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A Methodology for Handling, Disposal and Management of Norm Waste in Oil and Gas Industry

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Abstract: Naturally occurring radioactive materials (NORM) associated with oil and gas production encompass hard and porous deposits, such as scales and sludges, found in tubulars and various topside equipment, as well as condensates that are extracted as liquids from natural gas. The activity concentrations of radium isotopes, specifically ^{226}Ra and ^{228}Ra, in these scales and sludges exhibit a wide range, from typical levels observed in soils and rocks below 1 Bq/g to concentrations exceeding 1000 Bq/g. Generally, the activity concentrations are lower in porous deposits and sludges compared to scales. The concentration of ^{210}Pb tends to be relatively low in hard deposits but can reach thousands of Bq/g in sludges and in the very thin layers encountered during gas production. Significant quantities of NORM waste, surpassing the exemption limit of 10 Bq/g for ^{226}Ra and ^{228}Ra, are produced through both onsite and offsite decontamination processes of tubulars and various topside equipment. Onsite decontamination is typically preferred when components cannot be feasibly removed and replaced or do not require additional treatment prior to reinstallation or continued use. An example of onsite decontamination is the removal of accumulated sludges from separators and systems that manage produced water. Conversely, offsite decontamination is necessary when onsite methods are ineffective or pose radiological safety concerns, when components require refurbishment by specialized companies before reuse, and when components that will not be reused for their original purpose need to be cleaned. Additionally, the management and treatment of waste generated from the decommissioning of oil and gas production facilities is an increasingly pressing issue. This paper outlines the NORM wastes management process cycle as well as the disposal options for NORM waste originating from the oil and gas sector. The discussion will concentrate on four disposal alternatives deemed most relevant: (Strand, T. *et al*., 1997) re-injection through hydraulic fracturing alongside cuttings and other production waste, (Lysebo, I. *et al*., 1997) injection into the wellbore during plugging and abandonment operations, (Lysebo, I. *et al*., 1998) land disposal through burial of waste with encapsulation or surrounded by a concrete barrier, and (ICRP, 1991) depository in an abandoned mine, tunnel or other types of underground facilities.

Keywords: Waste, Oil and Gas Industry, Oil and Natural Gas.

INTRODUCTION

When oil and natural gas are extracted from the earth, they are often accompanied by solid materials and formation water. Under specific conditions, naturally occurring radioactive salts dissolved in the produced water may precipitate, leading to the formation of sulfate and carbonate scales that deposit on the inner surfaces of production tubulars, valves, pumps, separators, and various types of topside equipment. Additionally, clay and sand particles co-produced from the reservoir can serve as surfaces that initiate scale deposition. The injection of seawater into the reservoir to maintain pressure can result in the mixing of this injected water with formation water after breakthrough, subsequently increasing the sulfate concentration in the produced water and enhancing the deposition of radium salts within the production system.

The activity concentrations of ^{226}Ra, ^{228}Ra, and their decay products in deposits and sludges can range from typical levels found in soils and rocks (less than 0.1 Bq/g) to over 1000 Bq/g (1,2). Nevertheless, these activity concentrations remain low compared to the specific activity of most man-made radioactive sources, leading to the classification of these deposits as low specific activity (LSA) scales.

The deposition of scales can sometimes disrupt the production process by obstructing flow through the production zone, flow lines, and produced water lines. As a result, oil companies endeavor to mitigate scale deposition through the use of inhibitors. While these scale inhibitors effectively prevent the deposition of radium salts within the system, they may also increase the concentration and release of radioactivity in the produced water. These organic compounds can further enhance the biological uptake of radioactivity. There has been a significant rise in the utilization of inhibitors over the past decade, and due to current and anticipated demands for reduced production costs, it is expected that the use of inhibitors will continue to grow in the coming years.

In the process of natural gas production, it has been noted that very thin layers or films with relatively high concentrations of ^{210}Pb can be present. Additionally, equipment utilized in gas treatment and transportation may accumulate these thin films of ^{210}Pb, which are formed by the decay of short-lived radon daughters that adhere to the inner surfaces. Nevertheless, the overall quantity of waste generated is significantly lower, and the presence of ^{210}Pb in gas production does not pose a

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waste management issue to the same degree as radium sulfates found in scales and sludges.

