SAFE AND SUSTAINABLE DECOMMISSIONING OF OFFSHORE STRUCTURES TAKING INTO CONSIDERATION THE PECULIARITIES OF THE ASEAN & SOUTH ASIA REGIONS

DEVELOPING A REGIONAL FRAMEWORK FOR OFFSHORE DECOMMISSIONING: INSIGHTS FROM SOUTHEAST ASIA

2024

AUTHORS

The authors of this document are as follows:

Omar Yaakob[1], Nik Mohd Ridzuan Shaharuddin[2], Mohd Arif Ismail[3], Noor Amila Wan Abdullah Zawawi[4], Huyen Thi Le[5], Wonsiri Punurai[6], Hooi-Siang Kang[7], Sarah Suherman[8], Nurul Anis Kamarudin[9], Jing-Shuo Leow[10], Farah Ellyza Hashim[11], Sari Amelia[12], Mohammad Nabil Jainal[13], Muhammed Amirul Asyraf Hasnan[14], Jin Wang[15], Arun Kr. Dev[16], Rakesh Bhargava[17], Thor Sterker[18], Klitsadee Yubonmhat[19], Evin Yuliati[20], Teng Iyu Lin[21], Pornpong Asavadorndeja[22], Nhung Thi Phuong Nguyen[23], Thanh Thanh Le[24], Kiet Van Nguyen[25], Sy Van Le[26], Dega Damara Aditramulyadi[27], Bisri Hasyim[28], Chintan Kalthia[29]

[1]Marine Technology Centre, Institute for Vehicle System & Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia. ORCID: https://orcid.org/0000-0002-3381-513X. Email: omaryaakob@utm.my.

[2]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia. ORCID: https://orcid.org/0000-0001-5007-8787. Email: nmridzuan@utm.my.

[3]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia. ORCID: https://orcid.org/0009-0002-4479-2671. Email: marif7@graduate.utm.my.

[4]Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia. ORCID: https://orcid.org/0000-0002-5699-5348. Email: amilawa@utp.edu.my.

[5]PetroVietnam University, 762 Cach Mang Thang Tam Street, Long Toan Ward, Ba Ria City, Ba Ria-Vung Tau Province 790000, Vietnam. ORCID: https://orcid.org/0000-0002-9720-8152. Email: huyenlt@pvu.edu.vn.

[6]Mahidol University Thailand, 999 Phuttamonthon 4 Road, Salaya, Nakhon Pathom 73170, Thailand. ORCID: https://orcid.org/0000-0003-1260-084X. Email: wonsiri.pun@mahidol.ac.th.

[7]Marine Technology Centre, Institute for Vehicle System & Engineering / Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Malaysia. ORCID: https://orcid.org/0000-0002-0292-4376. Email: kanghs@utm.my.

[8]Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia. Email: sarah_20001834@utp.edu.my.

[9]Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak Darul Ridzuan, Malaysia. Email: anis.kamarudin@utp.edu.my.

[10]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia. ORCID: https://orcid.org/0009-0001-1606-9569. Email: jsleow2@graduate.utm.my.

[11]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Skudai, Johor Darul Takzim, Malaysia. ORCID: https://orcid.org/0000-0002-6540-2145 Email: farahellyza@utm.my.

[12]Institut Teknologi Bandung, Jl. Ganesa No.10, Lb. Siliwangi, Kecamatan Coblong, Kota Bandung, Jawa Barat 40132, Indonesia. Email: sariameliaaa@gmail.com.

[13]Department of Deputy Vice Chancellor (Research and Innovation), Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia. Email: mohammadnabil@utm.my.

[14]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia. Email: muhammedamirulasyraf@utm.my

[15]Liverpool John Moores University, 70 Mount Pleasant, Merseyside L3 5UX, United Kingdom. ORCID: https://orcid.org/0000-0003-4646-9106. Email: j.wang@ljmu.ac.uk.

[16]Naval Architecture Marine Technology Programmes, Newcastle University, Singapore. Email: a.k.dev@newcastle.ac.uk.

[17]Sea Sentinels Pte Ltd, One Raffles Place #34-04, 1 Raffles Place 048616, Singapore. Email: rakesh.bhargava@sea-sentinels.com.

[18]PB Consultants, Heerhugowaard, The Netherlands. Email: sterker@planet.nl.

[19]Radioactive Waste Management Center, Thailand Institute of Nuclear Technology, Bangkok 10900, Thailand. ORCID: https://orcid.org/0000-0003-2815-1209. Email: klitsadee@tint.or.th.

[20]Nuclear Energy Regulatory Agency, Jl. Gajah Mada No. 8, Jakarta Pusat 10120, Indonesia. Email: y.evin@bapeten.go.id.

[21]Department of Atomic Energy Malaysia, Ministry of Science, Technology and Innovation, Batu 24, Jalan Dengkil, 43800 Dengkil, Selangor Darul Ehsan, Malaysia. Email: yulin@aelb.gov.my.

[22]Synterra Co. Ltd, 129/9 Soi Hatsadisewi, Sutthisan Winitchai Road, Huai Khwang Subdistrict, Huai Khwang District, Bangkok, 10310, Thailand. Email: p.asavadorndeja@synterra.co.th.

[23]PetroVietnam University, 762 Cach Mang Thang Tam Street, Long Toan Ward, Ba Ria City, Ba Ria-Vung Tau Province 790000, Vietnam. Email: nhungntp@pvu.edu.vn.

[24]PetroVietnam University, 762 Cach Mang Thang Tam Street, Long Toan Ward, Ba Ria City, Ba Ria-Vung Tau Province 790000, Vietnam. Email: thanhlt@pvu.edu.vn.

[25]PetroVietnam University, 762 Cach Mang Thang Tam Street, Long Toan Ward, Ba Ria City, Ba Ria-Vung Tau Province 790000, Vietnam. Email: kietnv@pvu.edu.vn.

[26]PetroVietnam Maintenance and Repair Corporation, 7th floor, Petrovietnam Tower, 1-5 Le Duan Street, Ben Nghe Ward, District 1, Ho Chi Minh City, Vietnam. Email: sylv@pvmr.vn.

[27]Institut Teknologi Bandung, Jl. Ganesa No.10, Lb. Siliwangi, Kecamatan Coblong, Kota Bandung, Jawa Barat 40132, Indonesia. Email: degadamara@itb.ac.id.

[28]PT. Meindo Elang Indah, Lt.27 Menara Batavia, Jl. K.H. Mas Mansyur No.126, Karet Tengsin, Kecamatan Tanah Abang, Kota Jakarta Pusat, Daerah Khusus Ibukota Jakarta 10220, Indonesia.

[29]R. L. Kalthia Ship Breaking Pvt. Ltd., 201, Sarthik Complex, Atabhai Chowk, Bhavnagar-364001, Gujarat, India. Email: ck7664@gmail.com.

The following is the suggested citation for this document:

Yaakob, O., Shaharuddin, N.M.R., Ismail, M.A., Zawawi, N.A.W., Le, H.T., Punurai, W., Kang, H.S., Suherman, S., Kamarudin, N.A., Leow, J.S., Hashim, F. E., Amelia, S., Jainal, M.N., Hasnan, M.A.A., Wang, J., Dev, A.K., Bhargava, R., Sterker, T., Yubonmhat, K., Yuliati, E., Lin, T.I., Asavadorndeja, P., Nguyen, N.T.P., Le, T.T., Nguyen, K.V., Le, S.V., Aditramulyadi, D.D., Hasyim, B., and Kalthia, C. 2024. *Safe and Sustainable Decommissioning of Offshore Structures Taking into Consideration the Peculiarities of the ASEAN & South Asia Regions Final Project Report*, Universiti Teknologi Malaysia, Johor Bahru.

ACKNOWLEDGEMENT

We are deeply grateful for the generous support provided by Engineering X Safer End of Engineered Life Mission for the research project *"Safe & Sustainable Decommissioning of Offshore Structures Taking into Consideration the Peculiarities of the ASEAN and South Asia Regions"* SEELOS1920\1\111. This award is part of the Engineering X Safer End of Engineered Life Mission, which aims to achieve safer and more sustainable decommissioning and waste disposal. Engineering X is an international collaboration founded by the Royal Academy of Engineering and Lloyd's Register Foundation. Their unwavering commitment and substantial resources, funding, and encouragement were instrumental in the success of this project. We sincerely appreciate their dedication and belief in our work. Without their invaluable support, this achievement would not have been possible. Thank you for making this project a reality.

We extend our heartfelt gratitude to the stakeholders, industry players, and academic institutions involved in the research project *"Safe & Sustainable Decommissioning of Offshore Structures Taking into Consideration the Peculiarities of the ASEAN and South Asia Regions"*. Your collaboration, insightful contributions, productive discussions, and expert input have played a crucial role in achieving significant project milestones. These include the development of comprehensive technical guidelines tailored towards the safe decommissioning of offshore structures in the ASEAN and South Asia regions, the establishment of facilities equipped to safely and sustainably recycle decommissioned offshore structures, the formulation of guidelines emphasizing recycling and hazardous material management from decommissioned structures, and the enhancement of a collaborative network between stakeholders that drives ongoing research and advances decommissioning practices. Your dedication, expertise, and support have been pivotal in advancing this critical initiative. Thank you for your unwavering commitment to ensuring a safer and more sustainable decommissioning processes in the ASEAN and South East Asia regions.

We are deeply grateful and sincerely appreciate the willingness of the following contributors to share their knowledge, provide valuable data, including insights, information, and datasets, as their contributions significantly enriched our research. Special thanks to those who participated in the joint workshop for data collection, representing academia, industry, and regulatory bodies.

Brunei

- Belait Shipping Co Sdn Bhd
- Brunei Shell Petroleum
- QESS Energy Support Services Sdn Bhd
- Serikandi Oilfield Services
- Petroleum Authority of Brunei Darussalam
- Universiti Brunei Darussalam
- Universiti Teknologi Brunei

India

- R.L.Kalthia Ship Breaking Pvt. Ltd.

Indonesia

- Basel Convention Regional Centre for Southeast Asia
- Institut Teknologi Bandung (ITB)
- Institut Teknologi Sepuluh November
- Ministry of Marine & Fisheries
- Nuclear Energy Regulatory Agency (BAPETEN)
- O&G Engineering and Environment, Ministry of Energy & Mineral Resources
- Pertamina
- PT. Meitech Eka Bintan
- PT Prasadha Pamunah Limbah Industri (PPLi)
- SKK Migas

Malaysia

- Asia Pacific University of Technology & Innovation (APU)
- Big Oil Ventures Sdn Bhd
- Berachah Group Sdn Bhd
- Department of Atomic Energy Malaysia, Ministry of Science, Technology and Innovation
- Genesis Oil and Gas Consultants
- International Islamic University Malaysia
- Kualiti Alam Waste Management Centre (newly named as Cenviro Waste Management Centre)
- Malaysia Marine and Heavy Engineering Sdn. Bhd. (MMHE)
- Muhibbah Engineering (M) BHD
- Multimedia University
- Perunding Primareka
- Petroliam Nasional Berhad (PETRONAS)
- Redtech Offshore Sdn. Bhd.
- S&P Global Kuala Lumpur (previously IHS Markit)
- Sabah International Petroleum
- Sapura Energy Berhad
- Shapadu Energy Services Sdn Bhd
- Sunway University
- Swinburne University of Technology Sarawak Campus
- The Malaysian Oil, Gas & Energy Services Council (MOGSC)
- Universiti Malaysia Pahang (UMPSA)

- Universiti Malaysia Sarawak (UNIMAS)
- Universiti Sains Malaysia (USM)
- Universiti Putra Malaysia (UPM)
- Universiti Teknologi Malaysia (UTM)
- Universiti Teknologi Mara (UiTM)
- Universiti Teknologi PETRONAS (UTP)

Netherlands

- PB Consultant

Norway

- AF Gruppen

Singapore

- Newcastle University
- Sea Sentinels Pte Ltd

Thailand

- BMT Thailand
- Chevron Thailand Exploration and Production
- Chulalongkorn University
- Department of Mineral Fuels, Ministry of Energy
- INSEE Ecocycle
- Italian-Thai Development Corporation Limited (ITD)
- Mahidol University (MU)
- Medco Energi
- Petroleum Institute of Thailand
- PTTEP (Thailand) Limited
- Radioactive Waste Management Center, Thailand Institute of Nuclear Technology (TINT)
- STP&I Public Company Limited
- Thai N. D. T. Company Limited
- Thai Nippon Steel Engineering & Construction Corporation Ltd
- Unithai Shipyard and Engineering Limited

Vietnam

- Ha Loc Hazardous Waste Treatment Plant
- Hanoi University of Science and Technology (HUST)
- Ministry of Industry and Trade
- PetroVietnam (PVN)
- PetroVietnam Domestic Exploration Production Operating Company Limited (PVEP POC)
- PetroVietnam Exploration Production Corporation (PVEP)
- PetroVietnam Maintenance and Repair Corporation (PVMR)
- PetroVietnam University (PVU)
- PTSC Supply Base
- Vietnam Petroleum Institute (VPI)
- Vietsovpetro

United Kingdom

- Able UK
- Liverpool John Moores University

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

As offshore structures in the ASEAN and South Asia regions reach the end of their operational life, the decommissioning process has become a critical focus. Southeast Asia, with its 1,700 fixed offshore structures, will see the decommissioning of over 500 structures soon. This project addresses the challenges and opportunities associated with the safe and sustainable decommissioning of offshore structures, emphasizing the need for region-specific strategies. The study explores regulatory frameworks, environmental impact assessments, socio-economic implications, innovative technologies, and best practices tailored to these geographies to minimize environmental impact and improve safety.

This project focuses on offshore decommissioning practices within Southeast Asia, assessing legislation, guidelines, and practices across the region. It highlights Thailand's leadership in prescriptive regulations and experience. It also develops safety enhancement methods for shallow water decommissioning and proposes a general decommissioning framework modeled after the United Kingdom’s practices to guide future initiatives. The need for a robust regime, drawing from established frameworks like those in the North Sea and the Gulf of Mexico, is emphasized, recommending adherence to international requirements and the development of a regional decommissioning framework.

The Southeast Asia region has limited onshore dismantling yards, mainly located in Thailand, Indonesia, and Malaysia. Due to legal restrictions on transboundary movement of hazardous waste, each country must handle decommissioned structures independently. The study suggests upgrading shipbuilding and offshore structure fabrication yards to include dismantling capabilities, given the presence of primary facilities. It reviews regulations and case studies from Indonesia and Malaysia, benchmarking them against North Sea yards. The research highlights the need for facilities capable of hazardous waste handling, systematic layout planning for yard rearrangement, and specific upgrades to support decommissioning. The study provides an overview of hazardous waste and mercury waste management legislation and facilities in ASEAN nations. It conducts a comparative analysis of hazardous waste management facilities in Indonesia, Malaysia, and Vietnam, assessing their compliance with national and international standards. For mercury waste, a case study of BMT Thailand, a leader in sustainable mercury and NORM waste management, is presented. Additionally, a review of NORM waste management systems in Indonesia, Malaysia, Thailand, and Vietnam is carried out. The study finds inconsistencies among ASEAN countries in developing hazardous waste management legislation and facilities. It suggests using conceptual designs and guidance from Indonesian and Malaysian agencies to develop proper NORM waste disposal facilities.

This comprehensive framework aims to facilitate a harmonized and efficient decommissioning process, promoting a transition towards a more environmentally responsible and economically viable offshore industry in the ASEAN and South Asia regions.

1. Introduction

1.1 Background

With the impending decommissioning of numerous oil fields in the coming years, there is an urgent need for research that enhances the decommissioning process and ensures its safety and sustainability. The specific challenges of the Southeast Asia region, characterized by its shallow waters (<100 m depth) and a tropical climate that increases structure marine growth, necessitates special considerations. In Southeast Asia (SEA), there are over 1800 offshore platforms, most of which are earmarked for decommissioning; however, asset owners lack experience and guidelines for this process. Moreover, the region lacks secure and sustainable decommissioning methods and dedicated onshore recycling facilities for retired offshore structures.

Hence, this project focused on the decommissioning of offshore structures in shallow water in ASEAN countries, particularly Malaysia, Indonesia, Thailand, and Vietnam. At this time, there are about 1700 offshore structures in Southeast Asia, with 800 of them possibly having operated for more than 20 years and have thus reached the decommissioning stage. Meanwhile, over half of the approximately 180 offshore installations in South Asia do not operate, and hence, can be decommissioned soon.

With the growing number of structures earmarked for decommissioning, the importance of a secure decommissioning process and facilities to address potentially hazardous waste from these structures has become increasingly apparent. Decommissioning cost are substantial, estimated at USD 5 billion in 2016 for Southeast Asia (SEA). Various stakeholders have distinct interests that have driven up costs: regulators emphasize security assurance, compliance with legislation, and job creation; operators prioritize sustainable operations, compliance with laws and PSC agreements, reputation protection, liability discharge, and HSSEQ performance; and industry seeks an open decommissioning market with shared risks and rewards. To strike a balance, there is a need to enhance the decommissioning process and establish a recycling yard capable of managing decommissioning assets.

As plans for decommissioning offshore installations are subject to change, the quantity of decommissioned installations to be transported onshore can be unpredictable. Consequently, not all countries see the need to construct junkyards/disposal facilities and may opt to transport decommissioned installations to existing regional facilities. In Southeast Asia, inadequate scrapyards for waste processing necessitate the construction of scrapyards. However, there is a lack of technical guidelines for specific decommissioning aspects in the region, including waste management, particularly for the recycling of decommissioned structures and the treatment of hazardous materials.

Given the scarcity of scrapyards in the region and the rising number of decommissioned offshore structures, issuing guidance for safe, green, and sustainable recycling facilities and downstream waste management facilities will create significant economic, environmental, and social investment opportunities. However, a challenge in issuing guidance lies in the absence of recycling facilities specialized for decommissioned offshore structures in countries such as in Vietnam, which was used for case analysis. In line with best practice techniques, the guidance of this research project is based on relevant national and international laws, guidelines, and standards. National guidelines, such as the Draft Thailand Decommissioning Guidelines for Upstream Installations 2008 and Section 485A of Malaysia’s Merchant Shipping Ordinance (1952), are referenced. Additionally, international regulations, including the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships 2009 and OSPAR Decision 98/3 are consulted for recycling facilities.

This project's primary objectives include the development of technical guidelines for a secure and sustainable decommissioning process, along with the establishment of safe and sustainable recycling facilities and downstream waste management systems for decommissioned offshore structures in ASEAN and South Asia. To achieve these goals, this project conducted a comprehensive review of current decommissioning methods and procedures, surveyed existing recycling facilities in the region, and analyzed an existing facility against the Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships 2009 (HKC 2009 standards). Additionally, the project examined safe, green, and sustainable recycling facilities in other regions, taking into account relevant national and international laws, guidelines, and standards.

The culmination of these activities resulted in guidelines for decommissioning and recycling facilities for the ASEAN and South Asia region that enhance and adhere to safe, green, and sustainable standards. A crucial outcome of this project was the establishment and strengthening of a collaborative network in ASEAN and South Asia focused on research related to decommissioning, recycling, and downstream waste management facilities for retired offshore structures in the region.

Photo by Muhammad ilham Marlis | Vecteezy.com

1.2 Objectives

1. Develop technical guidelines for a secure and sustainable decommissioning process tailored to the unique characteristics of the ASEAN and South Asia regions.

2. Establish safe and sustainable recycling facilities for decommissioned offshore structures, with consideration for environmental and economic aspects.

3. Enhance waste management practices, particularly the recycling of decommissioned structures and the treatment of hazardous materials.

4. Foster collaboration between stakeholders in ASEAN and South Asia to create a network for ongoing research that will enable improvements in decommissioning, recycling, and waste management.

