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**Naturally Occurring Radioactive Material Waste Management in the ASEAN Oil and Gas Industry: A Review**

# Naturally occurring radioactive materials waste management in the ASEAN oil and gas industry: A review

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**Abstract**

Naturally Occurring Radioactive Materials (NORM) are found in the earth crust and ubiquitous in all oil and gas formations. Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) are arisen during oil and gas exploration, extraction and production processes. TENORM waste induced from oil and gas activities can make radiological impacts to human health and the environment, thus how to manage it safely and sustainably is crucially important. In this paper, the researchers review the TENORM waste management systems for oil and gas activities in four ASEAN countries (i.e. Indonesia, Malaysia, Thailand and Vietnam), conduct SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis and compare the related aspects to make recommendations for efficient management. The key findings include: 1) among the four countries, Malaysia has the most comprehensive legal framework for TENORM waste management and only it currently has proper radioactive waste (RW) disposal facilities; 2) some legal/guiding documents on RW or NORM/TENORM waste have been drafted in Indonesia, Thailand and Vietnam; 3) there are challenges in monitoring and sanctioning the oil and gas industry's violations of TENORM-related regulations in Indonesia, Malaysia faces radiation exposure issues, and Thailand will confront with insufficient RW storage, whilst TENORM waste from Vietnam's oil and gas activities is not strictly managed.

**Keywords**

Naturally Occurring Radioactive Materials; Technologically Enhanced Naturally Occurring Radioactive Materials; NORM; TENORM; radioactive waste; oil and gas industry

## Introduction

Naturally Occurring Radioactive Materials (NORM) are present in the earth crust and human beings are exposed to them daily (Ali et al., 2019). At present, there are 12 industries that induce NORM, including (i) extraction and manufacture of Uranium; (ii) extraction of rare-earth elements; (iii) manufacture and use of Thorium and its compounds; (iv) manufacture of Niobium and Ferroniobium; (v) extraction of minerals other than Uranium; (vi) oil and gas production; (vii) manufacture of Titanium dioxide; (viii) Phosphate industry; (ix) Zircon and Zirconia industries; (x) manufacture of tin, copper, aluminum, zinc, lead, iron and steel; (xi) coal combustion; and (xii) water treatment (Dang, 2020). NORM is ubiquitous in petroleum formations worldwide and can become TENORM (Technologically Enhanced Naturally Occurring Radioactive Materials) due to oil and gas exploration, extraction and production activities (Al-Nabhani et al., 2016b). TENORM waste released from such activities and decommissioning activities can make toxicological impacts on marine organisms although there are still very little data to draw such conclusions on this (Jensen et al., 2016; MacIntosh et al., 2022). Some studies show the most occurrence of radium isotopes among radioactive elements in produced water, especially Ra-226, Ra-228 and Ra-224. Inhaling or ingesting just small amounts of radium can result in accumulation of them in the human body, causing bone and sinus cancer (Ali et al., 2020). Produced water also contains the potassium isotope K-40, lead isotopes, especially Pb-214 and Pb-210 and uranium isotopes, especially U-238 and U-235 (Ali et al., 2020). Ionizing radiation resulting from K-40's radioactive decay can damage cells and subsequently lead to cancer while Pb-214 and Pb-210 can be inhaled and retained in the lung causing cancer (Summerlin and Prichard, 1985; Health Physics Society, 2001; Mohankumar, 2005). Inhalation of high concentrations of uranium can also cause lung cancer due to the exposure to alpha particles. Especially, since uranium is a toxic chemical, ingesting uranium can damage kidney from its chemical properties much sooner than its radioactive properties, resulting in bone or liver cancer (CDC, 2022).

Historically, most rules and regulations governing the handling and storage of radioactive materials were intended to apply to the products of nuclear reactors. However, since the discovery of TENORM in the petroleum wastes such as scales, sludges and produced water in the North Sea Oil platforms and US oil field equipment in early 1970s

(Mohsen et al., 2019), many oil and gas industries have sought out ways to detect, forecast, correct, eliminate and manage TENORM waste from the fields and their facilities. Among the ASEAN oil and gas industries, those in Indonesia, Malaysia, Thailand and Vietnam are of interest to make investigations in TENORM waste management. This is due to the fact that Indonesia, Malaysia and Thailand have the strongest oil and gas sectors in ASEAN while Vietnam is also a significant oil and natural gas producer in the region, with great potential in oil and gas reserves which contained 4.4 billion barrels of oil and 0.6 Tcm of natural gas at the end of 2020, being ranked 1st and 3rd, respectively in ASEAN and the likely accelerated upstream sector in the next five years (Austrade, n.d.; Mordor Intelligence, n.d.; BP, 2021; Energy-pedia News, 2021; Le et al., 2023). Furthermore, these countries will experience many oil fields to be decommissioned in the coming years, given the reserve exhaustion (Burdon et al., 2018; Viet Nam News, 2019; Sukbanjongwatthana, 2022; Zawawi, 2022). In such contexts, how to manage TENORM waste from the petroleum industries in these nations safely and sustainably is of high importance. Thus, this research reviews the management systems for TENORM waste from oil and gas operations, including the legal and institutional frameworks as well as current practices in Indonesia, Malaysia, Thailand and Vietnam, carries out SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis and compares the associated aspects so as to make recommendations for better management.

The literature on TENORM waste management in the global oil and gas industry has focused on investigating the activity concentrations of NORM/TENORM in produced water, oil sludge and oil scales (Attar et al., 2015; Ratnayake et al., 2017; De-Paula-Costa et al., 2018; Afifi et al., 2023). Many researchers have also put efforts on developing/describing treatment methods for NORM/TENORM waste from oil and gas fields (Awwad et al., 2015; Al-Nabhani et al., 2016a; Attar et al., 2016; Abdullah et al., 2017; Dwipayana et al., 2019b; Alcântara and Cuccia, 2021; Godoy et al., 2022; Hoang and Pham, 2021). Some researchers paid attention to health impacts of TENORM by proposing a new approach for establishing clearance levels for NORM waste (Sedighian et al., 2015); applying MCNP (Monte Carlo N-Particle) simulation to observe absorbed dose rates of NORM in human body parts (Wang and Landsberger, 2015); examining the annual dose of occupational workers (Khalil et al., 2021); and presenting how the human body can be contaminated with and affected by TENORM (Salama, 2021). Some researchers surveyed laws and regulations on NORM/TENORM, examined how they can protect public health and provided recommendations for better management (Al-Nabhani et al., 2016c; Geltman and LeClair, 2018; Okoro et al., 2019; Cuccia et al., 2021). It should be highlighted that some factors coded in Geltman and LeClair's (2018) survey such as licensing of NORM/TENORM, disposal limits, and definitions of NORM and TENORM are also dealt with in this study. However, while Geltman and LeClair (2018) only counted how many states in the US mentioned these aspects in their laws and regulations, this study scrutinises the content of such aspects as specified in the related legal frameworks in four ASEAN countries.

There have been very few studies on managing NORM/TENORM waste, including the waste from oil and gas activities in Indonesia, Malaysia, Thailand and Vietnam. Regarding Indonesia, researchers estimated the radiological effects of NORM/TENORM waste disposal landfills (Dwipayana1 et al., 2019a, 2020; Anggraini et al., 2021) and investigated the readiness of onshore yards for the upcoming decommissioned offshore structures, including a containment area to collect TENORM waste (Amelia et al., 2021). Meanwhile, Suhana et al. (2015) analysed radioactivity concentration of feed coal burned and ashes from a typical coal fired power plant and Rahmat et al. (2022) estimated the potential exposure and health impacts of tin tailing processing in Malaysia. TENORM waste management in the Malaysian oil and gas industry was explored in terms of the waste management framework (Mohamad, 2015) and a vitrification process to immobilize oil sludge containing NORM (Ruzali et al., 2020). For Thailand, Chanyotha et al. (2012) investigated NORM (i.e., Ra-226, and Ra-228) distributed in different materials produced from mineral industries; Chanyotha et al. (2015) presented the systematic approach to measure NORM concentrations in different industrial wastes; Srisuksawad et al. (2005) reported on TENORM inventory, regulations, laws and the associated problems; whereas Yubonmhat et al. (2022) discussed the progress and challenges in managing radioactive waste (RW), including NORM and TENORM. Vietnamese scholars reviewed the national and international regulations related to NORM waste management; described the characteristics of NORM in some industries; indicated the situation of NORM/TENORM waste management, including NORM/TENORM waste storage; predicted the generation of such waste in the near future; pointed out the shortcomings in NORM waste management in Vietnam and made relevant policy recommendations (Nguyen, 2005, 2019; Bui, 2019; Dang, 2020). Regarding NORM/TENORM waste management in Vietnam's oil and gas industry, Le et al. (2009) examined a method for separation of radionuclides from oil sludge and scales, O'Brien and van Rooyen (2016) reported the NORM survey of a floating production, storage and offloading (FPSO) to facilitate actions for the decontamination and removal of NORM waste from the vessel while Hoang et al. (2017) analysed and evaluated the NORM exposure levels during the oil production process at Bach Ho oil field. However, to the authors' knowledge, no research has been conducted so far to compare the TENORM waste management systems for oil and gas activities, including legal and institutional frameworks as well as practices in these four countries. This study will make such comparisons, particularly with the SWOT analysis in order to make recommendations for safer and more sustainable management in the nations. The researchers obtained data via the Internet search, interviews, online meetings, emails and internal documents of some national agencies dealing with RW in Indonesia and Thailand.

## Overview of NORM/TENORM in the oil and gas industry

The radionuclides found in oil and gas streams mainly belong to the decay chains of the naturally occurring primordial radionuclides U-238 and Th-232 which have very long half-lives and varying activity concentrations in different rock types (IAEA, 2003; Salazar et al., 2021). The most concerned radionuclides are Ra-226 (U-238 decay) and Ra-228 (Th-232 decay) given their radiotoxicity and long half-lives (see Table 1) (Awwad et al., 2015).

In the natural petroleum reservoirs, there is water apart from oil and gas. Such water, normally called produced water, comes along with oil and gas during the production process and contains dissolved mineral salts, some of which may be radioactive, given the existence of Ra-226 and Ra-228 and their decay products (Gazineu et al., 2005; Ali et al., 2020). Since the produced water can be the major waste in terms of size from the oil and gas industry, those radionuclides are the main source of TENORM in the industry (Ali et al., 2020). Radium, the primary radionuclide transported to the surface, can either stay in solution in the produced water or co-precipitate with barium in the form of complex compounds of sulfates, carbonates and silicates present in sludge and scales (Gazineu et al., 2005). The amounts of sludge and scales from extraction and processing activities are relatively significant. For example, the American petroleum industry has the annual production of 225,000 t of sludge and 25,000 t of scales while the European Union produces 10,000 $m^3$ of sludge annually (Gazineu et al., 2005). The typical activity concentrations of TENORM in produced water, sludge and scales are presented in Table 2, while the related concentrations in the actual oil fields of some countries are indicated in Table 3. It can be seen that TENORM concentrations vary in different oil fields, some are far below and some are far above the International Association of Oil & Gas Producers (IOGP)'s (2016) exemption limits (Table 4).