Provided that appropriate personal protective equipment, such as dust masks and protective clothing, is utilized during operations involving the handling and treatment of contaminated equipment and waste, the occupational radiation doses remain generally low (Strand, T. *et al*., 1997; Lysebo, I. *et al*., 1998). Measurements and calculations indicate that these doses are two to three orders of magnitude below the limits recommended for workers by the International Commission on Radiological Protection (ICRP, 1996).

Due to the substantial volume of material that exceeds the recommended clearance levels, naturally occurring radioactive materials (NORM) in oil and gas production present a significant waste management challenge for the industry. The exemption and clearance levels suggested by the International Atomic Energy Agency (International Atomic Energy Agency, 1996) are designed to limit the annual radiation doses to the public to 1 mSv (International Atomic Energy Agency, 1988). According to the International Basic Safety Standards (IAEA, 1996), the recommended exemption values for the primary naturally occurring radionuclides found in NORM waste from oil and gas production are set at 10 Bq/g for ^{226}Ra, ^{228}Ra, and ^{210}Pb, and 1 Bq/g for ^{228}Th. However, the application of these exemption values to naturally occurring radionuclides is restricted to their incorporation into consumer products or their use as radioactive sources, such as ^{226}Ra and ^{210}Po, or for their elemental properties, like thorium and uranium. Consequently, NORM in oil and gas production is not fully encompassed by these guidelines.

The deposits consists mainly of sulphates and carbonates and these elements are classified at non- toxic and not harmful to the environment. Consequently disposal of this type of waste is not restricted by the legislation on pollution. In a complete discussion, the environmental aspects related to the non-radioactive components/substances should also be addressed.

NORM Management Process Cycle

The positive indication of NORM associated with operations required a solution in the form of a management process to control it. The process required to be sold to operational management and as such needed to have clear benefits, be easily implemented and be cost-effective. The benefits were the provision of protection for their workers, communities and the environment. This was achieved by communication with operators to ensure that procedures and guidance fitted with their operations taking into consideration the working environment and work to be done. To that end operators felt involved in the process as it was tailored to their requirements. Cooperation and inclusion rather than imposition, provided a means whereby operators bought in to the process. Although no direct cost benefit analysis has been completed costs associated are in line with the control and management of other occupational hazards. Also, potential future litigation against the company if it took no action to manage a hazard with known causes and effects may be significant. The following process cycle (Figure 1) was established as the optimum means by which control can be established in all areas of operation

