall) and should (must) indicates a requirement
- Should indicate a recommendation.

2 Scope of application of the recommended guidelines

The DCE recommendations for guidelines apply to:

- Holding, handling, use, transport, import to, and export from Greenland of NORM / TENORM waste
- Storage and / or disposal of NORM / TENORM waste resulting from exploration, exploitation, and closure of mining, onshore and offshore hydrocarbons activities (existing, planned, and future projects).

Out of the scope of application of the recommended guidelines DCE recommendations for guidelines do not apply to:

- Domestic and non-radiological waste
- Exposure to the natural level of radiation such as radionuclides contained in the human body, indoor radon, external exposure from cosmic radiation prevailing at the ground level
- Aboveground exposure to naturally occurring radionuclides present in the undisturbed earth's crust
- Disused sealed sources and repatriation of disused sealed sources.

3 Radioactive waste practice in Greenland

The Greenlandic practice for radioactive waste management is based on the principles of the Mineral Resources Act (Ref. 1) and require a licensee to:

- Minimize the generation of waste to the practicable extent by implementing design measures, operating procedures, and decommissioning practices. The licensee has the responsibility to keep the exposure to ionizing radiation as low as reasonably achievable (ALARA) and under legislated radiation dose limits
- Reuse, recycle, characterize, segregate, manage, store and / or dispose of all NORM / TENORM waste under safe and secure conditions in approved waste facilities
- Manage radioactive waste commensurate with its radiological, chemical, and biological hazard to the health and safety of people and the environment
- Ensure that impacts on people's health and safety and the environment from managing radioactive waste facilities are mitigated.

The recommended herein waste management practice is a graduated approach. This means that the greater the risk, the more stringent the mitigation measures should be. The policy, practice, regulation, and supervision should (shall) be continuously improved to comply with the existing best available technologies (BAT), best environmental practices (BEP), and changing levels of understanding within the management of radioactive waste.

4 The first stage in assessing the need to regulate NORM/TENORM waste

4.1 Identification of practices that generate NORM/TENORM waste

The licensee should (must) identify activities involving NORM before seeking approval to commence exploration and/or exploitation, or, for existing practices, as soon as possible once this requirement is applicable. Such identification should (shall) consider the industries, facilities, and activities for which materials with concentrations of naturally occurring radionuclides (^{238}U and ^{232}Th) above 1 Bq/g and above the clearance and exemption threshold values (Tables 5.1, and 5.2) trigger the requirements of herein recommendations for guidelines. Specific clearance and exemption threshold values for activity concentration of radionuclides are included in Tables 5.1, and 5.2. Industries that may generate NORM/TENORM waste and are likely to require regulatory control are included in Table 4.1.

Table 4.1. Industries that may generate NORM/TENORM waste

Mining and milling of uranium and thorium ores, use of uranium or uranium compounds, use of thorium or thorium compounds
Extraction and production of rare earth elements and rare earth element alloys
Mining and milling of ores other than uranium ore where radionuclides are present in the ore bearing parent material
Metal extraction and milling: copper, aluminum, zinc, lead, iron, and steel
Production of niobium and its compounds and tantalum ore
Production of titanium dioxide pigments
Bauxite mining/aluminum industry
Zircon and zirconia industries
Industrial activities utilizing phosphate ore
Sulphuric acid production
Remediation of contamination from industrial activities listed above
Combustion of coal
Water treatment
Offshore and onshore oil and gas
Other

NORM/TENORM waste my include but to not be limited to:

Mineral resources waste:

- Drilling liquids, mud
- Waste rock
- Tailings
- Furnace slag and dust
- Liquid NORM residues (e.g., rainfall runoff from the process plant area, waste management area, and ore stockpiles; seepage from the waste, and stockpiles; mine water, used process water separated from slurry streams, wash water, flotation water, leaching fluids; water from decontamination of equipment, etc.
- Gaseous NORM residues (generated by furnaces, chemical processes and ventilation systems)

- Contaminated parts of installation / equipment used in exploration / exploitation activities
- Other.

Hydrocarbon waste:
- Scale, sediment, sludge, produced sand
- Drilling muds and drill cuttings
- Liquid NORM residues (e.g., flow back resulting from hydraulic fracturing, residuals, transformation products of hydraulic fracturing fluids, produced water from oil and gas production)
- Contaminated parts of installation / equipment used in exploration / exploitation activities, process filters
- Other.

4.2 Graded approach to regulation

The licensee (Table 4.1), the waste generator performs an initial screening risk assessment to estimate:
- The activity concentrations of naturally occurring radionuclides in the raw materials, in processed materials and facilities, and generated waste
- The magnitude of doses to workers and members of the public arising from the operation
- Environmental radiological impact(s) arising from the proposed activity, generated waste, long term management of generated waste, contaminated materials that may be recycled, and manufactured items containing NORM / TENORM
- The level of optimization of radiation protection to protect the workers, the public, and the environment
- The impact of waste containing NORM and / or contaminated materials that may be recycled.

The initial screening assessment is intended to be used to decide the need for regulation using a graded approach consistent with the optimization principle and commensurate with the characteristics of the practice and / or radiation source and the magnitude and likelihood of the exposure to ionizing radiation.

If the screening assessment indicates that the activity concentrations of ^{238}U and ^{232}Th in the raw materials and waste exceed the 1 Bq / g and exceed the exemption and clearance threshold values (Tables 5.1, and 5.2.), a more detailed safety assessment should be conducted (details in Chapter 8).

The graded approach includes exemption and clearance, notification, license, release from license, and appropriate inspections, commensurate with the magnitude and likelihood of exposures resulting from the proposed activity and commensurate with the impact that the regulatory control may have in reducing such exposure or improving radiological safety.

4.2.1 Exemption and clearance

Management, storage, and disposal of materials, facilities, NORM / TENORM waste generated from industrial activities (Table 4.1) do not require a license and specific environmental approvals (Ref. 1 and herein recommendations for guidelines) from Greenland authorities if the materials, facilities, and the

waste contains radionuclides with an activity concentration at and below the clearance and exemption threshold values set out in Tables 5.1 and 5.2.

4.2.2 Notification

The licensee has the responsibility to notify and obtain relevant approvals from the Relevant Greenland Authority regarding:

- Planned or existing practices listed in Table 4.1
- Activities involving the processing, use, storage, or utilization of materials including natural radionuclides or waste in which the activity concentration of uranium-238 is higher than 1 Bq / g, and the activity concentration of thorium-232, is higher than 1 Bq / g.

The notification should (shall) be made before practice commencing or, for existing practices, as soon as possible once this requirement is applicable.

Activities involving naturally occurring radioactive materials do not need to be notified if:

- The activity concentrations of radionuclides of the involved material are below 1 Bq / g and below the exemption and clearance threshold values set out in Chapter 5 of the herein document. Confirmation of the activity levels of radionuclides is required to ensure they are below the exemption and clearance threshold values set out in Chapter 5 of herein document.

4.2.3 License and Specific Approvals

Waste containing naturally occurring radionuclides with activity concentrations higher than 1 Bq / g and the clearance and exemption threshold values set out in Chapter 5 must be safely managed in accordance with the license for exploration, exploitation, and closure license (Ref. 1 and 16) and specific environmental approvals granted by the Relevant Greenland Authority.

A license should (shall) include conditions and requirements for environmental protection, especially on the discharge of radioactive material with airborne or liquid effluent into the environment. The conditions and requirements are to be set under the Greenland Parliament Act no. 7 of 7 December 2009 on mineral resources and mineral resource activities with later amendments (Mineral Resources Act).

4.2.4 Release from regulatory control

Materials can be released from the regulatory control providing that the activity concentrations of naturally occurring radionuclides comply with the clearance and exemption threshold values set out in Chapter 5.

In Greenland, deliberate dilution of radioactive materials for them being released from regulatory control is not permitted.