**Table 1.** Radioactive decay characteristics of naturally occurring radionuclides associated with oil and gas production (IAEA, 2003)

| Radionuclide | Half-life | Mode of decay | Main decay product(s) |
|---|---|---|---|
| Ra-226 | 1600 a | Alpha | Rn-222 (noble gas) |
| Rn-222 | 3.8235 d | Alpha | Short-lived progeny |
| Pb-210 | 22.30 a | Beta | Po-210 (alpha emitter) |
| Po-210 | 138.40 d | Alpha | Pb-206 (stable) |
| Ra-228 | 5.75 a | Beta | Th-228 |
| Th-228 | 1.9116 a | Alpha | Ra-224 |
| Ra-224 | 3.66 d | Alpha | Short-lived progeny |

**Table 2.** Concentration of TENORM in oil, gas and byproducts (IAEA, 2003)

| Radionuclide | **Crude oil** (Bq/g) | **Natural gas** (Bq/$m^3$) | **Produced water** (Bq/L) | **Hard scale** (Bq/g) | **Sludge** (Bq/g) |
|---|---|---|---|---|---|
| Ra-226 | 0.0001-0.04 | | 0.002-1200 | 0.1-15 000 | 0.05-800 |
| Ra-228 | | | 0.3-180 | 0.05-2800 | 0.5-50 |

**Table 3.** Concentration of TENORM (Bq/kg) in oil and gas fields worldwide

| Sample | Country/Region | Ra-226 | Ra-228 | Reference |
|---|---|---|---|---|
| Produced water | Egypt | 1.07-34.15 | <0.02-13.26 | Saleh et al. (2018) |
| | Iraq | 20.3-67.3 | | Ali et al. (2017) |
| Oil scales | Brazil | 16100-93200 | 4040-36800 | Matta et al. (2002) |
| | Iraq | 44.8-152.4 | | Ali et al. (2017) |
| | Oman | 3380-17300 | 1360-4310 | Al-Farsi (2008) |
| | UK (East Midlands) | 58800-131600 | 17000-59600 | Garner et al. (2015) |
| Sludge | Brazil | 120-331000 | 110-244000 | Matta et al. (2002) |
| | Iraq | 68.7-312.8 | | Ali et al. (2017) |
| | Oman | 1700-223000 | 1212-34413 | Al-Farsi (2008) |
| | UK (East Midlands) | 480-27700 | 280-8580 | Garner et al. (2015) |

**Table 4.** Exempt activity concentrations of TENORM (IOGP, 2016)

| Radionuclide | Exemption level (Bq/g) |
|---|---|
| Ra-$226_{eq}$ | 10 |
| Ra-$228_{eq}$ | 10 |

Note:
The parent isotopes and their daughter isotopes in secular/transient equilibrium are as follows:
- Ra-$226_{eq}$: Rn-222, Po-218, Pb-214, Bi-214, Po-214
- Ra-$228_{eq}$: Ac-228

## TENORM waste management systems in four ASEAN countries

### 1. Indonesia

#### *1.1 Legal framework*

In 1997, Indonesia issued the Act No.10 Year 1997 on Nuclear Energy to regulate all facilities and activities using nuclear energy. However, the definition of RW[1] as indicated in this Act does not include NORM/TENORM (NECB, 1997). Given its objectives[2], this Act is being amended to include TENORM, covering TENORM from the oil and gas industry. TENORM is managed under (i) the Government Regulation (GR) No. 33 Year 2007 on Safety of Ionizing Radiation and Security of Radioactive Sources, (ii) BAPETEN Chairman Regulation (BCR) No. 9 Year 2009 on Intervention on Exposure from TENORM, and (iii) BAPETEN Chairman Regulation (BCR) No. 16 Year 2013 on Radiation Safety of the TENORM Storage. The latter two are the regulatory basis for BAPETEN as the nuclear regulator in Indonesia to introduce legal requirements for the non-nuclear industry that generates TENORM (Nugroho and Yuliati, 2020).

#### *1.2 Institutional framework*

The National Nuclear Energy Agency (BATAN) is liable for conducting research, development and utilization of nuclear energy and RW management while the Nuclear Energy Regulatory Agency (BAPETEN) is a regulatory body responsible for inspecting, licensing and establishing regulations on these matters, thus authorizing TENORM in Indonesia (Government of the Republic of Indonesia, 2017). BAPETEN is the government institution directly responsible for the President of Republic of Indonesia. In conducting its duties, BAPETEN cooperates with other institutions such as Ministry of Environment and Forestry, Ministry of Energy and Mineral Resources, Ministry of Transportation, Ministry of Trade, Ministry of Research and Technology, National Research and Innovation Agency (BRIN), and Customs. Since 2019, BATAN is part of BRIN. BATAN's unit, the Center for Radioactive Waste Technology (CRWT), is in charge of managing spent fuel and RW with advanced interim storage facilities for them, including treatment and conditioning facilities (Government of the Republic of Indonesia, 2017). Cooperation with those ministries and agencies is essential for issuance of operational licenses of companies which generate TENORM, regulation of transportation, radionuclide content examination, as well as container and personnel certification. The institutional framework for TENORM waste management in Indonesia since 2 September 2021 is as follows:

[1] RW is defined as "any radioactive material and any material as well as equipment that has been contaminated by radioactive material or becomes radioactive due to the operation of a nuclear installation and cannot further be used" (Nuclear Energy Control Board 1997).
[2] As identified in Article 15, this Act aims to ensure "the welfare, the security and the peace of people", as well as "the safety and the health of workers and public, and the environmental protection" (Nuclear Energy Control Board 1997).

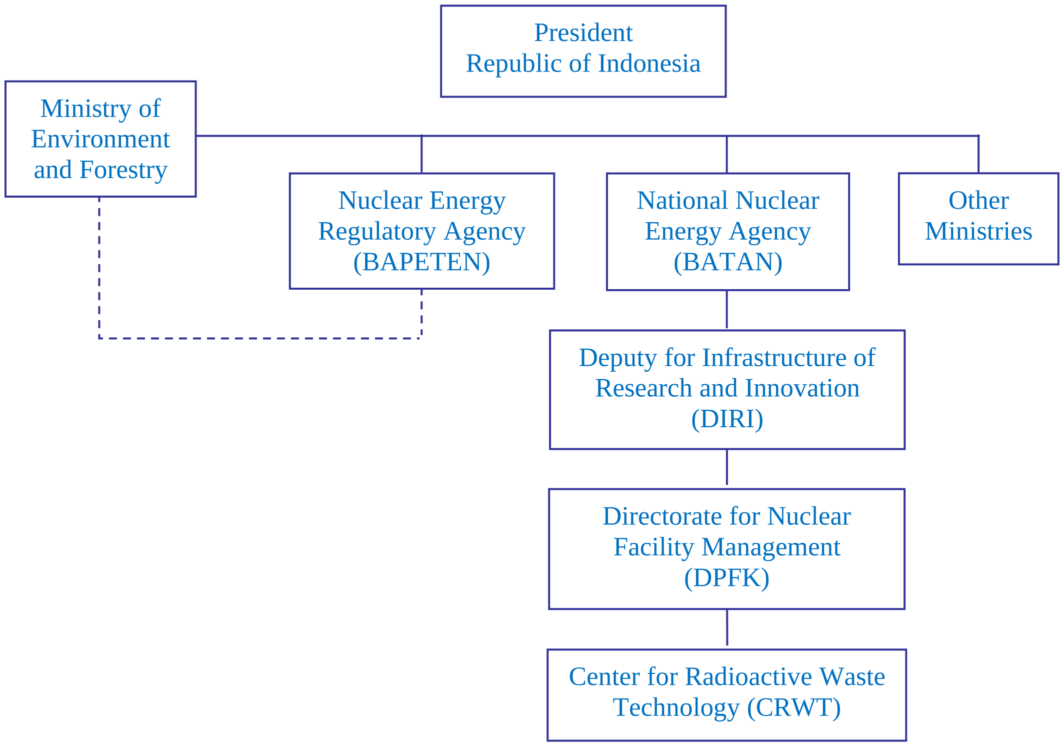


**Fig. 1.** Institutional framework for TENORM waste management in Indonesia (BAPETEN, 2022)

### *1.3 TENORM waste management under current legislation*

#### 1.3.1 Definition of TENORM waste

Based on the GR No. 33 Year 2007, TENORM is the material containing natural radionuclides of U/Th series or K-40 that arise from human activities or technology processes (such as mining or milling) resulting in the increase of potential exposure compared to the initial condition (Government of the Republic of Indonesia, 2007).

#### 1.3.2 Classification of TENORM waste

According to Article 3 of the BCR No.16 Year 2013, TENORM is materials containing radionuclides of U/Th series Th > 1Bq/g or K-40 > 10 Bq/g (BAPETEN, 2013).

#### 1.3.3 TENORM intervention level

The BCR No. 9 Year 2009 specifies rules on radiation safety analysis, evaluation of radiation safety analysis, the intervention level, and implementation of interventions (BAPETEN, 2009). Following this Regulation, every TENORM generator shall undertake a TENORM radiation safety analysis for each TENORM location owned or within the generator's control, considering (i) types and processes of activities implemented; (ii) quantity of TENORM; (iii) type and level of radionuclide concentration; and (iv) radiation exposure and/or highest contamination at TENORM surface. BAPETEN will evaluate the results of such analysis based on the intervention level, comprising (a) the quantity of TENORM being a minimum of 2 tons; and (b) the contamination level ≤ 1

Bq/cm$^2$ and/or activity concentration of 1 Bq/g for each radionuclide in the Uranium and Thorium series or 10 Bq/g for Potassium (BAPETEN, 2009).

1.3.4 Licensing

According to the BCR No. 16 Year 2013, any TENORM storage facilities must obtain a licence for storing radioactive substances from BAPETEN and fulfill radiation safety requirements, including management, radiation protection and technical requirements as well as safety verification (BAPETEN, 2013).

1.3.5 Transportation, including transboundary movement of TENORM waste

Articles 44 and 45 of the GR 61 Year 2013 only regulate transboundary movement of nuclear materials for research reactor fuel and nuclear spent fuel. Moreover, Article 46 states that it is prohibited for RW entering Indonesian territory, except the waste originating from radioactive materials or sources produced in Indonesia (Government of the Republic of Indonesia, 2013). If re-exporting is impossible, RW will be transferred to and managed by the CRWT (Government of the Republic of Indonesia, 2017).

1.3.6 Handling facilities and techniques

Following the BCR No. 16 Year 2013, the design of the TENORM storage facility must meet the dose limit for the public that does not exceed 0.3 mSv/year. In order to protect the public from radiation exposure and contamination, the TENORM storage facility shall be located in the area not easily accessible by the public, controlled for access and equipped with radiation signs. For environmental protection, it shall be designed to avoid or minimize the potential for spreading TENORM to the environment by water, wind or air; equipped with a system to prevent contamination of surface water and ground water; and located away from the reach of tides/waves and free flooding (BAPETEN, 2013).

*1.4 TENORM waste management practices*

1.4.1 TENORM waste generated from the oil and gas industry

By 2021, there were no databases and inventories for TENORM waste in Indonesia (Wisnubroto et al., 2021). TENORM resulting from oil and gas companies is generally in the form of slag from pipe cleaning using garnet. All waste is usually collected in an intended area within the company's boundary. Such waste needs to be examined whether its radionuclide content is higher than 1Bq/g for U/Th series or higher than 10 Bq/g for K-40. If the result is higher than those values, the company should apply for storage licence by fulfilling all the related requirements.

1.4.2 Handling facilities and techniques

TENORM at present is managed by companies generating TENORM. Currently, there is no final disposal available or plan to develop final disposal for TENORM in the near future due to difficulties to find location and necessity to conduct coordination among institutions. A conceptual design for a pilot TENORM waste landfill (Fig. 2) was devised by BATAN with the principle that the landfill must ensure radiation safety in the long term while saving the costs for TENORM generators (Wisnubroto et al., 2021).

