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Original Article

Assessment of Internal and External Occupational Exposure to NORM in the Brazilian Oil and Gas Industry

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Abstract: The Oil and Gas industry is one of twelve industries that can involve Naturally Occurring Radioactive Material (NORM), generating a considerable volume of waste in Brazil. The petroleum industry, NORM, is present in geological formations and is accumulated as a function of the process. The most important radionuclides found in scale and sludge are Radium-226 and Radium-228, with activity concentrations that can reach 3,500 Bq/g in the country. The management of NORMs, vital for the safety of workers and the population, as well as for minimizing environmental impacts, encompasses six stages: production and extraction, monitoring, cleaning and decontamination, radiological analysis of NORMs, transportation, and storage. In each phase, workers are exposed to radiological risks through external exposure (gamma radiation) and/or internal exposure (inhalation or ingestion of radioactive particles). Given the large volume of NORM (Naturally Occurring Radioactive Material) and the growing demand for decommissioning offshore platforms in Brazil, which involves handling these materials, the understanding and rigorous application of radiological protection protocols become crucial. Although regulations require occupational health services and individual monitoring, a gap exists in occupational radiological assessments for this sector in the country. Estimated effective doses for the ten workers were comparable and consistently below the LD (Detection Limit) throughout the period of routine NORM exposure. These values fluctuated according to the nature of the work performed. Results confirm that *in vitro* bioassay is a reliable monitoring method for the oil and gas industry, particularly when integrated with $H_p(10)$ personal dosimetry and stringent safety protocols, ensuring comprehensive monitoring of occupationally exposed workers.

Keywords: NORM, internal dose, external dose, individual monitoring, oil and gas

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Avaliação da Exposição Ocupacional Interna e Externa a NORM na Indústria de Óleo e Gás Brasileira

Resumo: A indústria de Óleo e Gás é uma das doze indústrias que podem envolver Materiais Radioativos de Ocorrência Natural (NORM), gerando um volume considerável de rejeitos no Brasil. O NORs esta presente em formações geológicas e se acumulam em função do processo. Os radionuclídeos mais importantes encontrados em incrustações e borras são o Rádio-226 e o Rádio-228, com concentrações de atividade que podem chegar a 3.500 Bq/g no país. A gestão do NORM, vital para a segurança dos trabalhadores e da população, bem como para a minimização dos impactos ambientais, abrange seis etapas: produção e extração, monitoração, limpeza e descontaminação, análise radiológica de NORM, transporte e armazenamento. Em cada fase, os trabalhadores estão expostos a riscos radiológicos por meio de exposição externa (radiação gama) e/ou exposição interna (inalação ou ingestão de partículas radioativas). Dado o grande volume de NORM (Material Radioativo de Ocorrência Natural) e a crescente demanda pelo descomissionamento de plataformas offshore no Brasil, que envolve o manuseio desses materiais, a compreensão e a aplicação rigorosa dos protocolos de proteção radiológica tornam-se cruciais. Embora as regulamentações exijam serviços de saúde ocupacional e monitoração individual, existe uma lacuna nas avaliações radiológicas ocupacionais para este setor no país. As doses efetivas estimadas para os dez trabalhadores foram comparadas e consistentemente abaixo do LD (Limite de Detecção) durante todo o período de exposição rotineira ao NORM. Esses valores variaram de acordo com a natureza do trabalho realizado. Os resultados confirmam que a bioanálise *in vitro* é um método de monitoração confiável para a indústria de óleo e gás, particularmente quando integrado à dosimetria pessoal $H_p(10)$ e a protocolos de segurança rigorosos, garantindo a monitoração abrangente dos trabalhadores ocupacionalmente expostos.

Palavras-chave: NORM, dose interna, dose externa, monitoramento individual, óleo e gás.

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1. INTRODUCTION

Normally, there are around 12 types of industries related to naturally occurring radioactive material (NORM) and among them, the oil and gas industry is presented [1]. In Brazil, the average annual oil production was 3,773 million barrels/day in 2025 [2]. In the oil industry, NORM are present in geological formations and are generated as a result of the process. Are related to the radioactive decay series of the primordial radionuclides ^{238}U and ^{232}Th. The most important daughter radionuclides present in sludge and scales are the Radium-226 (^{226}Ra), Radium-228 (^{228}Ra), Lead-210 (^{210}Pb), Radon-222 (^{222}Rn) and Radon-220 (^{220}Rn) [3].