A radioactive waste facility may be released from its license only if it fulfills the requirements set under the Greenland Parliament Act no. 7 of 7 December 2009 on mineral resources and mineral resource activities with later amendments (Mineral Resources Act), EIA (2015), hydrocarbons guidelines, and recommendations applicable in Greenland and the herein recommendations for guidelines.

5 Exclusion, exemption and clearance levels

NORM / TENORM waste is any material that arises from NORM industrial activities listed in Table 4.1 and in which the activity concentrations of radionuclides are above 1 Bq / g and those set out in Chapter 5. Waste with activity concentrations below 1Bq / g and those set out in Chapter 5 are not deemed radioactive.

5.1 Exclusion from scope

Excluded exposure includes exposure to the natural level of radiation such as radionuclides contained in the human body, cosmic radiation prevailing at ground level and in-flight or space (here excluding the air or space crew), and from radionuclides present in the undisturbed earth's crust. Undisturbed mineral deposits are also excluded from regulatory control.

5.2 Exemption and clearance

A single set of threshold values for clearance and exemption are recommended to apply to Greenland. Management, storage, and disposal of NORM / TENORM waste generated from industrial activities (Table 4.1) require a license and specific environmental approvals (Ref. 1 and herein guidelines) from Greenland authorities if the waste contains radionuclides with an activity concentration above 1 Bq / g and above the clearance and exemption threshold values set out in Tables 5.1 and 5.2. Below 1 Bq / g and the clearance and exemption, threshold values there are no radiological restrictions.

Table 5.1. Clearance and exemption threshold values for activity concentration of radionuclides for industrial activities

Radionuclide	Solid (Bq/g)	Liquid (Bq/L)	Air (Bq/m^3)
U-238 Series (all progeny)	0.3	1	0.001
U-238 (U-238, Th-234, Pa-234m, U-234)	10	10	0.01
Th-230	10	5	0.001
Ra-226 (in equilibrium with its progeny)	0.3	5	0.01
Pb-210 (in equilibrium with Bi-210)	0.3	1	0.01
Po-210	0.3	1	0.01
Th-232 Series (all progeny)	0.3	1	0.001
Th-232	10	1	0.001
Ra-228 (in equilibrium with Ac-228)	0.3	5	0.005
Th-228 (in equilibrium with all its progeny)	0.3	1	0.001
K–40	17	n/a	n/a

The clearance and exemption threshold values (Table 5.1) were derived, taking into account the following radiation exposure pathways:

1. Aquatic
2. Terrestrial (external ground-shine from soil contaminated to infinite depth, soil-veg-ingestion / soil ingestion, inhalation of re-suspended material)
3. Air (inhalation at concentration resulting in 0.3 mSv, exposure factor of 25 % assumed).

Activity concentrations of naturally occurring radionuclides resulting in a 0.3 mSv / y for any member of the public above the natural background level of radiation were used to define the radionuclide clearance and exemption threshold values as included in Table 5.1 (Ref.17).

In practice, NORM / TENORM waste usually contains a mixture of different naturally occurring radionuclides. A summation formula can be used to determine if a material containing a mixture of radionuclides is below the clearance and exemption level:

$$\sum_{i=1}^{n} \frac{Ci}{CU,i} \leq 1$$

Where:

Ci is the specific activity of radionuclide i (Bq / g)

CU, i is the clearance threshold value in the table 5.1. of radionuclide i (Bq / g)

N is the number of radionuclides in the mixture

In the above expression, the ratio of the concentration of each radionuclide to the clearance threshold value is summed over all radionuclides in the mixture. If the sum is less than one, the material complies with the clearance requirements.

Discrete NORM / TENORM sources are small and generally exceed the concentrations criteria in Table 5.1. Because of the possibility of high radiation dose rates close to the source, the clearance and exemption threshold values for discrete sources are lower than those in Table 5.1 and are included in Table 5.2. The NORM / TENORM sources must also meet the applicable radioactive surface contamination values, shown in Table 5.3.

Table 5.2. Clearance and exemption threshold values for activity of radionuclides for discrete NORM/TENORM sources.

Radionuclide	**Bq**
Uranium ore (in equilibrium with all progeny)	1000
U-238 (partitioned) (in equilibrium with Th-234 and Pa-234m)	10 000
Th-230 (no progeny)	10 000
Ra-226 (in equilibrium with its progeny)	10 000
Pb-210 (in equilibrium with Bi-210)	10 000
Po-210	10 000
Th-232 Series (all progeny)	1000
Ra-228 (in equilibrium with Ac-228)	100 000
Th-228 (in equilibrium with its short-lived progeny)	10 000
K–40	1 000 000

A summation formula can be used to determine if a discrete NORM / TENORM source that contain a mixture of different naturally occurring radionuclides, is below the clearance and exemption level:

$$\sum_{i=1}^{n} \frac{Ci}{CU,i} \leq 1$$

Where:

Ci is the activity of radionuclide i (Bq)

CU, i is the clearance threshold value in the table 5.2 of radionuclide i (Bq)

N is the number of radionuclides in the mixture.

In the above expression, the ratio of the activity of each radionuclide to the clearance threshold value is summed over all radionuclides in the mixture. If the sum is less than one, the material complies with the clearance requirements.

Surface contamination

Limits for radioactive surface contamination on equipment, tools, or scrap surfaces intended for release from radiological restrictions are based on personal radiation exposure pathways to a maximum annual dose of 0.3 mSv. Discrete NORM / TENORM sources with surface contamination less than the limits in Table 5.3 can be released without radiological restrictions.

Table 5.3. Surface contamination clearance and exemption threshold values for discrete NORM/TENORM sources

	Limit
Dose rate	0.5 µSv/h at 50 cm
Surface contamination	1 Bq/cm^2 averaged over a 100 cm^2 area

A thin window radiation detector is recommended when monitoring alpha / beta / gamma sources of surface contamination. Table 5.3 clearance and exemption threshold values are only applicable to fixed surface contamination. Surface contamination must be removed entirely, or all accessible surfaces stripped to ensure complete removal. In most cases, decontamination efforts that meet beta surface contamination limits (Table 5.3) will concurrently provide for the control of mixed alpha / beta / gamma sources.

The clearance and exemption threshold values in Table 5.1. and Table 5.2. relate to the long-lived parent radionuclide in equilibrium with its progeny. Where the equilibrium has been disturbed by partitioning of decay series, the activity of each long-lived radionuclide must be found and compared to its appropriate clearance and exemption threshold value.

It shall be underlined that the considerations above focus on radiation protection and that health aspects other than radiation, like chemical toxicity, may be prominent. The chemical risk may be well above the radiological risk.

6 Radiation protection

Fundamental principles as justification, optimization, and limitation of radiological protection recommended by ICRP (Ref. 3, 8, and 11) are recommended to be applied to Greenland. To be clear, the Relevant Greenland Authority is responsible for ensuring the licensee will put in place measures for radiation protection of the workers (occupational exposure) and the public. Radiation protection should be managed effectively with other health and safety disciplines, such as industrial safety, industrial hygiene, and fire safety. Radiation protection requirements to protect the workers and public should (shall) be developed in detail by Relevant Greenland and Danish Authority within Health.

6.1 Occupational and members of the public

The industry generating NORM/TENORM waste should (shall) perform a radiation risk assessment from exposure to ionizing radiation to members of the public and employees and all workers at the site, including also contractors and subcontractors. The radiation risk assessment needs to be approved by the Relevant Greenland Authority before any activities at the waste facility commence. Before the commencement of a waste management facility, the licensee should (shall) complete an environmental impact assessment (EIA) (Ref. 29) and should (shall) have a granted license for the proposed activity. Before the commencement of a waste management facility, the NORM/TENORM waste facility's licensee should (shall) prepare and obtain approval for a radiation management plan (RMP).

Relevant Greenland and Danish Authority should (shall) prepare specific radiation protection requirements for the RMP for industries and should (shall) assess and approve the RMP before the NORM/TENORM waste facility's commencement.