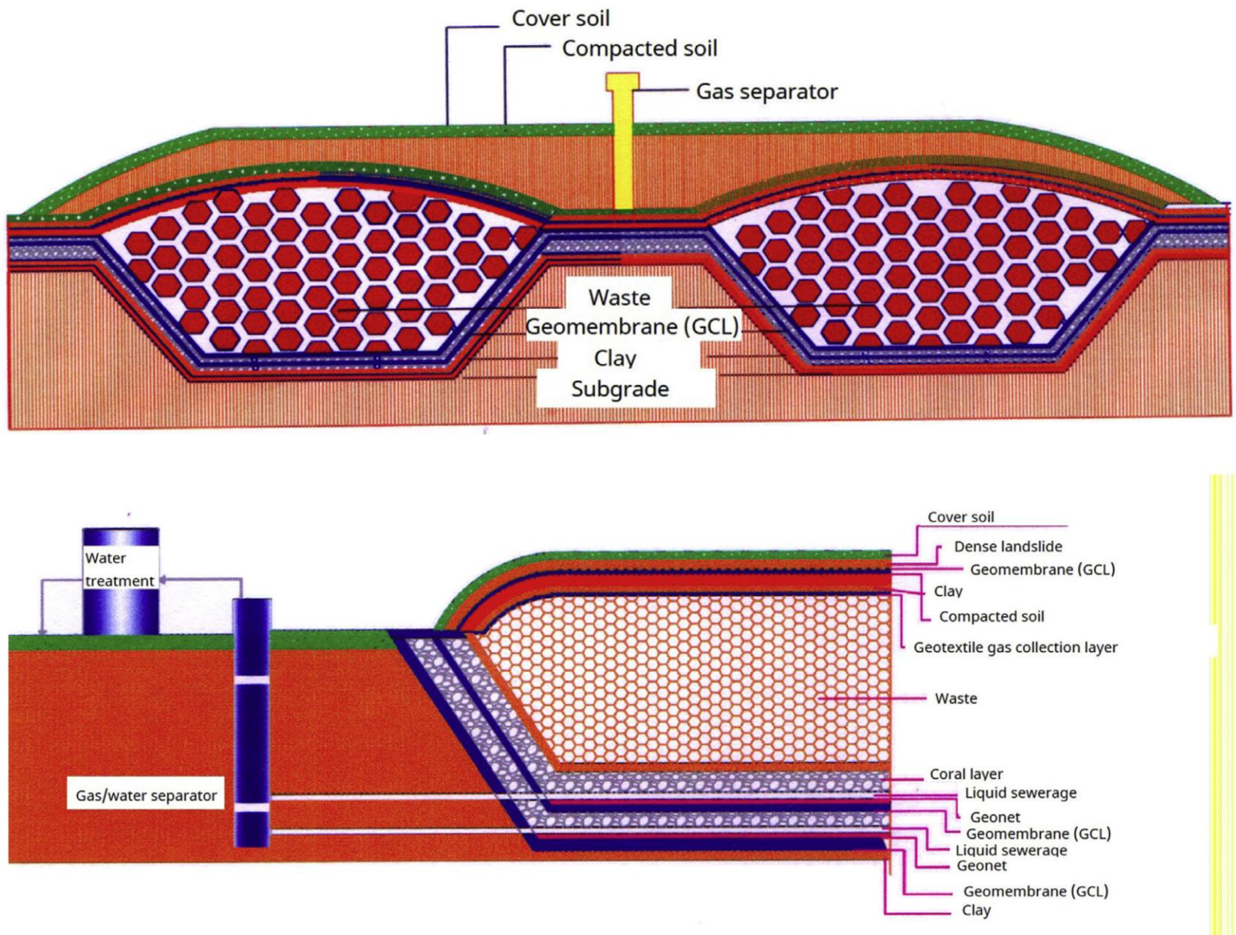


**Fig. 2.** BATAN's conceptual design of TENORM waste landfill (Wisnubroto et al., 2021)

## 2. Malaysia

### *2.1 Legal framework*

In Malaysia, the main legal document directly related to TENORM is the Atomic Energy Licensing Act 1984 (Act 304) which provides the regulation and control of atomic energy. With the presence of Act 304, the standards on liability for nuclear damage are established and the matters therewith or related thereto are connected. The scope of Act 304 is to control any radioactive materials which include nuclear materials, prescribed substances, or irradiating apparatus in medical and non-medical application (Parliament of Malaysia, 1984).

The hierarchy of Malaysian legal system for radioactive material management consists of four parts and is shown in Fig. 3.

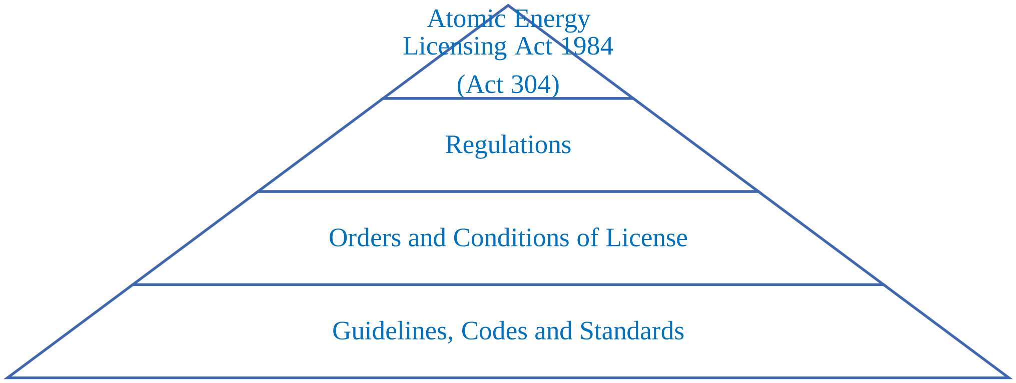


**Fig. 3.** Malaysian legal system for radioactive material management (Muhamad and Afidah, 2018)

The explanation of the hierarchy system is as follows:

- **Act**: Provides the basic law for the control and regulation of atomic energy, establishing the standards on liability for nuclear damage and connecting matters therewith or related thereto.
- **Regulations**: Provide more detailed provisions entrusted by the Act. The regulations would include
  - Radiation Protection (Licensing) Regulations 1986
  - Radiation Protection (Transport) Regulations 1989
  - Atomic Energy Licensing (Radioactive Waste Management) 2011
  - Atomic Energy Licensing (Basic Safety Radiation Protection) Regulations 2010
- **Orders and Conditions of License**: Provide additional requirements which are not indicated in the regulations or special issues relating to the provisions entrusted by the Act.
- **Guidelines, Codes and Standards:** Provide guides, codes and standards to follow and attain goals set in the regulations (Muhamad and Afidah, 2018). As of July 2022, there are 61 technical guidelines (LEM/TEK) and 8 general guidelines. The main guidelines that are related to TENORM waste management in the oil and gas industry include:
  - Guidelines on Radiological Monitoring for Oil and Gas Facilities Operations Associated with Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) (LEM/TEK/30);
  - Code of Practice on Radiation Protection Relating to Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) In Oil and Gas Facilities. (LEM/TEK/58); and
  - Guidelines on Preparation Program for Radiation Protection (LEM/TEK/45).

If a person violates Act 304, such as discharging TENORM to the environment or causing health, safety and welfare impacts at workplace due to the absence of appropriate licences, the person will also violate Environmental Quality Act, 1974 (Act 127) under Section 51(d) and Occupational Safety and Health Act 1994 (Act 514), respectively (DOE, 1974; DOSH, 1994).

*2.2 Institutional framework*

In Malaysia, the main institute in charge of NORM waste management is the Atomic Energy Licensing Board (AELB). The AELB is established under Section 3 of the Act 304 with the responsibilities to supervise and control the RW management in Malaysia, which also includes the potential radioactivity harm to human and the environment. The objective of the AELB is to ensure safety, security and safeguard of peaceful nuclear activities (Parliament of Malaysia, 1984). Fig. 4 shows the AELB's institutional framework.

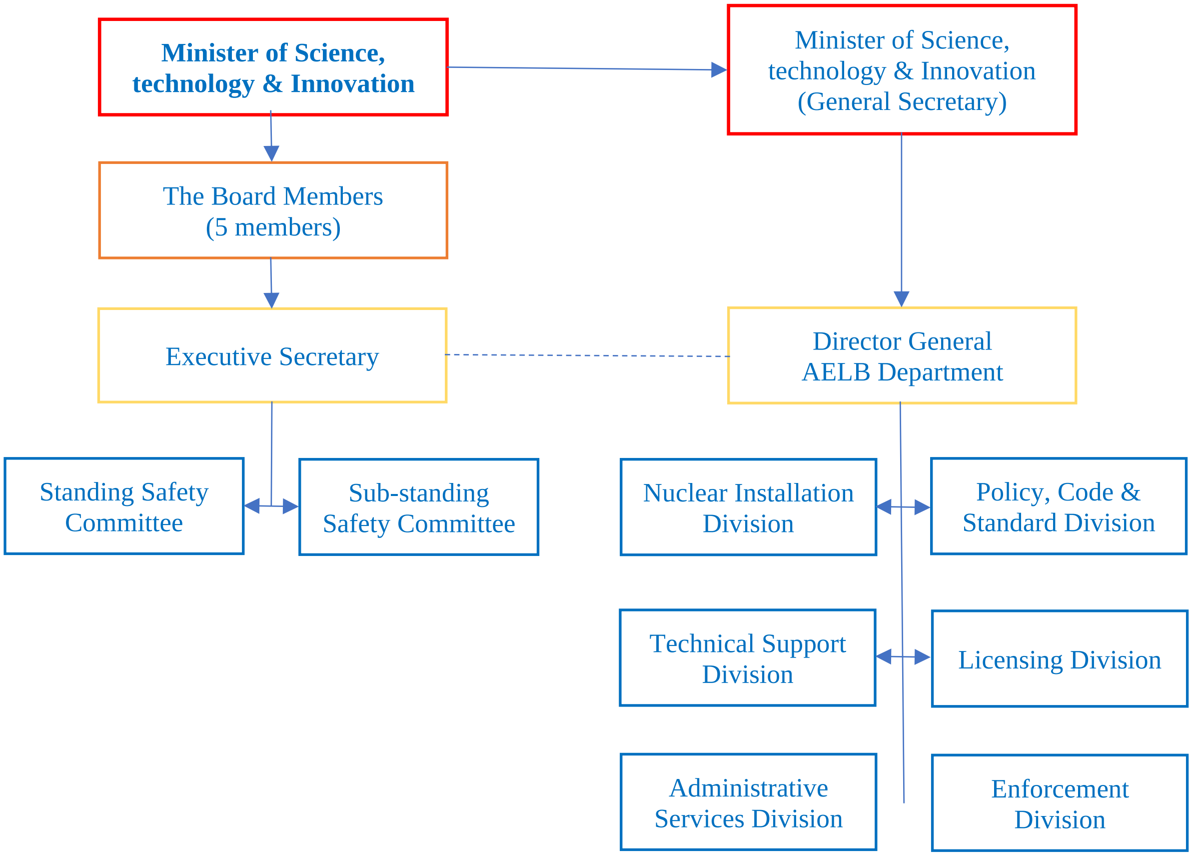


**Fig. 4.** AELB's institutional framework (Teng, 2015b)

The AELB is formulated under the Ministry of Science, Technology and Innovation (MOSTI), Malaysia. The Board consists of total five members which are appointed by the Minister. A Chairman will be appointed among the five members who shall have technical or scientific qualifications related to atomic energy or other disciplines connected therewith (Parliament of Malaysia, 1984). The Board shall include two representatives, one from the Ministry of Health and one from the MOSTI (Parliament of Malaysia, 1984; Radioactive Waste Management Project Group, 2007). The executive secretary of the Board shall be the head of the department in the MOSTI (Parliament of Malaysia, 1984). Under the executive secretary, the Standing Safety Committee and Sub-standing Safety Committee will assist the Board and under the Director General of the AELB, there are six divisions which provide technical support and assistance in the administration of the Board as illustrated in Fig. 4.

### *2.3 TENORM waste management under current legislation*

#### 2.3.1 Definition of TENORM waste

NORM, TENORM and TENORM wastes are clearly defined in the LEM/TEK/58 as follows:

- ‘NORM’ means ‘a radioactive material in its natural state containing no significant amounts of radionuclides other than naturally occurring radionuclides’;
- ‘TENORM’ means ‘a material in which the activity concentrations of the naturally occurring radionuclides have been technologically enhanced from its natural state’; and
- ‘TENORM waste’ means ‘materials having no foreseeable use that contains or is contaminated with radionuclides at concentrations or activities greater than control limit as established by the appropriate authority’ (AELB, 2016).

#### 2.3.2 Classification of TENORM waste

According to the LEM/TEK/58, there are two groups/categories of TENORM waste that can be found at oil and gas facilities:

- Group I - waste activity concentration radionuclide in sludge and scales; and
- Group II - waste measured by way of external dose rate (contaminated materials such as tubular, pump etc.) (AELB, 2016).