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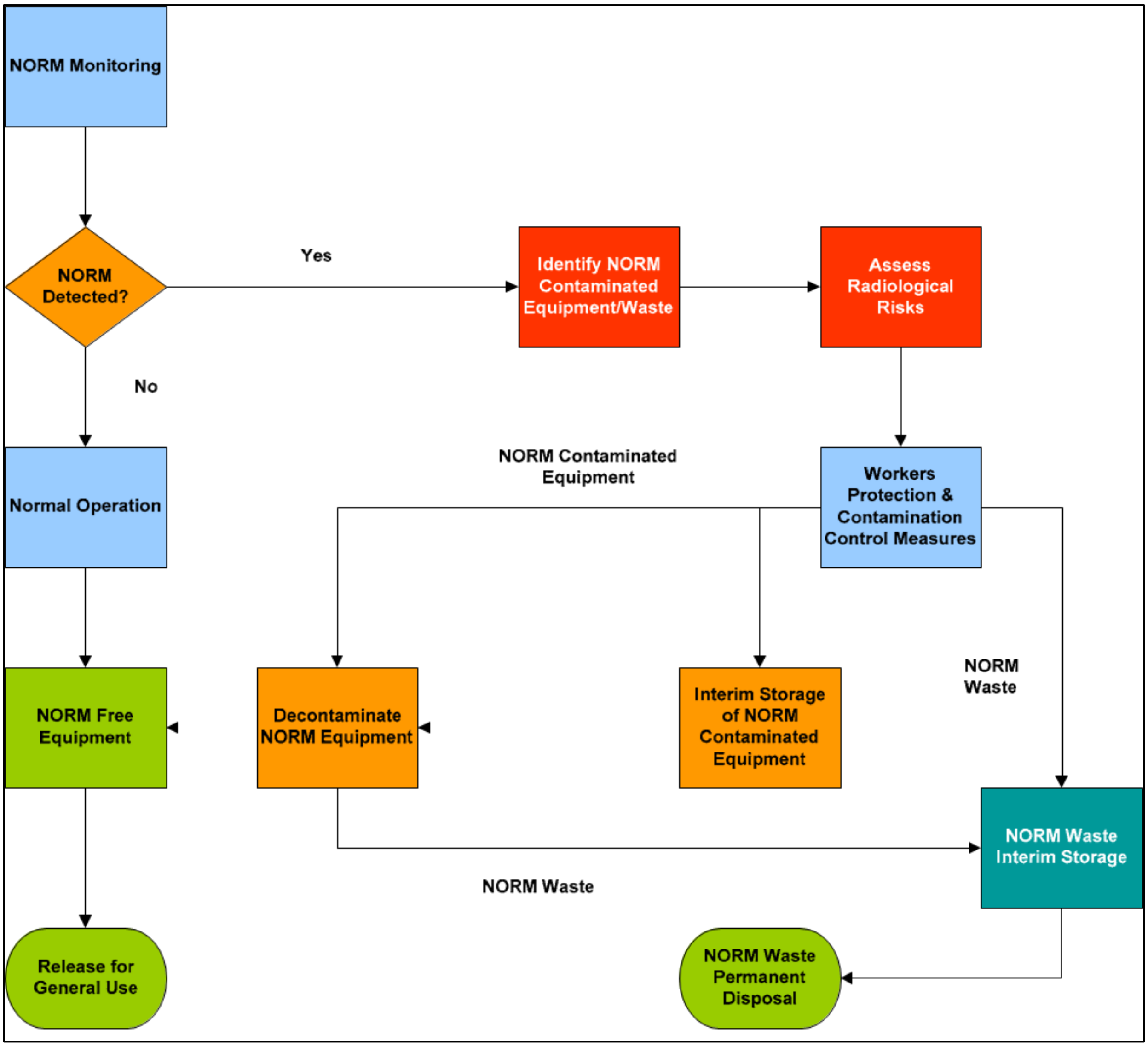

Figure 1: NORM Management Process Cycle

The NORM Management Process Cycle required a strategy to be implemented to ensure that all components of the process cycle could be adequately completed.

NORM Management Strategy

The NORM management strategy (Figure 2) contains five key elements, namely;

- NORM monitoring
- Safe management of NORM contaminated equipment
- Control of NORM waste
- Worker's protection and training
- Sharing Best Practice

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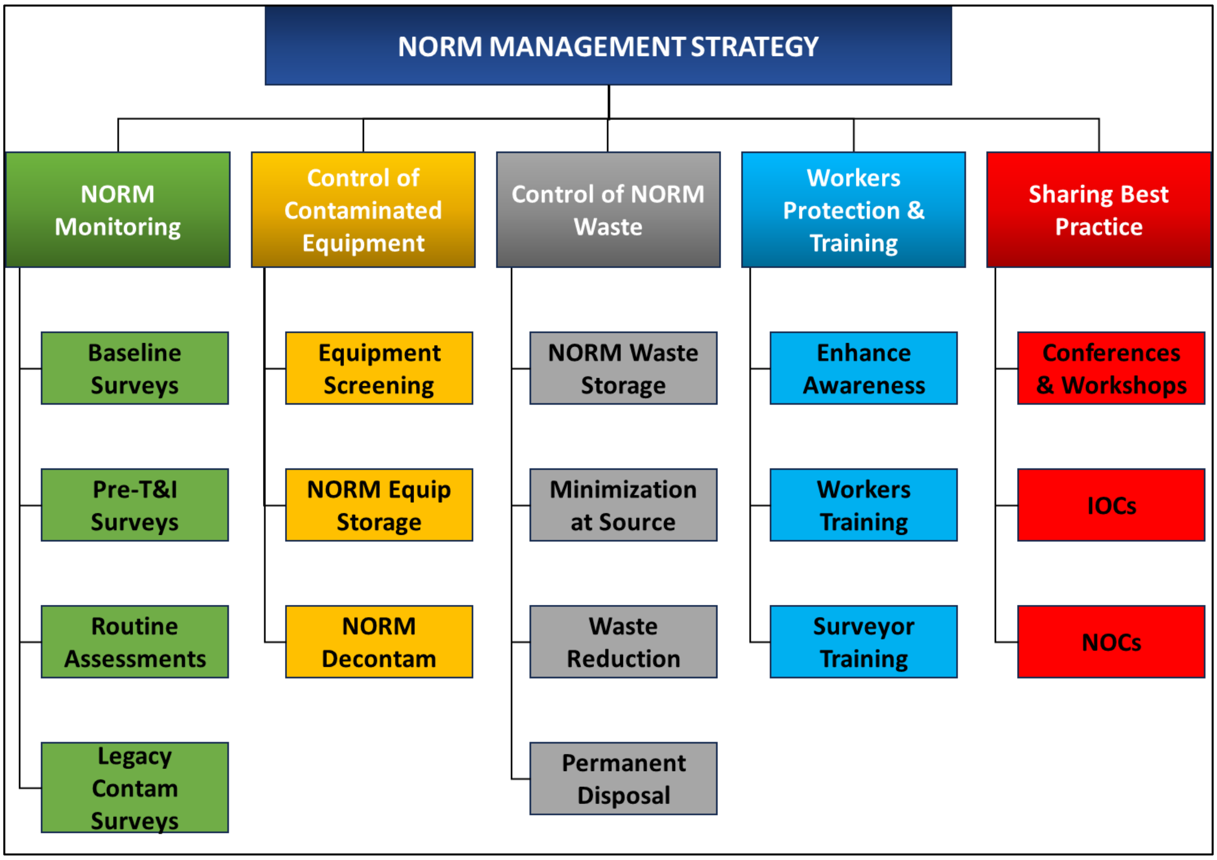