Occupationally exposed employees, workers, and members of the public dose limits apply to the sum of exposures from sources related to practices that are already justified in normal conditions. Occupational and members of the public dose limits that should (shall) apply in Greenland are included in Table 6.1. For occupational exposure, a limit on the effective dose of 20 mSv per year, averaged over five years (100 mSv in 5 years), with the further provision that the effective dose should not exceed 50 mSv in any single year should apply in Greenland. For public exposure, the limit of the effective dose is one mSv above background in a year.

The annual limits apply to the total dose received from operational sources, including external gamma exposure and inhalation of radon decay products and dust (with the dose from natural background being excluded).

Table 6.1. Radiation dose limits (based on BSS, 2013, ICRP 1991)

Annual Effective Dose Limit (mSv/y)	**Occupationally Exposed employees 20[1]**	**Members of the public 1[2]**	**Embryo/ fetus till childbirth/Pregnant women 1**
Annual Equivalent Dose			
Lens of the eye	150 mSv	15 mSv	
Skin [3,4]	500 mSv	50 mSv	
Hands and feet	500 mSv	-	

[1]Averaged over defined periods of 5 years. Five years cumulative dose limit 100 mSv, provided that the dose in each year does not exceed 50 mSv.

[2]Five years - cumulative dose limit 5 mSv.

[3]The limitation on effective dose provides sufficient protection for the skin against stochastic effects. An additional limit is needed for localized exposures in order to prevent tissue reactions.

[4]Averaged over 1 cm^2 area of skin regardless of the area exposed.

6.2 The environment

The licensee generating NORM / TENORM waste should (shall) perform a radiological and environmental (Ref.29) impact assessment (EIA, 2015) to demonstrate the protection of the environment. The radiological assessment should be performed by using internationally radiological models. Examples of radiological models that are available, but not limited to, include Environmental Risks from Ionizing Contaminants (ERICA) (Ref. 31), Environmental Modelling for Radiation Safety (EMRAS) (Ref. 32), and RESidual RADioactivity (RESRAD) – Biota (Ref. 33), etc.

6.3 Human resources

The licensee generating NORM / TENORM waste should (shall) ensure that a radiation protection expert (RPE) or a radiation protection officer (RPO) is available at the waste facility site (Ref. 16, 36, and 37).

An RPE advice the licensee, but not be limited to, the following (Ref.16 and 36):

- Optimization and establishment of appropriate dose constraints
- Plans for new installations and the acceptance into service of new or modified radiation sources in relation to any engineering controls, design features, safety features, and warning devices relevant to radiation protection
- Categorization of controlled and supervised areas
- Classification of workers
- Workplace and individual monitoring programmes and related personal dosimetry
- Appropriate radiation monitoring instrumentation
- Quality assurance
- Environmental monitoring programme
- Arrangements for radioactive waste management
- Arrangements for prevention of accidents and incidents
- Preparedness and response in emergency exposure situations
- Training and retraining programmes for exposed workers
- Investigation and analysis of accidents and incidents and appropriate remedial actions
- Employment conditions for pregnant and breastfeeding workers

- Preparation of appropriate documentation such as prior risk assessments and written procedures.

An RPO's tasks cover where relevant, but not be limited to, the following (Ref.16):

- Ensuring that work is carried out in accordance with the radiation protection requirements of any specified procedures or local rules
- Maintaining adequate records of all radiation sources
- Carrying out periodic assessments of the condition of the relevant safety and warning systems
- Supervise the implementation of the work and personal monitoring programme
- Supervise the implementation of the health surveillance programme
- Providing new workers with an appropriate introduction to local rules and procedures
- Giving advice and comments on work plans
- Establishing work plans
- Providing reports to the local management
- Participating in the arrangements for prevention, preparedness, and response for emergency exposure situations
- Information and training of exposed workers
- Liaising with the radiation protection expert.

The European Commission (EU), the International Radiation Protection Association (IRPA), and IAEA requirements and recommendations (Ref. 16, 36, 37, 38, 39, 40, and 41) for RPE and RPO competence (e.g., education, training, and work experience), suitability, appointment, and recognition / certification by Relevant Greenland Authority should (shall) be followed in Greenland.

The licensee should (shall) ensure that all employees, contractors, subcontractors, and guests undergo an appropriate training program regarding environmental and radiation safety awareness.

The training program (Ref. 36, 37, and 38) should(shall) enable all employees, workers, short-term visitors, contractors, and subcontractors to understand the risk from exposure to radiation and the methods of reducing and controlling the radiation dose (limiting potential exposure times, maintaining safe distances from sources, and using appropriate shielding) for themselves and others. An appropriate training program for members of the public in basic radiation safety principles should be available.

The qualification and experience of the person conducting the training (if not the RPE / RPO) and the RPE and the RPO should (shall) be provided (Ref. 16, 36, 37, 38, 39, 40, and 41).

Records of all training programs should (shall) be maintained and should (shall) include information on the person trained, and its position, the period of training, the trainer, and a general description of the training content, duration, and frequency.

Training programs (Ref. 16, 36, 37, 38, 39, 40, and 41) should (shall) include, but not be limited to:

- Training of all employees, workers, short-term visitors, contractors, and subcontractors – induction program. All employees, workers, short-term visitors, contractors, subcontractors, and new staff should complete an induction program including a description of the working environment, radiation protection measures, training on local equipment, tasks related to their specific role, etc.
- Targeted training for specific personnel
- Training of management personnel
- Training of administrative employees
- Periodic retraining
- Emergency response and preparedness training
- Training of visitors and short-term workers on site.

All employees should (shall) commit to radiation safety. This commitment should be demonstrated by adherence to radiation protection practices and periodic safety audits as appropriate.

7 Classification of NORM/TENORM waste

Exploration and exploitation of minerals and hydrocarbons have a potential to generate large volumes of NORM/TENORM waste. This waste typically contains relatively low activity concentrations of radionuclides in a variety of physical and chemical forms. TENORM waste can include but not be limited to tailings, scale and sludge, contaminated equipment and materials, drilling muds and drilling cuts, process water including leaching solutions, and contaminated rainfall and snowmelt runoff and seepage. NORM waste can include but not be limited to waste rock, untreated ore, or any other material with activity concentrations of radionuclides above clearance and exemption levels included in Chapter 5.

Prior to its generation, the NORM/TENORM waste should (shall) be characterized and classified according to its origin, the physical, chemical, biological, radiological properties, and other factors such as, e.g., volume, the amount generated per unit of time, etc. (Appendix B). The characteristics of waste should (shall) be included in the plans for its generation and management in accordance with the regulatory scrutiny and approval processes.

7.1 Classification of NORM/TENORM waste

The system for the classification of NORM/TENORM waste generated from the mineral and hydrocarbons industries in Greenland is adopted from the IAEA (Ref.24). In Greenland, three classes of waste are recommended to be used as the following classification scheme:

1. Exempt Waste (EW): Waste that meets the criteria for clearance and exemption from regulatory control for radiation protection purposes (Chapter 5). This type of waste is not considered NORM waste.
2. Very Low-Level Waste (VLLW): Waste that does not meet the criteria of EW but contains radionuclides with activity concentrations in the region of or slightly above 1 Bq/g and the levels specified for the clearance and exemption of material from regulatory control. This type of waste is suitable for disposal in engineered near-surface landfill-type facilities. Such landfill-type facilities may also contain other hazardous waste. The licensee proposes the handling and the safe management, storage, and disposal method of generated waste.
3. Low-Level Waste (LLW): Waste that contains radionuclides with activity concentrations above 1 Bq/g and above clearance and exemption threshold values. Such waste requires long-term robust isolation and containment and is suitable for disposal in engineered surface facilities or below-grade engineered waste facilities, like an in-pit waste management facility or a below-grade shallow purpose-built pit containment system. The licensee proposes the handling and the safe management, storage, and disposal method of generated waste.