#### 2.3.3 TENORM intervention level

Following the LEM/TEK/58, the control limit for radionuclides of $^{238}$U and $^{232}$Th is 1 Bq/g and K-40 is 10 Bq/g (AELB, 2016). Any material that contains TENORM which exceeds these limits is seen as radioactive material (Teng, 2014). The LEM/TEK/58 also sets the control limits for different parameters in order to provide guidance on the level of radiation or activity of a practice that needs to be controlled by the AELB (AELB, 2016). The summary of the limits is given in Table 5.

**Table 5.** Control limits (AELB, 2016)

| Item | Parameter | Limit |
|---|---|---|
| 1. | External dose rate | 0.5 μSv/h |
| 2. | Contaminated materials:<br>- External dose rate at 5 cm from surface | 0.5 μSv/h |
| 3. | Waste categorization based on activity concentration of radionuclide from U-238 and Th-232 series | 1 Bq/g (inclusive background) |
| 4. | Waste disposal:<br>- Dose to critical group | 0.3 mSv/y |

Before comparing the actual exposures with the control limits, the background radiation levels will be usually subtracted and in practice, only working areas with potential radiation exposures are monitored. The RW having the activity levels lower than the control limits will be exempted from the control by the Board; however, they may still be subjected to other legislative requirements, such as Act 127. The operators still bear the responsibility to manage the exempted RW in compliance with such legislative requirements (AELB, 2016).

For the handling of TENORM waste, including solid or semi-solid waste induced from offshore and onshore oil and gas facilities, the control limit is set to be 1 Bq/g (inclusive background) based on the radionuclide of U-238 and Th-232. The handling activities referred here include accumulation, storage, treatment, recycling and disposal. The waste resulted from oil and gas activities could be in the form of sludge, scales, contaminated sand, etc. (AELB, 2016).

### 2.3.4 Licensing

There are eight classes of licences corresponding to different types of material and activity under the Radiation Protection (Licensing) Regulations 1986 (MOSTI, 1986). As stated earlier, according to Act 304, a licence is required prior to activity execution. The description of the licence classification is as follows.

**Table 6.** Licence classification (MOSTI, 1986)

| Class | Material Type | Activity |
|---|---|---|
| Class A | Radioactive Materials (sealed source and unsealed source) | Manufacture, Trade in, Produce, Process, Purchase, Own, Possess, Use, Transfer, Handle, Sell or Store |
| Class B | Nuclear Materials | Same as Class A |
| Class C | Irradiating Apparatus | Same as Class A |
| Class D | Radioactive Materials, Nuclear Materials, Prescribed Substances or their wastes | Transport |
| Class E | Radioactive Materials, Nuclear Materials, Prescribed Substances, Irradiating Apparatus or their wastes | Import or Export |
| Class F | Nuclear Installations | Site, Construct or Operate |
| Class G | (i) Radioactive Materials, Nuclear Materials, Prescribed Substances or their waste<br>(ii) Milling Installations, Nuclear Installations, Waste Treatment Facilities, Irradiating Apparatus or Sealed Source Apparatus | - Dispose or Store (i)<br>- Decommission (ii) |
| Class H | Others | Control of activities not covered by Classes A to G, inclusive |

### 2.3.5 Transportation, including transboundary movement of TENORM waste

The transportation of TENORM waste shall comply with Radiation Protection (Transport) Regulation 1989. According to the regulation, TENORM waste of each radionuclides from U-238 and Th-232 series, which has the activity level more than the control limit, 1 Bq/g, will be classified as Low Specific Activity (LSA) material under category LSA-I. The transportation package required shall satisfy the requirement of Industrial Package Type 1 (IP-1). The radiation level shall be kept under 0.1 mSv/h at any point 2 meters from the outer lateral surfaces of the conveyance, at any point 2 meters from the vertical planes projected from the outer edges of the conveyance and 2 mSv/h at the surface (MOSTI, 1989; AELB, 2016).

### 2.3.6 Handling facilities and techniques

*Accumulation and Storage*

The storage of TENORM waste generated from petroleum operations is only temporary while waiting for further processing or disposal. The waste shall be sufficiently contained such as in drums and shall not contaminate other items. It shall also be stored in a designated area. The operator shall comply with a required Radiation Protection Program in order to protect the employees at the storage facility from TENORM exposure. The waste shall be separated following the source of origin and appropriately labelled (AELB, 2016).

*Recycling, Treatment or Recovery*

The methods of waste recycling, treatment or recovery include low temperature recovery, incineration or thermal treatment, and biological treatment or land farming. However, such activities could induce secondary waste with potential magnification of radioactivity (AELB, 2016).

*Disposal*

For the disposal of NORM waste in the oil and gas industry, according to LEM/TEK/58, the control limit is set to be 0.3 mSv/y, based on dose constraint. A Radiological Impact Assessment (RIA) shall be undertaken to assess the dose received by a critical group of the public resulting from TENORM waste disposal for each radionuclide from U-238 and Th-232 series higher than 1 Bq/g. The calculated dose shall not go beyond the imposed control limit (AELB, 2016). Waste generated from oil and gas operations may be contaminated by other toxic or hazardous materials, then a TENORM disposal method may not be appropriate for such materials. Thus, a preferred method for TENORM disposal shall solve all issues of radioactive and non-radioactive contaminants in accordance with all the relevant regulations. Some possible disposal methods include: reinjecting aqueous or slurry wastes into the oil field or abandoned well; diluting produced water and aqueous wastes by discharging into the sea; encapsulating and burying solids, sludge and scales; constructing engineered facilities for burying encapsulated or unencapsulated wastes; landfilling treated sludge or slag or ash and scales, etc. (AELB, 2016). The design of TENORM waste disposal facilities is detailed in Section 6 of LEM/TEK/76 (AELB, 2020). The TENORM waste with activity concentration lower than 100 Bq/g is classified as very low-level waste (VLLW) and the suitable landfilling facilities for it would be engineered surface type with limited regulatory control (see Fig. 5). The TENORM waste with activity concentration higher than 100 Bq/g and up to 400 Bq/g is classified as low-level waste (LLW) and the suitable landfilling facilities for it would be engineered near surface type, which can provide robust containment and isolation for several centuries (see Fig. 6) (AELB, 2020).

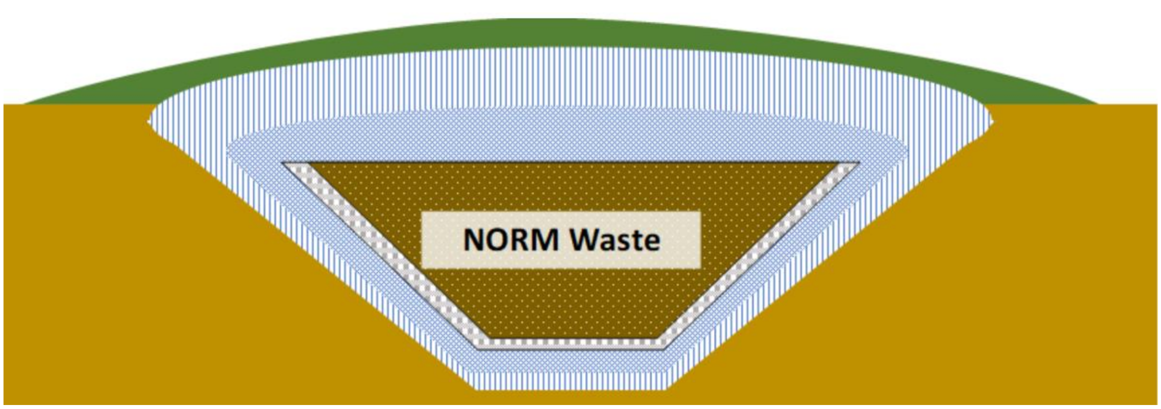


**Fig. 5.** Example illustration of a landfill disposal facility with engineered surface features (AELB. 2020)

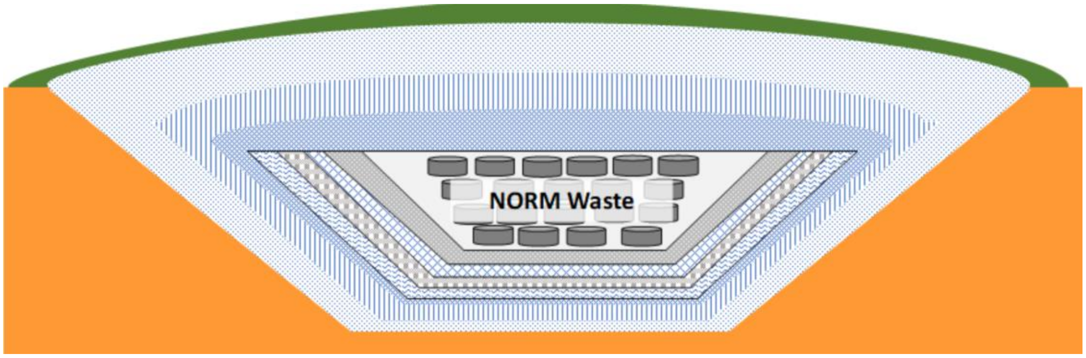


**Fig. 6.** Example illustration of a landfill disposal facility with engineered near surface features (AELB, 2020)

*2.4 TENORM waste management practices*

2.4.1 TENORM waste generated from the oil and gas industry

A study shows that oil sludge-based TENORM waste from Labuan crude oil terminal (LCOT) has the total activity concentration (TAC) values higher than the limit set by the AELB for all licensed NORM waste while that from Miri and Terengganu crude oil terminals (MCOT and TCOT, respectively) has TAC values less than the limit (Ismail et al., 2011) (see Table 7).

**Table 7.** Activity concentration of oil sludge-based TENORM waste from Malaysian oil fields (Ismail et al., 2011)

| Sample | Activity concentration (Bq/kg) | | | | | TAC (Bq/g) |
|---|---|---|---|---|---|---|
| | Th-232 | U-238 | Ra-226 | Ra-228 | K-40 | |
| LCOT | NA | NA | 246 ± 47 (210-320) | 256 ± 157 (21-420) | NA | 3.5 ± 2.7 (1.4-5.3) |
| MCOT | NA | NA | 97 ± 73 (17-260) | 82 ± 76 (14-270) | NA | 1.2 ± 1.0 (0.3-3.7) |
| TCOT | 22 ± 14 (9-48) | 22 ± 17 (14-53) | 13 ± 8 (7-45) | 16 ± 7 (11-28) | 334 ± 113 (238-600) | 0.2 ± 0.1 (0.1-0.5) |
| Control limit | | | | | | 3 |

Note:

- NA: data not available
- TAC = (6 × $^{226}$Ra) + (8 × $^{228}$Ra)[(7)]. Error bar indicates 1 standard deviation.

2.4.2 Handling facilities and techniques

Disposal options available in Malaysia include: (i) disposal of at municipal disposal sites (for RW with radioactivity of extremely low level (and below the AELB's limit) and the radiation hazard being technically negligible or insignificant) and (ii) shallow land burial (for waste containing short to medium half-lived radionuclides). Examples of shallow land burial facilities are Engineered Cell 1 and Engineered Cell 2 in Bukit Kledang, Mukim Belanja (Nuclear Malaysia Training Centre, n.d.; Teng, 2015a). Kualiti Alam Waste Management Centre does not have licence from the AELB for disposing RW but has the licence for temporary disposal of TENORM (Noordin, 2013).