1.3 Output

The project's key deliverables include:

1. Comprehensive technical guidelines for the safe decommissioning of offshore structures, reflecting the specific challenges posed by the ASEAN and South Asia regions.

2. Development and establishment of safe and sustainable recycling facilities capable of handling the unique requirements of decommissioned offshore structures.

3. Guidelines for effective waste management that emphasize the recycling of decommissioned structures and the treatment of hazardous materials.

4. Creation and strengthening of a collaborative network among stakeholders in ASEAN and South Asia that facilitate ongoing research and improvements in decommissioning practices.

2. Method and Guidelines for Safety Enhancement in the Decommissioning Process

2.1 Introduction

Chapter 2 of this report produces the key findings and objectives of the three Work Packages (WP1A, WP1B, and WP1C) focused on offshore decommissioning practices within Southeast Asia. WP1A assessed decommissioning legislation, guidelines, and practices across Southeast Asian countries, with Thailand showcasing leadership in prescriptive regulations and experience. WP1B aimed to develop safety enhancement methods and guidelines for offshore decommissioning, particularly in shallow waters, by uniting subject matter experts across Southeast Asia. WP1C proposed a general decommissioning framework, modelled after the United Kingdom's, to guide future initiatives in the region. The immature state of offshore decommissioning in Southeast Asia underscores the need for a robust regime, drawing from established frameworks like those in the United Kingdom and the Gulf of Mexico, with recommendations emphasizing adherence to international requirements and the development of a regional decommissioning framework.

2.1.1 Overview of Offshore Decommissioning

In the Asia Pacific region, approximately 2,600 offshore structures and 35,000 wells are nearing the end of their production life, with an estimated cost of US $100 billion. This presents a significant opportunity for the decommissioning sector, with over 1,700 fixed offshore structures and 7,000 wells requiring decommissioning (Wood, 2018). However, decommissioning activities face challenges due to unclear regulations, inadequate enforcement, and a lack of experienced manpower in the region. Despite these challenges, efforts are being made to develop decommissioning frameworks and prioritize structures for decommissioning. Collaboration between stakeholders and adherence to best practices are crucial to ensuring safe and efficient decommissioning processes across Southeast Asia.

According to the ASEAN Council on Petroleum (ASCOPE) (2012), decommissioning marks the final phase of oil and gas operations and should be considered throughout a facility's life cycle. It is essential to plan for cost-effective disposal of facilities at the end of their useful life. Decommissioning involves various stakeholders such as international and national government agencies, oil and gas companies, third parties, local communities, and non-governmental organizations. Decommissioning is described as the process of removing, disposing, and dismantling a structure (Nåmdal, 2011; Zainai, 2022) with different options depending on location, structural integrity, and legal requirements. Typically, there are three main methods: total removal, partial removal, and leaving structures in situ. This process follows the phases of planning, preparation, dismantling, recycling/disposal, and monitoring, with decommissioning plans needing approval before implementation.

2.1.2 Type of Offshore Structures in Southeast Asia

Offshore structures are important for hydrocarbon production, storage, and offloading. They vary in design based on operational requirements and conditions. In Southeast Asia, various typical oil and gas offshore structures are present, including fixed steel structures, Gravity Based Structures (GBS) and Tension Leg Platforms (TLP), similar to those found in UK waters. The first TLP project, Shell Malikai, is located around 100 kilometres from Sabah and represents a collaboration between Shell, ConocoPhillips Sabah, and Petronas Carigali. Another significant TLP project is situated in Indonesia's West Seno field, approximately 50 kilometres from the Attaka field and 60 kilometres from the Santan terminal in East Kalimantan. Additionally, Southeast Asia has fixed steel monopods structures, also known as cable guyed caissons. The structures may have one, three, four, six or eight caisson type legs. One example is the Tarpon Monopod, located around 76 meters deep offshore Terengganu in Malaysian waters. These structures are innovative minimal platform designs commonly used for the development of marginal fields. They involve a main caisson anchored with three sets of cables to seabed piles that support a topside superstructure. This design offers a simpler alternative to jacket platforms and is well-suited for specific offshore applications (Eika & Liew, 2014). Spar platforms are also present in Southeast Asia's waters and are utilized for offshore oil production in very deep waters. These platforms, named for their resemblance to buoyant logs, consist of rigid cylinders anchored to the seabed by vertical or catenary cables. Spar platforms float vertically in the water, with their weight counteracting surface wave action. Stability is further enhanced by fin-like structures called strakes, with station keeping provided by lateral, multi-component catenary anchor lines. Malaysia installed its first Spar at the Kikeh field in 2007, situated in waters approximately 1330 meters deep off the shores of Sabah (Agarwal & Jain, 2003; Islam et al., 2012).

Photo by julesromero70 | pixaby.com

Regardless of type, these installations are complex, consisting of thousands of tonnes of steel and various equipment for hydrocarbon production, power generation, and safety. The decommissioning process is influenced by platform type, size, and structural integrity. Topsides are typically comprised of drilling, production, and cellar decks, housing equipment like drill rigs, processing systems, and utility systems.

2.1.3 Decommissioning Activities in Southeast Asia

In Southeast Asia, countries like Malaysia, Indonesia, Thailand, Vietnam, and Brunei are actively engaged in offshore oil and gas activities. Malaysia boasts over 390 fixed offshore structures, of which 26 are earmarked for decommissioning, with 8 already decommissioned (Zainai, 2022). Indonesia, on the other hand, has more than 600 fixed offshore structures, with 9 identified for decommissioning (Amelia et al., 2020; Bambang, 2022). Thailand's Gulf of Thailand hosts over 450 offshore structures, and 23 of them are anticipated to be decommissioned in the next five years, with 25 already decommissioned by December 2021 (Rittichai, 2022). Vietnam operates 60 offshore structures but has not as yet identified any for decommissioning, while Brunei plans to decommission 53 structures by 2030 (Bui & Nguyen, 2021). Water depths in these regions typically range from 15 to 100 meters.

2.2 Current Decommissioning Guidelines and Practices in Southeast Asia

This section focuses on decommissioning laws, guidelines, and practices from representatives of Southeast Asian countries, along with information from workshops and seminars. Its objective was to compare these components across countries as illustrated in Figure 2.1.

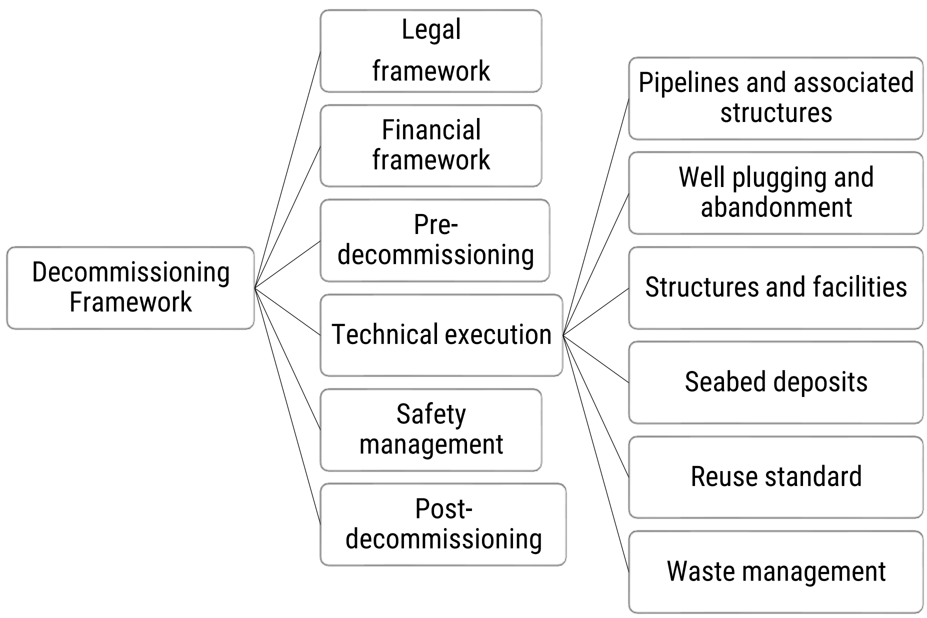

Figure 2.1 Components for Comparison Decommissioning Framework

A summary of findings on decommissioning practices and guidelines across five Southeast Asian countries is presented in Table 2.1. While the region lacks specific regional regulations for decommissioning, each country follows its own guidelines. For instance, Malaysia refers to technical documents from PETRONAS, particularly the PETRONAS Procedure and Guidelines for Upstream Activities (PPGUA), while Indonesia utilizes the Code of Work (PTK) from the Oil and Gas Task Force SKK Migas. Thailand has a decommissioning legal framework established through amendments to the Petroleum Act 1971. Vietnam revised its Law on Petroleum in 2015 to align with UNCLOS. In Brunei, the Decommissioning and Restoration Guidelines for Onshore and

Offshore Facilities were implemented in 2009. Additionally, the region relies on ASCOPE Decommissioning Guidelines for Oil and Gas Facilities (ADG). Despite variations, all Southeast Asian countries adhere to similar technical standards, with Thailand demonstrating the highest level of detail and experience.

Photo by Puwadol Jaturawutthichai | Vecteezy.com

Table 2.1 Comparison in Decommissioning Requirements for Southeast Asia

		Malaysia	Indonesia	Thailand	Vietnam	Brunei
Financial Framework	Financial Framework	Cessation Fund (Since 1998) - contribute by operators	Post Operation Fund - contribute by operators	Financial Security by individual or combination	Financial Guarantee Fund - set up by Operator	Cost estimation by Duty Holders
Pre-decommissioning	Decommissioning Plan	Yes	3-5 years prior to execution schedule	2-5years prior (dependent on remaining reserves)	Yes	Yes
	Comparative Assessment	Yes - DOA	NA	Yes - BPEO	NA	Yes
	Environmental Appraisal	Yes	NA	Yes	Yes	NA
	HSE Risk Assessment	Yes	Yes	Yes	Yes	Yes
Technical Execution	Well, Plugging & Abandonment	Yes	Yes	Yes	Yes	Yes
	Structure & Facilities	Yes	Yes	Yes	Yes	Yes
	Pipelines & Associated Structures	Yes	NA	Yes	Yes	Yes
	Seabed deposit management – Site specific evaluation	NA	NA	Yes	NA	NA
	Seabed deposit management – Debris survey & clearance	Yes	NA	NA	NA	Yes
	Safety – risk assessment	Yes	NA	Yes	Yes	NA
	Safety – prohibit the explosive use	Yes – Jacket & substructure and piles	NA	NA	Yes – cutting wellhead	NA
	Reused Standard – Artificial reef	Yes	Yes	Yes	Yes	Yes
	Reused Standard – Structure evaluation	Yes	Yes	Yes	NA	NA
	Waste Handling	Yes	Yes	Yes	Yes	Yes
Post decommissioning	Close out report	Yes - 1 month	Yes - 14 days	Yes - 12 months	Yes - 9 months	NA
	Monitoring program	Yes		Yes	NA	Yes

2.3 Safety Enhancement for Fixed Offshore Structures

Consultative workshops were conducted to identify the optimal removal method for fixed offshore structures in the region. These workshops gathered insights from subject matter experts on risk factors and mitigation strategies related to safety, environmental impact, and economic considerations. The main objectives were to pinpoint key challenges in the removal process, evaluate which options posed the highest risks, and develop effective mitigation plans. Figure 2.2 illustrates the timeline and specifics on the conducted workshops. In addition, a focus group discussion was conducted to refine mitigation plans. Following the completion of the 3rd International Seminar on "Challenges and Opportunities in Offshore Decommissioning in Southeast Asia and Beyond", a short focus group session was organized on November 28, 2022. The flow of the discussion followed the questionnaire used in Workshops 1 and 2, where participants rated selected risks before and after the implementation of mitigation measures.

The Delphi study methodology was used to collect expert opinions, while the Wilcoxon signed-rank test was utilized for data analysis.

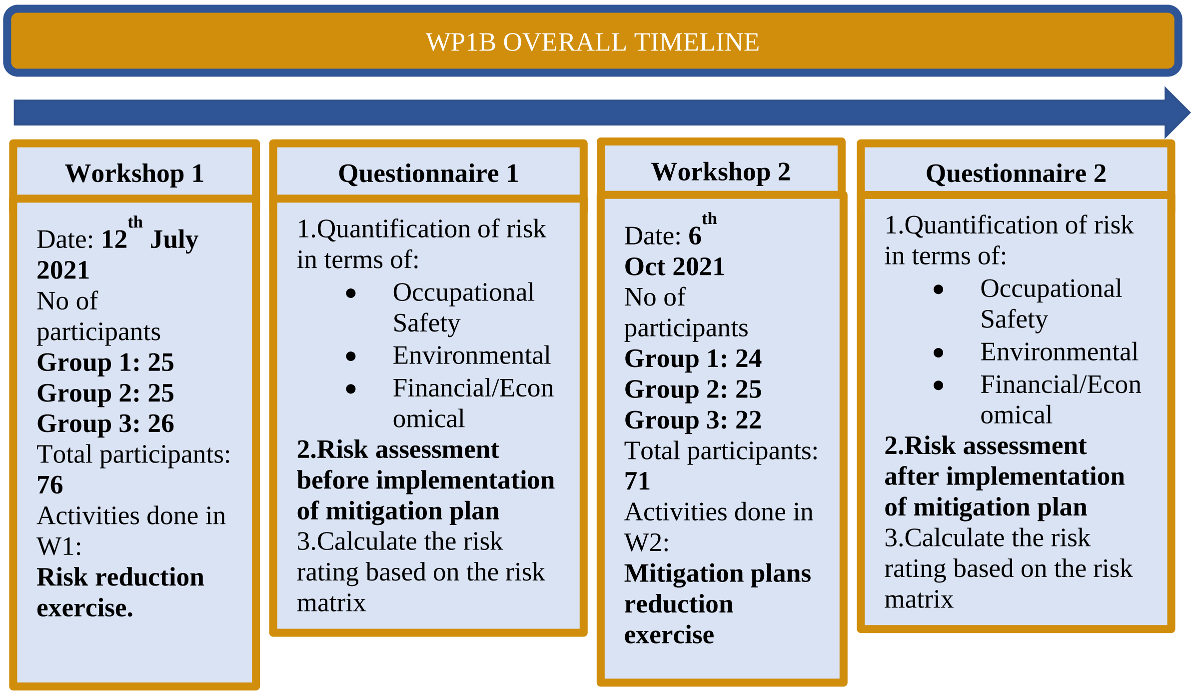

Figure 2.2 WP1B Overall Workshops Timeline

The results of the study, aimed at developing safety enhancements for offshore structures, were obtained through consultative workshops that focused on identifying the optimal removal method for fixed offshore structures in the region. These workshops brought together subject matter experts to gather insights on risk factors and mitigation strategies related to safety, environmental impact, and economic considerations. Upon reviewing the implementation plan and considering expert opinions, the analysis of best removal methods (before and after implementation of mitigation plans) is presented in Figure 2.3. The least preferred removal option across all risk factors appears to be complete removal. The most preferred options fall between partial removal and leaving in situ.

In terms of occupational safety, partial removal emerges as the best option, followed by leaving in situ. Among the hazards associated with leaving in situ, explosive cutting stands out as a significant concern. This method requires more explosives to cut the platform into smaller pieces, potentially contributing to the preference for partial removal.

Regarding environmental impact, partial removal is favoured as the most preferred option, with leaving in situ as the next favourable choice. Similarly, explosive cutting is identified as the primary hazard associated with leaving in situ, mirroring concerns observed in the realm of occupational safety.

From a financial perspective, leaving in situ is prioritized as the most favourable option, followed by partial removal. Notably, one of the main hazards associated with partial removal is the risk of ship or vessel collisions, highlighting the multifaceted considerations involved in the decision-making process for offshore decommissioning activities.

Overall, the findings suggest that partial removal and leaving in situ are the preferred options across various risk factors, with the specific choice depending on factors such as safety, environmental impact, and financial considerations.

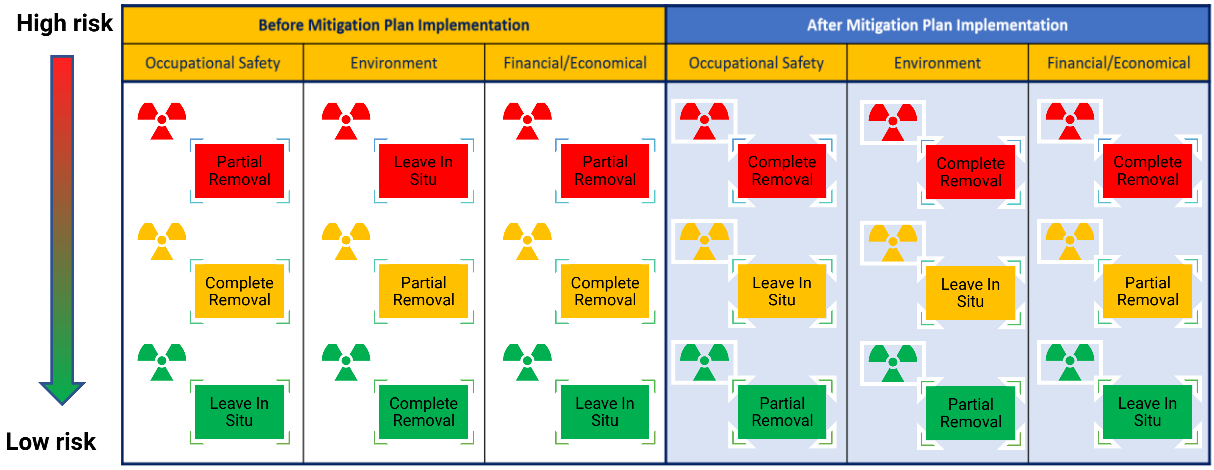

Figure 2.3 Ranking of Best Removal Methods (Before and After Implementation of Mitigation Plans

2.4 Proposed Decommissioning Guidelines

A general decommissioning framework is proposed based mainly on the North Sea's model. This framework is developed using data collected in an earlier phase, aiming to facilitate the future development of relevant guidelines in the Southeast Asian region.

Following the outcomes of Work Packages 1A (WP1A) and 1B (WP1B), a legal framework and general decommissioning framework are proposed, considering the safe decommissioning, or repurposing of structures in the ASEAN and South Asia regions. These proposed frameworks are planned with the UK and GoM serving as a benchmark.

All five Southeast Asian countries have ratified the UNCLOS and Basel Convention, while Malaysia and Thailand have also ratified the Geneva Convention. However, additional international conventions are proposed for the region which are IMO 1989 and London Convention and Protocol. OSPAR is a good reference to Southeast Asia, as a guideline from a mature region. The details regarding these international conventions can be found in Table 2.2. This alignment is crucial to maintain consistency across decommissioning regulations and provide clear guidance to operators.

Table 2.2 International Convention Summaries

Convention	Summary
UNCLOS 1982	Applies to structures within signatory states' offshore waters, requiring removal of abandoned or unused installations in their Exclusive Economic Zones (EEZ) to prevent marine pollution; allows for abandonment if navigation safety meets international standards.
Geneva Convention 1958	Recognizes states' sovereign rights to explore natural resources; coastal states can establish, maintain, or operate installations, with complete removal of disused structures for safety reasons.
IMO 1989	Prioritizes safety and navigation, requiring removal of abandoned offshore structures unless consistent with IMO guidelines; coastal states may decide if structures can remain for new use or without unjustifiable interference with other sea users.
London Convention & Protocol	Aims to prevent marine pollution by prohibiting deliberate disposal of vessels or structures at sea; permits certain obsolete infrastructure to remain or be repurposed under special permits, such as for creating artificial reefs.
OSPAR Convention	Emphasizes complete removal of offshore installations to protect the marine environment in the Northeast Atlantic; mandates all parties to prevent pollution and requires permits for any disused offshore structures left in place, with exceptions for large structures on a case-by-case basis.