LLW may include long-lived naturally occurring alpha-emitting radionuclides at relatively low levels of activity concentrations. Waste that contains radionuclides with activity concentrations slightly above 1 Bq/g should be classified as radioactive waste category 2, and waste that contains radionuclides with activity concentrations ≥ 10 Bq/g should be classified as radioactive waste category 1. An electronic system of declaration of waste, nuclide(s), volume/amount, activity concentration of each radionuclide in the waste,

physical and chemical properties, and other waste characteristics (Appendix B) should be developed by the Relevant Greenland Authority.

The waste classification scheme is developed only considering the radiological properties of waste, such as the activity and half-life of radionuclides in the waste. Activity may be expressed in terms of the total activity of the waste or activity concentrations of individual radionuclides. The boundaries between the waste classes should be seen as transition zones rather than fixed lines. The classification scheme does not replace the specific safety assessment, and the radiological and non-radiological environmental impact assessment required by the Relevant Greenland Authority for approval of a project / waste facility (Ref.1).

8 Radioactive Waste Management Plan (RWMP)

The licensee generating NORM / TENORM waste should (shall) develop and implement a Radioactive Waste Management Plan (RWMP). The RWMP includes various streams of waste and provides full coverage of the life cycle from generation to long-term management. The waste facility's life cycle phases can be defined as 1) planning and design, 2) operational: construction, management, and maintenance, and 3) closure and after-closure. Given the broad spectrum of NORM / TENORM waste arising from a wide range of activities (Table 4.1), it is important that a graded approach is adopted for the development of the RWMP. The RWMP should (shall) be periodically reviewed and updated accordingly in compliance with regulatory requirements and consistent with the facility policy and strategy for safety, environmental management, and waste management. The Relevant Greenland Authority should (shall) approve the RWMP before the NORM / TENORM waste facility's operation commence.

The RWMP should (shall) demonstrate that the planned activities minimize as far as practicable, the generation of NORM / TENORM waste in terms of type, activity, volume, and its harmfulness by considering:

- Best available techniques (BAT), best environmental practices (BEP), The OSPAR Convention recommendations, and good practice guide (Ref. 52) in the design of the project and waste management
- Short- and long-term changes in NORM / TENORM waste properties such as physical, geochemical, biological, and radiological
- Use of less dangerous chemicals and reagents in the proposed processes
- Waste characterization, classification, segregation, and monitoring
- Maximize the recycling, reuse (Fig. 8.1), or reclamation of NORM / TENORM waste, based on clearance and exemption criteria (Chapter 5) and the requirements under the Mineral Resource Act (Ref.1) and EU MWEI BREF, 2018 (Ref.18).

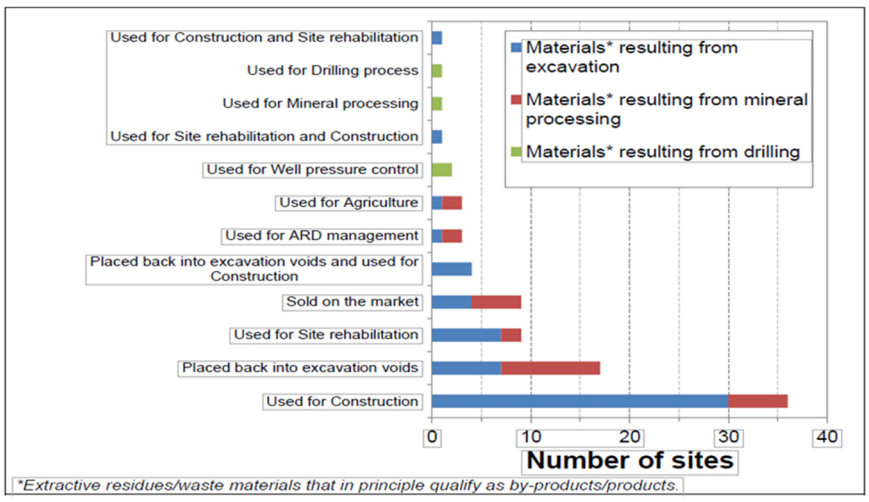

Figure 8.1. Examples of reported use of extractive residues/waste materials. Modified from Ref.18, EU, MWEI BREF, 2018.

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The RWMP should (shall) ensure short and long-term:

- Geotechnical stability of the waste deposition area / waste facility and any structures (dams, ditches, or dykes) or grade piles extending above the pre-existing ground surface
- Geotechnical stability of waste facilities under extreme events (e.g., floods, droughts, freezing conditions, earthquakes, and perpetual disruptive forces, including wind and water erosion)
- Chemical, biological, and radiological stability of the waste
- Reduce risks of negative impacts on the environment and human health
- Exposure to ionizing radiation as low as reasonably achievable (ALARA) and under legislated radiation dose limits
- Passive management systems for long-term waste disposal where possible or minimal or no institutional controls.

The RWMP should (shall) be developed according to Greenland Mineral Resource Act and Radiation Protection Act, Greenland Guidelines (Ref. 1, 2, 29, 42, 43-46), EU Directives and BAT / BREF documents (Ref. 13, 16-18), and international recommendations by ICRP (Ref. 3-12), IAEA (Ref. 19-28, 30, 40, 41), and ICMM (Ref. 52). In Appendix C, a list is presented of what the RWMP should (shall) include but not be limited to. A graded approach should be adopted for the development of the RWMP.

The RWMP should (shall) be reviewed every five years and / or amended, as appropriate:

- In the event of substantial changes in the processes generating waste, the waste facility's operation, change of disposal facility or its ownership, and any unforeseen events that may affect the approved RWMP, etc.
- In the light of information exchange on substantial changes in the BAT, regulatory requirements, etc.

Amendments of RWMP should (shall) be submitted for approval to the Relevant Greenland Authority.

Assessment documents produced under Mineral Resource Act and other guidelines in force in Greenland (Ref.1 and 29) and containing the information required herein may be used where this prevents the unnecessary duplication of information and the repetition of work by the licensee, on condition that all requirements for the development of an RWMP are met.

9 Emergency preparedness

Before commencing operation, each licensee shall develop an emergency preparedness plan.

The emergency preparedness plan should (shall) include, but not be limited to, the following:

- Protocol for immediate accident notification of the competent authority including the information required to help minimize consequences for human health and assess and minimize the extent, actual or potential, of the environmental impacts
- Protocol for immediate information of public and stakeholders
- Assigned roles and responsibilities
- Describe any warning or emergency alarm systems
- Describe implemented methods to control accidents and minor incidents
- Rehabilitation, restoration, and cleanup methods of the environment following an accident, including monitoring of personnel and the environment
- A plan and schedule for periodic testing of the plan and evaluation of the test results and recommendations for improvements based on those results.

The emergency plan should (shall) be reviewed every three years and, where necessary, updated. Emergency preparedness exercises should (shall) be conducted at regular intervals.

10 Closure and long – term stewardship

10.1 Closure

The closure includes decommissioning and rehabilitation of the waste facilities. As promoted by the IAEA, "start with the end in mind," in the project's design phase, the licensee should (shall) prepare an initial closure plan for the waste facility. The initial closure plan should (shall) be updated every five years and when necessary throughout the facility's major milestones. The licensee should (shall) submit the initial closure plan and its updates to the Relevant Greenland Authority for review and approval (Ref.1).

Financial assurances or mechanisms shall be put in place to ensure funds are available to safely shut down, maintain, or decommission the waste management area. Before the start of construction, the funding shall be in place and periodically reviewed and updated as the operation continues, and the liabilities increase. Before commencement of closure activities at the NORM / TENORM waste facility, the licensee should (shall) prepare and submit a final closure plan for review and approval by the Relevant Greenland Authority (Ref. 1). The final closure plan shall be supported by technical studies, including a radiation safety assessment addressing the planned decommissioning and rehabilitation activities, management of generated waste, and accidents that may occur during the closure.