## 3. Thailand

*3.1 Legal framework*

Thailand is a member state of IAEA (IAEA, 2021). With the cooperation with the IAEA, Thailand has established the national Act to regulate, inspect ad monitor the activities regarding radioactive and nuclear materials. The Nuclear Energy Act for Peace Act, B.E. 2559 (2016) entered into force in February 2017. The Act was established in order to replace the Atomic Energy for Peace Act B.E. 2504 (1961) and provide basic law to regulate radiation and nuclear activities on safety, security and safeguards; and to comply with necessary international legal instruments (NAT, 2016). The Act was amended by the Nuclear Energy Act for Peace No. 2, B.E. 2562 (2019). Any intended activities related to radioactive materials and RW, such as production, ownership, utilization, importation, exportation, transition, and discharge must comply with this Act and a licence must be obtained from the regulatory body (NAT, 2016, 2019). The related legislations include:

Ministerial Regulation:

- Ministerial Regulation on Radioactive Waste Management, B.E. 2561 (2018)
- Ministerial Regulation on Radiation Safety, B.E. 2561 (2018)
- Ministerial Regulation on Permission to Import Radioactive Waste into and Export out of the Kingdom, B.E. 2561 (2018)
- Draft Ministerial Regulation on Rules, Procedures, and Conditions Regarding Nuclear and Radiation Safety and Security in Transportation of Radioactive Material, Nuclear Material, Radioactive Waste, Nuclear Fuel, and Spent Nuclear Fuel (2017)
- Draft Ministerial Regulation on Prescribing Rules, Procedures, and Conditions for Radioactive Waste Management by Radioactive Waste Producers and Radioactive Waste Transferred to the Government Agency for Management (2017)

Nuclear Energy for Peace Commission (NEPC) Requirement:

- NEPC Requirement on Safety Criteria, B.E. 2562 (2019)

Office of Atoms for Peace (OAP) Guideline:

- Draft OAP Guideline on Designation of the Customs Checkpoints that License Imports, Exports, or Transits Radioactive Material, Nuclear Material, or Radioactive Waste (2016)

### *3.2 Institutional framework*

Under the Act (NAT 2016), three governmental units: the Ministry of the Higher Education, Science, Research, and Innovation (MHESI), the NEPC and the OAP are assigned to control the energy utilisation and establish the relevant regulations, requirements and fundamental guidelines. OAP is permitted to be the regulatory body. OAP performs regulatory functions such as developing regulation, licensing and performing assessment and inspection. Therefore, all the activities must obtain a licence from the Secretary-General of the OAP. Prior to 21 April 2006, OAP was assigned to function as both utilising nuclear energy and radiation and regulating its safety. To allow OAP to become an effective regulator, the Cabinet resolution on November 21, 2006 established Thailand Institute of Nuclear Technology (TINT) and ordered the transfer of business functions and budget involving nuclear research and development from OAP to TINT. Both units are working hand in hand to promote continuous development of policies and strategies for RW management (Yubonmhat et al., 2022). TINT is a waste operator that is responsible for RW management operation in the country while OAP issues licences to the waste producers and waste operators. The RW in the correct form is transferred from the waste producers to the unit subordinate to TINT, Radioactive Waste Management Center (RWMC) based on the waste acceptance criteria (WAC). As part of the waste acceptance process, the operator should carry out verifications and controls when waste is received for disposal. The major elements of the waste acceptance process should be presented to the regulatory body for approval, for example as part of the safety case for the application of a licence. The waste is then managed and ultimately, the waste will be disposed of in a licensed RW disposal facility. However, to date, disposal of RW containing artificial radionuclides is still not permitted in Thailand, except NORM disposal (Yubonmhat et al., 2022). The hierarchy of the regulatory bodies and the associated legislation are depicted in Fig. 7.

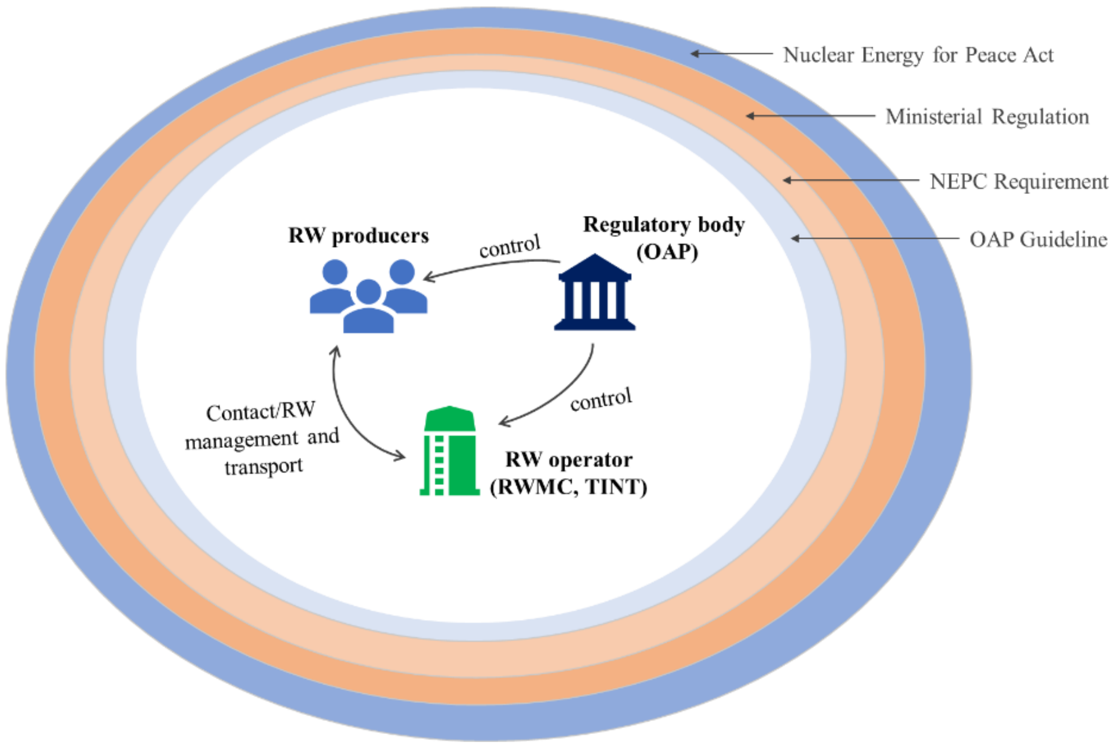


**Fig. 7.** Nuclear and radiation legislations in Thailand and the organisations associated with RW.

### *3.3 TENORM waste management under current legislation*

#### 3.3.1 Definition of TENORM waste

According to the NEPC Requirement on Safety Criteria, B.E. 2562 (2019), the material that has the activity content (i.e., activity concentration, total activity) higher than the specified levels must be considered as RW (NEPC, 2019). By interpretation of the Act and the NEPC Requirement, NORM waste can be considered as RW. NEPC specifies the activity concentrations for the materials (with a volume of more than 3 tons) contaminated with NORM not to exceed the values indicated in Table 8. Therefore, the materials contain or are contaminated with NORM in the levels of higher than these values must be considered as RW.

**Table 8.** Levels of activity concentration for materials contaminated with NORM (NAT, 2019).

| Radionuclide | Activity concentration (Bq/g) |
|---|---|
| **K-40** | 10 |
| **Radionuclides in the Uranium Series** | 1 |
| **Radionuclides in the Thorium Series** | 1 |

### 3.3.2 Classification of TENORM waste

According to the Ministerial Regulation on Radioactive Waste Management, B.E. 2561 (2018), Thai RW can be divided into 5 classes (MOST (Thailand), 2018c) (see Table 9). This regulation also permits TENORM waste producers to manage their own waste (if capable) using the following methods: treatment, conditioning and disposal.

**Table 9.** Classification of RW (MOST (Thailand), 2018c)

| Waste class | Half-life ($T_{1/2}$) | Activity concentration or total activity (A) |
|---|---|---|
| Very short-lived waste (VSLW) | $T_{1/2} \leq$ 100 days | A > B |
| Very low-level waste (VLLW) | $T_{1/2}$ > 100 days | A ≤ 100×B |
| Low level waste (LLW) | 100 days < $T_{1/2} \leq$ 30 years | A > 100×B |
| | $T_{1/2}$ > 30 years, for alpha emitting radionuclides | A ≤ 4000 Bq/g, for each package |
| | | Average ≤ 400 Bq/g |
| Intermediate level waste (ILW) | $T_{1/2}$ > 30 years | Restricted A, not to generate the heat quantity of 2 kW/m3 (or less) |
| | $T_{1/2}$ > 30 years, for alpha emitting radionuclides | A > 4000 Bq/g, for each package |
| | | Average> 400 Bq/g |
| High level waste (HLW) | - | High A, enough to generate the heat quantity of over 2 kW/m3 |

Note:

- B is the activity content levels specified in the NEPC Requirement (NEPC, 2019)
- $T_{1/2}$ = Half-life

### 3.3.3 TENORM intervention level

Thailand establishes the levels at which controls are needed to protect workers, the public, and the environment. According to the Ministerial Regulation on Radiation Safety, B.E. 2561 (2018) (MOST (Thailand), 2018b), equipment and waste materials shall be considered to be contaminated with TENORM if the external surface contamination contains TENORM at levels exceeding those specified in Table 9 and shall be decontaminated before being reused (MOST (Thailand), 2018b). However, if it is not possible to decontaminate the material surfaces, the materials must be considered as RW and managed according to the regulation (MOST (Thailand), 2018c). Materials and waste media containing TENORM at levels lower than those listed in Table 10 shall be exempted.

**Table 10.** Thailand TENORM exemption levels (MOST (Thailand), 2018b)

| Radionuclide | Activity concentration (Bq cm$^{-2}$) |
|---|---|
| **Beta and Gamma emitters and low toxicity Alpha emitters** | 0.4 |
| **All other Alpha emitters** | 0.04 |

In operating facilities, situations arise where workers might need to conduct intrusive work, such as clean-up or maintenance, on equipment that is potentially contaminated with TENORM. In the regulation (MOST (Thailand), 2018b), the dose limit to occupational workers and members of the public are set. The details are shown in Table 11.

**Table 11.** Thailand dose limit for occupational workers and members of the public (MOST (Thailand), 2018b)

| | **Occupational** | | | **Public** |
|---|---|---|---|---|
| **Type of limit** | ***General radiation worker*** | ***Pregnant or breastfeeding woman*** | ***16 to 18 year-old apprentices or*** **students** ***who are being trained for employment involving radiation or use sources in the course of their studies*** | |
| **Annual effective dose** | **20 mSv**, averaged over 5 consecutive years. The dose in any one year shall not exceed 50 mSv and 100 mSv in 5 years. | **1 mSv**<br>- A higher annual dose could be allowed in a single year in special circumstances.<br>- However, the average over 5 consecutive years shall not exceed 1 mSv/year. | **6 mSv** | **1 mSv**<br>- A higher annual dose could be allowed in a single year in special circumstances.<br>- However, the average over 5 consecutive years shall not exceed 1 mSv/year. |
| **Annual equivalent dose to:** | | | | |
| Eye lens | **20 mSv**, averaged over 5 consecutive years. The dose in any one year shall not exceed 50 mSv and 100 mSv in 5 years. | **15 mSv** | **20 mSv** | **15 mSv** |
| Skin | **500 mSv**, averaged over 1 cm$^2$ of the most highly irradiated area of the skin. | **50 mSv** | **150 mSv,** averaged over 1 cm$^2$ of the most highly irradiated area of the skin. | **50 mSv** |
| Hands and feet | **500 mSv** | **50 mSv** | **150 mSv** | **50 mSv** |

### 3.3.4 Licensing

Following Section 19 of the Nuclear Energy Act for Peace Act, B.E. 2559 (2016), anyone who (i) produces, possesses, or uses a radioactive material; and (ii) imports, exports, or transits a radioactive material shall obtain a licence from the Secretary General (NAT, 2016). The application for a licence and the granting of a licence or licence substitute shall comply with the rules, procedures, and conditions as prescribed by the Ministerial Regulation (NAT, 2016).

#### 3.3.5 Transportation, including transboundary movement of NORM waste

As specified in the Act (NAT, 2016), a person possessing RW, who wishes to arrange for RW transport, shall submit a notice to the OAP Secretary General. Moreover, the person and a carrier who agrees to transport RW have a duty to comply with the rules, procedures, and conditions regarding nuclear and radiation safety and security as prescribed by the Draft Ministerial Regulation (OAP, 2017). The key details provided in this regulation include:

- Specifications or limitations regarding the transportation, either by ground, by sea or by air;
- Types, specifications and approval of the packages used during transportation;
- Affixation of a label displaying a radiation symbol;
- Inspection and control of the transportation (OAP, 2017).