Figure 2: NORM Management Strategy

The strategy formed the focus of attention to allow activities to be planned and executed utilizing the available resource to maximum effect. The implementation of NORM strategy required significant management support from all sections of the organization. Action is required to commence on many fronts over a relatively short period of time. Initial reactions across the organization varied considerably so effort was placed on ensuring a common message was portrayed with the emphasis on assisting proponents in problem solving, rather than imposing restrictions and constraints on their operations.

Wastes Disposal

A variety of disposal alternatives is outlined in Table 1, categorized into four distinct groups, resulting in a total of fourteen options. The discussion surrounding these disposal methods necessitates consideration of several factors. The disposal of Naturally Occurring Radioactive Material (NORM) waste must comply with national regulations, environmental policies, and international agreements. The government is committed to maintain a high environmental standard, enforcing stringent policies regarding the disposal and release of hazardous waste, including radioactive materials. Consequently, alternatives that involve the dumping of waste or equipment are deemed unacceptable. Nevertheless, research indicates that the release of radioactivity into seawater from the disposal or sea bed burial of waste in steel drums or other sealed containers is almost zero. Despite this, such alternatives have been dismissed through political decisions, which may not necessarily reflect scientific assessments of the potential environmental and radiological impacts.

The discharge of NORM as production waste, resulting from the cleaning and maintenance of topside equipment at offshore installations, is highly restricted and should be treated as NORM wastes as per recent guidelines of EAEA and EGPC (Safe Handling Guideline for Sources of Ionizing Radiation in Oil and Gas Sector's Companies).(EGPC, 2024)

The disposal of Naturally Occurring Radioactive Material (NORM) waste through hydraulic fracturing has been explored by various companies (Gardiner, N. H, 1994; Fletcher, P. A, 1995) and is routinely executed for the re-injection of cuttings, drilling mud, and various forms of non-radioactive production waste resulting from the cleaning of topside equipment (COWIconsult, 1993).

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Hydraulic fracturing involves the incorporation of pulverized waste into a carrier fluid, which is then pumped into the well at high pressure to induce fractures in permeable formations. This injection may occur during the drilling process or while the well is in production. The depth of these fractures is contingent upon the well's depth and the characteristics of the reservoir, typically ranging from 500 to 1000 meters below the seabed and beneath both existing and potential drinking water sources. The fractures can extend several hundred meters from the wellbore, effectively trapping the waste between the fracture walls and preventing its re-entry into the wellbore. A well designated for this purpose can undergo multiple fracturing events, with the capacity to accommodate over one hundred thousand tons of solid waste. Once the well is no longer needed for this function, it is generally sealed with cement to avert fluid migration within the wellbore. An alternative method involves injecting the waste into the reservoir using a seawater injection system, while another option is to inject the waste during the plugging and abandonment phase. Accumulated deposits within the well tubing may either be left in situ or placed in a well that is being plugged and abandoned.