A closure plan should include, but not be limited to:

- Current site conditions and history
- Previous site assessments
- Regulatory end-state criteria to be met, based on new or existing EIA
- General description of proposed activities planned, and the Management System to be put in place to ensure approved work will be undertaken correctly
- Geology
- Seismology
- Geotechnical stability
- Hydrology and Groundwater, including contaminant transport modelling
- Resistance to fluctuations in climatic conditions
- Air quality
- Radiological and non-radiological monitoring of the environment and the authorized liquid and air discharges
  The Monitoring program shall include:
    - Surveillance and periodic maintenance of all structures, systems, and components of the waste management facility
    - Environmental, authorized liquid, and atmospheric discharges
    - Occupational, members of the public, and radiological (environmental) assessment
    - Procedures to report to the competent authority the results of the monitoring and assessments
- Intern inspection procedures and plans for taking action(s) in the event of results indicating no compliance and provision to handle no compliance
- Public information or stakeholder engagement plan
- Decommissioning activities and decontamination procedures for land and structures

- Rehabilitation activities for waste facilities
- Measures to be implemented for radiation protection during decommissioning and rehabilitation
- Procedures for managing the waste generated during the decommissioning and rehabilitation and segregation of waste as required
- Final radiation survey and environmental monitoring of the closed site
- Procedures for long-term stewardship (institutional controls), as described below
- Procedures to report the results of the surveillance, monitoring, and institutional controls.

The Relevant Greenland Authority should (shall) carry out on-site inspections and assess all documents submitted by the licensee. Release from Decommissioning and Reclamation Requirements approval should be issued to operations that demonstrate that decommissioning, reclamation work has been completed and that the objectives of that work have been achieved to the satisfaction of the Relevant Greenland Authority. In this case, the Relevant Greenland Authority can certify the land affected by the closed waste facility has been rehabilitated and communicates the licensee and the stakeholders its approval for closure.

10.2 Long – term stewardship

Long-term stewardship includes institutional controls. To demonstrate the long-term radiological, chemical, and geotechnical stability of the closed facility, the licensee should (shall) perform environmental monitoring for some years (e.g., 5 to 30 years in Canada and Australia) after completion of decommissioning and rehabilitation of the site. Monitoring should be continued after the waste disposal facility's closure for as long as the facility is deemed to remain a potential hazard (site-specific). Based on the surveys of the closed facility's geotechnical, chemical, and radiological stability, it should (shall) be decided if there is a need for further rehabilitation. The licensee or another designated party will be responsible for the institutional control for as long as the Relevant Greenland Authority may require it (see, as an example, the Saskatchewan "Reclaimed Industrial Sites Act"). The institutional control program's design should (shall) be based on a safety assessment and the radiological and non-radiological impact assessment on human health and the environment. The assessments (including contaminant transport modelling) shall be performed for a minimum of 200 years and for as long as it is necessary (e.g., ice age) beyond site closure. The need for, and dependence on, active institutional controls should be minimized during the project site's design and closeout.

Institutional control may be:

- Active, requiring continuous or intermittent human activity to maintain the closed site (e.g., monitoring, surveillance, remedial work, fences, diversion or drainage ditches, etc.)
- Passive, not requiring human intervention and with on-site preventive measures to prevent disturbance of the remediated site (e.g., land use control / restrictions, markers, records, durable engineered covers that withstand intrusion and erosion, etc.).

The licensee should (shall) submit yearly all monitoring results of institutional controls to the Relevant Greenland Authority.

Following the closure of the waste facility, the licensee or designated party should (shall), without delay, notify the appropriate authority of any events or developments likely to affect the stability of the waste facility and any environmental impacts revealed by the institutional controls monitoring results.

When the licensee has completed the work involved in decommissioning, rehabilitation, and institutional controls and the monitoring results shows over the years that the closed tailings facility is physical, chemical and radiological stable, the responsibility for long-term surveillance, monitoring, and maintenance of the site is transferred to the Relevant Greenland Authority or an appointed independent institution.

The time requiring monitoring by the Relevant Greenland Authority or an appointed independent institution shall be projected for a minimum of 200 years and for as long as it is necessary (e.g., ice age).

11 Open and sealed radioactive sources

Open and sealed radioactive sources and radiation generators are used extensively by the oil and gas and minerals industry, and various solid and liquid wastes are produced. The Danish orders, guidelines, and requirements (Ref. 47-50) for import, export, transport, and the safe management of open, sealed, and radiation generators, should (shall) apply in Greenland.

12 Transport

During uranium mining operations, the transportation of various hazardous materials is necessary. These comprise operating materials, like acid, alkali, fuel or explosives, low-level radioactive waste rock, and the final or interim product, like uranium ore concentrates (UOC) or uranium-containing resin. Dangerous goods are transported in Greenland by road (at the site), air, and / or sea.

Transport of hazardous materials and NORM / TENORM waste in Greenland should (shall) follow the international transport regulations and recommendations by IAEA (Ref.27), United Nations (Ref. 34), and International Maritime Dangerous Goods Code (IMDG Code) (Ref. 35).

The IAEA regulations (Ref. 27) contain a classification scheme for radioactive materials, transportation, and packaging requirements, and testing procedures. The focus lies on the provision of adequate packaging to contain safely the radioactive material during normal handling and accident conditions.

13 Management System

The licensee should (shall) prepare and implement a Management System (MS) program for the safe management of NORM / TENORM waste facilities. The program should (shall) be developed following the requirements set out in ISO 14001 or equivalent standards. The management program should be certified (e.g., ISO 9001 and ISO 14001). The licensee should (shall) submit the program to the Relevant Greenland Authority accordingly before starting the planned activity.

A management system shall include, but not be limited to:

- Integration with the site-training program, the corrective actions management, management accountability, and the safety culture
- Management of operational risk
- Assurance of overall improvement of the company's performance
- An accountability system that verifies the completion of activities on schedule
- A process for continuous improvement
- Auditing tools.

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Appendix A Abbreviations and Definitions

Activity	The activity of an amount of radionuclide in a particular energy state at a given time. The unit of activity is Becquerel (Bq).
ALARA	"As Low As Reasonably Achievable", social and economic factors being taken into account. ALARA is a guiding principle in radiation protection, and encourages managers to reduce dose levels as much as possible, even if they are already meeting allowable levels.
BAT	Best Available Technology.
BPT	Best Practicable Technology
BEP	Best Environmental Practice.
Becquerel (Bq)	Becquerel is defined as the activity of a quantity of radioactive material in which one nucleus decays per second.
Clearance	The removal of radioactive materials or radioactive objects within the authorised practices from any further regulatory control.
Competent authority	an authority or a system of authorities in Greenland that regulate the safety of radioactive waste management.
Decay	A process followed by an unstable nucleus to gain stability by the release of energy in the form of particles and / or electromagnetic radiation.
Decay products	A succession of radionuclides, each member of which transforms by radioactive decay into the next member until a stable nuclide results. The first member is called the parent, the intermediate members are called progeny / daughters and the final stable member is called the end product.
Dose constrain	Specific value of individual dose used for the optimization process for planned exposure situations. It is always a fraction of the dose limit.
Dose limit	Means the value of the effective dose (where applicable, committed effective dose) in a specified period which shall not be exceeded for an individual.
Disposal	Emplacement of radioactive waste without the intention of retrieval.
Disposal facility	Facility with primary purpose of which is radioactive waste disposal.
Disused sealed sources	A radioactive sealed source that is no longer used, and is not intended to be used, for the practice for which an authorization has been granted. See HASS below.
Effective dose	Is the sum of the weighted equivalent doses in all the tissues and organs of the body from internal and external exposure.
EIA	Environmental Impact Assessment.