The regulation also sets the exemption criteria in transport control, following which TENORM that has the levels of activity concentration ≤ 10 times the specified levels shown in Table 12 shall not be under its control (OAP, 2017).

**Table 12.** Activity concentration for exempt material (OAP, 2017)

| Radionuclide | Activity concentration (Bq/g) |
|---|---|
| Only beta or gamma emitting nuclides are known to be present | 10 |
| Only alpha emitting nuclides are known to be present | 0.1 |
| No relevant data are available | 0.1 |

In addition to managing RW, the RWMC provides the service of RW transport. The waste producers are required to pay for the costs of both RW management and RW transport (if requested). The service costs are presented in Yubonmhat et al. (2022). In case of TENORM, the management cost is set to be 42,800 THB/ton (Yubonmhat et al., 2022). Before receiving RW, the RWMC shall consider RW from the producers and shall not accept the waste that is not complied with the WAC developed by the RWMC (Yubonmhat et al., 2022).

According to the Act (NAT, 2016, 2019), Thailand allows RW producers or holders to transfer their RW to destination countries for management purposes. Thailand does not permit importation of RW into the Kingdom unless such RW is exported for treatment outside the Kingdom. Any person who wishes to import RW into the Kingdom, or to export it out of the Kingdom, must obtain a licence from the OAP Secretary General. The importation and exportation shall be undertaken through the customs checkpoints designated by the OAP Secretary General. Despite not being designated, 21 checkpoints have been proposed in the Draft OAP Guideline on Designation of the Customs Checkpoints that Licensee Imports, Exports, or Transits Radioactive Material, Nuclear Material, or Radioactive Waste (Draft OAP Guideline on Designation of the Customs Checkpoints - Appendix 1) (OAP, 2016). The rules, procedures, and conditions for RW exportation and importation are provided in the Ministerial Regulation on

Permission to Import Radioactive Waste into and Export out of the Kingdom, B.E. 2561 (2018) (MOST (Thailand), 2018a).

#### 3.3.6 Handling facilities and techniques

Waste producers can transfer their waste to the waste operator for further management. To date, the RWMC is the only waste operator managing RW generated in Thailand.

Regarding NORM disposal, RW containing NORM is allowed to be disposed of in different ways depending on the waste classes as follows:

- VLLW containing NORM that does not need a high level of containment and isolation is allowed to be disposed in near surface landfill type facilities;
- LLW containing NORM that requires containment and isolation for periods of up to 300 years can be disposed at the depths of at least 30 meters below the ground level;
- ILW containing NORM that requires containment and isolation for periods of over 300 years can be disposed at the depths between 30 and 300 meters below the ground level; and
- HLW disposal methods are not given in this regulation (MOST (Thailand), 2018c).

### *3.4 TENORM waste management practices*

#### 3.4.1 TENORM waste generated from the oil and gas industry

As reported in Srisuksawad et al. (2005), many groups of industries in Thailand generate NORM and TENORM waste, including the oil and gas industry. TENORM waste was also generated from disused Pathum-Thani Rare Earth Processing Facility (Yubonmhat et al., 2022; Yaanant et al., 2017a, 2017b). Such waste is kept at the original sites and the levels of activity concentrations were reported in FNCA (2005). However, the waste types and quantities are still unknown.

Thailand has a small amount of TENORM from oil and gas production to manage compared with other countries. This statement is confirmed by the measurement of gamma radiation exposure rate carried out previously by the Radionuclides Analysis Research Project conducted in 2002 under the collaboration between the Thai-Japan governmental bodies, academic institutions and private sectors (Chanyotha et al., 2015). Table 13 shows the Ra-226 and Ra-228 contents in various materials from some approved oil and gas production facilities located in Thailand. The measurements were made along the external surface of any accessible in-process production facilities and/or equipment in production chain which were suspected to be TENORM contaminated.

**Table 13.** Concentrations of radioactive isotopes found at some approved oil and gas production facilities in Thailand (Chanyotha et al., 2015)

| NORM materials | Number of samples | Activity concentration | | | |
|---|---|---|---|---|---|
| | | Ra-226 | | Ra-228 | |
| | | Mean | Range | Mean | Range |
| Produced water (onshore) (kBq/m$^3$) | 32 | 0.97 | 0.08-4.02 | 1.05 | 0.03-2.4 |
| Scale (onshore) (Bq/g) | 16 | 10.13 | 0.009-18.3 | 3.1 | 0.01-12.8 |
| Cutting (onshore) (Bq/g) | 21 | 0.03 | 0.009-0.063 | 50 | 0.0106-0.102 |
| Sludge (onshore) (Bq/g) | 5 | 0.18 | 0.004-0.4 | 0.187 | 0.002-0.463 |
| Produced water (offshore) (kBq/m$^3$) | 33 | 0.89 | 0.09-2.12 | 0.72 | 0.15-2.11 |
| Sludge (offshore) (Bq/g) | 15 | 0.09 | 0.015-1 | 0.029 | 0.013-0.044 |
| Local Soil (Bq/g) | 83 | 0.09 | 0.014-0.107 | 0.075 | 0.009-0.169 |

### 3.4.2 Handling facilities and techniques

*Control of TENORM contaminated equipment*

A practical control of TENORM-contaminated equipment and waste materials from the oil and gas industry in Thailand is usually done at the decommissioning yard in three stages: screening; storage; decontamination. The screening process is undertaken to identify and segregate TENORM-contaminated parts using portable radiation detection devices. TINT provides the service for TENORM screening upon the arrival of platforms at decommissioning yards. This is implemented by the thirst for knowledge and for operational control to prevent contractors from selling or disposing TENORM-contaminated parts to the public. Once detected, the contaminated parts will be isolated and stored in a designated area so that they cannot be a source of radiation hazard. For temporary storage solutions, the objective is to prevent improper disposal of TENORM waste on a temporary basis. Temporary storage at yards is provided in metal drums. Interim storage facilities of TENORM waste could also be used to receive TENORM waste generated by various RW operators over a period of time. For the parts that are contaminated with TENORM but needed to be returned to operation, disposal or release for sale, decontamination of TENORM must be conducted in specially designed facilities. Such facilities should be designed to prevent radiological exposure to workers and workplaces. Currently, Thailand does not have such facilities and the contaminated parts will be sent out to capable countries for handling.

*Current status of RW storage*

At present, there are three storage buildings used to store different types of RW (Yubonmhat et al., 2022). One is for storing disused sealed radioactive sources (DSRS), the rests are for storing the unsealed RW. One of the unsealed RW buildings is specially designed to store only the Cs-137 contaminated dust. As a result, there is only one building that can support the general unsealed RW, including materials contaminated with NORM. The problem is that there is approximately 30% of the storage space that can support the incoming unsealed RW. By this reason, the RWMC has to conduct actions to increase the storage capacity, such as volume reduction of the existing unsealed RW (especially the contaminated metals), and the construction of an additional storage building. With the problem of limited storage space, some of the NORM/TENORM residues were kept in metal drums and temporarily stored in the nearby buildings of the generators.

*Disposal facilities*

At present, Thailand does not have RW disposal facilities, given its small amount of RW; however, the RWMC researchers have commenced a study on the siting process for a disposal facility (Yubonmhat et al., 2022). Such study is in the conceptual and planning stage which is the first stage in the total four stages of the siting process[3] (IAEA, 2014; Yubonmhat et al., 2022).

## 4. Vietnam

### *4.1 Legal framework*

At present, RW, including NORM/TENORM waste in Vietnam is managed under the Law on Atomic Energy (2008). NORM/TENORM waste is particularly not controlled under Circular 22/2014/TT-BKHCN on the Management of Radioactive Waste and Used Radioactive Sources. Although a National Technical Regulation on Management of NORM 2022 (QCVN No. …/2022/BKHCN) has been drafted, it only applies to the activities of extracting and manufacturing Uranium, Thorium, Titanium, Titanium dioxide, rare-earth elements, Zircon and Zirconia (MOST (Vietnam), 2022b). Related regulations include:

- *Circular No. 04/2016/TT-BKHCN on Appraisal of Radiation Safety Evaluation Reports on Exploration and Exploitation of Radioactive Ores*.
- *Ordinance No. 50-L/CTN on Radiation Safety and Control* (ORSC) dated 25/6/1996
- *Decree No. 50/1998/ND-CP on Implementation of the ORSC*
- *National Standard on Radiation Protection, Radioactive Waste management & Classification of Radioactive Waste TCVN 6868-2001*
- *Circular No. 23/2012/TT-BKHCN on Safe Transportation of Radioactive Materials* (*Circular No. 23/2012/TT-BKHCN*)
- *Decree No. 142/2020/ND-CP on Implementation of Radiation Activities and Support Services for Using Atomic Energy (Decree No. 142/2020/ND-CP).*

### *4.2 Institutional framework*

- Ministry of Science and Technology (MOST): According to *Decree No. 95/2017/ND-CP on the Functions, Missions, Rights and Organisation Structure of the MOST*, the MOST undertakes the State management of science and technology related to atomic energy, radiation and nuclear safety, including RW management (Government of Vietnam, 2017).

[3] The four stages comprise: (i) the conceptual and planning stage; (ii) the area survey stage; (iii) the site investigation stage; and (iv) the stage of detailed site characterisation leading to site confirmation for construction of the disposal facility (IAEA, 2014).

- Vietnam Agency for Radiation and Nuclear Safety (VARANS) is an agency under the MOST, providing support for the MOST's State management on radiation and nuclear safety, security of radioactivity sources, nuclear materials, nuclear units and nuclear control (MOST (Vietnam), 2014). Regarding NORM waste management, a NORM waste storage facility shall submit a liability transfer contract to the VARANS before transferring its liabilities to another individual or organization. For NORM waste type A, the waste generator shall send a copy of the Minutes of Handover-Receipt to the VARANS within 5 working days of handing over the waste to a treatment and storage facility while the treatment and storage facility shall notify the VARANS once receiving the waste, using the template given in Annex V of the Circular 22/2014/TT-BKHCN (MOST (Vietnam), 2022b). The VARANS is also responsible for appraising radiation safety and inspecting and handling violation of radiation safety of NORM waste storage facilities (NAV, 2008). In addition, it controls the transportation of NORM waste at the national level and issues licences for NORM waste treatment and storage facilities as well as transboundary movement of NORM waste (MOST (Vietnam), 2012b, 2022a).
- Vietnam Atomic Energy Institute (VINATOM) is a public administrative science agency under the MOST. One of its functions is to provide technical support for the MOST's State management on the atomic energy, radiation and nuclear safety (MOST (Vietnam), 2016). It also assists the VARANS on technical aspects (FNCA, 2020).
- Institute for Technology of Radioactive and Rare Elements (ITRRE) is a public service organization under the VINATOM (MOST (Vietnam), 2016). Its function includes doing scientific research and developing technologies for treating and manufacturing radioactive minerals (VINATOM, n.d.). One of its research focuses is to develop NORM waste treatment techniques (ITRRE, n.d.).
- Provincial People's Committees (PPC) have duties for radiation safety and control at the provincial level, particularly those related to radiation incidents (Standing Committee of the National Assembly, 1996).
- Departments of Science & Technology (DOST) are liable for radiation protection and nuclear safety at the provincial level under supervision by VARANS (FNCA, 2020), including control of NORM waste transportation (MOST (Vietnam), 2012b).

Fig. 8 illustrates the institutional framework of NORM/TENORM waste management in Vietnam, which was built based on the description of the agencies mentioned above and the Vietnamese State mechanism diagram indicated in LuatVietnam (2022).