The proposed general decommissioning framework comprises three stages: pre-decommissioning, decommissioning plan and execution, and post-decommissioning. In the pre-decommissioning stage, plans should be submitted five years in advance, allowing for adequate preparation time, a departure from the current practices in Southeast Asian countries. This stage includes a detailed timeline, as depicted in Figure 2.4. The decommissioning plan must encompass various elements such as a comparative assessment, integrity of installations, environmental appraisal, material inventory, waste management, risk assessment, cost estimation, decommissioning schedule, and stakeholder consultation.

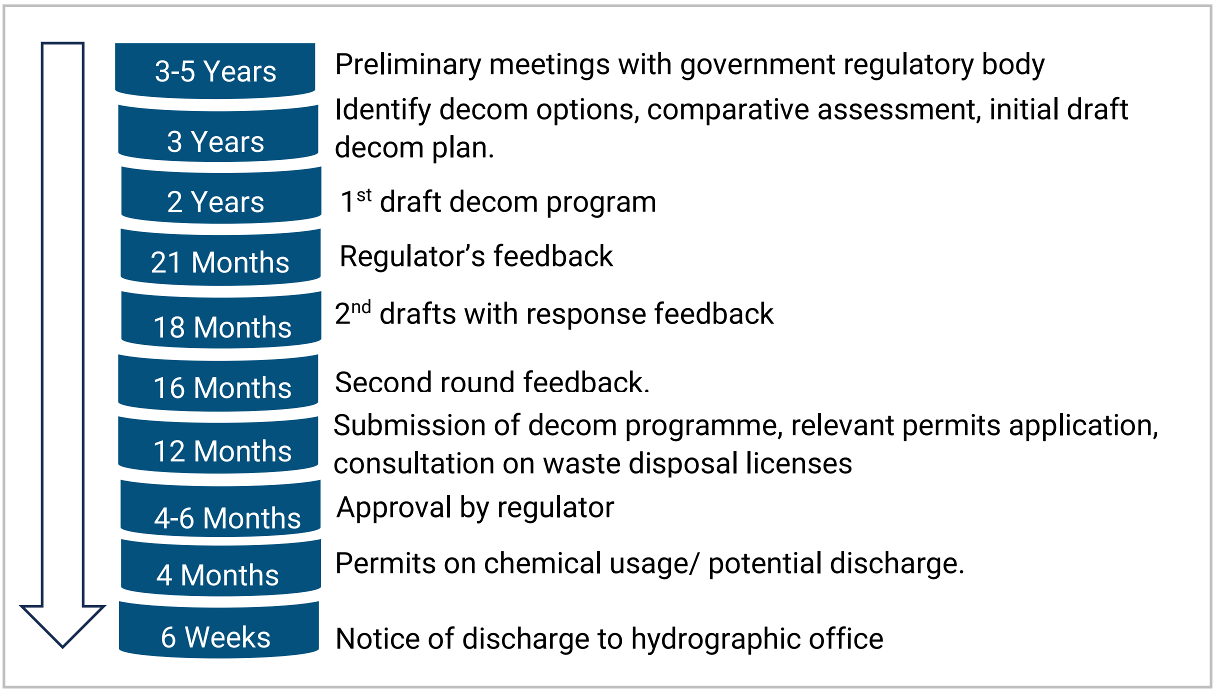

Figure 2.4 Propose Generic Timeline for Pre-Decommissioning

In the execution phase of decommissioning, several key activities are emphasized. First, the use of explosives for cutting operations necessitates careful consideration to minimize underwater noise impact on marine life, with guidelines for risk mitigation developed by relevant national environmental bodies. Operators must report any dropped objects at sea and take preventive measures against adverse weather impacts before commencing decommissioning operations. Additionally, detailed plans for depressurizing and cleaning operations, including managing hydrocarbons and adhering to abandonment criteria, are crucial. Finally, measures to prevent vessel collisions, such as establishing safety zones and maintaining navigational aids, underscore the importance of safety throughout the decommissioning process.

In the post-decommissioning phase, a comprehensive monitoring program is essential, encompassing activities such as seabed sampling, structure inspection, and pipeline monitoring. Additionally, close-out reporting is crucial, involving lessons learned, project timeline, waste inventory, and monitoring schedule. These reports should be submitted within four months, mirroring the practices observed in the UK. This phase ensures thorough oversight and documentation of the decommissioning process, facilitating the evaluation of its outcomes and adherence to regulations and standards.

2.5 Conclusion

In conclusion, the WP1 has been effectively executed, yielding valuable insights into decommissioning practices and guidelines across Southeast Asian countries. While lacking specific regional regulations, all countries adhere to similar technical standards, with Thailand demonstrating the highest level of detail and experience. The proposed general decommissioning framework, influenced by international conventions and best practices, offers a structured approach across three key stages: pre-decommissioning, execution, and post-decommissioning. Emphasizing safety, environmental protection, and stakeholder consultation, this framework aims to ensure consistency and clarity in decommissioning regulations, thereby facilitating safe and responsible decommissioning, or repurposing of offshore structures in the region. The study underscores the importance of aligning with international conventions, leveraging expert insights, and implementing robust monitoring and reporting mechanisms to enhance the effectiveness and sustainability of decommissioning activities in Southeast Asia.

Photo by wasi1370 | pixabay.com

3. Identification and Improvement of Recycling Facilities for the Decommissioning of Offshore Structures in The Region

3.1 Introduction

Onshore dismantling yard plays a critical role in offshore oil and gas decommissioning, especially in decommissioning of fixed platforms' topsides. Nevertheless, the number of well-equipped onshore dismantling yards to support offshore oil and gas decommissioning in Southeast Asia is very limited, although the region has more than 500 offshore structures to be decommissioned soon. Following some recent investigations, there is high potential for shipbuilding and offshore structure fabrication yards to upgrade their facilities to include dismantling capability due to the presence of required primary facilities. However, research studies on this area are relatively scarce and most of the past studies mainly focus on the North Sea region. This research aims to bridge the gap in the literature by investigating the potential of upgrading shipbuilding and offshore structure fabrication yards in Southeast Asia to include oil and gas decommissioning. Two case studies were undertaken, with the cases being onshore dismantling facilities in Indonesia and Malaysia, which were benchmarked with the facilities in the North Sea to identify their technical preparedness. Note that onshore dismantling of offshore structures is not just a simple reverse engineering of shipbuilding. While decommissioned offshore structures contain hazardous waste residues accumulated from oil and gas production, shipbuilding yards often lack adequate waste handling capability to handle such residues. Therefore, this research also aims to provide guidance for the existing dismantling facilities as well as shipbuilding yards in the region to improve and achieve standards of safe, green and sustainable recycling facilities.

Another focus of this research is to assess the compliance of downstream waste management facilities to deal with hazardous materials (especially mercury and Naturally Occurring Radioactive Material (NORM)) with respect to the related national and international regulations. Despite accounting for a small part of total waste materials from offshore structures, hazardous waste could pose significant health and environmental risks if being carelessly recycled and disposed. Mercury and NORM waste should be of particular concern, given their serious impacts on human beings and the environment. This research provides updated overviews of hazardous waste and mercury waste management legislation and facilities in all ASEAN nations. For hazardous waste, a comparative case analysis of three hazardous waste management facilities in Indonesia, Malaysia and Vietnam was conducted to investigate how they comply with relevant national and international regulations and standards. For mercury waste, a case study of BMT Thailand, the only branch in Asia/Southeast Asia of BMT – a world leader in sustainable mercury and NORM waste management was conducted. Furthermore, a holistic review of the NORM waste management systems, particularly for oil and gas operations in Indonesia, Malaysia, Thailand and Vietnam was carried out.

3.2 Identify Existing Facilities in The Region & Select One as A Case Study for Gap Analysis Against the HKC 2009 Standards for Standards for Safe and Sustainable Recycling of Decommissioned Offshore Structures

3.2.1 PT. Meitech Eka Bintan (MEB) offshore fabrication yard in Indonesia

Table 3.1 presents the results of the comparative analysis between MEB yard and ABLE Seaton Port (ASP) yard in the UK - a world-leading service provider for offshore structure dismantling. Such results show that MEB yard is relatively comparable with ASP yard in respect of depth at the quayside, mooring facilities, maximum load-out capacity, size of laydown area, ground bearing capacity, availability of liquid containment system, and distance to a disposal center.

Table 3.1 Comparison between MEB and ASP yards (Amelia et al., 2021)

Criteria	MEB	ASP
Depth at quayside	8 to 12 m	9.5 m
Mooring facilities	Capable of mooring barges and HLV	Capable of mooring barges and HLV
Maximum load-out capacity	10,000 MT	More than 22,000 MT
Laydown area	26,000 m2	185,000 m2
Ground bearing capacity	25 to 100 MT/m2	75 MT/m2
Liquid containment at fabrication area	Yes	Yes
Distance to disposal center	3 km	0.5 km

The study conducted the assessment of MEB yard's preparedness to receive decommissioned offshore structures, using CRF Consultant's (2016) criteria. The assessment scores were compared with those of other decommissioning yards in the North Sea as indicated in CRF Consultant (2016). MEB yard's preparedness to receive decommissioned offshore structures can be ranked at the upper tier level as tabulated in Table 3.2. Note that the North Sea is regarded as one of most experienced and active regions in terms of onshore dismantling, given the regulation of *OSPAR Decision 98/3 on the Disposal of Disused Offshore Installations*.

Table 3.2 Ranking of MEB yard's preparedness compared to North Sea decommissioning yards (Amelia et al., 2021)

Rank	Yard	Location	Facilities	Sea Accessibility	Proximity to waste disposal	Waste License	Liquid Containment
1	VATS	5	5	5	H	Y	Y
2	STORD	5	5	5	H	Y	Y
3	ABLE UK	5	4	3	H	Y	Y
4	Greenhead Base	5	3	4	H	Y	Y
5	Nigg Energy	4	4	4	H	N	Y

Rank	Yard	Location	Facilities	Sea Accessibility	Proximity to waste disposal	Waste License	Liquid Containment
6	Montrose	4	3	2	H	N	Y
7	Port of Dundee	3	4	3	H	N	N
8	**MEB**	**3**	**4**	**4**	**M**	**N**	**Y**
9	Kishorn	3	3	4	L	N	N
10	Harland & Wolff	3	3	3	H	Y	Y
11	Burntisland	3	3	3	H	N	N
12	Peterhead	3	3	3	M	Y	Y
13	Swan Hunter	3	3	3	M	Y	Y
14	Ardesier	3	3	3	L	N	N
15	Leith	3	3	3	M	N	N
16	Methil	3	3	1	H	N	N
17	Dales Voe	3	3	1	H	N	N
18	Wick	3	2	3	L	N	N
19	Ardyn Point	2	2	3	L	N	N
20	Hunterston	2	2	2	L	N	N

Based on the above-mentioned analysis, the facilities at MEB yard can be evaluated as highly ready to receive decommissioned offshore structures. MEB yard has sufficient water depth to moor alongside the quay. It also has a liquid containment system to collect any liquid waste or rainwater run-off from decommissioned structures to avoid the release of contaminants to the surrounding environment. However, despite having a high reach crane to support demolition activities, current load-out operation may only be capable of receiving a single piece of a wellhead structure or a heavy structure that is removed in several large pieces. Given its spacious fabrication area and the limited number of fixed buildings, most space at the yards is still in open space and can be upgraded with required facilities for dismantling and disposing decommissioned offshore structures.

A SWOT analysis of MEB yard was also conducted, with the results tabulated in Table 3.3. The SWOT analysis demonstrates that MEB yard has more strengths than weaknesses, and more opportunities than threats.

Table 3.3 SWOT Analysis of MEB yard (Amelia et al., 2021)

Strengths	**Weaknesses**
1. Compliance with the International Ship and Port Facility Security (ISPS) Code 2. ISO 9001, ISO 14001 and ISO 45001 certificates 3. Daily operation (7 days/week) 4. Up-to-1-ha quarantine area and 0.5-ha emergency area 5. 3 km away from the waste disposal centre 6. 26,000m^2 laydown area 7. Availability of a high-reach crane to support demolition of tall structures (>500MT) 8. Local waste management licence (AMDAL) 9. Marine Warranty Survey licence 10. Past load-out experience of 5,000 MT and 10,000 MT 11. Availability of mooring facilities 12. Availability of a liquid containment system at the fabrication area near the quayside	1. No demolition license 2. No international waste management licence 3. No capability to handle hazardous waste from decommissioned offshore structures 4. No waste handling capacity
Opportunities	**Threats**
1. Potential upgradation to include decommissioning activities 2. Possible extension up to 46 ha 3. Possible engagement with 3rd-party waste management vendors	1. Dependent on 3rd-party vendors for waste management 2. Unable to load-out structures with weight more than 10,000 MT.

In addition, MEB's actual layout was compared with UNEP's (2003) conceptual layout for the yard upgrading assessment. The assessment result is demonstrated in Figure 3.1.

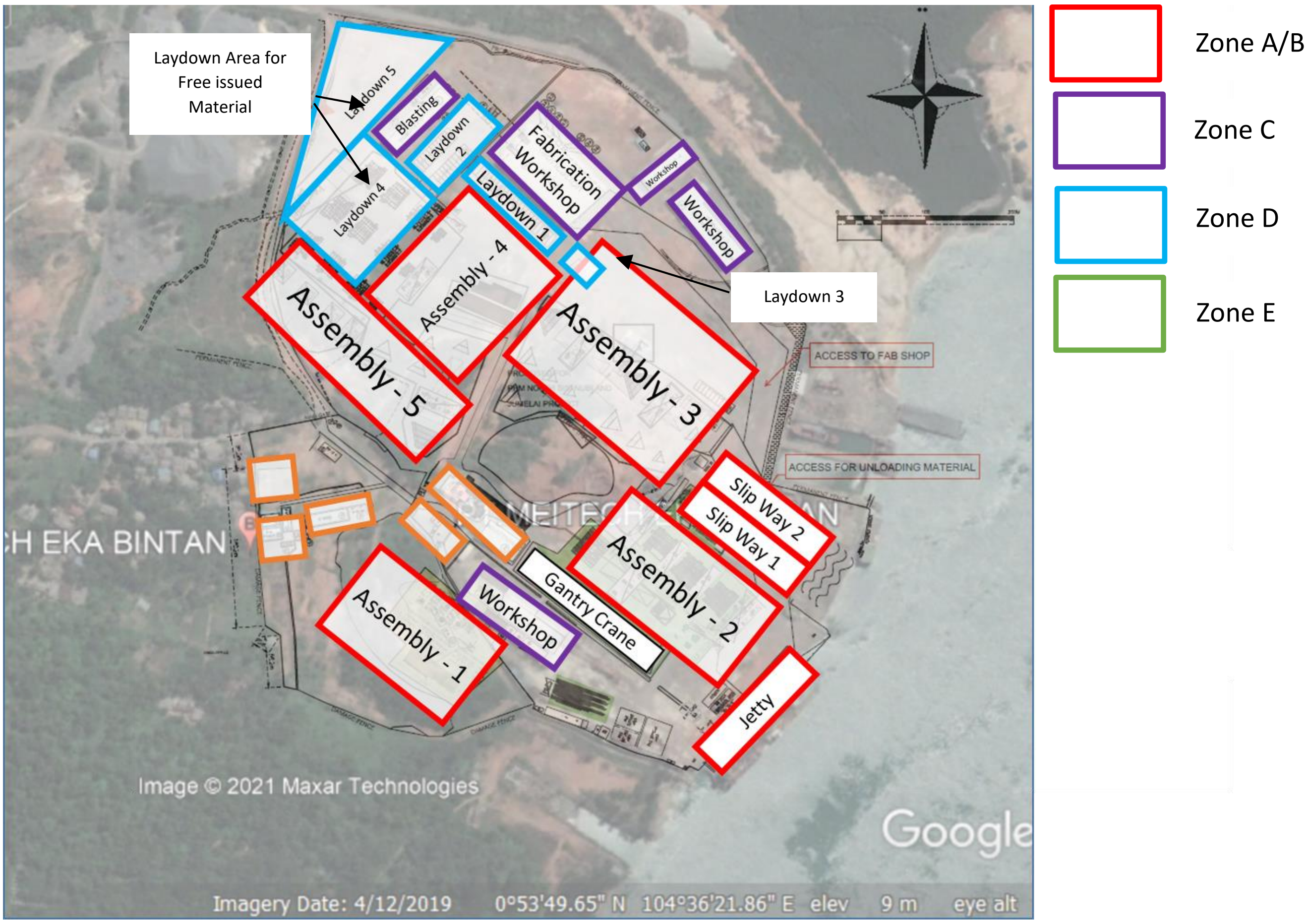

Figure 3.1 MEB yard zonation against UNEP's (2003) conceptual layout (Amelia et al., 2021)

In order to be capable of carrying out offshore decommissioning projects, the yard needs to be equipped with the following facilities:

1. A water treatment system to clean any residues on the structure;
2. Availability of specific tools to support dismantling activities, such as the excavator with a rip blade;
3. Closed waste storage facilities to store hazardous materials such as metal parts contaminated by asbestos, mercury, or radioactive waste for further treatment by a licensed waste management vendor;
4. A workshop or space for the licensed waste management vendor to pre-treat the contaminated material for sophisticated transportation; and
5. A dedicated area for the demolition work, which contains a liquid containment system and fulfils the following requirements: (a) it has the least interference

with the yard's main operation; (b) it is close to a quayside, given the uncertainties associated with the structure integrity that may face on land transportation of aged structures; and (c) it does not need to be close to the material laydown area and the assembly area since the one nearby the existing laydown area is more crucial for fabrication purpose.

Based on the above-mentioned criteria, the following layout (Figure 3.2) is recommended for the yard to enable it to receive decommissioned offshore structures.

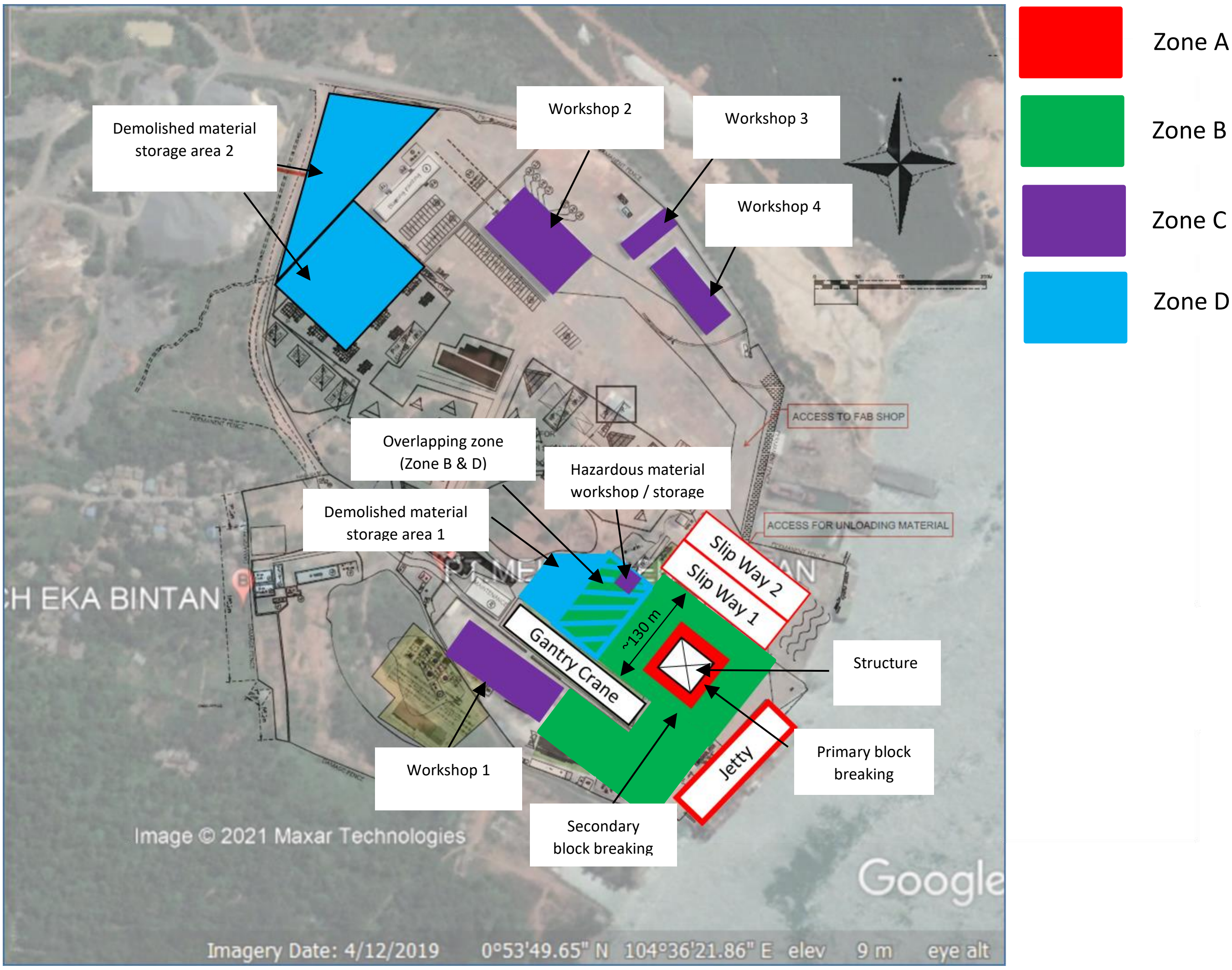

Figure 3.2 Proposed layout for the dismantling function on MEB yard (Amelia et al., 2021)

3.2.2 Yard X in Malaysia

The research uses the Systematic Layout Planning (SLP) method to rearrange the facilities of Yard X, a leading offshore and marine service provider in Malaysia for more than 40 years, to create an isolated space for the dismantling work. Yard X facilities can be grouped into three clusters, two for ship repair and conversion, and one for fabrication of offshore structures.