Exclusion	The deliberate exclusion of a particular category of exposure from the scope of an instrument of regulatory control on the grounds that is it not considered amenable to control through the regulatory instrument in question.
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 due to the source or practice is too small to warrant the application of those aspects. IAEA International Atomic Energy Agency.
ICRP	International Commission on radiological Protection.
Inspection	Investigation by or on behalf of any competent authority to verify compliance with national and legal requirements.
Institutional control	Control of a site by an authority or institution designated under the laws of a State. This control may be active (monitoring, surveillance, remedial work) or passive (land use control) and may be a factor considered in the design of a facility.
Ionizing radiation	Energy transferred in the form of particles or electromagnetic waves of a wavelength of 100 nanometers or less (a frequency of 3×10^{15} hertz or more) capable of producing ions directly or indirectly.
Justification	No activities involving ionizing radiation for any purpose can be justified unless it is possible to demonstrate that it will lead to a positive net benefit than harm. The benefits apply to humans and society as a whole while the harm encompasses any increased risk from radiation exposure and apply to humans and the environment. Justification is a necessary prerequisite for any decision regarding radiation exposure.
License	Permission granted in a document by the competent authority to carry out a practice in accordance with specific requirements, conditions laid down in that document.
Licensee	A legal or natural person having overall responsibility for any activity or facility related to the management of radioactive waste as specified in the license.
Limitation	The maximum acceptable radiation exposure and hence the radiation dose of any individual from a regulated radiation source shall not exceed the dose limits established by the regulatory body. In this case, dose limits do not apply to medical exposure or emergencies. ICRP, (Ref.8) suggests that for the control of public exposure an appropriate value for the dose constraint is 0.3 mSv in a year. Greenland NORM guidelines have adopted the dose constraint of 0.3 mSv / y as its first investigation level. Table 5 list the specific activity of radioactive materials that if released to the environment without further controls will not cause a dose above 0.3 mSv / y.
Members of the public	Individuals, who may be subject to public exposure.
Milling	Physical or chemical processes applied on ore.
Natural radiation	Ionizing radiation of natural, terrestrial or cosmic origin.
NORM	Naturally Occurring Radioactive Material.

NORM / TENORM waste	Material in gaseous, liquid or solid form for which no further use is foreseen or considered and which is regulated as radioactive waste (waste containing radionuclides above the clearance levels) by competent regulatory authority under the Greenland legislative and regulatory framework.
Notification	Submission of information to the competent authority to notify the intention to carry out a practice within the scope of this guideline.
Occupational exposure	Means exposure of workers, apprentices and students, incurred in the course of their work.
Open radioactive source	Un-encapsulated radioactive material in the form of gas, aerosol, liquid, or solid, where contact with or spread of the material may occur during use.
Optimization	All exposures shall be kept as low as reasonably achievable (the ALARA principle), technical knowledge, economic and social factors being taken into consideration. ALARA principle is an important component of the ICRP recommended system for radiation protection and is relevant to the management of NORM waste because of the large volumes of material involved. The optimization may include the use of “dose constraints”, which are upper limits on the predicted doses used in the optimization process. These are predetermined levels of dose for particular situations, above which it is unlikely that radiation protection is optimized. In Greenland, authorized liquid and atmospheric discharge limits for NORM management are established, considering a dose constraint of 0.3 mSv / y. The clearance and exemption levels that apply in Greenland have been calculated considering all possible pathways of radiation exposure and a dose constrain of 0.3 mSv / y.
Radioactive material	Material incorporating one or more radionuclides including naturally occurring radionuclides of which the activity or activity concentration cannot be disregarded from a radiation protection point of view.
Radiation exposure	Pathway or exposure route between the radioactive material and the person Exposed.
Radiation generator	A device capable of generating *ionizing radiation*, such as X rays, neutrons, electrons or other charged particles, that may be used for scientific, industrial or medical purposes.
Radiation protection expert	Means an individual or, if provided for in the national legislation, a group of individuals having the knowledge, training and experience needed to give radiation protection advice in order to ensure the effective protection of individuals, and whose competence in this respect is recognised by the competent authority.
Radiation safety officer	Means an individual who is technically competent in radiation protection matters relevant for a given type of practice to supervise or perform the implementation of the radiation protection arrangements, and whose competence in this respect is recognised by the competent authority.
NORM waste management	Handling, pretreatment, treatment, storage or disposal, excluding off-site transportation.
Radon	Radionuclide Rn-222 and its progeny.

Regulatory control	Any form of control or regulation applied to human activities for the enforcement of safe management of radioactive waste and radiation protection.
RWMP	Radioactive Waste Management Plan.
Sealed source	A radioactive source in which the radioactive material is permanently sealed in a capsule or incorporated in a solid form with the objective of preventing, under normal conditions of use, any dispersion of radioactive substances.
Sievert (Sv)	The unit of effective dose. One Sievert is equivalent to one joule per kilogram. 1 Sv = 1 joule / kilogram – a biological effect. The Sievert represents the equivalent biological effect of the deposit of a joule of radiation energy in a kilogram of human tissue.
Storage	Holding of radioactive waste in a facility with the intention of retrieval.
TENORM	Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) – NORM that have been concentrated or exposed to the accessible environment as a result of human activities such as manufacturing, mineral extraction, or water processing.
Waste rock	Material that is excavated from a mine and which does not present any economic value, and therefore have to be disposed of.

Appendix B Parameters to be considered when classifying NORM waste

Origin

Radiological properties:
- Half-lives of radionuclides
- Activity concentration of radionuclides
- Surface contamination
- Dose factors of relevant radionuclides
- Decay products.

Mechanical and physical properties:
- Physical state (solid, liquid or gaseous)
- Size and weight
- Shear strength
- Particle size distribution (which influences shear strength)
- Density
- Plasticity
- Moisture content
- Saturation rate
- Permeability. According to their hydraulic conductivity or coefficient of permeability k (in m/s), extractive waste can be classified in five groups (Ref.18)
- Consolidation
- Porosity
- Compactibility
- Dispersibility
- Volatility
- Miscibility
- Free liquid content.

Chemical properties:
- Mineralogy
- Chemical composition, including the change of chemistry through the treatment of minerals and weathering
- Leaching behaviour
- Physical stability
- Behaviour under pressure
- Erosion stability
- Settling behaviour
- Hard pan behaviour (e.g., crust formation on top of the extractive waste from mineral processing)
- Solubility and chelating agents
- Potential chemical hazard
- Corrosion resistance/corrosiveness
- Organic content
- Combustibility and flammability
- Chemical reactivity and swelling potential
- Gas generation
- Sorption of radionuclides.

Biological properties:

- Potential biological hazards
- Bio-accumulation.

Other factors:

- Volume
- Amount arising per unit of time
- Physical distribution.

Appendix C - RWMP

The RWMP should be developed by the license considering a graded approach commensurate with the project complexity, the physical, geochemical and radiological properties of the generated waste, volume of waste, and its environmental impacts. RWMP should (shall) include but not be limited to:

- Describe how the outcomes of EIA were addressed. Describe how the environment and human health may be affected by the deposition of waste. Describe the preventive measures to be taken
- Radiological impact assessment of waste facilities. The assessment shall cover the full life cycle of the waste facility, including the demonstration that the statutory radiation protection requirements will be met both now and in the future. Describe how the outcomes of radiological impact assessment were addressed
- Risk assessment of the proposed waste facility, covering a minimum of 200 years in the future and up to the next ice age including, i.e., including contaminant transport modeling with stated assumptions and other studies required by the Relevant Greenland Authority. Describe how the outcomes of the risk assessment were addressed
- Description of the processes in which the facility generates NORM/TENORM waste. This information shall also be submitted electronically when the Relevant Greenland Authority develops an electronic system
- Description of each of the waste streams and applied BAT and BEP to minimize the generation of waste
- Estimation of the annual and total volume of waste streams per life of the project
- Waste characterization (Appendix B)
- Waste classification (Chapter 5) and segregation based on maximum inventory radioactivity per year and life of the project
- Description of the proposed preventive, control, and monitoring procedures for:
    - Waste water discharge. Mining and Milling wastewater should (shall) be treated and should (must) meet the authorized discharge limits set by the Relevant Greenland Authority. It is recommended, if possible, that the produced water generated from hydrocarbons, being injected back into the drilling well. If it is not possible to reinject the produced water, the license should provide information on their proposed annual discharges to the marine environment and an environmental and radiological assessment of the marine environment, including also biota. Based on the information provided by the license and the assessed risks to the marine environment, the Relevant Authority may or may not approve the discharge of produced water into the marine environment. The license should commit to monitor (e.g., ^{226}Ra, ^{228}Ra, ^{210}Pb, and ^{228}Th) their discharge of produced water and the surrounding marine environment, e.g., water column, sediment, fish, molluscs. Monitoring results should be used for risk assessment of the marine environment, biota.
    - Emissions to air from the handling, transport, and disposal and from the waste facility itself (emissions e.g., Radon (^{222}Rn) and Thoron (^{220}Rn), Total Suspended Solids (TSS) and Total

Suspended Particles (TSP), e.g., PM10 and / or PM2.5 particles in the air or suspended particles of hydrocarbons (oil and grease) in the liquid waste, volatile compounds emissions from oil and gas, etc.)
    - Acid / Neutral Rock Drainage, and seepage
    - Prevention of water status deterioration
    - Gamma radiation
    - Others.