The processes of re-injection and injection involve returning waste to its original source, and research indicates that these methods are highly safe, with an almost negligible risk of radioactivity being released into the seabed and seawater. From a radiological perspective, all three methods should be considered safe and acceptable. When personal protective equipment is utilized during the handling and pre-treatment of waste, such as crushing, the occupational exposure levels are expected to remain very low and manageable.

In contrast, methods such as land-spreading, with or without dilution, and the burial of waste without protective barriers, as well as the disposal of contaminated equipment, are deemed to be of limited interest. A land depository must be encircled by a protective barrier, and waste should be contained in suitable corrosion-resistant containers to mitigate the risk of runoff into groundwater or the dispersion of radioactivity into the environment. Additionally, a permanent monitoring program will be essential, and no intrusive activities or the construction of habitable structures on the site should be allowed for thousands of years.

Minimizing the waste volume of Naturally Occurring Radioactive Material associated with the oil and gas industry offers significant environmental, economic, and operational benefits. By implementing advanced waste management techniques, such as dry decontamination, closed incineration, and recycling, companies can reduce the environmental footprint associated with radioactive waste disposal. This approach not only lowers the risks of soil and groundwater contamination but also aligns with global sustainability goals, enhancing the industry's reputation for environmental stewardship. Additionally, waste minimization reduces the financial burden of transportation, storage, and disposal, providing a cost-effective solution for operators. Most importantly, it contributes to improved workplace safety by decreasing workers' exposure to radioactive materials, fostering a healthier work environment.

Establishing a national central repository facility for low-specific-activity radioactive waste is a critical step in ensuring the safe and sustainable management of NORM waste in country oil and gas industry. Such a facility would provide a secure and centralized location for the long-term storage and disposal of radioactive waste, mitigating risks associated with scattered or improperly managed waste sites. A central repository would also ensure compliance with international standards and regulatory frameworks, enhancing country credibility in the global oil and gas market. Furthermore, it would support research and development efforts by providing a controlled environment for studying radioactive waste management practices, ultimately fostering innovation and capacity building within the sector.

Table 1: NORM waste disposal alternatives.

Category	Disposal alternative
Injection/re-injection of waste together with cuttings and other types of non-radioactive production waste	Well injection/re-injection into the reservoir Well injection by hydraulic fracturing Injection into the well during plugging and abandonment operations
Sea disposal of waste or dumping of equipment with or without encapsulation	Disposal of solid waste into the sea Dissolution of solid waste by use of chemicals followed by

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	disposal into the sea Encapsulation of the waste in drums followed by dumping or burial in the sea bed Sealing of tubulars and other types equipment without removal of NORM followed by dumping
Land disposal of waste or equipment with or without encapsulation	Depository in an abandoned mine, tunnel or other types of underground facility Burial of waste with encapsulation or surrounded by a concrete barrier Burial of waste or sealed equipment without encapsulation Landspreading of solid waste with or without dilution At approved depositories for inorganic waste or depositories for other types of waste from he oil industry Volume reduction (of waste) and thereby classified as radioactive waste followed by deposition at national depositories for radioactive waste
Scrap metal recycling of contaminated equipment	Equipment smelting without decontamination followed by recycling of the metal and disposal of the slag

Of the fourteen alternatives in Table 1, only five is assumed to be of main interest:

- Injection or re-injection by hydraulic fracturing together with cuttings and other types of production waste
- Injection into the well during plugging and abandonment operations
- Depository in an abandoned mine, tunnel or other types of underground facilities
- Land depository by burial of waste enclosed in corrosion resistant drums and/or surrounded by a concrete barrier.
- At approved depositories for inorganic waste or depositories for other types of waste from the oil industry

For all five alternatives, the occupational radiation doses remain exceedingly low. Assuming the appropriate personal protective equipment is utilized during the handling of waste and equipment, conservative estimates indicate that the annual occupational doses are below a few tenths of a millisievert (mSv). In the cases of injection and re-injection alternatives, the environmental discharges and the radiation doses to the public are nearly negligible. For the remaining three alternatives, the release of radioactivity and the associated doses to the public are well within permissible limits, provided that the facilities are situated away from residential areas and at a safe distance from surface and groundwater sources intended for household use.

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