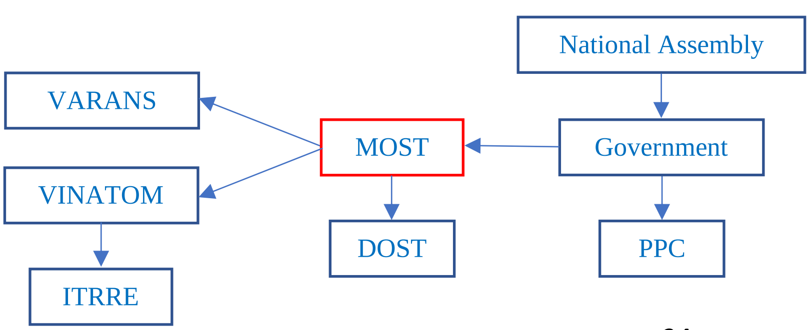


**Fig. 8.** Institutional framework of NORM/TENORM waste management in Vietnam

### *4.3 TENORM waste management under current legislation*

#### 4.3.1 Definition of TENORM waste

According to Section 1.3.1 of the draft National Technical Regulation on Management of NORM (QCVN No:…:2022/BKHCN), NORM waste is defined as waste containing natural radioactive nuclei, including K-40 and radioactive nuclei in the natural radioactive chains of Uranium and Thorium, and arising from radioactive mineral extraction and manufacturing (MOST (Vietnam), 2022b).

#### 4.3.2 Classification of TENORM waste

Following Section 1.4 of the draft National Technical Regulation on Management of NORM (QCVN …:2022/BKHCN), NORM waste is classified into 3 types, based on the activity level of natural radioactive nuclei in NORM waste and the annual dose of radiation exposure potentially perceived by a staff or public member:

(1) Type A: NORM waste that has the activity level of the natural radioactive nuclei in the radioactive chains of Uranium (or Thorium) > 1 Bq/g or has the activity level of K-40 > 10 Bq/g, and can cause the annual dose of radiation exposure potentially perceived by a staff or public member > 1 mSv/year;

(2) Type B: NORM waste that has the activity level of the natural radioactive nuclei in the radioactive chains of Uranium (or Thorium) > 1 Bq/g or has the activity level of K-40 > 10 Bq/g, and can cause the annual dose of radiation exposure potentially perceived by a staff or public member <= 1 mSv/year;

(3) Type C: NORM waste that has the activity level of the natural radioactive nuclei in the radioactive chains of Uranium (or Thorium) <= 1 Bq/g or has the activity level of K-40 <= 10 Bq/g. NORM waste type C is managed as waste without radioactivity (MOST (Vietnam), 2022b).

Such classification is summarised in Table 14.

**Table 14.** Classification of NORM waste (MOST (Vietnam), 2022b)

| **Type** | **Activity level of the natural radioactive nuclei in NORM waste** | | **Annual dose of radiation exposure potentially perceived by a staff or public member** |
|---|---|---|---|
| | **In the radioactive chains of U (or Th)** | **Of K-40** | |
| A | > 1Bq/g | > 10 Bq/g | > 1 mSv/year |
| B | > 1Bq/g | > 10 Bq/g | <= 1 mSv/year |
| C | <= 1 Bq/g | <= 10 Bq/g | |

#### 4.3.3 TENORM intervention level

The *National Technical Regulation on Radiation Safety- Exemption from requirements of notification, registration and licencing* (TCVN 6870:2001) specifies the exemption levels of RW. The RW that has the specific activity or total activity equal to or lower that the values mentioned in Table 15 shall not be under control of the State management agency regarding radiation safety and control (MOST (Vietnam), 2001b).

**Table 15.** Exempt levels of RW (MOST (Vietnam), 2001b)

| Radionuclide | Specific activity (Bq/g) | Total activity (Bq) |
|---|---|---|
| K-40 | $10^2$ | $10^6$ |
| Ra-226$_{eq}$ | 10 | $10^4$ |
| Ra-228$_{eq}$ | 10 | $10^5$ |
| Th-232 | 1 | $10^3$ |
| U-238$_{eq}$ | 10 | $10^4$ |

Note:
The parent isotopes and their daughter isotopes in secular/transient equilibrium are as follows:
- Ra-226$_{eq}$: Rn-222, Po-218, Pb-214, Bi-214, Po-214, Pb-210, Bi-210, Po-210
- Ra-228$_{eq}$: Ac-228
- U-238$_{eq}$: Th-234, Pa-234m

### 4.3.4 Licensing

As specified in Article 25 of the Law on Atomic Energy (2008), individuals or organisations shall have licences to perform RW storage services (NAV, 2008).

### 4.3.5 Transportation, including transboundary movement of TENORM waste

TENORM waste transportation shall follow the *Circular No. 23/2012/TT-BKHCN*, except the waste that has the TENORM's specific activity level lower than that of the exempt material or the waste whose total activity level is lower than the activity limit of the exempt package as specified in the *TCVN 6867-1:2001 - National Technical Regulation on Radiation Safety – Safe Transportation of Radioactive Materials – Part 1: General Requirements* (see Table 16) (MOST (Vietnam), 2012b).

**Table 16.** Basic radioactive nucleus values (MOST (Vietnam), 2001a)

| Radionuclide | Specific activity level of the exempt material (Bq/g) | Activity limit of the exempt package (Bq) |
|---|---|---|
| K-40 | $1 \times 10^2$ | $1 \times 10^6$ |
| Ra-226 | $1 \times 10^1$ (b) | $1 \times 10^4$ (b) |
| Ra-228 | $1 \times 10^1$ (b) | $1 \times 10^5$ (b) |
| Th-232 | $1 \times 10^1$ | $1 \times 10^4$ |
| U-238 (all of its types are absorbed by the lung) (a, b, c) | $1 \times 10^1$ (b) | $1 \times 10^4$ (b) |

Note:
a) These activity levels only apply to the following uranium compounds: $UF_6$, $UO_2F_2$ and $UO_2(NO_3)$ in both normal transportation and accidents;
b) These activity levels only apply to the following uranium compounds: $UO_3$, $UF_4$, $UCl_4$ and U(VI) in both normal transportation and accidents;
c) These activity levels only apply to the uranium compounds not specified in a) and b) above.

Transboundary movement as well as import and export of TENORM waste are allowed, provided that the activities comply with the *Decree No. 142/2020/ND-CP* and the *Circular No. 23/2012/TT-BKHCN*, respectively and the relevant national and international regulations (MOST (Vietnam), 2012b; Government of Vietnam, 2020). Particularly, import or export TENORM waste packages shall be labelled in Vietnamese or English while the containers can be labelled in English. The sender shall attach the transport documents with the packages, including the codes issued by the authority of the producing country in the approval certificate (MOST (Vietnam), 2012b). The transportation shall be equipped with a radioactivity measuring instrument to monitor the safety during the process (Government of Vietnam, 2020).

#### 4.3.6 Handling facilities and techniques

***Storage***

Solid NORM waste after being conditionalized must be stored following one of the following methods:

- Storage at ponds or landfill sites: The ponds shall meet the requirements in the *Circular No. 41/2020/TT-BCT on Management of Operation of Tailing Ponds in Mineral Exploitation and Manufacturing* following which their safety must be monitored with displacement monitoring, filtration control, monitoring of the pond's water levels and the flows to the pond, control of stress status, control of the adjacent areas, and the readiness of operational equipment (MIT, 2020; MOST (Vietnam), 2022b).
- Storage at containers: There are three types of containers: underground, semi-submerged and on-the-ground containers. The walls and floor of the container shall be non-absorbent concrete with steel reinforced structures. The submerged walls and the part under the floor shall be supplemented with a non-absorbent layer. The container shall be fully roofed and there shall be methods for limiting direct wind into the container during the operation. For semi-submerged containers: after being full, the container shall be fully covered by a lid which is unleakable, non-absorbent concrete with a steel reinforced structure and supplemented with a non-absorbent layer (MOST (Vietnam), 2022b).
- Storage at stores: The stores shall meet safety conditions as required in the *Circular No. 19/2012/TT-BKHCN on Control and Assurance of Radiation Safety in Professional and Public Radioactivity* following which the stores shall be safe, well shielded and provided with radioactivity and radioactive pollution control methods (MOST (Vietnam), 2012a).

***Treatment***

According to the National Technical Regulation on Management of NORM (QCVN No. …/2022/BKHCN), liquid NORM waste can be treated according to one or several methods of the following: evaporation, filtration, ion exchange, precipitation or coagulation, absorption, etc. Whilst, solid NORM waste can be pressed if pressable to reduce its volume and after being treated, it can be solidified by cementation, bitumentation and polymerization, etc. (MOST (Vietnam), 2022b).

### *4.4 TENORM waste management practices*

#### 4.4.1 TENORM waste generated from the oil and gas industry

Oil and gas production waste in Vietnam has low level of radioactivity, which has been proved through some studies. Table 17 shows the concentration of basic radioactive elements in oil scales in Vietnam, with two samples of oil scales taken in Ba Ria – Vung Tau province. Such results mean that radioactivity of oil scales in Vietnam is lower than the exemption limit following the *National Technical Regulation on Radiation Safety- Exemption from* *requirements of notification, registration and licencing* (TCVN 6870:2001) and the IOGP's guidance mentioned in Table 15 and Table 4 above.

**Table 17.** Concentration of basic radioactive elements in oil scales in Vietnam (Le et al., 2009)

| No. | Symbol sample | Concentration of basic radioactive elements (Bq/kg) | | | | |
|---|---|---|---|---|---|---|
| | | K | U | Th | Ra | Total radioactivity |
| 1 | M1 | 155.22 | 7.32 | 5.52 | 17.52 | 322.8 |
| 2 | M2 | 942 | 30.56 | 56.25 | 55.5 | 1606 |

Another study undertaken in Bach Ho field shows that all the parameters of the samples of produced water, crude oil, oil sludge, oil residue, drilling mud and drilling fluids have the values lower than the exemption values as specified in *TCVN 7889:2008 - National Technical Regulation on natural Radon activity in buildings - levels and general requirements of measuring methods* (Hoang et al., 2017).

**Table 18.** Rn concentration in air & accumulated Rn concentration in some places potentially causing radioactive exposure (Hoang et al., 2017)

| No. | Sampling position | Rn concentration (Bq/m$^3$) | | Rn concentration (Bq/m$^3$), sampling in 30 days | |
|---|---|---|---|---|---|
| | | Concentration | Deviation | Concentration | Deviation |
| 1 | Gas-liquid separator | 17 | 4 | 17.34 | 4.16 |
| 2 | Oil container | 25 | 5 | 32.54 | 5.71 |
| 3 | Gas container | 37 | 6 | 43.83 | 6.62 |
| 4 | Preliminary separator | 31 | 6 | 30.67 | 5.54 |

**Table 19.** The annual average limit of Rn in buildings following TCVN 7889:2008 (MOST (Vietnam), 2008)

| Level | Applying to | Limit |
|---|---|---|
| Action | Working building | >300Bq/m$^3$ |
| Warning | Newly constructed building | <100Bq/m$^3$ |
| | Currently used building | <200Bq/m$^3$ |
| Encouraging | | <60Bq/m$^3$ |

### 4.4.2 Handling facilities and techniques

In practice, for NORM waste arisen from oil and gas production and manufacturing, phosphate and bauxite exploitation, etc., the treatment and burial techniques are similar to those for chemical hazardous waste and heavy metal waste and have not focused on radioactivity of the waste (Bui, 2019). For example, a concrete tank was built for storing 100 tons of NORM waste arisen from Uranium exploitation activities in Pa Lua, Quang Nam Province. The NORM waste was cemented and then put into the concrete tank. After that, the tank was sealed and covered with a layer of 1-metre soil (Bui, 2019). Operated by ITRRE, the Phung Interim Storage Facility has a monazite pilot plant whose operation commenced in 1992 but stopped in 2001 because of low demand of rare earth elements in Vietnam. The facility has one warehouse and two concrete tanks to store NORM/TENORM wastes induced from the pilot plant. The uranium-containing waste is solidified by cement and their surface dose rates are around 10 $\mu Sv^{*} hr^{-1}$ (Nguyen, 2005).

It is unclear whether Vietnam is undertaking research on final disposal facilities for NORM/TENORM waste or not. However, the country plans to carry out research on permanent disposal mechanisms for high-level RW, particularly spent fuel from nuclear power plants, once such a plant is commissioned, while the processed waste is temporarily stored in a makeshift storage area for minimum three decades (Naidu and Moorthy, 2022).