The SLP analysis steps were undertaken in the research as follows: (1) *Flow of materials*: the material flow of the fabrication and dismantling process was identified; (2) *Activity relationships*: the activity relationships between each pair of buildings was identified, based on which the activity relationship chart was built; (3) *Activity relationship diagram*: an activity relationship diagram was constructed to summarise the relationships between the buildings and was used for the rearrangement; (4) *Space available*: the space available or the boundary for the rearrangement layout was identified; (5) *Space requirements*: space requirements of the Fabrication Area (no. 16), Open Space 1 (no. 18) and Open Space 2 (no. 19) for the rearrangement were considered; (6) *Modifying considerations*: the storage areas (from no. 1 to no. 3), free space, offices (from no. 12 to no. 15) and workshop buildings (from no. 4 to no. 11, and no. 17) that are in the fabrication cluster were rearranged; (7) *Practical limitations*: constraints on workshop buildings, Open Space 1 and Open Space 2 were proposed to ensure the least interference of the dismantling operation with the fabrication operation, and the cleaner fabrication operation with reduction in material transportation waste; (8) *Develop layout alternatives*: a new layout was proposed; and (9) *Evaluation*: the new layout was evaluated.

Figure 3.3 presents one of the alternative new layouts based on the SLP method, with Open Space 1 and Open Space 2 being converted into Dismantling Area 1 and Dismantling Area 2, respectively. Following the hypothesised layout, the two dismantling areas would be located in the middle of the workshop buildings, whereas in the proposed new layout, the two dismantling areas are isolated from the workshop buildings and not located at the entrance of the fabrication area. This will eliminate the interference of the dismantling operation with the fabrication operation and enhance control on the movement of irrelevant personnel around the dismantling areas.

In the proposed new layout, the buildings are clustered into four categories: 1) office, 2) storage, 3) workshop and 4) dismantling areas. This layout will allow a smoother material flow for the fabrication operation and prevent material backflow. Figure 3.3 illustrates the material flow in the proposed new layout. With this layout, about 35% of the material travel distance for the overall fabrication operation can be reduced, by which 41% reduced for topside fabrication operation and 1.5% reduced for jacket leg fabrication operation.

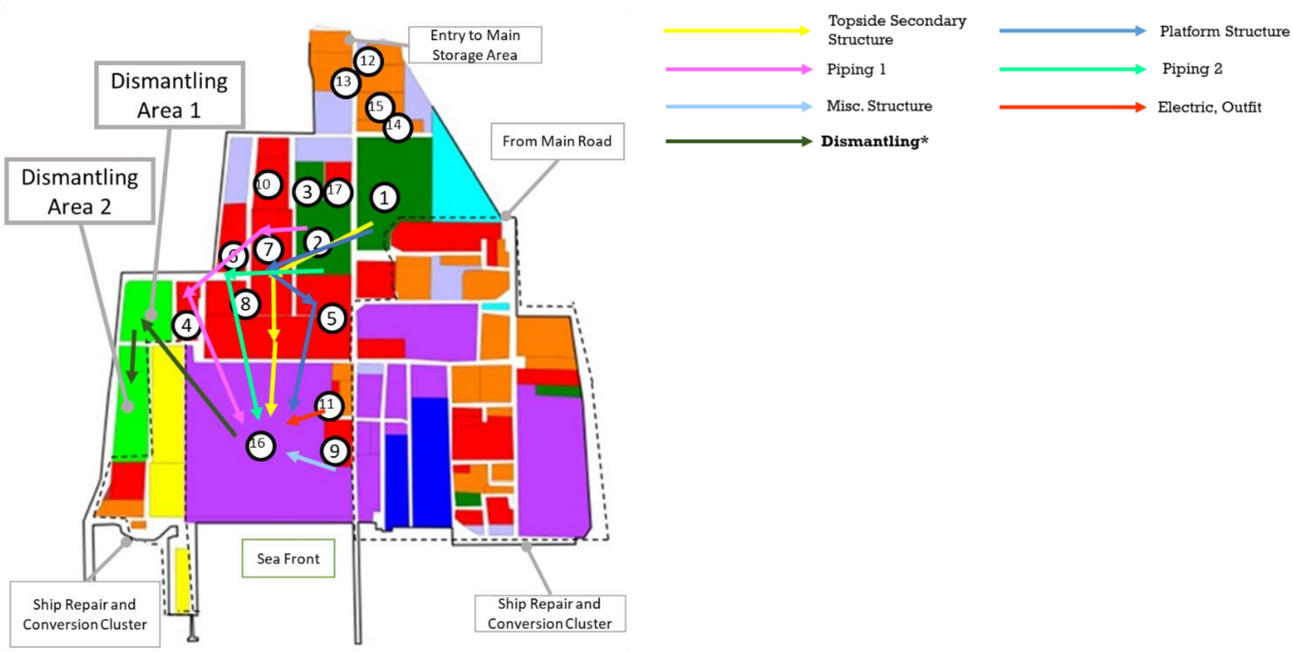

Figure 3.3 Proposed layout and the new material flow

3.3 Assess the Compliance of Downstream Waste Management Facilities to Deal With Hazardous Materials (Especially Mercury and NORM) with respect to the Related National and International Regulations

3.3.1 Hazardous Waste Management in ASEAN

3.3.1.1 Hazardous Waste Management Legislation and Facilities in ASEAN

Table 3.4 summarises the legal frameworks for hazardous waste management in ASEAN. The review of such legal frameworks shows that, among the ASEAN member states, Brunei, Indonesia, Lao PDR, Malaysia, the Philippines, Singapore and Vietnam have dedicated laws and/or legal and guiding documents on hazardous waste management, whereas Cambodia, Myanmar and Thailand only have the relevant ones. Compared to other countries, the Philippines has the most comprehensive legal framework for hazardous waste management. According to Table 3.5, Indonesia, Malaysia, the Philippines, Thailand and Vietnam have most waste management facilities available for handling hazardous waste although the facilities' standards may vary among countries. Meanwhile, Cambodia, Lao PDR and Myanmar have very few waste management facilities.

Table 3.4 Legal frameworks for hazardous waste management in ASEAN (updated from Le et al. (2022), under the copyright of ASRANet)

Country	Legal framework
Brunei	Hazardous waste management is based on the Poisons Act. The hazardous waste export, import and transit are controlled under the Hazardous Waste Order of 2013 (Constitution of Brunei Darussalam 2013).
Cambodia	Hazardous waste is managed under the Environmental Protection and Natural Resources Management Law 1996 and its Sub-Decree on Solid Waste Management 1999 (MOE (Cambodia) 1999; Royal Government of Cambodia 1996).
Indonesia	Hazardous waste is regulated under: (1) Law No. 32 of 2009 on Environmental Protection and Management; (2) Government Regulation No. 22 of 2021 on

Country	Legal framework
	Environmental Protection and Management; and (3) Regulation of the Ministry of the Environment and Forestry No. 6 of 2021 on the Procedures and Requirements for the Management of Hazardous Wastes.
Lao PDR	Hazardous waste is regulated under: (1) the Environmental Protection Law (2013, revised) and (2) the Ministerial Instructions on Hazardous Waste Management, No. 0744/MONRE (2015).
Malaysia	Hazardous waste is mainly regulated under: (1) the Environmental Quality Act (EQA) of 1974 and (2) the Environmental Quality (Scheduled Wastes) Regulations 2005.
Myanmar	No specific law on hazardous waste management. Hazardous waste is managed under: (1) Environmental Conservation Law (No. 9/2012); (2) Environmental Conservation Rules (No. 50/2014); (3) National Waste Management Strategy and Master Plan for Myanmar (2018-2030); and (4) National Environmental Policy of Myanmar 2019.
Philippines	Hazardous waste is regulated under: (1) Republic Act 6969 (1990); (2) DENR Administrative Order (DAO) 1992-29; (3) DAO 2004-36; and (4) DAO 2013-22.
Singapore	Hazardous waste is regulated under: (1) Environmental Public Health Act 1987 (revised 2002); (2) Environmental Public Health (Toxic Industrial Waste) Regulations 1988 (revised 2000); (3) Hazardous Waste (Control of Export, Import and Transit) Act 1997 (revised 2020).
Thailand	Hazardous waste is regulated under the Notification of the Ministry of Industry B.E.2548 (2005) (MOI (Thailand) 2005a).
Vietnam	Hazardous waste is mainly regulated under: Hazardous waste and mercury waste are mainly regulated under: (1) Law on Environmental Protection No. 21/VBHN-VPQH; (2) Decree No. 38/2015/ND-CP on Regulation of Waste and Discarded Materials; and (3) Circular 02/2022/TT-BTNMT Detailing on Implementation of the Law on Environmental Protection.

Table 3.5 Hazardous waste management facilities in ASEAN (Le et al.2022, under the copyright of ASRANet)

Country	Hazardous waste management facilities
Brunei	32 waste collection and disposal, 20 recycling, 1 treatment and 2 recovery companies (DEPR (Myanmar) 2021, 2022; Bukit Udal Material Recovery Center n.d.; CIC n.d.c; Green Depot n.d.), and 1 main landfill (*Borneo Bulletin* 2021).
Cambodia	No hazardous waste disposal or recycling facilities, no sanitary landfill, 106 final disposal sites operated as open dump sites (Suraadiningrat 2017; Pariatamby et al. 2020).
Indonesia	1108 transporters; 123 collectors; 236 recovery, 21 treatment and 22 disposal facilities (Suraadiningrat 2017).
Lao PDR	2 companies for solid waste management; sanitary landfills exist only in Vientiane, Luang Prabang, Thakek, Savannakhet and Pakse (Suraadiningrat 2017).
Malaysia	606 recovery, 43 treatment and 39 incineration facilities; 296 landfills, 8 of which are secured landfills (Suraadiningrat 2017; Pariatamby et al. 2020).
Myanmar	No sanitary landfill, 1 hazardous waste management facility constructed in 2015 in Thilawa Special Industrial Zone, 1 waste-to-energy (incinerator) model plant operated since 2017 in Yangon (Suraadiningrat 2017; Karstensen et al. 2017; Pariatamby et al. 2020).
Philippines	Transporters: 116 for D407, 97 for M506 and 67 for M57; Treatment, storage and disposal facilities: 49 capable of managing D407, 43 for M506 and 25 for M507 (Suraadiningrat 2017).
Singapore	4 waste-to-energy plants and 1 landfill which accepts treated hazardous waste residues (Suraadiningrat 2017; NEA (Singapore) n.d.b).
Thailand	109 sanitary landfills, 465 controlled dump sites, 45 incinerators and 23 mechanical-biological treatment systems that meet Thailand's standards (Pariatamby et al. 2020).
Vietnam	660 landfills, 203 of which considered to be sanitary, 300 small-capacity incinerators, 3 waste-to-energy (incineration) projects being developed, 114 licensed hazardous waste treatment facilities (Pariatamby et al. 2020).

3.3.1.2 Case studies

The research conducted case studies of three hazardous waste management facilities: Kualiti Alam Waste Management Centre (Kualiti Alam) in Malaysia, PT Prasadha Pamunah Limbah Industri (PPLi) in Indonesia, and Ha Loc Hazardous Waste Treatment Plant (Ha Loc) in Vietnam. Kualiti Alam is the only integrated hazardous waste management centre in Malaysia and the biggest integrated waste management facility that handles hazardous and clinical waste in Southeast Asia (Kualiti Alam 2019, 2021). PPLi is the first integrated waste management company in Indonesia and the only waste company that has commercial hazardous waste landfill in the country (PPLi 2021b). Meanwhile, Ha Loc has most contracts of handling waste from offshore platforms in Vietnam (SB1 2020).

The cases were compared in respect of their compliance with national and international standards and regulations. All the cases have been certified with ISO 9001 and ISO 14001 which are the standards for quality management systems and environmental management systems, respectively (ISO n.d.a, n.d.c). Kualiti Alam and PPLi have also been certified with ISO 45001 (for occupational health and safety) and ISO 17025 (for testing and calibration laboratories) (ISO n.d.b, n.d.d). Furthermore, Kualiti Alam and PPLi have received MS 1722 and SMK3 – Malaysian and Indonesian certificates for their occupational health and safety management systems. Some of the services and facilities of Kualiti Alam and PPLi also comply with EU, American and World Bank standards. This means that all the cases meet crucial international standards for their operations while Kualiti Alam and PPLi meet additional national and international standards for their operations and facilities. Both Kualiti Alam and PPLi are also members of international waste management associations, which shows their endeavour to be sustainable. Moreover, all the cases conform to the national requirements for their operations and have developed their own policies to ensure safe and environmentally sound management of hazardous waste.

The cases were also compared in respect of hazardous waste management procedures, hazardous waste management facilities, and hazardous waste treatment capability. The comparison (details can be found in Le et al. (2022)) shows that all the cases have facilities that meet national standards for handling permitted hazardous waste while Kualiti Alam and PPLi have more modern and sophisticated facilities, some of which comply with EU, American and World Bank standards. Nevertheless, Ha Loc is more experienced in treating waste from offshore structures as this is part of its focal activities and the plant has most contracts of this kind in Vietnam (Ha Loc n.d.; SB1 2020). Despite not having handled waste from decommissioned offshore structures, all the cases are ready for this. Different from mercury-containing waste, NORM waste has not been treated and probably will not be treated by these hazardous waste management facilities in the coming years, given it is out of their permits.

3.3.2 Mercury Waste Management in ASEAN

3.3.2.1 Mercury waste management legislation and facilities in ASEAN

The summary of the ASEAN legal frameworks for mercury waste management is presented in Table 3.6, more details can be found in Le et al. (2023). Mercury waste is regulated as part of hazardous waste management in most ASEAN member states, except the Philippines which has specific legal documents on mercury waste management. The Philippines also has the most comprehensive legal framework for mercury waste management. All the countries have set mercury emission standards for different activities; however, only Myanmar and the Philippines have specific standards for oil and gas activities.

Table 3.6 Legal frameworks for mercury waste management in ASEAN (reproduced from Le et al. (2023), with permission from ASCE)

Country	Legal framework
Brunei	Mercury waste is covered under the Poisons Act and Hazardous Waste Order of 2013 (Constitution of Brunei Darussalam 2013; MOH (Brunei) 2004). It is also managed in accordance with the Pollution Control Guidelines for Industrial Development 2003 and the Guideline on Healthcare Waste Management 2019 (MOD (Brunei) 2003; MOH (Brunei) 2019). The Pollution Control Guidelines for Industrial Development 2003 set out the mercury emission standards for discharge to the water and air environment for any trade, industry or process (MOD (Brunei) 2003).
Cambodia	Mercury waste is regulated as hazardous waste under the Sub-Decree on Solid Waste Management 1999 (MOE (Cambodia) 1999). It is also

Country	Legal framework
	managed under the Sub-Decree on Water Pollution Control 1999 (with revisions in 2021) where standards for effluent discharge which contain mercury are specified (Council of Ministers (Cambodia) 1999; Umeyama 2021).
Indonesia	Mercury waste is regulated as hazardous waste under: (1) Law No. 32 of 2009 on Environmental Protection and Management; (2) Government Regulation No. 22 of 2021 on Environmental Protection & Management; and (3) Regulation of the Ministry of the Environment and Forestry (MOEF) No. 6 of 2021 on the Procedures & Requirements for the Management of Hazardous Wastes. It is also regulated specifically under the Ministry of Health Regulation No. 41 of 2019 on the Elimination and Withdrawal of Mercury-Containing Medical Devices in Healthcare Facilities (AIT 2021). The MOEF Regulation No. 6 of 2021 sets out mercury standards for hazardous waste (B3 waste) treatment-related activities (MOEF (Indonesia) 2021).
Lao PDR	Mercury waste is regulated under: (1) Environmental Protection Law (2012, revised); and (2) Ministerial Instructions on Hazardous Waste Management No. 0744/MONRE (2015). The Decision on National Environmental Standards (2017) specifies the mercury emission levels released into the air, water and soil environment from different industries; nevertheless, it does not refer to the oil and gas industry (MONRE (Lao PDR) 2017).
Malaysia	Mercury waste is mainly regulated under: (1) Environmental Quality Act (EQA) of 1974; and (2) Environmental Quality (Scheduled Wastes) Regulations 2005. The permissible exposure limit for the level of mercury exposure at the workplace is indicated in the Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health) Regulations 2000 (MOHR (Malaysia) 2000).
Myanmar	There is no specific law on mercury waste management. Mercury waste is managed under: (1) Environmental Conservation Law (No. 9/2012); (2) Environmental Conservation Rules (No. 50/2014); (3) National Waste Management Strategy & Master Plan for Myanmar (2018-2030); and (4) National Environmental Policy of Myanmar 2019. A National Hazardous

Country	Legal framework
	Waste Management Master Plan (2020-2030) and Hazardous Waste Management Rules have also been drafted for the nation (Government of Myanmar 2020; Win 2021). The mercury emission levels for oil and gas activities are specified in the National Environmental Quality (Emission) Guidelines (MONREC (Myanmar) 2015).
Philippines	Mercury waste is regulated as hazardous waste under: (1) Republic Act 6969 (1990); (2) DENR Administrative Order (DAO) 1992-29; (3) DAO 2004-36; and (4) DAO 2013-22. It is also regulated specifically as commodity and as waste under the DAO 1997-38 and the DAO 2019-20 (DENR (the Philippines) 1997, 2019). The Republic Act 8749 sets out the mercury emission standard (maximum permissible limit of 5 mg Hg/NCM) for any trade, industry, process, fuel-burning equipment or industrial plant emitting air pollutants (Congress of the Philippines 1999), whereas the DAO 2016-08 specifies the mercury standards for effluents from different sectors, including the oil and gas industry into different water bodies (DENR (the Philippines) 2016).
Singapore	Mercury is regulated as hazardous waste under: (1) Environmental Public Health Act 1987 (revised 2002); (2) Environmental Public Health (Toxic Industrial Waste) Regulations 1988 (revised 2000); and (3) the Hazardous Waste (Control of Export, Import and Transit) Act 1997 (revised 2020). Mercury and its compounds are regulated as commodities under (4) the Environmental Protection and Management Act (EPMA) 1999 (revised 2020) and (5) the Environmental Protection and Management (Hazardous Substances) Regulations 2008. Compared to the Philippines, Singapore sets out a stricter mercury emission standard (maximum permissible limit of 0.05 mg Hg/Nm^3) for any trade, industry, process, fuel-burning equipment or industrial plant emitting air pollutants in the Environmental Protection and Management (Air Impurities) Regulations 2001 (revised 2008) (NEA (Singapore) 2008a). The mercury limits for trade effluents into controlled watercourses and other watercourses are specified in the Environmental Protection and Management (Trade Effluent) Regulations 1999 (revised 2008) (NEA (Singapore) 2008b).
Thailand	Mercury is regulated as hazardous waste under the Notification of the Ministry of Industry B.E.2548 (2005) and as a commodity under the

Country	Legal framework
	Notification of the Ministry of Industry B.E. 2556 (2013) (MOI (Thailand) 2005a, 2013). The Notifications of the Ministry of Industry B.E. 2548 (2005), B.E. 2545 (2002) and B.E. 2549 (2006) set out the mercury emission limits for furnace oil in industry, industrial hazardous waste incinerators and general manufacturing (MOI (Thailand) 2002, 2005b, 2006).
Vietnam	Mercury waste is regulated as hazardous waste under: (1) Law on Environmental Protection No. 21/VBHN-VPQH; (2) Decree No. 38/2015/ND-CP on Regulation of Waste and Discarded Materials; and (3) Circular 02/2022/TT-BTNMT Detailing on Implementation of the Law on Environmental Protection. The maximum mercury limit for air emissions from industrial waste incinerators is specified in the National Technical Regulation on Industrial Waste Incinerator (QCVN 30:2012/BTNMT), while the value of mercury parameter, which is used to calculate the maximum mercury limit in industrial wastewater, is indicated in the National Technical Regulation on Industrial Wastewater (QCVN 40:2011/BTNMT) (MONRE (Vietnam) 2011, 2012).