- Operational limits, conditions, and administrative controls necessary for the waste to be managed safely
- Provisions for personnel training in radiation safety and an appointed RPE or an RPO
- Waste facility site selection, including alternatives. The licensee selects a preferred site and prepares a documented rationale justification for its selection, including an analysis of the alternative sites studied and rejected.
- For hydrocarbons waste, it is recommended, where it is possible, to reinject the sludge in the drilled well. If it is not possible to reinject the sludge, this must be treated and disposed of in an approved radioactive waste disposal facility. Usually, the sludge is treated and fixed in concrete and disposed of in drums, containers.
- Scale disposed of in the instruments can be removed by applying chemicals. In this case, the scale will be dissolved in the produced water. If the scale is removed mechanically, this will not be dissolved in the produced water, and this must be treated and disposed of in the repository facility.

Issues to consider in the site selection process includes but not be limited to the following:

- Environmental considerations:
    - Waste treatment requirements
    - Emissions to surface water
    - Emissions to groundwater (hydrogeological containment)
    - Historical use of the receiving watershed
    - Background environmental conditions
    - Impact on vegetation, wildlife, and aquatic life
    - Natural flora and fauna
    - Archaeological considerations
    - Potential emissions to air
    - Aesthetic considerations
    - Conceptual water balance analysis
    - The effect of climate change on weather conditions
    - Other.

- Planning considerations:
    - Accessibility (road construction)
    - Distance from the mineral processing plant
    - Relative elevation from the mineral processing plant
    - Distance from habitation and areas of human activity
    - Topography (including bedrock topography underlying the quaternary sediment bed when relevant)
    - Existing land and resource use
    - Transportation corridors, power lines, etc.
    - Watershed and surface area considerations
    - Volumetric capacity

    - Pond volume / storage capacity ratio
    - Geology, including potential orebodies
    - Construction material availability
    - Dam foundation conditions
    - Basin foundation conditions (including hydrogeological and compressibility properties of quaternary sediments when relevant, and hydrogeological properties, permeability, and fracture zones of underlying bedrock)
    - Downstream hazards
    - Hydrology
    - Groundwater and contaminant seepage
    - Potential impact area
    - Human and environmental radiological and non-radiological risk
    - Water management scheme and preliminary water balance
    - Operational plan
    - Deposition plan
    - Preliminary containment and water management structures
    - Conceptual risk assessment (including assessment of induced seismicity risks)
    - Health and safety assessment
    - Other.

- Decommissioning and rehabilitation considerations:
    - Flood routing requirements
    - Revegetation potential
    - Long-term physical and chemical, and radiological stability
    - Ease of establishing permanent drainage
    - Reduction and / or control of acid drainage and other contaminants
    - Dust control
    - Long-term maintenance, monitoring, and treatment requirements
    - Other.

- Waste facility site characterization includes but to not be limited to:
    - Climate and meteorology (e.g., rainfall patterns, evaporation rates, prevailing winds, etc.)
    - Geology (e.g., bedrock structure, faults, fractures, shear zones, areas of instability, etc.)
    - Geochemistry (e.g., baselines)
    - Radioactivity (e.g., baselines)
    - Site condition (e.g., physical properties and geotechnical stability of the site)
    - Hydrology (e.g., the potential for flooding and flood volumes, drainage patterns)
    - Hydrogeology (e.g., the potential impact on groundwater and surface water resources and characteristics of quaternary overburden and underlying bedrock, e.g., water permeability of glacial / postglacial sediments, potential compaction, and topography, fracture zones and permeability of underlying bedrock, etc.)
    - Topography of long-term construction (e.g., the influence of watershed, streams, creek system)
    - Proximity to surface water

- Proximity to the coast (seawater)
- Adaptation of the waste deposition area to the surrounding area (e.g., dust, noise, and odor control if there is a residential population nearby)
- Seismic
- Existing land use
- Natural and cultural environment
- Local communities, public perception issues related to the waste facility
- Biodiversity
- Other studies may be required by the Relevant Greenland Authority.

- Detailed design of the waste facility. The licensee applies an integrated design approach that considers all the relevant parameters to optimize the overall environmental, human health, and safety aspects of a project in the short and long term. Parameters to be considered but not limited to:
  - Design
    - Type of facility
    - Topography
    - Waste classification (according to Chapter 7 of herein document and Annex II to Directive 2006/21/EC, the Annex to Commission Decision 2009/360/EC)
    - Construction plan
    - Closure considerations
    - Stability design criteria (hydrology and hydrogeology specific environmental considerations, construction materials, foundations, stability under static and dynamic conditions – failure mode analysis for operational phase, and closure and after-closure phase)
    - Monitoring systems (e.g., piezometers, inclinometers, settlement gauges, drainage water flow monitoring, seepage or leakage detection, temperature, surveillance methods)
    - Other.

  - Hydrology and hydrogeology
    - Hydrological and hydrogeological studies
    - Water balance analysis
    - Water quality
    - Flood design criteria
    - Freeboard requirements
    - Drought design (i.e., water cover requirement)
    - Catchment run-off and diversion arrangements
    - Deposition plan
    - Supernatant (or free) water management (e.g., decant systems, spillways, siphons, pumping stations, natural hazards handling requirements)
    - Drainage water management (e.g., drainage systems, pipes)
    - Seepage management (e.g., filters design, cut-off trench, grout curtain, ditching, dam core design, interception wells, basal structure design)
    - Erosion management plan
    - Other.

- Special environmental considerations
  Seismic risk, seismic attenuation of foundation strata and construction materials, liquefaction potential of foundation strata and construction materials, and climatic conditions are assessed and considered for the design of the waste facility. This includes:

  - Extreme values to be expected (flood, earthquakes)
  - Wind and free water wave impacts
  - Permafrost effects, when relevant
  - Climate (e.g., frost)
  - Fauna and flora (e.g., biodiversity, specific protection measures).
  - Other.

- Foundations, geology, and geotechnical engineering
  - Geomorphology
  - Regional and local geology, faults
  - Stratigraphy
  - Bedrock and soil characteristics (including bedrock fracture zones and quaternary sediment characteristics in glaciated areas)
  - Geotechnical information, including:
    - Compressibility
    - Shear strength
    - Angle of friction
    - Grain size
    - Density
    - Plasticity
    - Fractures
    - Liquefaction potential
    - Permeability
    - Erosion potential
    - Hydraulic fracture
    - Other.

  - Foundation preparation before construction considering:
    - Vegetation removal, including merchantable timber
    - Excavation of organic soils
    - Cut-off walls
    - Groundwater control and containment
    - Bedrock cleaning and slush grouting
    - High-pressure grouting
    - Diversion wells
    - Diversion channels
    - Dewatering requirements
    - Stability
    - Constructability
    - Other construction requirements.

- Construction materials
  The availability of naturally occurring construction materials is assessed, as are the engineering characteristics of these potential construction materials, tailings, grout/concrete, or other

potential liner materials (both natural and synthetic), i.e., with regards to:

- Grain size
- Density
- Volume
- Shear strength
- Permeability
- Acid-generating potential
- Chemical reactivity (acid-generating potential, reaction with pond water, thiosalt-generating potential)
- Wind and water erosion potential
- Other.