**SWOT analysis of the NORM/TENORM waste management systems in four ASEAN countries**

| Country | Strengths | Weaknesses | Opportunities | Threats and challenges |
|---|---|---|---|---|
| **Indonesia** | The legal framework includes specific regulations on TENORM waste management. | There are no databases and inventories as well as final disposal facilities for TENORM waste in Indonesia. The country has also not planned to develop final disposal for TENORM in the near future due to difficulties to find location and necessity to conduct coordination among institutions.<br><br>By 2020, BAPETEN issued 36 licences, including 3 licences for the oil and gas industry. Such number of licensees and their distribution are much different from the potential TENORM producers across Indonesia. While BAPETEN has coordinated and cooperated with the Ministry of Environment and the Ministry of Energy and Mineral Resources in communicating the regulations to industries, the lack of knowledge in local governments as well as the lack of laboratories that can conduct activity concentration analysis have led to the insufficient execution of the regulations (Nugroho and Yuliati, 2020). | The amendment of the Act No.10 Year 1997 to include TENORM, covering TENORM from the oil and gas industry will foster the regulatory basis for TENORM waste management in Indonesia.<br><br>The BCR No. 16 Year 2013 only considers temporary TENORM storage in a specific time period and does not cover the final disposal of TENORM. Nevertheless, the Minister of Environment and Forestry Regulation No. 63 Year 2016 on Requirements and Procedures for Hazardous and Toxic Waste in Final Disposal Facilities uses the terminology of "radioactive contaminated hazardous waste" which can be understood to include hazardous waste contaminated with TENORM. Following this Regulation, hazardous waste contaminated with TENORM can be disposed of in class I or class II landfill facilities (Yuwana and Sanyoto, 2020). | As BAPETEN does not regulate the licences for setting up and operating the non-nuclear industry, it cannot impose sanctions/punishment on such industry's violations of radiation safety regulations but can only recommend sanctions to other authorized agencies such as the Ministry of Environment or local governments (Wisnubroto et al., 2021). |
| **Malaysia** | The legal framework for NORM/TENORM waste management in Malaysia is comprehensive, including a law and regulations for RW management which cover TENORM. Importantly, the country has specific guidelines for managing TENORM waste from the oil and gas industry as well as a technical guideline for | While Malaysia has disposal facilities for RW with radioactivity of extremely low level or containing short to medium half-lived radionuclides, it does not have disposal facilities (deep geological burial) for RW with high-level radioactivity or containing medium to long half-lived radionuclides (Nuclear Malaysia Training Centre, n.d.). | The public acceptance and confidence towards the atomic energy supervising authority have fostered the implementation of the authority's policies especially related to mineral processing and radioactive/TENORM waste disposal (Teng, 2015b). | According to Teng (2015b), one of the challenges in Malaysia TENORM waste management is the presence of existing exposure situations. The situation caused the contamination of areas by residual radioactive materials from, for example tin mining activities, and with radionuclide in either the uranium or thorium decay chains greater than 1 Bq/g or the activity concentration of K-40 greater than 10 Bq/g (Teng, |

| | | | | |
|---|---|---|---|---|
| | designing TENORM waste disposal facilities.<br><br>AELB, the main institute in charge of TENORM waste management in Malaysia, consists of members coming from different ministries will help deal with the related issues thoroughly and effectively. | | | 2015b). Besides, the processing of raw materials from e.g.: rare earth extraction plants may result in radiation exposure due to materials which have the activity concentration of any radionuclide in the uranium or thorium decay chains exceeding 1 Bq/g or the activity concentration of K-40 exceeding 10 Bq/g (Teng, 2015b). |
| **Thailand** | Thailand has a relatively comprehensive legal framework for NORM/TENORM waste management, including a law and regulations for RW management which cover NORM/TENORM. | The types and quantities of NORM/TENORM waste from different industries, including the oil and gas industry are unclear. However, these could be completed if the Draft Ministerial Regulation (MOST (Thailand), 2017) is promulgated, following which the waste inventory must be established.<br><br>At present, Thailand does not have RW disposal facilities although the RWMC researchers have commenced a study on the siting process for a disposal facility (Yubonmhat et al., 2022). | The Draft Ministerial Regulation (OAP, 2017) once put into effect will help ensure radiation safety and security while transporting NORM/TENORM. Whilst, the enforcement of the Draft Guideline on Designation of the Customs Checkpoints will facilitate transboundary movement of NORM/TENORM into or out of Thailand and also help ensure radiation safety and security. | Regarding transboundary movement of RW, in principle, countries in which RW treatment or spent fuel processing companies offer services to foreign clients usually prohibit the disposal in their territory of the foreign waste concerned. Thus, all the treated RW must be returned to the country of origin, usually within a specified period. Transboundary movement may involve more than just the sending and receiving countries when the carriage needs to transit through the territory of other countries. This can complicate the logistics (e.g. circuitous routes to avoid non-agreeing countries, or multiple handovers between transport operators), including the legal aspects relating to such carriage. Many of these activities are costly, very specialized and could incur increase in expenditures. Therefore, most RW generated will be managed within the country and is transferred to the RWMC while the RWMC has limited storage space and no disposal facility for RW. As stated in the Draft Ministerial Regulation (MOST (Thailand), 2017), it seems that only the VSLW and the VLLW containing NORM will be permitted to be managed by RW producers. The |

| | | | | |
|---|---|---|---|---|
| | | | | remaining types of waste (see Table 9) must be sent to an authorized RW operator. This will further burden the RWMC as the waste operator. |
| **Vietnam** | Vietnam has a relatively comprehensive legal framework for NORM/TENORM waste management, including a law and regulations for RW management which cover NORM/TENORM. It also has a draft national technical regulation dedicated to NORM waste management, but it does not apply to the oil and gas industry. | The treatment and burial techniques for TENORM waste are similar to those for chemical hazardous waste and heavy metal waste and have not focused on radioactivity of the waste (Bui, 2019). These practices could induce radiation hazards to the public and environment. | The draft National Technical Regulation on Management of NORM 2022 is rather detailed (with the definition and classification of NORM waste, methods for determining the activity level of natural radioactive nuclei in NORM waste and the annual dose of radiation exposure potentially perceived by a staff or public member, solutions for NORM waste management, and requirements for NORM waste generators and NORM waste treatment and storage facilities). This can be used for establishing a similar technical regulation for managing TENORM waste from the oil and gas industry. | In Vietnam, the oil and gas industry has not been considered as the industry associated with NORM/TENORM. The waste arisen from oil and gas activities are still regarded as industrial solid waste or hazardous industrial waste and are controlled by the respective laws and regulations which do not pay attention to RW. Therefore, the management activities are not strict (Nguyen, 2019). Despite being rather detailed, the draft National Technical Regulation on Management of NORM 2022 does not apply to the oil and gas industry (MOST (Vietnam), 2022b). Furthermore, it does not address disposal of TENORM waste. |

## Discussion

*Strengths*

Among the four countries, Malaysia has the most comprehensive legal framework for TENORM waste management, including a dedicated law and regulations for RW management which cover TENORM. Malaysia even has specific guidelines for managing TENORM waste from the oil and gas industry and a technical guideline for designing TENORM waste disposal facilities – a very important issue in TENORM waste management. Especially, there is a specialised board in charge of TENORM waste management in Malaysia, with members coming from different ministries, which will help deal with the related issues thoroughly and effectively.

*Weaknesses*

Among the four countries, only Malaysia has proper RW disposal facilities at present. However, such facilities are only suitable for the waste with radioactivity of extremely low level or containing short to medium half-lived radionuclides. The country still lacks disposal facilities for RW with high-level radioactivity or containing medium to long half-lived radionuclides.

It is unclear whether Vietnam is conducting research on final disposal facilities for NORM/TENORM waste or not while Indonesia does not have plan to develop such facilities in the coming years. Indonesia also experiences the insufficient implementation of the regulations due to the lack of knowledge in local governments and the lack of NORM concentration analysis laboratories. Both Indonesia and Thailand lack databases and inventories for NORM/TENORM waste could hamper the national waste management. The treatment and burial techniques for TENORM waste in a similar manner to those for chemical hazardous waste and heavy metal waste in Vietnam could pose radiation hazards to the public and environment.

*Opportunities*

Some legal/guiding documents on RW or NORM/TENORM waste specifically have been drafted in Indonesia, Thailand and Vietnam, which will facilitate safe and sustainable management of NORM/TENORM waste, including the waste from the oil and gas industry in these countries. Following the Minister of Environment and Forestry Regulation No. 63 Year 2016 on Requirements and Procedures for Hazardous and Toxic Waste in Final Disposal Facilities, TENORM waste in Indonesia can be disposed of in class I or class II landfill facilities. Malaysia is fortunate to have the public acceptance and confidence towards the atomic energy supervising authority, which has strengthened the execution of the authority's policies relating to radioactive/TENORM waste disposal.

*Threats and challenges*

In Indonesia, since BAPETEN does not regulate the licences for setting up and operating the non-nuclear industry, there are challenges in monitoring and sanctioning the oil and gas industry's violations of TENORM-related regulations. Malaysia faces radiation exposure issues, including the contamination of areas by residual radioactive materials and radiation exposure from processing of raw materials, although it is unclear whether such issues exist in the petroleum industry or not. Meanwhile, there will be insufficient RW storage space and no disposal sites for NORM/TENORM waste in Thailand when the Draft Ministerial Regulation (MOST (Thailand), 2017) is promulgated. There are also challenges associated with transboundary movement of NORM/TENORM waste into and out of Thailand, leading to the waste management burden on the RWMC, further worsen the management situation given the RWMC's limited storage space and unavailability of a disposal facility for RW. In Vietnam, the management of TENORM waste from oil and gas activities is not strict because it is still considered as industrial solid waste or hazardous industrial waste.

**Conclusions**

In all four countries, NORM/TENORM waste is mainly managed under the laws and regulations on RW management. While specific regulations and guidelines on NORM/TENORM waste management have been established in Indonesia, Malaysia and Vietnam, for better management of the waste, particularly the one from the oil and gas industry, dedicated laws should be developed in the four countries. Specific regulations/guidelines for managing TENORM waste from the oil and gas industry should also be developed where lacking, particularly Indonesia, Thailand and Vietnam. These three countries also lack proper TENORM waste disposal facilities, although developing such facilities is not easy and it might take some decades to find the appropriate site for waste disposal (Yubonmhat et al., 2022). Given the potential increase of TENORM waste from oil and gas activities in the future, such facilities should definitely be developed. Thailand will also face the increasing inadequacy of storage space for RW when the related Draft Ministerial Regulation is promulgated, thus additional storage facilities should also be built.

In Indonesia, the lack of knowledge in local governments and the lack of NORM concentration analysis laboratories have led to the inadequate execution of the related regulations, thus capacity building for local governments should be enhanced and existing laboratories should be upgraded or new ones should be set up to be capable of NORM concentration analysis. Given their unavailability, databases and inventories for NORM waste should be developed in Indonesia and Thailand so that the regulatory bodies can track the waste easily. In Vietnam, the management of NORM/TENORM waste, including one from the oil and gas industry should be stricter so that the waste is handled as RW.

While it is legal to dispose of TENORM waste in class I or class II landfill facilities in Indonesia, the capability of these landfill facilities when utilized as TENORM waste disposal facilities should be more thoroughly examined (Yuwana and Sanyoto, 2020). The draft National Technical Regulation on Management of NORM 2022 in Vietnam is a rather detailed, which can be used for developing a similar technical regulation for managing TENORM waste from the oil and gas industry. Such regulation and the future regulation on managing TENORM waste from the oil and gas industry in Vietnam should also deal with disposal of TENORM waste because whether treated or untreated, the disposal of such waste is a critical issue in order to prevent any associated harmful effects to the surrounding environment and human beings.

In order to facilitate the monitoring and sanctioning process of the violations of TENORM waste management in the Indonesian oil and gas industry, a joint regulation between BAPETEN and the Ministry of Environment could be set up (Wisnubroto et al., 2021). In Malaysia, the contamination of areas by residual radioactive materials can be remediated by landfilling or reclamation while radiation exposure from processing of raw materials can be dealt with by licensing for import, export, storage and processing activities as well as through RW management, including waste minimization and disposal facilities (Teng, 2015b).


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