Table 3.7 provides an overview of mercury waste management facilities in Southeast Asia; more details can be found in Le et al. (2023). As can be seen from the table, there are no or very few proper hazardous waste management facilities in Cambodia, Lao PDR and Myanmar. The remaining ASEAN member states have proper hazardous waste management facilities as well as mercury waste management facilities. The available information shows that Brunei, Singapore and Thailand have facilities which can recover elemental mercury from waste through thermal desorption/ vacuum distillation technique.

Table 3.7 Mercury waste management facilities in ASEAN (reproduced from Le et al. (2023), with permission from ASCE)

Country	Mercury waste management facilities
Brunei	There are hazardous waste management facilities for the oil and gas industry, including Bukit Udal Material Recovery Center and CIC Environmental Services Sdn Bhd (CIC) (BUMRC n.d; CIC n.d.b). CIC's mercury treatment system can

Country	Mercury waste management facilities
	recover mercury with thermal desorption/vacuum distillation technology (CIC n.d.a).
Cambodia	No proper facility exists for managing (transporting, recovering, treating and disposing) mercury/hazardous waste (Suraadiningrat 2017). Except Stueng Meanchey Dumpsite, most dumpsites are generally utilized without high technology and 95% of them do not have a collection system for water, gases and leachate (MOE (Cambodia) 2016).
Indonesia	Although Indonesia possesses many hazardous waste management facilities, none of them can recover mercury (Suraadiningrat 2017). Only PT Prasadha Pamunah Limbah Industri (PPLi) is capable of treating and disposing of mercury waste, most of which originates from oil and gas activities (PPLi 2021a, 2022). The company can treat mercury-contaminated waste with the mercury content of or less than 260 ppm by the stabilization method and will export the waste with the mercury content higher than 260 ppm to Japan for recovery.
Lao PDR	In most parts of the country, hazardous waste is not separated from other solid waste for proper treatment and disposal. Sanitary landfills are present only in Vientiane and four secondary towns (Luang Prabang, Thakek, Savannakhet and Pakse) (MONRE (Lao PDR) 2017). No proper facility is available for hazardous waste management (Suraadiningrat 2017).
Malaysia	There are many hazardous waste management facilities in Malaysia, including 606 recovery, 43 treatment and 39 incineration facilities and 8 secured landfills (Pariatamby et al. 2020; Suraadiningrat 2017). Seven off-site recovery facilities are available for mercury waste (DOE (Malaysia) 2017). Kualiti Alam Waste Management Centre can treat mercury-containing waste listed under the Environmental Quality (Scheduled Wastes) Regulations 2005 by the stabilization method (Kualiti Alam 2019, 2022).
Myanmar	Given the shortage of proper hazardous waste management facilities, hazardous waste is dealt with and treated together with municipal solid waste (Suraadiningrat 2017). One hazardous waste management facility was commissioned in 2016 in Thilawa Special Economic Zone and one waste-to-energy (incinerator) model plant has operated in Yangon since 2017 (Karstensen et al. 2017; Pariatamby et al. 2020).

Country	Mercury waste management facilities
Philippines	Regarding transporters, there are 116 for D407, 97 for M506 and 67 for M507 while treatment, storage and disposal facilities include 49 capable of managing D407, 43 for M506 and 25 for M507 (Suraadiningrat 2017); nevertheless, it is unclear whether such facilities can recover mercury from the waste.
Singapore	About 100 facilities are capable of treating and recycling various types of toxic industrial waste (NEA (Singapore) n.d.a). There are mercury waste management facilities in the country, for example: ECO Special Waste Management, Aroma Chemical, Chem-Solv Technologies, and Technochem Environmental Complex (Seng 2017). Industrial mercury waste can be treated by stabilization and thermal methods, between which the thermal method can recover mercury (Lee et al. 2017; UNEP 2017).
Thailand	Industrial hazardous waste treatment and disposal facilities exist in all six regions of Thailand, concentrating mostly in the eastern region (Pariatamby et al. 2020). INSEE Ecocycle and BMT Thailand are typical examples of mercury waste management facilities in the nation, between which BMT Thailand can recover mercury with thermal desorption/vacuum distillation technology (BMT Thailand 2021; INSEE Ecocycle 2022).
Vietnam	There are 114 licensed hazardous waste treatment facilities but no mercury recovery facilities in Vietnam. Ha Loc Hazardous Waste Treatment Plant, which holds the most contracts for handling waste from offshore structures in Vietnam, can incinerate oil-contaminated waste and recycle used lubricant oils (Ha Loc n.d.; SB1 2020).

3.3.2.2 Case study

BMT Thailand was selected for this study since it is the only branch in Asia/Southeast Asia of BMT (BMT Mercury Technology) – a world leader in sustainable mercury and NORM waste management (BMT n.d.b; internal document, 2021). BMT primarily treats mercury and NORM contaminated waste from the oil and gas industry apart from waste from other sources such as other large-scale industries, laboratories and hospitals, etc. (BMT, internal document, n.d.a). For mercury waste, it provides full services: from onsite packing to disposal and recycling ones (BMT, internal document, 2021).

BMT Thailand has been certified with ISO 9001, ISO 14001 and ISO 45001 issued by SGS (BMT Thailand 2021). ISO 9001, ISO 14001 and ISO 45001 (previously OHSAS 18001) are international standards for quality management systems, environmental management systems and OHS (occupational health and safety) management systems, respectively (OSHAS Project Group 2007). The Company's operations also comply fully with the *Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal* (Basel Convention) and *the Minamata Convention on Mercury* (Minamata Convention) (BMT, internal document, 2021) which are the most important global conventions that govern hazardous waste. The case study analysis, which is detailed in Le et al. (2023), indicates that BMT Thailand operates in accordance with the technical guidelines of the Basel Convention and the Minamata Convention. It also shows that the company's operations follow the requirements of the Ministry of Industry and the Ministry of Transport in Thailand.

3.3.3 NORM Waste Management in ASEAN

3.3.3.1 NORM waste management systems in four ASEAN countries

A summary of the legal frameworks for NORM waste management in Indonesia, Malaysia, Thailand and Vietnam is presented in Table 3.8, more details can be found in Le et al. (2024).

Table 3.8 Legal frameworks for NORM waste management in four ASEAN countries (reproduced from Le et al. (2024), with permission from ASCE)

Country	Legal framework
Indonesia	NORM is managed under (i) Government Regulation (GR) No. 33 Year 2007 on Safety of Ionizing Radiation and Security of Radioactive Sources; (ii) GR No. 58 Year 2015 on Radiation Safety and Security on the Transport of Radioactive Materials; (iii) BAPETEN Chairman Regulation (BCR) No. 9 Year 2009 on Intervention on Exposure from TENORM; and (iv) BAPETEN Chairman Regulation (BCR) No. 16 Year 2013 on Radiation Safety of the TENORM

Country	Legal framework
	Storage. In addition, the Act No.10 Year 1997 on Nuclear Energy is being amended to include NORM.
Malaysia	The overarching legal document related to NORM is the Atomic Energy Licensing Act 1984 (Act 304). NORM is also managed under the following documents: **Regulations:** (i) Radiation Protection (Licensing) Regulations 1986; (ii) Radiation Protection (Transport) Regulations 1989; (iii) Atomic Energy Licensing (Basic Safety Radiation Protection) Regulations 2010; and (iv) Atomic Energy Licensing (Radioactive Waste Management) Regulations 2011. **Orders and Conditions of License:** (i) Atomic Energy Licensing (Exemption) (Small Amang Factory) 1994; and (ii) Atomic Energy Licensing (Exemption) (Low Level Radioactive Material) Order 2020. **Guidelines, Codes and Standards:** (i) Guidelines for the Preparation of a Radiation Protection Program (LEM/TEK/45, 2021); (ii) Guidelines on Radiological Monitoring for Oil and Gas Facilities Operations Associated with Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM) (LEM/TEK/30, 2016); (iii) Code of Practice on Radiation Protection Relating to Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) in Oil and Gas Facilities (LEM/TEK/58, 2016); and (iv) Criteria for Siting of Disposal Facility for Waste Containing Naturally Occurring Radioactive Material (NORM) (LEM/TEK/76, 2020).
Thailand	The principal law related to radioactive waste management is the Nuclear Energy for Peace Act, B.E. 2559 (2016) which was amended by the Nuclear Energy Act for Peace No. 2, B.E. 2562 (2019). NORM is also managed under the following documents: **Ministerial Regulations (MR):** (i) MR on Radioactive Waste Management, B.E. 2561 (2018); (ii) MR on Radiation Safety, B.E. 2561 (2018); (iii) MR on Permission to Import Radioactive Waste into and Export out of the Kingdom, B.E. 2561 (2018); (iv) Draft MR 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); and (v) Draft MR on Prescribing Rules, Procedures, and Conditions for Radioactive Waste Management by Radioactive Waste Producers and

Country	Legal framework
	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).
Vietnam	Radioactive waste, including NORM waste is managed under the Law on Atomic Energy (2008). Although a National Technical Regulation on Naturally Occurring Radioactive Material Waste (QCVN 23:2023/BKHCN) has been adopted, it does not apply to the oil and gas industry. Related regulatory documents include: • Ordinance No. 50-L/CTN on Radiation Safety and Control (ORSC) 1996; • Decree No. 50/1998/ND-CP on Implementation of the ORSC 1996; • 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. 04/2016/TT-BKHCN on Appraisal of Radiation Safety Evaluation Reports on Exploration and Exploitation of Radioactive Ores; and • Decree No. 142/2020/ND-CP on Implementation of Radiation Activities and Support Services for Using Atomic Energy.

The following are the institutional frameworks for NORM waste management in four ASEAN countries.

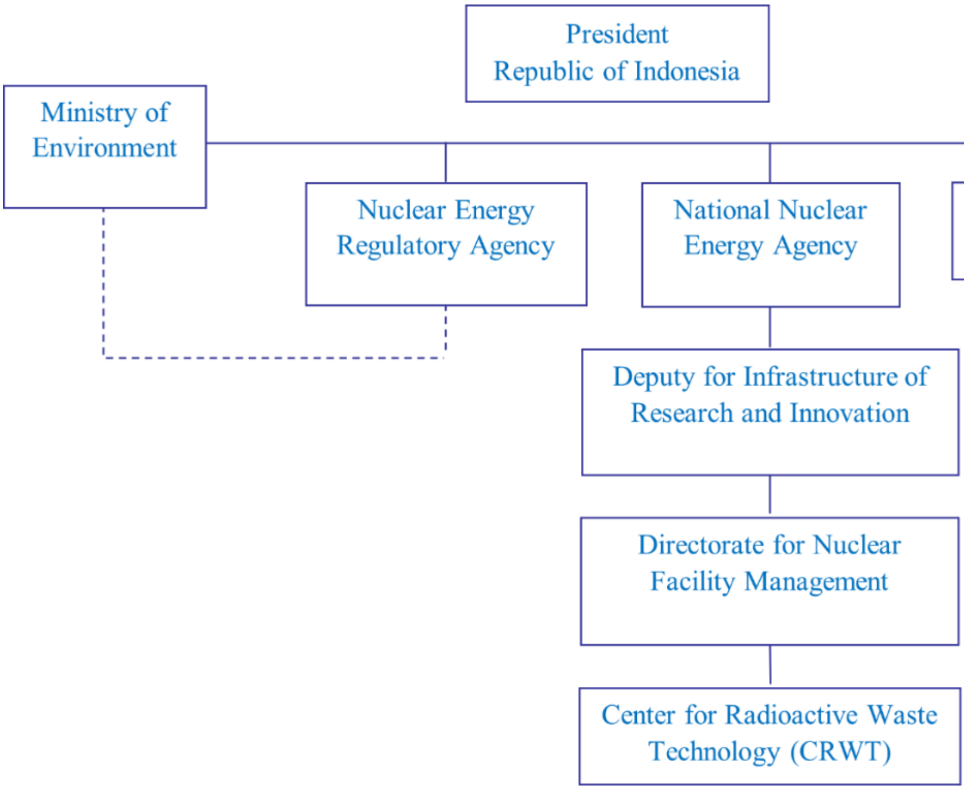

Figure 3.4 Institutional framework for NORM waste management in Indonesia (reproduced from BAPETEN (2022), with permission)

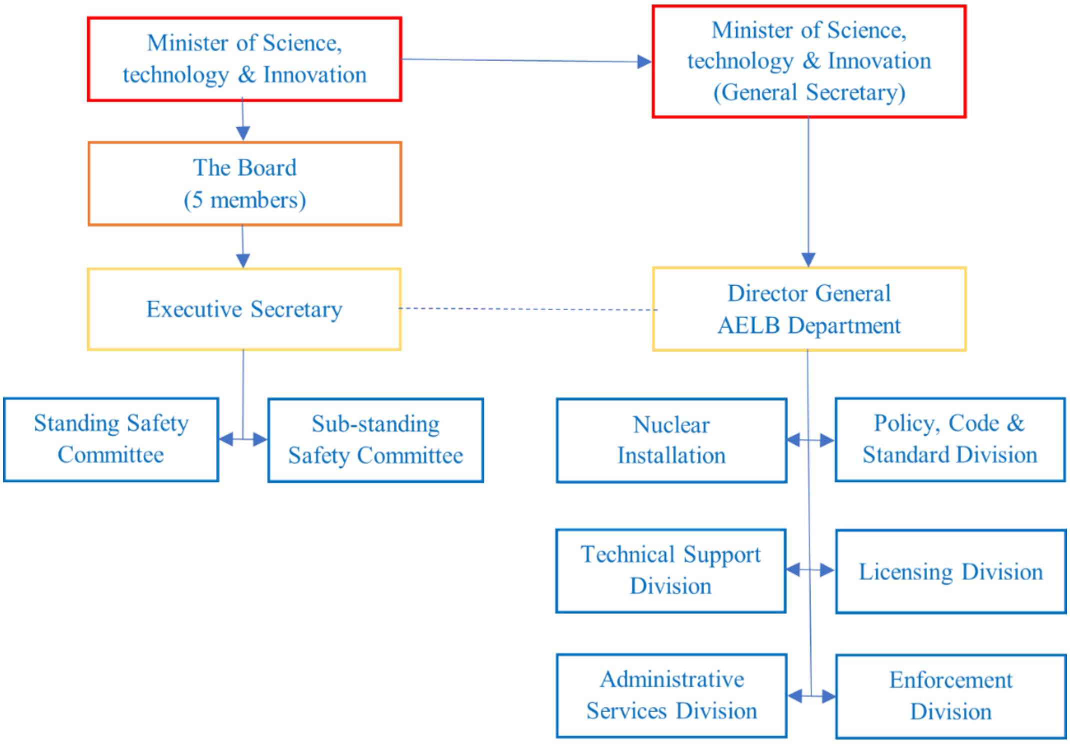

Figure 3.5 The Atomic Energy Licensing Board (AELB)'s institutional framework (reproduced from Teng (n.d.), with permission)

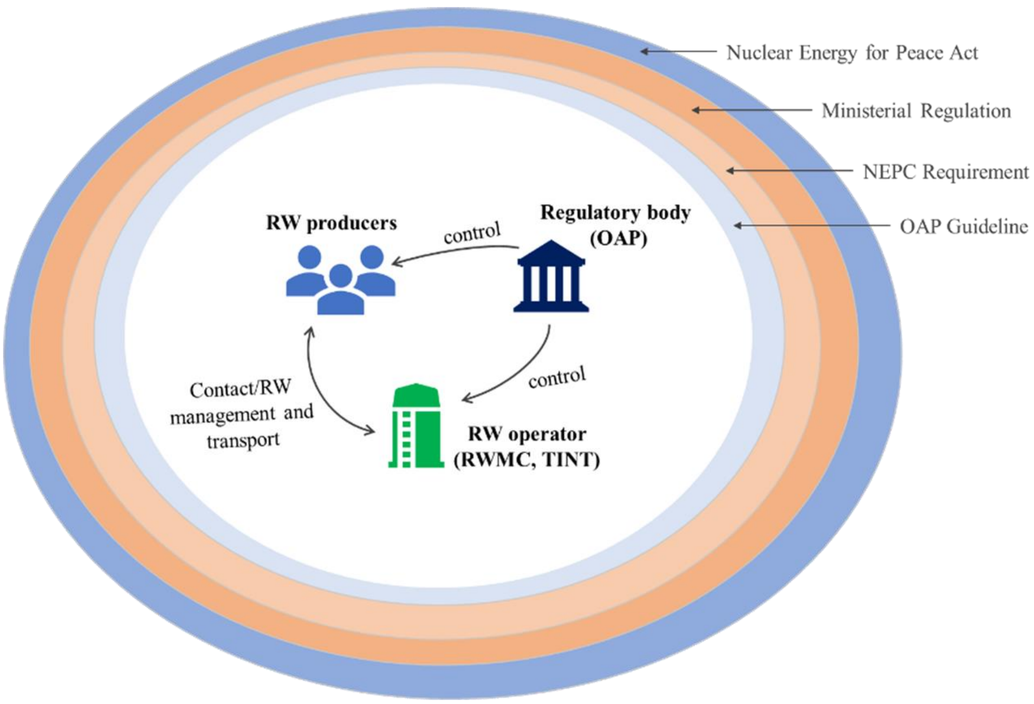

Figure 3.6 The regulatory bodies and the associated legal system for radioactive waste management in Thailand (reproduced from Le et al. (2024), with permission from ASCE)

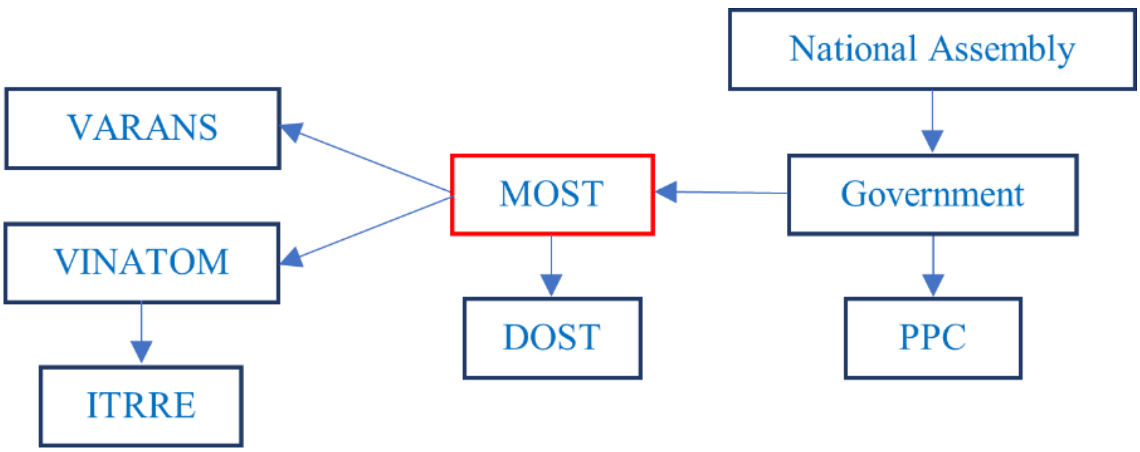

Figure 3.7 Institutional framework of NORM waste management in Vietnam (reproduced from Le et al. (2024), with permission from ASCE)

3.3.3.2 NORM waste management practices in four ASEAN countries

Table 3.9 and Table 3.10 present information of NORM waste from the oil and gas industry and NORM waste management facilities in Indonesia, Malaysia, Thailand and Vietnam. More details can be found in Le et al. (2024).