- Environmental impacts, stability, and rehabilitation requirements related to the use of any construction materials are considered at this stage.
- Detailed construction plan and qualifications of the contractors and their supervision
- Detailed operation, control, and monitoring procedures in the operational phase
  A comprehensive operation, control, and monitoring plan is developed and covers the entire site life cycle regarding control of the emissions and impacts, their monitoring, monitoring of waste characteristics, and stability.
  It may include but not to be limited:
  - Quality Assurance / Quality Control (QA / QC) system:
    Maintain and have the following elements available throughout the construction, operation, and closure phases:
    - Construction drawings and as-built construction records, including revisions
    - Test results
    - Meeting minutes
    - Construction photographs
    - Monitoring notes
    - Other.

  - Construction control:
    - Planning and scheduling
    - Survey control (layout, as-built records)
    - Grouting monitoring
    - Foundation preparation monitoring
    - Material quality control
    - Compaction control
    - Instrumentation monitoring and data synthesis
    - Record-keeping
    - Construction safety
    - Construction environmental criteria
    - Other.

- Procedures for handling, treatment, storage, and safe disposal of waste
- Gamma radiation, radon, and dust, control:
  It is necessary to minimise gamma radiation, radon, and dust releases from the waste facility area. This may involve keeping the waste wet and / or using short- or long-term chemical or organic covers.
- Conformance checks of waste facility areas

    - Performance monitoring – i.e., visual conformance checks – with a high frequency
    - Groundwater pressure (pore water pressure)
    - Seepage
    - Deformation (settlement and stability)
    - Weather influence
    - Seismic events
    - Special inspection programmes after major events (earthquakes, hurricanes, spring break-up, floods)
    - Indicators of instability:
        - Soft zones and boils along the toe
        - Dirty sediment in seepage
        - Increased seepage rates
        - New areas of seepage
        - Longitudinal and transverse cracking
        - Settlement
        - Other.
    - Areas requiring special attention:
        - Spillways
        - Decant structures
        - Drain and pressure relief wells
        - Concrete structures
        - Pipes and conduits through dams
        - Riprap areas
        - Siphons
        - Weirs
        - Trees and animal dens
        - Other.
- Physical stability monitoring plan:
    - Location of control stations
    - Scheduling (control periods and conformance checks)
    - Type of monitoring (visual conformance checks, measures, and parameters)
    - Appropriate level of instrumentation (e.g., piezometers) with a clearly identified purpose
    - Conformance check methods, data compilation, and evaluation
    - Persons responsible for monitoring
    - Data storage and reporting systems
    - Criteria to assess the monitoring programme
    - Other.

- Water management plan:
    - Hydrology:
        - Severe storm events and drought events
        - Necessary information and parameters for water management activities
        - Criteria to manage water levels within safe limits, including any required daily or seasonal water level control
        - Other.

    - Water control, ensuring that:
        - Safe water management is carried out within the boundaries of the system

        - Water balance analysis is reviewed based on the monitoring findings
        - Damage to all structures is prevented / controlled / repaired
        - Reviews and revision are carried out as required after changes in the design or the construction method and when the pond level exceeds the specified critical elevation and must be performed after major storm or spring melt events
        - Other.

    - Perimeter seepage:
        - Evaluating the potential for seepage from the waste facility area
        - Defining levels and characteristics of acceptable seepage
        - Preparing action plans to deal with deviations from design seepage
        - Measuring performance, including control of seepage within design rates
        - Monitoring and controlling to ensure that systems are performing as per design
        - Other.

    - Hydrogeology and groundwater quality:
        - Monitoring and controlling hydrogeology to ensure that systems are performing as per design
        - Monitoring and controlling groundwater quality to ensure that systems are performing as per design
        - Other.

- Mass balance of extractive waste:
  This ensures the efficient use of the capacity and effective closure of the waste facility area. Short- and long-term scheduling of lifts and raises are also covered in the plan. At present intervals, a schedule for deposition of the waste and a filling curve (volume / elevation graph) are validated against actual field conditions.

- Procedures for health, safety, and environment. This may include but do not limit:
    - Occupational monitoring
    - Training requirements and schedules; monitoring triggers and initiating appropriate responses
    - Adequate control of emissions and discharges of effluents to the environment
    - Maintenance, maintenance requirements and schedules; ongoing verification requirements and schedules
    - A management system that includes periodic internal audit, assessment, and review of the adequacy and effectiveness of procedures instituted under the RWMP to ensure they are up to date and take account of potential improvements consistent with best practicable technology (BPT)
    - An operational stage hazard register
    - Emergency response; and rehabilitation trials, plans, and schedules
    - Safe waste handling and transport procedures

    - Emergency preparedness procedures and a safety management system for implementing it
    - Clearance procedures for materials to be removed or released from the site
    - Procedures for records and reviews
    - Other.

- Monitoring and inspection procedures and plans for taking action(s) in the event of results indicating a rise in environmental impacts or triggers before potential contamination becomes an issue
  The monitoring and records program should (shall) include but not limited to:
    - Surveillance and periodic maintenance by qualified persons of all structures, systems, and components of the waste management facility
    - Monitoring of the environment and authorized liquid and atmospheric discharges to the environment
    - Monitoring of exposures to workers and members of the public
    - Procedures to report to the competent authority in a timely manner the monitoring and assessments results, including any plans for immediate action
    - Other.

  The results should be reported quarterly in the first five years of operation and with monitoring periods and frequency to be re-evaluated and adjusted to achieve stability.

- Waste facility closure plan including decommissioning and rehabilitation outcomes, activities, schedule, after closure institutional control procedures, monitoring, cost estimates, and financial assurances remain up to date to cover those decommissioning costs.
- A plan explaining how any early shutdown or temporary suspension of operations will be managed safely and effectively

- Financial assurances or mechanisms to ensure funds are available to safely shut down, maintain, or decommission the waste management area. Before the start of construction, the funding will be in place and periodically reviewed and updated as the operation continues, and the liabilities increase. Plans for the provision of financial assurances for decommissioning if the licensee is unable to complete decommissioning work (e.g., bankruptcy).

DCE RECOMMENDATIONS FOR GUIDELINES FOR THE SAFE MANAGEMENT OF RADIOACTIVE WASTE GENERATED FROM THE MINERAL AND HYDROCARBONS INDUSTRIES IN GREENLAND

These recommendations for guidelines provide safety requirements and guidance to ensure the safe management of waste containing naturally occurring radioactive materials (NORM) and technologically enhanced naturally occurring radioactive material (TENORM) generated from Greenland's mineral and hydrocarbons industries. The recommendations for guidelines include requirements for all phases of the waste facility, e.g., site selection, site assessment, site design and preparation, construction, operation (e.g., treatment, disposal), closure, site release from licensing, and long-term stewardship. Herein recommendations for guidelines are based on the most recent international standards recommended by the International Commission on Radiological Protection, European Union, International Atomic Energy Agency, and International Council on Mining and Metals. The recommended herein waste management practice is a graduated approach. This means that the greater the risk, the more stringent the mitigation measures should be. The policy, practice, regulation, and supervision should (shall) be continuously improved to comply with the existing best available technologies (BAT), best environmental practices (BEP), and changing levels of understanding within the management of radioactive waste. The Environmental Agency for Mineral Resources Activities (EAMRA) requested in 2018 recommendations for ''Guidelines for the safe management of radioactive waste generated from the mineral activities in Greenland.'' In 2020, EAMRA requested that the DCE also include the safe management of radioactive waste generated from Greenland's hydrocarbons activities in the recommendations. As requested, the recommendations are provided in the format of draft guidelines. However, the Greenland administration's administrative setup is only tentatively indicated and should be further addressed by EAMRA.

ISBN: 978-87-7156-689-5
ISSN: 2244-999X