Table 3.9 NORM waste from the oil and gas industry in four ASEAN countries (reproduced from Le et al. (2024), with permission from ASCE)

Country	NORM waste management practices
Indonesia	There are no databases and inventories for NORM waste in Indonesia (Wisnubroto et al. 2021). NORM waste from the oil and gas industry is generally in the form of slag from pipes cleaning using garnet. At present, NORM is managed by companies producing NORM.
Malaysia	A study shows that oil sludge-based NORM waste from Labuan, Miri and Terengganu crude oil terminals has the activity concentration of Ra-226 and Ra-228 lower than AELB's control limit (AELB 2016; Ismail et al. 2011).
Thailand	NORM waste is generated from many industries in Thailand, including the oil and gas industry (Srisuksawad et al. 2005). Following the Radionuclides Analysis Research Project conducted by Chulalongkorn University in 2002, the Ra-226 and Ra-228 content in different materials of oil and gas platforms in Thailand is lower than the International Association of Oil & Gas Producers (IOGP)'s limits (Chanyotha et al. 2015; IOGP 2016).
Vietnam	The waste generated from the oil and gas industry is still considered as industrial solid waste or hazardous industrial waste (Nguyen 2019). Techniques for treating and burying NORM waste arisen from oil and gas activities are similar to those for chemical hazardous waste and heavy metal waste (Bui 2019). According to two studies which measure the radioactivity of oil and gas production waste in Vietnam, the radioactivity levels in the samples of oil scales and crude oil are lower than the national exemption limits and the IOGP's limits (Hoang et al. 2017; IOGP 2016; Le et al. 2009; MOST (Vietnam) 2001).

Table 3.10 NORM waste management facilities in four ASEAN countries (reproduced from Le et al. (2024), with permission from ASCE)

Country	NORM waste management facilities
Indonesia	There are no final disposal facilities available or plan to develop such facilities for NORM in the coming years, given the challenges associated with finding suitable locations and the need for institutional coordination. A conceptual design for a pilot NORM waste landfill was developed by the National Nuclear Energy Agency (BATAN) which aims to ensure long-term radiation safety and cost saving for NORM producers (Wisnubroto et al. 2021).
Malaysia	Disposal options available include: (i) disposal of at municipal disposal sites and (ii) shallow land burial. Examples of shallow land burial facilities include Engineered Cell 1 and Engineered Cell 2 in Bukit Kledang, Mukim Belanja, which have been used for disposing NORM residue but not from the oil and gas industry (Teng 2016, 2023). The AELB has developed a guidance for designing NORM waste disposal facilities (LEM/TEK/76, 2020).
Thailand	At present, there are no radioactive waste disposal facilities in Thailand since the country has a small amount of radioactive waste; nevertheless, the researchers in the Radioactive Waste Management Center have started a study on the siting process for a disposal facility. Such study is still in its infancy – the first stage out of four stages of the siting process which might take several decades (Yubonmhat et al. 2022).
Vietnam	There is no information about whether Vietnam has planned to develop final disposal facilities for NORM waste or not. Nevertheless, the nation plans to implement research on permanent disposal mechanisms for high-level radioactive waste, particularly spent fuel from nuclear power plants, once such a plant is commissioned (Naidu and Moorthy 2022).

3.4 Guidance for the Candidate Facilities to Improve and Achieve Standards of Safe, Green and Sustainable Recycling Facilities

3.4.1 Criteria for Evaluating Shipbuilding / Onshore Dismantling Facilities' Preparedness to Receive Decommissioned Offshore Structures

As part of our research, the following checklist of shipbuilding/ onshore dismantling facilities was developed based on the literature review, with additional information from the checklist utilised by Sea Sentinels, a ship recycling compliance auditor, for Green Ship Recycling yard audit, and in consultation with the *Basel Convention's Technical Guidelines on the Environmentally Sound Management of the Full and Partial Dismantling of Ships* (Basel Convention's Technical Guidelines) (2003), the *Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships* (Hong Kong Convention) (2009), and the *European Council Directive 89/656/EEC on the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace* (European Council Directive 89/656/EEC). This checklist is highly recommended for assessing the technical preparedness of shipbuilding/ onshore dismantling facilities to receive decommissioned offshore structures.

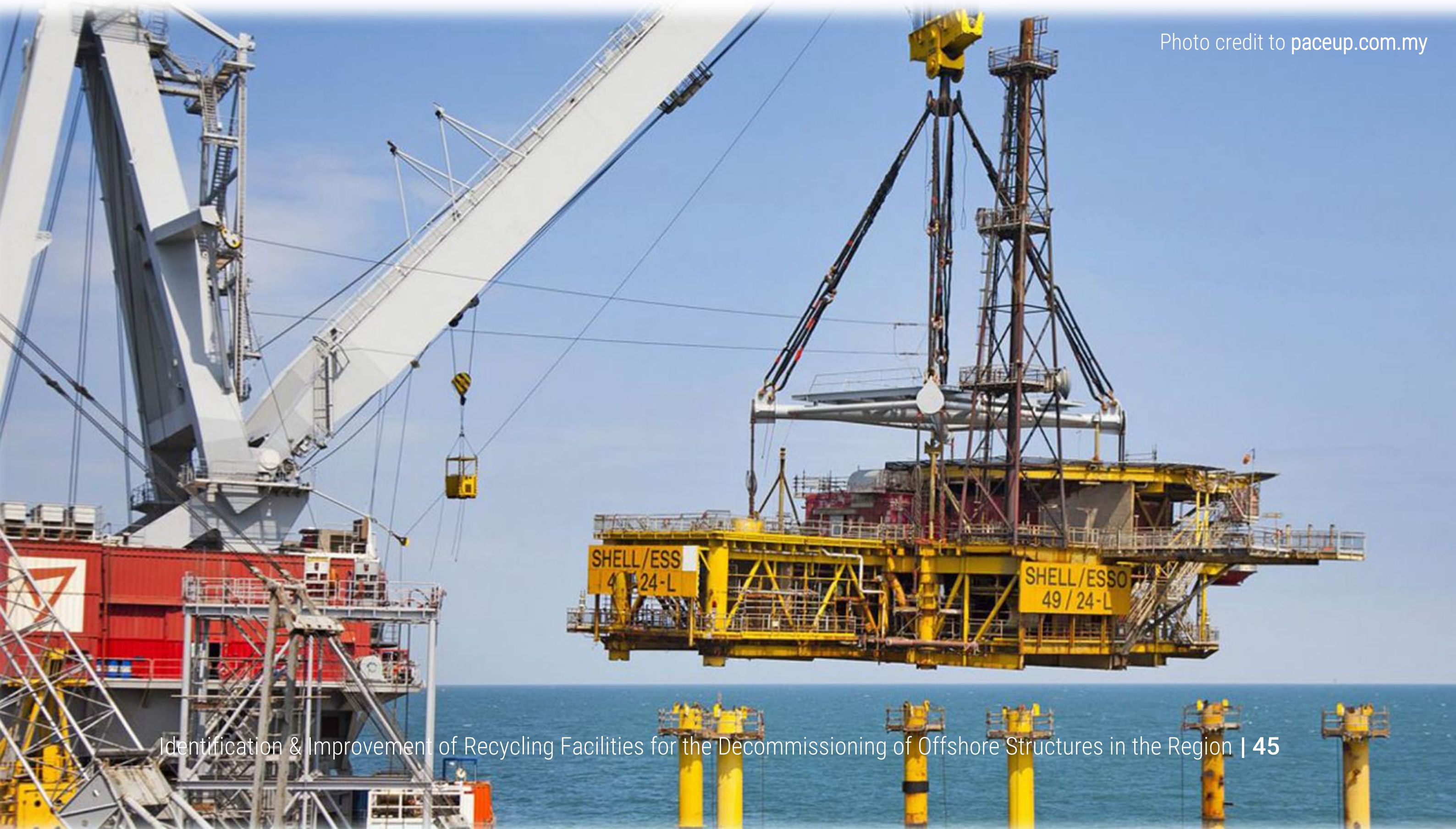

Photo credit to paceup.com.my

Table 3.11 Self-developed technical preparedness checklist of shipbuilding/ onshore dismantling facilities (adapted from Leow et al. (2023), with permission from OSE)

Zone	Characteristic		Description	Requirement
	Site Description	Site General Info	Facility Location	Where is the dismantling yard located?
			Facility Area (m^2)	- Do you have an approved yard layout plan/ map? - Do you have a secondary recycling site apart from the main one (Backyard)? If yes, is the secondary recycling site certified by the state authority? - Does the yard have sufficient area for large-scale demolition of modules/ topsides and jackets?
			Distance to Open Sea	How far is it from the oil and gas platform to the dismantling yard by sailing?
			Restriction in the Approach Channel (Air Draft/ Width)	What are the draft and air draft restrictions in the approach channel for heavy lift vessels and barges?
			Approach Channel Depth (m)	What is the depth of the approach channel?
			Past Offshore Construction Project	How many decommissioning projects has the yard undertaken so far?
			Demolition License Permit	Do you hold a dismantling permit issued by the state authority of your country? If yes,

Zone	Characteristic		Description	Requirement
				please give reference to respective documents.
			Certification	- What valid certificates does the yard have? For example, ISO 9001, 14001 and 45001, International Association of Classification Societies (IACS) certificates, etc. and issued by whom? Any other valid certificates and issued by whom? - Are you a member of any registered ship recycling association?
			Structure Dismantling Facility Plan and Structure Dismantling Plan	- Do you have a Structure Dismantling Facility Plan? If yes, please give reference to the respective document. - Do you have procedures in place for preparation of a Structure Dismantling Plan? If yes, please give reference to the respective documents.
			Inventory of Hazardous Materials (IHM)	- Do you have procedures in place to identify hazardous materials from decommissioned offshore structures? If yes, please give reference to the respective documents. - Do you have procedures in place to receive and use IHM from decommissioned offshore structures? If yes, please give reference to the respective documents.

Zone	Characteristic		Description	Requirement
				- Do you have an IHM for decommissioned offshore structures? Who develop the IHM?
			Safe and environmentally sound management of hazardous materials	- Do you provide any kind of barrier to prevent hazardous materials accessing the marine environment, shore, land and air? If yes, which ones? - Do you have procedures in place describing how to handle hazardous materials during dismantling activities? If yes, please provide reference to the documents. - Do you have overflow water/ rainwater collection, treatment and disposal systems on site? - Do you distinguish between normal operational emissions and polluting incidents/ accidents? If yes, please specify the monitoring method. - Is the waste generated from the dismantling activity and its quantity well documented?
			Prevention of accidents	- Do you have procedures/permits in place to ensure 'safe-for-entry" and "safe-for-hot work" in enclosed/ open spaces or protection of working at heights? If yes, please give reference to the relevant documents.

Zone	Characteristic		Description	Requirement
				- Does the facility establish management and monitoring systems, procedures and techniques which have the purpose of preventing, reducing, minimising and to the extent practicable, eliminating health risks to the workers concerned and to the population in the vicinity of the dismantling facility, and adverse effects on the environment caused by structure dismantling? - Do you maintain an accident/ incident/ injury record and who is the person responsible for doing this?
			Emergency preparedness and response	- Have you established a list of possible emergency situations? If yes, please give reference to the respective document. - Does the dismantling facility establish and maintain an emergency preparedness and response plan; ensure rapid access for emergency response equipment, such as fire-fighting equipment and vehicles, ambulances and cranes, to all areas of the dismantling facility? - Do you provide first-aid and medical assistance in your dismantling facility in case of emergency? Do you have a dedicated first-aid room?

Zone	Characteristic		Description	Requirement
				- Do you have a procedure to carry out emergency preparedness mock drills? - Do emergency vehicles have access to your dismantling facility in case of emergency? If yes, please describe how and locations.
			Worker safety and training	- Do you provide personal protective equipment (PPE)? If yes, please describe the standards and types of PPE, and for which purposes. - Do you check if your staff is capable of performing the job they are assigned to? If yes, how? - Do you provide training for the staff to perform safe and environmentally sound structure dismantling? If yes, please give reference to the respective documents. - Do you provide worker safety and training, including ensuring the use of PPE for operations requiring such use? Do you have qualified safety inspectors on site who can ensure compliance? - Do you impart periodic training to the yard and sub-contractor's workers? Do you have an induction and familiarization training for all new and existing workers?

Zone	Characteristic		Description	Requirement
				- Do you maintain a training record book and who is the person responsible for maintaining this?
			Reporting	- Do you report on incidents, accidents, and/ or chronic effects regarding environmental and/ or safety issues? How is the record maintained? If yes, how and to whom? - What procedures are followed to prove that the relevant authorities are being notified on the respective dismantling activities?
			Workers' health and welfare	- Do you provide accommodation for your workers? If yes, what facilities do you provide them? - Do you provide periodic health checkups for your workers? If so, please provide the details. - Do you provide a clean canteen and a mess room? - Do you provide any recreational area for workers? - Do you have an equipped emergency medical room on site? - Do you have a process whereby yard workers can voice and resolve concerns and

Zone	Characteristic		Description	Requirement
				grievances regarding all workplace issues without fear of retribution? - Does the company require facilities to enable yard workers to associate and bargain collectively?
		Site Restriction	Limit for Release to Air	Which air emission limit does the yard follow? Which regulation/ standard does it come from?
			Limit for Release to Water	Which water pollution limit does the yard follow? Which regulation/ standard does it come from?
			Noise Limit	Which noise exposure limit does the yard follow? Which regulation/ standard does it come from?
			Permitted Working Hour	What are the permitted working hours in the yard? Which regulation/ standard specifies these?
			Requirement For an Impermeable Surface	Do you provide impermeable floor(s) for the dismantling area(s)?
		Facility Future Potential	Industrial Footprint Area (m^2)	How large is the industrial footprint area in the yard? Have you planned to upgrade it?
			Potential Area for Future Development (m^2)	Can the yard be extended (especially the dismantling area) to enhance its activities

Zone	Characteristic		Description	Requirement
				(e.g.: receiving large topsides and jackets)? How large is the extended area?
		On land Transportation	On land Transportation Facilities	Name the types, quantities and capacities of on land transportation facilities that the yard possesses.
A, B	Facilities Information	Heavy Lifting Machine Info	Crane Number	Do you have lifting devices (e.g.: heavy lift cranes) for lifting the structure/ structure´s sections directly to the yard? If yes, how many?
			Crane Type	Please provide the crane type(s).
			Crane Capacity (t)	- Please provide the crane capacity(ies). - Can your heavy lifting machines lift off all the structure/ structure´s sections to the yard without dropping them in the beach area/water? Are the heavy lifting machines rated for this? Please provide the ratings and inspection/ certification documents for the heavy lifting machines.
C		Workshop Info	Workshop Number	How many workshops are there in the yard?
			Workshop Type	What types or workshops are they? Were they designed to accommodate a particular hazardous material, e.g.: mercury or NORM?
			Workshop Area (m^2)	How large are the workshops?

Zone	Characteristic		Description	Requirement
D		Storage Area Info	Storage Area Size (m^2)	How large is the storage area?
			Storage Site Characteristics	- What are the characteristics of the storage site(s)? - How is the storage of potentially oil leaking equipment managed?
E		Emergency Facilities	Quarantine Area (m^2)	Does the yard have a quarantine area to prevent the spread of disease? How large is it?
			Emergency Area (m^2)	Does the yard have an emergency refuge area to hold occupants during a fire or other emergency situations when evacuation may not be safe or possible? How large is it?
A, B	Working Area Information	Load-In Capabilities	Bollard Pull Capacity (t)	What are the pull capacities of the bollards in the yard?
			Load-In Points Capacity (t/m^2)	Can the yard offload barges, sheer legs, mono hull vessels and heavy lift/ single lift vessels? What are the capacities of the load-in points?
		Quay Info	Quay Numbers	How many quays does the yard possess?
			Quay Foundation Bearing Capacity (t/m^2)	What are the quay foundation bearing capacities?

Zone	Characteristic		Description	Requirement
			Berthing Capacity	Can the yard berth barges, sheer legs, mono hull vessels and heavy lift/ single lift vessels? What is the berth capacity?
			Water depth Near Quay (m)	What are the water depths near the quays?
		Working Area Properties	Facilities to Contain Liquid Waste Within Working Area	- Do you have containment areas to limit oil spill at key locations so that the yard contamination can be avoided? - Do you have an adequate liquid waste collection system on site?
			Working Area Size (m^2)	What is the size of the working area?
			Impermeable Surface	Do you provide impermeable floor(s) for the dismantling area(s)?
D	Scrap Storage Area Information	Laydown and Pad Info	Laydown Area Size (m^2)	What is the size of the laydown area?
			Pad Capacity (Length and Maximum Pressure)	What is the pad capacity, i.e. its length and maximum pressure?
			Pad Characteristic (Material)	What is the pad made of?
			Presence/ Availability of Impermeable Surface	Do you provide impermeable floor(s) for the storage area(s)?
C, D, F	Waste Management Information		Waste storage	Do you have storage areas for non-hazardous materials, scrap metals, reusable materias and hazardous materials prior to

Zone	Characteristic	Description	Requirement
			disposal, sale or further treatment? Are these areas in accordance with the regulations and properly maintained?
		Waste Handling Capacity (ton per year)	What is the waste handling capacity (ton per year) of the yard?
		Distance to a Waste Management Center	How far is it from the yard to the closest waste management center?
		Downstream Waste Management	- Do you have procedures in place to control downstream waste handling? If yes, please give reference to the respective documents. - Do you choose specific downstream waste management facilities? If yes, please provide a list of companies and the waste they´re handling.

3.4.2 Guidance

The following guidance was developed for upgrading shipbuilding/ onshore dismantling facilities to become safe, green and sustainable recycling facilities for decommissioned offshore structures, based on the self-developed technical preparedness checklist mentioned above.

3.4.2.1 Critical aspects and environmental challenges

The Basel Convention's Technical Guidelines specify important aspects to be considered during the dismantling process of ships and the potential environmental challenges, including access, containment, recycling, removal and disposal activities, and training (UNEP, 2003). Given the similarities between ship dismantling and oil and gas structure decommissioning, such aspects should also be considered during onshore dismantling of offshore structures.

3.4.2.2 Site Procedures

3.4.2.2.1 Structure Dismantling Facility Plan and Structure Dismantling Plan

- Structure Dismantling Facility Plan: Based on Hong Kong Convention's requirements for a Ship Recycling Facility Plan, a Structure Dismantling Facility Plan should be prepared by the dismantling facility (adapted from IMO (2009)).
- Structure Dismantling Plan: Based on Hong Kong Convention's requirements for a Ship Recycling Plan, a Structure Dismantling Plan should be developed by the dismantling facility prior to dismantling a structure (adapted from IMO (2009)).

3.4.2.2.2 Inventory of Hazardous Materials (IHM)

Based on Hong Kong Convention's requirements about IHM for ships, an offshore oil and gas platform must have an IHM that is verified by the government which has the authority over it, taking into account the national legal framework, including any threshold values and exemptions set out in such legal framework, and updated before dismantling (adapted from IMO (2009)).

3.4.2.2.3 Prevention of Accidents

- Safe-for-entry

According to Hong Kong Convention, "safe-for-entry" means the space that fulfils the following criteria: (i) the oxygen content of the atmosphere and the concentration of flammable vapours are within safe limits; (ii) any toxic materials in the atmosphere are within permissible concentrations; and (iii) any residues or materials associated with the work authorized by the governmental authority will not produce uncontrolled release of toxic materials or an unsafe concentration of flammable vapours under existing atmospheric conditions while maintained as directed (adapted from IMO (2009)).

- Safe-for-hot work

According to Hong Kong Convention, "safe-for-hot work" means a space that fulfils the following criteria:

- a safe, non-explosive condition, including gas-free status, exists for using electric arc or gas welding equipment, cutting or burning equipment or other forms of naked flame, as well as heating, grinding, or spark generating operations;
- safe-for-entry requirements are met;
- existing atmospheric conditions will not change due to the hot work; and
- all adjacent spaces have been cleaned, or inerted, or treated adequately to prevent the start or spread of fire.

- Working at heights

According to the European Council Directive 89/656/EEC, the following PPE can be used for protection against falls from a height, such as retractable type fall arresters, full body harnesses, sit harnesses, belts for work positioning and restraint and work positioning lanyards, energy absorbers, guided-type fall arresters including an anchor line, rope adjustment devices, anchor devices that are not designed to be permanently fixed and that do not require fastening works before use, connectors, lanyards, rescue harness (European Council, 1989).

3.4.2.2.4 Emergency preparedness and response

Based on IMO's (2009) requirement for a ship dismantling facility, an oil and gas decommissioning facility must establish and maintain an emergency preparedness and response plan. Such plan must be prepared with consideration of the location and environment of the decommissioning facility, as well as the size and nature of activities associated with each platform decommissioning operation.

3.4.2.2.5 Worker safety and training

Based on Hong Kong Convention's requirements, dismantling facilities must provide for worker safety by measures including:

- ensuring the availability, maintenance and use of personal protective equipment and clothing needed for all dismantling operations;
- ensuring that training programmes are provided to enable workers to safely undertake all dismantling operations they are tasked to do; and
- ensuring that all workers at the dismantling facility have been provided with appropriate training and familiarization prior to performing any platform decommissioning operation (IMO, 2009).

3.4.2.3 Site Restriction

- Limit for Release to Air, Limit for Release to Water, Noise Limit

The yard must adhere to national regulations and standards for air emission limit, water pollution limit and noise exposure limit, and if possible, international standards for these. Since there are risks associated with exposure limits, a general assessment of exposure risks in the dismantling facility should be conducted for different waste streams (UNEP, 2003).

3.4.2.4 Stepwise Improvement Approach for Upgrading Existing Dismantling Facilities

The upgradation of existing dismantling facilities can be achieved by applying a stepwise improvement approach, with the actions reflecting their impacts on human health and the environment (UNEP, 2003). The stepwise improvement approach adapted from UNEP (2003) for dismantling of offshore structures in ASEAN is presented in Table 3.12.

Table 3.12 Stepwise upgradation of existing dismantling facilities in ASEAN for offshore structures (adapted from UNEP (2003))

<table>
<tr><th>At the latest within 1 year</th><th>At the latest within 5 years</th><th>At the latest within 10 years</th></tr>
<tr><td>Inventory of hazardous materials</td><td rowspan="9"></td><td rowspan="14"></td></tr>
<tr><td>Hot work certification</td></tr>
<tr><td>Cleaning and testing before dismantling</td></tr>
<tr><td>Hazardous waste storage</td></tr>
<tr><td>Firefighting equipment</td></tr>
<tr><td>Basic PPE</td></tr>
<tr><td>Suitable protective equipment against respiratory hazards</td></tr>
<tr><td>Waste segregation and collection</td></tr>
<tr><td>Hazardous waste (especially mercury and NORM) handling procedures</td></tr>
<tr><td colspan="2">Sufficient transfer operations facilities</td></tr>
<tr><td colspan="2">Spill containment equipment</td></tr>
<tr><td colspan="2">Sufficient stormwater discharge facilities</td></tr>
<tr><td colspan="2">Special respiratory protective equipment for paint removal operations</td></tr>
<tr><td colspan="2">Improved hazardous waste (especially mercury and NORM) removal facilities</td></tr>
<tr><td colspan="3">Sufficient draining and pumping equipment</td></tr>
<tr><td colspan="3">Provide sufficient treatment/ disposal facilities for different hazardous materials</td></tr>
<tr><td colspan="3">Spill cleanup equipment</td></tr>
</table>

Separate area for paint removal operations, with impermeable floor. Cover, isolate area, and ventilate. Install proper air filtering system.
Create a dedicated area for segregation of hazardous materials
Complete containment for all structure dismantling activities
Removal of mercury by high standards

3.5 Conclusion

While Southeast Asia is expected to experience a significant number of offshore structures to be decommissioned in the near future, the region currently lacks onshore dismantling facilities to support the decommissioning process. Although there is a potential to upgrade the existing shipbuilding yards in this region, the technical gaps, in both facilities and environmental sustainability, must be clearly identified. Two case studies were undertaken, one about MEB yard in Indonesia, and one about yard X in Malaysia. The case studies show the most important aspect to be considered for upgrading a shipyard or a fabrication yard to a qualified decommissioning yard is the capability of hazardous waste handling. The case study in Malaysia also shows the effectiveness of the SLP method, which allows the rearrangement of the buildings within the yard to create an isolated area for onshore dismantling without interfering with the original fabrication operation and help reduce waste from material transportation for the fabrication operation. The case study in Indonesia shows the MEB yard is comparable with ASP yard, a world-leading decommissioning yard in the UK, and at the upper tier ranking compared to other decommissioning yards in the North Sea. It also has more strengths than weaknesses, and more opportunities than threats. However, in order to be able to receive decommissioned offshore structures, MEB yard needs to be upgraded with the following facilities: (i) a water treatment system, (ii) specific tools to support dismantling activities, (iii) closed waste storage facilities to store any hazardous waste, (iv) workshop or space to pre-treat the contaminated material for sophisticated transportation, and (v) a dedicated area for the demolition work.

Regarding hazardous waste management, an incompatibility can be seen among ASEAN countries in developing hazardous waste management legislation and facilities. The Philippines has both the most comprehensive hazardous waste management legislation and facilities while Myanmar is the least developed in these respects. According to the case study analysis, Kualiti Alam, PPLi and Ha Loc conform to relevant national regulations and standards and important international standards. Kualiti Alam and PPLi are more advanced than Ha Loc with modern and sophisticated facilities; however, Ha Loc is likely to be more experienced in treating waste from offshore structures. For mercury waste management, mercury waste is regulated as part of hazardous waste management in most ASEAN member states, except the Philippines which has specific legal documents in this regard. The Philippines also has the most comprehensive legal framework for mercury waste management. Following the case study analysis, BMT Thailand's handling of mercury waste complies with the national legal requirements and many international standards and conventions. For NORM waste management, the legal frameworks in Malaysia, Thailand and Vietnam have included NORM in the national overarching laws for radioactive waste. Indonesia has also been revising the respective law to include NORM. Some studies show NORM waste from oil and gas fields in Malaysia, Thailand and Vietnam has the radioactivity levels lower than the national limits and IOGP's limits. Proper NORM waste disposal facilities should be developed where lacking, particularly in Indonesia, Thailand and Vietnam, using the conceptual design and the guidance for designing NORM waste disposal facilities that have been devised by Indonesia and Malaysia.

As part of this research, a checklist was developed for evaluating the technical preparedness of an onshore dismantling yard to receive decommissioned offshore structures, in consultation with the checklist used by Sea Sentinels, a ship recycling compliance auditor, for Green Ship Recycling yard audit, and some international and regional regulations. Given the availability of many shipbuilding yards in Southeast Asia and their potential to be upgraded for onshore dismantling activities, such checklist can be used as a reference for upgradation. The upgradation should also take into account the stepwise improvement approach as suggested by UNEP (2003).

4. Conclusion and Recommendation

4.1 Overall Summary

In conclusion, this project has been effectively executed, yielding valuable insights into decommissioning practices and guidelines across Southeast Asia. This research has provided key findings regarding the specific challenges and requirements for decommissioning offshore structures in the ASEAN and South Asia regions. The study highlights the lack of onshore dismantling facilities to support the decommissioning process and underscores the importance of upgrading existing shipyards to handle hazardous waste effectively.

The evaluation of existing recycling facilities, waste management practices, and relevant regulations reveals that while regional regulations are lacking, countries adhere to similar technical standards, with Thailand demonstrating the highest level of detail and experience. The proposed general decommissioning framework, influenced by international conventions and best practices, offers a structured approach across three key stages: pre-decommissioning, execution, and post-decommissioning. This framework emphasizes safety, environmental protection, and stakeholder consultation.

Case studies of the MEB yard in Indonesia and yard X in Malaysia identify gaps and opportunities for improvement in the decommissioning, recycling, and waste management processes. The MEB yard, for instance, is comparable to world-leading decommissioning yards and demonstrates the potential for regional facilities if upgraded with necessary systems and tools. Recommendations for these upgrades include water treatment systems, specific tools for dismantling, closed waste storage facilities, workshops for pre-treating contaminated material, and dedicated demolition areas.

Hazardous waste management varies significantly across ASEAN countries, with the Philippines having the most comprehensive legislation and facilities, while Myanmar is the least developed. Case studies reveal that Kualiti Alam, PPLi, and Ha Loc conform to national and international standards, with Kualiti Alam and PPLi being more advanced. For mercury and NORM waste management, the Philippines and Malaysia lead with comprehensive legal frameworks, while other countries are developing their regulations.

To align practices with international standards and best practices, a checklist for evaluating the technical preparedness of onshore dismantling yards was developed, aligning with international standards and providing a reference for upgrading shipbuilding yards. This research underscores the importance of aligning with international conventions, leveraging expert insights, and implementing robust monitoring and reporting mechanisms to enhance the effectiveness and sustainability of decommissioning activities in Southeast Asia.

4.1.1 Project Findings

1. Insights into the specific challenges and requirements for decommissioning offshore structures in the ASEAN and South Asia regions.
2. Evaluation of existing recycling facilities, waste management practices, and relevant regulations in the regions.
3. Identification of gaps and opportunities for improvement in the decommissioning, recycling, and waste management processes.
4. Recommendations for aligning practices with international standards and best practices.

4.2 Recommendation

It is imperative to regularly reassess and refine decommissioning guidelines to keep pace with evolving regulatory landscapes, technological advancements, and insights gained from decommissioning activities. Adapting these guidelines ensures alignment with industry standards and best practices, which is crucial for maintaining the relevance and effectiveness of decommissioning processes.

Anticipated future enhancements should focus on integrating innovative technologies to streamline monitoring and data acquisition processes. Additionally, refining stakeholder engagement tactics for optimal inclusivity, augmenting training initiatives to bolster expertise, and cultivating collaborative platforms to facilitate knowledge exchange among industry peers are vital steps. These measures will contribute to a more efficient and effective decommissioning process.

Recognizing the dynamic nature of decommissioning practices, it is essential to design guidelines that evolve iteratively. This requires continual evaluations and adaptations to maintain their relevance and effectiveness. By doing so, we can ensure that the guidelines remain up-to-date with the latest industry developments and best practices.

Southeast Asia currently possesses very few onshore dismantling yards capable of handling decommissioned offshore structures, despite the impending decommissioning of many such structures in the region. With capable yards mainly located in Thailand, and some in Indonesia and Malaysia, it is critical to address this scarcity. Given the legal restrictions on the transboundary movement of hazardous waste, each nation must dismantle decommissioned offshore structures independently.

To address the need for more dismantling facilities, the developed checklist—based on international and regional regulations and guidelines—should be used to evaluate the technical preparedness of onshore dismantling yards. This checklist, informed by international standards and technical reports from dismantling yards in the North Sea, will help ensure that shipbuilding yards in Southeast Asia are properly upgraded to support onshore dismantling activities.

Specific guidance has been provided for critical aspects of the checklist, drawing from the Basel Convention's Technical Guidelines for the Dismantling of Ships, the Hong Kong Convention, and the European Council Directive 89/656/EEC. These guidelines focus on the operational procedures of waste management facilities and the techniques used for treating hazardous waste, mercury waste, and NORM waste.

The development of these guidelines is based on a comprehensive review of regulatory frameworks for hazardous waste management facilities in Southeast Asia, relevant international guidelines, and case studies of hazardous waste, mercury waste, and NORM waste management facilities in the region. This thorough review ensures that the guidelines are well-informed and robust, providing a solid foundation for safe and effective decommissioning practices.

By following these recommendations, we can ensure a safe, efficient, and environmentally responsible decommissioning process that aligns with global best practices and addresses the unique challenges of the ASEAN and South Asia regions.

REFERENCES

AELB (Atomic Energy Licensing Board). 2016. *Code of Practice on Radiation Protection Relating to Technologically Enhanced Naturally Occurring Radioactive Material (TENORM) in Oil and Gas Facilities* (LEM/TEK/58, 2016). Kuala Lumpur, Malaysia: AELB.

Agarwal, A., and A. Jain. 2003. Dynamic behavior of offshore spar platforms under regular sea waves. *Ocean Engineering*, *30*(4), 487-516.

AIT (Asian Institute of Technology). 2021. “Situation Assessment of the Management of Mercury-Containing Medical Measuring Devices in Indonesia.” Accessed April 17, 2022. https://www.warm.rrcap.ait.ac.th/media/file/sa-hg-indo-eng.pdf.

Amelia, S., Rarasati, A. D., and A.J. Santos. 2020. Universuum of Institutional Development for Post Production Offshore Platform Decommissioning in Indonesia. *International Journal of Business Studies*, *4*(1), 1-7.

Amelia, S., Leow, J.S., Hasyim, B., Aditramulyadi, D.D., Kang, H.S., Yaakob, O., and W. Punurai. 2021. *Onshore yard readiness for upcoming oil and gas offshore structure decommissioning projects in Indonesia*. Paper presented at the SPE Symposium: Decommissioning and Abandonment. November 30-December 2, 2021. Virtual.

ASEAN Council on Petroleum (ASCOPE). 2012. *International decommissioning laws, regulations & guidelines referenced in decommissioning. In: The ASEAN Council on Petroleum (Ed.), ASCOPE Decommissioning Guidelines (ADG) for Oil and Gas Facilities.*

Bambang, E. S. 2022. *Implementaion of Abandonment and Site Restoration (ASR) in Upstream Oil and Gas Business Activities in Indonesia* [Slide Presentation]. 3rd International Seminar on "Challenges and Opportunities in Offshore Decommissioning in South East Asia and Beyond", Millennium Hilton Bangkok, Thailand.

BAPETEN. 2022. *Radiation Safety Assessment Report on Radioactive Waste Management*. Unpublished Report. Jakarta, Indonesia: BAPETEN.

BMT (BMT Mercury Technology). n.d.a. “BMT Mercury Management.” Corporate presentation. Internal document.

BMT (BMT Mercury Technology). n.d.b. “Global leader in mercury and NORM waste management.” Accessed November 5, 2021. https://bmt-mercury.com/who-we-are/.

BMT (BMT Mercury Technology). 2021. BMT Asia Brochure 2021. Samut Prakan, Thailand: BMT Asia.

BMT Thailand. 2021. BMT Thailand’s questionnaire response. July 12, 2021.

Borneo Bulletin. 2021. “No time to waste.” February 8, 2021.

Bui, D.T. 2019. “Quản lý chất thải NORM và đề xuất cho Việt Nam” [NORM waste management and recommendations for Vietnam]. [In Vietnamese.] Tập san Thông tin Pháp quy Hạt nhân, 17, 23-29. Accessed April 25, 2023. https://www.varans.vn/lib/ckfinder/files/Tap%20san%20PQHN/TapsanThongtinphapquyhatnhanso17_final1.pdf.

Bui, M. T., and H.M. Nguyen. 2021. Determinants Affecting Profitability of Firms: A Study of Oil and Gas Industry in Vietnam. *The Journal of Asian Finance, Economics, and Business*, *8*(1), 599-608. https://doi.org/10.13106/jafeb.2021.vol8.no1.599

Bukit Udal Material Recovery Center. n.d. "Home." Accessed March 2, 2022. http://www.bukitudal.com/.

BUMRC (Bukit Udal Material Recovery Center). n.d. "Home." Accessed May 31, 2022. http://bukitudal.com/.

CIC (CIC Environmental Services Sdn Bhd). n.d.a. "CIC Mercury Treatment System." Accessed 31 May 31, 2022. http://cicgrp.com/cic-mercury-treatment-system-2/.

CIC (CIC Environmental Services Sdn Bhd). n.d.b. "Leading the force for Green." Accessed 31 May 31, 2022. http://cicgrp.com/about-us/.

CIC (CIC Environmental Services Sdn Bhd). n.d.c. "Solutions & Services." Accessed March 2, 2022. http://cicgrp.com/.

Chanyotha, S., Kranrod, C., and P. Pengvanich. 2015. "Systematic approach to characterisation of NORM in Thailand." *Radiation Protection Dosimetry*, 167(1-3), 15-21.

Congress of the Philippines. 1999. Republic Act No. 8749 (Philippine Clean Air Act of 1999). Manila, Philippines: Congress of the Philippines.

Constitution of Brunei Darussalam. 2013. Hazardous waste (control of export, import and transit) order, 2013. Bandar Seri Begawan, Brunei Darussalam: Constitution of Brunei Darussalam.

Council of Ministers (Cambodia). 1999. Sub-Decree on Water Pollution Control (unofficial translation). Phnom Penh, Cambodia: Council of Ministers.

CRF Consultants. 2016. "Status Capacity and Capability of North Sea Decommissioning Facilities." GMB Scotland.

DENR (Department of Environment and Natural Resources) (the Philippines). 1997. Chemical Control Order for Mercury and Mercury Compounds. Manila, Philippines: DENR.

DENR (Department of Environment and Natural Resources) (the Philippines). 2016. Water Quality Guidelines and General Effluent Standards of 2016. Manila, Philippines: DENR.

DENR (Department of Environment and Natural Resources) (the Philippines). 2019. Revised chemical control order (CCO) for mercury and mercury compounds (revising DAO 1997-38). Manila, Philippines: DENR.

DEPR (Department of Environment, Parks and Recreation) (Myanmar). 2021. "List of waste collection service providers." Accessed March 2, 2022. http://www.env.gov.bn/Shared%20Documents/SENARAI%20SYARIKAT%20BERDAFTAR%20DI%20BAWAH%20JASTRE%2007102021.pdf.

DEPR (Department of Environment, Parks and Recreation) (Myanmar). 2022. "List of recycling companies." Accessed March 2, 2022. http://www.env.gov.bn/Shared%20Documents/SENARAI%20SYARIKAT%20KITAR%20SEMULA%20YANG%20BERDAFTAR%202021%20-%20as%20of%2020%20Jan%202022.pdf.

DOE (Department of Environment) (Malaysia). 2017. "Updates of national regulations to the implementation of the Basel Convention in Malaysia." Accessed April 7, 2022.

https://www.env.go.jp/en/recycle/asian_net/Annual_Workshops/2017_PDF/Day1_S1/S1_06_Malaysia.pdf.

Eika, L. H., and M.S. Liew. 2014. Structural Sensitivity of Tarpon Monopods in Intermediate Water Depths for Marginal Field Development. *Science and Engineering*, *7*.

European Council. 1989. European Council Directive 89/656/EEC on the minimum health and safety requirements for the use by workers of personal protective equipment at the workplace. Brussels, Belgium: European Council.

Government of Myanmar. 2020. "Country Report (draft) – Myanmar." Accessed April 19, 2022. https://sdgs.un.org/sites/default/files/2020-11/UNCRD_10th%203R%20Forum%202020_Country%20Report_Myanmar.pdf.

Green Depot. n.d. "Green Depot." Accessed March 2, 2022. http://recover.green-brunei.com/index.php/auth/login.

Ha Loc. n.d. Capacity profile. (In Vietnamese.) Internal document.

Hoang, T.A., Tran, D.N., Hoang, L.L., Nguyen, H.T., Le, H.Q., Ta, M.Q., Nguyen, T.K., and T.B. Nguyen. 2017. "Nghiên cứu, phân tích, đánh giá mức độ ô nhiễm phóng xạ trong hoạt động khai thác dầu khí tại mỏ Bạch Hổ, thềm lục địa Việt Nam" [Research, analysis and evaluation of radioactive pollution levels in oil and gas exploitation activities in Bach Ho field.] [In Vietnamese.] *PetroVietnam Journal*, 4, 60-65. Accessed April 25, 2023. http://tapchidaukhi.com/index.php/TCDK/article/view/149/128.

IMO (International Maritime Organization). 2009. Hong Kong International Convention for the Safe and Environmentally Sound Recycling of Ships, 2009. London, UK: IMO.

INSEE Ecocycle. 2022. Group meeting with INSEE Ecocycle. March 2, 2022.

IOGP (International Association of Oil & Gas Producers). 2016. Managing Naturally Occurring Radioactive Material (NORM) in the oil and gas industry. IOGP Report 412. London, the UK: IOGP.

Islam, A. S., Jameel, M., Jumaat, M. Z., Shirazi, S., and F.A. Salman. 2012. Review of offshore energy in Malaysia and floating Spar platform for sustainable exploration. *Renewable and Sustainable Energy Reviews*, *16*(8), 6268-6284.

Ismail, B., Teng, I.L., and Y.M. Samudi. 2011. "Relative radiological risks derived from different TENORM wastes in Malaysia." *Radiation Protection Dosimetry*, 147(4), 600-607. https://doi.org/10.1093/rpd/ncq577.

ISO (International Organization for Standardization). n.d.a. "ISO 14000 family environmental management." Accessed February 20, 2022. https://www.iso.org/iso-14001-environmental-management.html.

ISO (International Organization for Standardization). n.d.b. "ISO 45000 family occupational health and safety." Accessed February 20, 2022. https://www.iso.org/iso-45001-occupational-health-and-safety.html.

ISO (International Organization for Standardization). n.d.c. "ISO 9000 family quality management." Accessed February 20, 2022. https://www.iso.org/iso-9001-quality-management.html.

ISO (International Organization for Standardization). n.d.d. "ISO/IEC 17025 – Testing and calibration laboratories." Accessed February 20, 2022. https://www.iso.org/ISO-IEC-17025-testing-and-calibration-laboratories.html.

Karstensen, K.H., Saha, P.K., Win, T.A., Oo, K.T. and Y.Y. Mar. 2017. "Generation and management of hazardous wastes in Myanmar." Forest Department. Accessed May 20, 2021. https://www.forestdepartment.gov.mm/sites/default/files/Research%20Books%20file/Leaflet%20No.5%20Kare%20Helge%20Karstensen.pdf.

Kualiti Alam. 2019. "Marketing Kits." Accessed October 21, 2020. https://www.cenviro.com/Cenviro/media/CenviroMedia/docs/Marketing-Kits.pdf?ext=.pdf.

Kualiti Alam. 2021. Kualiti Alam's questionnaire response. August 4, 2021.

Kualiti Alam. 2022. Kualiti Alam's email response. May 23, 2022.

Le, H.T., Le, T.T., Nguyen, N.T.P., Nguyen, K.V., Amelia, S., Zawawi, N.A.W.A., Punurai, W. and S.V. Le. 2022. "Challenges and prospects of hazardous waste management in ASEAN offshore decommissioning." Proceedings of the 3rd International Conference on the Decommissioning of Offshore & Subsea Structures (online), 21-22 February 2022. British Library, London.

Le, H.T., Punurai, W., Yubonmhat, K., Yuliati, E., Leow, J.S., Kang, H.S., Amelia, S., Yaakob, O.B., Zawawi, N.A.W., Wang, J., and S.V. Le. 2024, 'Naturally Occurring Radioactive Material waste management in the ASEAN oil and gas industry: a review', *Journal of Hazardous, Toxic, and Radioactive Waste*, 28 (1). http://dx.doi.org/10.1061/JHTRBP.HZENG-1247.

Le, H.T., Punurai, W., Zawawi, N.A.W., Yaakob, O.B., Nguyen, N.T.P., Le, T.T., Nguyen, K.V., Amelia, S., Kamarudin, N.A., Kang, H.S., and S.V. Le. 2023. "A review of mercury waste management in the ASEAN oil and gas industry." *Journal of Hazardous, Toxic, and Radioactive Waste*. 27(1): 04022044-1. http://dx.doi.org/10.1061/(ASCE)HZ.2153-5515.0000737.

Le, H.X., Nguyen, T.B., Ngo, T.V., Vu, T.T., Pham, T.K., and H.T. Doan. 2009. "Research the method for separating some radioactive contaminants from oil sludge." The annual report for 2008. Hanoi, Vietnam: Vietnam Atomic Energy Commission.

Lee, W.R., Eom, Y., and T.G. Lee. 2017. "Mercury recovery from mercury-containing wastes using a vacuum thermal desorption system." *Waste Management*, 60, 546-551.

Leow, J.S., Leow, J.S., Kang, H.S., Yaakob, O., Punurai, W., Amelia, S. and H.T. Le. 2023. "Technical preparedness in Southeast Asia region for onshore dismantling of offshore structures: Gaps and opportunities." Ocean Syst. Eng., 13(1), 79-95. https://doi.org/10.12989/ose.2023.13.1.079.

MOD (Ministry of Development) (Brunei). 2003. Pollution Control Guidelines for Industrial Development. Bandar Seri Begawan, Brunei Darussalam: MOD.

MOE (Ministry of Environment) (Cambodia). 1999. Sub-Decree on Solid Waste Management (unofficial translation). Phnom Penh, Cambodia: MOE.

MOE (Ministry of Environment) (Cambodia). 2016. "National Assessment Report on Mercury in Cambodia." Accessed April 16, 2022. https://www.mercuryconvention.org/Portals/11/documents/2016%20call%20for%20submissions/Cambodia%20MIA%20report.pdf.

MOEF (Ministry of Environment and Forestry) (Indonesia). 2021. Procedures and Requirements for the Management of Hazardous Wastes (in Indonesian). Jakarta, Indonesia: MOEF.

MOH (Ministry of Health (Brunei). 2004. Poisons Act. Bandar Seri Begawan, Brunei Darussalam: MOH.

MOH (Ministry of Health) (Brunei). 2019, Guideline on Healthcare Waste Management. Bandar Seri Begawan, Brunei Darussalam: MOH.

MOHR (Ministry of Human Resources) (Malaysia). 2000. Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health) Regulations 2000. Kuala Lumpur, Malaysia: MOHR.

MOI (Ministry of Industry) (Thailand). 2002. Notification of the Ministry of Industry Re: Stack Emission Standard from Industrial Waste Incinerator, B.E.2545 (2002) (in Thai). Bangkok, Thailand: MOI.

MOI (Ministry of Industry) (Thailand). 2005a. Notification of the Ministry of Industry Re: Industrial Waste Disposal, B.E. 2548 (2005) (unofficial translation). Bangkok, Thailand: MOI.

MOI (Ministry of Industry) (Thailand). 2005b. Notification of the Ministry of Industry Re: Prescribing of Specification of Processed Used Oil and Synthetic Fuel as Alternative Fuel for Furnace Oil in Industry, B.E. 2548 (2005) (in Thai). Bangkok, Thailand: MOI.

MOI (Ministry of Industry) (Thailand). 2006. Notification of the Ministry of Industry Re: Prescribing of air pollutant concentrations from factory B.E. 2549 (2006) (in Thai). Bangkok, Thailand: MOI.

MOI (Ministry of Industry) (Thailand). 2013. Notification of Ministry of Industry: List of hazardous substances B.E. 2556 (2013) (unofficial translation). Bangkok, Thailand: MOI.

MONRE (Ministry of Natural Resources and Environment) (Lao PDR). 2017. National Pollution Control Strategy and Action Plan 2018-2025, with Vision to 2030. Vientiane, Lao PDR: MONRE.

MONRE (Ministry of Natural Resources and Environment) (Vietnam). 2011. National Technical Regulation on Industrial Wastewater (QCVN 40:2011/BTNMT) (unofficial translation). Hanoi, Vietnam: MONRE.

MONRE (Ministry of Natural Resources and Environment) (Vietnam). 2012. National Technical Regulation on Industrial Waste Incinerator (QCVN 30:2012/BTNMT) (in Vietnamese). Hanoi, Vietnam: MONRE.

MONREC (Ministry of Natural Resources and Environmental Conservation) (Myanmar). 2015. National Environmental Quality (Emission) Guidelines. Nay Pyi Taw, Myanmar: MONREC.

MOST (Ministry of Science and Technology) (Vietnam). 2001. TCVN 6870:2001 - National Technical Regulation on Radiation Safety- Exemption from requirements of notification, registration and licensing. [In Vietnamese.] Hanoi, Vietnam: MOST.

Naidu, L., and R. Moorthy. 2022. "Ethics and risks in sustainable civilian nuclear energy development in Vietnam." *Ethics in Science and Environmental Politics*, 22, 1-12. https://doi.org/10.3354/esep00198.

Nåmdal, S. 2011. Decommissioning of offshore installations. *Climate and Pollution Agency*, Oslo.

NEA (National Environment Agency) (Singapore). n.d.a. "Management of toxic industrial waste in Singapore." Accessed April 27, 2022. https://www.nea.gov.sg/docs/default-source/our-services/pollution-control/hazardous-waste/management-of-toxic-industrial-waste.pdf.

NEA (National Environment Agency) (Singapore). n.d.b "Solid Waste Management Infrastructure." Accessed March 2, 2022. https://www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/waste-management-infrastructure/solid-waste-management-infrastructure#:~:text=Currently%2C%20Singapore's%20solid%20waste%20disposal,well%20as%20the%20Semakau%20Landfill.

NEA (National Environment Agency) (Singapore). 2008a. Environmental Protection and Management (Air Impurities) Regulations 2001 (revised 2008). Singapore, Singapore: NEA.

NEA (National Environment Agency) (Singapore). 2008b. Environmental Protection and Management (Trade Effluent) Regulations 1999 (revised 2008). Singapore, Singapore: NEA.

Nguyen, T.B. 2019. "Vấn đề quản lý chất thải dạng NORM/TENORM tại các cơ sở khai thác, chế biến quặng có chứa các nguyên tố phóng xạ" [Problems in NORM/TENORM waste management in the facilities that extract and manufacture minerals containing radioactive elements.] [In Vietnamese.] International Atomic Energy Agency. Accessed June 22, 2022. https://inis.iaea.org/collection/NCLCollectionStore/_Public/51/066/51066737.pdf.

OSHAS Project Group. 2007. "Occupational health and safety management systems – Requirements." Accessed February 10, 2020. http://www.aims.org.pk/wp-content/uploads/2014/08/OHSAS-18001-2007-Standards.pdf.

Pariatamby, A., Hamid, F.S. and M.S. Bhatti (eds.). 2020. Sustainable waste management challenges in developing countries. Hershey, PA: IGI Global.

PPLi. 2021a. PPLi's email response. November 25, 2021.

PPLi. 2021b. PPLi's questionnaire response. July 20, 2021.

PPLi. 2022. PPLi's email response. April 27, 2022.

Rittichai, S. 2022. *The Challenges of Offshore Facilities Decommissioning and Environmental Management* [Slide Presentation]. 3rd International Seminar on "Challenges and Opportunities in Offshore Decommissioning in South East Asia and Beyond".

Royal Government of Cambodia. 1996. Environmental Protection and Natural Resources Management Law (unofficial translation). Phnom Penh, Cambodia: Royal Government of Cambodia.

SB1. 2020. Group interview with PTSC Supply Base. May 14, 2020.

Seng, Q.Y. 2017. "Updates on national regulations and implementation status." Accessed April 7, 2022. https://www.env.go.jp/en/recycle/asian_net/Annual_Workshops/2017_PDF/Day1_S1/S1_03_Singapore.pdf.

Srisuksawad, K., Thiangtrongjit, S., and N. Chantaraprachoom. 2005. "Report on Recent Status of TENORM in Thailand." *Japanese Journal of Health Physics*, 40(1), 99-103. https://doi.org/10.5453/jhps.40.99.

Suraadiningrat, D.W.H. 2017. "Regional Study on Mercury Waste Management in the ASEAN Countries." United Nations Environment Programme. Accessed November 17, 2020. https://environment.asean.org/wp-content/uploads/2020/03/Regional-Study-on-Mercury-Waste-Management-in-ASEAN-Countries-UNEP.pdf.

Teng, I.L. 2016. "Decommissioning of Mineral Processing Plant and Remediation of Norm Contaminated Sites." Accessed July 15, 2022. https://nucleus.iaea.org/sites/orpnet/resources/Shared%20Documents/Teng-NORM-Contaminated-Sites-Remediation.pdf.

Teng, I.L. 2023. Email response to the paper authors. July 4, 2023.

Umeyama, K. 2021. "Cambodia amends Sub-Decree on Water Pollution Control." Accessed April 17, 2022. https://enviliance.com/regions/southeast-asia/kh/report_3360.

UNEP (United Nations Environment Programme). 2003. "Technical Guidelines for the Environmentally Sound Management of the Full and Partial Dismantling of Ships." Châtelaine: Secretariat of the Basel Convention. Accessed March 15, 2022. https://www.basel.int/Portals/4/Basel%20Convention/docs/meetings/sbc/workdoc/techgships-e.pdf.

UNEP (United Nations Environment Programme). 2017. "Global Mercury Waste Assessment: Review of Current National Measures." Accessed April 27. 2022. https://wedocs.unep.org/bitstream/handle/20.500.11822/22766/Global_mercury_waste_assessment_EN.pdf?sequence=1isAllowed=y.

Yubonmhat, K., Akharawutchayanon, T., Nuanjan, P., Issarapanacheewin, S., Katekaew, W., and N. Prasertchiewchan. 2022. "Progress and challenges of radioactive waste management in Thailand." *Journal of Hazardous, Toxic, and Radioactive Waste*, 26(2): 04022009. https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000693.

Win, T.A. 2021. "Country Updates & Response to Plastic Amendment of Myanmar." Accessed April 19, 2022. https://www.env.go.jp/en/recycle/asian_net/Annual_Workshops/2021_PDF/Presentations/2_Country%20update%20and%20response%20to%20plastic%20amendment/Myanmar.pdf.

Wisnubroto, D.S., Zamroni, H., Sumarbagiono, R., and G. Nurliati. 2021. "Challenges of implementing the policy and strategy for management of radioactive waste and nuclear spent fuel in Indonesia." *Nuclear Engineering and Technology*, 53(2), 549-561. https://doi.org/10.1016/j.net.2020.07.005.

Wood, M. 2018. *Offshore decommissioning in Asia Pacific could cost US$100 billion*. https://www.woodmac.com/press-releases/asia-decom/.

Zainai, A. I. 2022. *SPEKL Technical Forum @ SOGSE Decommissioning of Oil & Gas Facilities - Challenges, Opportunity & Way Forward.* SPE Kuala Lumpur. Retrieved 13 September 2021 from https://www.youtube.com/watch?v=S6z_zNiEF28&t=2550s.

PUBLICATION

Amelia, S., Hasyim, B., Aditramulyadi, D. D., Tawekal, R. L., Ilman, E.C., Bakti, F.P., Widyarsana, I.M.W, Kariem, M.A., Pravi, M., Tawekal, J.R., and L.M. Masturi. 2022. "Dismantling Yard Readiness Assessment for Indonesia's Planned Offshore Structural Decommissioning: Case of MEI Handil Yard." *International Journal of Research in Engineering and Science*. 10(2), 294-303.

Amelia, S., Leow, J.S., Hasyim, B., Aditramulyadi, D.D., Kang, H.S., Yaakob, O., and W. Punurai. 2021. Onshore yard readiness for upcoming oil and gas offshore structure decommissioning projects in Indonesia. Paper presented at the SPE Symposium: Decommissioning and Abandonment. November 30-December 2, 2021. Virtual.

Kamarudin, N.A., Zawawi, N.A.W.A, Liew, M.S., Lim, E.S., Hashim, F.E., Yaakob, O, Punurai, W, Le, H.T., Amelia, S., Dev, A.K, Wang, J., Danyaro, K.U., and S. Suherman. 2024. "Review of the Current Offshore Decommissioning Practices and Guidelines in Five Southeast Asia Countries." *Modern Subsea Engineering and Technology*, 2(3).

Le, H.T., Le, T.T., Nguyen, N.T.P., Nguyen, K.V., Amelia, S., Zawawi, N.A.W.A., Punurai, W. and S.V. Le. 2022. "Challenges and prospects of hazardous waste management in ASEAN offshore decommissioning." Proceedings of the 3rd International Conference on the Decommissioning of Offshore & Subsea Structures (online), 21-22 February 2022. British Library, London.

Le, H. T., Leow, J. S., Kang, H. S., Lin, T. I., and O.B. Yaakob. 2024. "NORM Waste Management in Vietnam's Oil and Gas Industry: Lessons from Malaysia." *Journal of Hazardous, Toxic, and Radioactive Waste,* 28(1), 04023043. https://ascelibrary.org/doi/10.1061/JHTRBP.HZENG-1283.

Le, H.T., Punurai, W., Yubonmhat, K., Yuliati, E., Leow, J.S., Kang, H.S., Amelia, S., Yaakob, O.B., Zawawi, N.A.W., Wang, J., and S.V. Le. 2024, 'Naturally Occurring Radioactive Material waste management in the ASEAN oil and gas industry: a review." *Journal of Hazardous, Toxic, and Radioactive Waste*, 28 (1). http://dx.doi.org/10.1061/JHTRBP.HZENG-1247.

Le, H.T., Punurai, W., Zawawi, N.A.W., Yaakob, O.B., Nguyen, N.T.P., Le, T.T., Nguyen, K.V., Amelia, S., Kamarudin, N.A., Kang, H.S., and S.V. Le. 2023. "A review of mercury waste management in the ASEAN oil and gas industry." *Journal of Hazardous, Toxic, and Radioactive Waste*. 27(1): 04022044-1. http://dx.doi.org/10.1061/(ASCE)HZ.2153-5515.0000737.

Leow, J. S., Leow, J. S., Kang, H. S., Yaakob, O., Punurai, W., Amelia, S., and H.T. Le. 2023. "Technical preparedness in Southeast Asia region for onshore dismantling of offshore structures: Gaps and opportunities." *Ocean Systems Engineering,* 13(1), 79-95. https://doi.org/10.12989/ose.2023.13.1.079.