The mixed flow of oil, gas, and water carries these radionuclides that can precipitate in the form of scales or sludge. The concentrations of ^{226}Ra and ^{228}Ra in scale and sludge can vary between less than 0.1 Bq/g and 15,000 Bq/g, in the world [3]. In Brazil, the range of ^{226}Ra activity concentration is from 0.12 Bq/g to 3,500 Bq/g [4].

These scales or sludges can occur on the internal walls of production pipes and other equipment and need to be cleaned and decontaminated to minimize radiological exposure to workers. The correct management of NORM also minimizes environmental impacts and guarantees the safety of individuals in the public [5].

Currently, due to the demand generated in the oil and gas sector, Petrobras, Brazil's leading oil and gas company, has employees who work directly in oil management, covering all stages, including NORM management. Furthermore, Petrobras' basins have already generated more than 10,000 drums of NORM oil and gas to date [6].

Additionally, the decommissioning market in Brazil has emerged as a vital segment of the oil and gas industry, reflecting the growing need to adapt offshore facilities to environmental regulations and safety standards. According to the Dynamic Panel for Decommissioning E&P Installations (2025) [7], there are 1,327 wells to be decommissioned

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in 13 basins, totaling an investment of R$72,36 billion. In this decommissioning process, NORMs from the oil production and extraction process will be encountered.

Given this reality, there is concern about the decommissioning of offshore platforms containing NORM, as it requires specific procedures for their decontamination and safe disposal. Improper handling of these materials can lead to environmental and health risks, requiring the implementation of strict protocols for their handling, storage, and disposal. These protocols must be aligned with current regulatory guidelines and continually updated to reflect industry's best practices. Furthermore, it is crucial to provide constant training for workers involved in these operations, ensuring they are informed about the risks associated with NORM and the safety measures to be adopted. Continuing education and practical training are essential to ensure that the team can perform their duties safely and efficiently, minimizing the risk of exposure and environmental impact [8].

Given the high demand, it is crucial to understand NORM management in the oil and gas industry, identifying the radiological risks associated with each stage of the process, and preventing risks arising from exposure to ionizing radiation to workers, the public, and the environment, based on the principles of radiological protection. Therefore, Brazilian Nuclear Safety Authority (ANSN) establishes the requirements to be implemented by companies and institutions that carry out activities involving naturally occurring radioactive material (NORM) within the oil and gas exploration and production industries. Among these requirements is the mandatory radiological protection service that includes individual monitoring of workers [9].

However, there is no data of radiological monitoring assessment of these workers in Brazil to evaluate internal occupational exposure resulting from handling and contact with materials containing NORM, which highlights a regulatory and radiological surveillance gap in the sector.

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The objective of this study is to conduct an internal and external monitoring radiological assessment of workers exposed to NORM at every stage of this material's management, to develop an appropriate radiological protection protocol that ensures the health and safety of these workers and the environment.

2. MATERIALS AND METHODS

The methodology for individual internal and external monitoring was applied according to the characteristics and objectives of each of the three companies participating in the research within the NORM management process.

Three stages were carried out: (1) characterization of the participating companies, (2) data collection and evaluation of individual external monitoring, and (3) sample collection and evaluation of individual internal monitoring.

Stage 1: Characterization of participating companies.

The first stage of this study consists of the characterization of the three participating organizations, involving a total of 10 (ten) survey participants.

Company A (Figure 1: Illustration of the activities performed by company A), which specializes in radiation protection and advisory services, is responsible for radiation safety and logistical activities regarding NORM (Naturally Occurring Radioactive Material). Its operations range from offshore radiometric surveys, for the identification and classification of contaminated areas, to the development of the Radiation Protection Plan (RPP). Furthermore, the company provides technical advice for the transport and export of these materials, ensuring compliance with both national and international regulations. Its team comprises five participants who divide their duties between administrative tasks in offices and operational activities on offshore platforms. Safety protocols include the use of personal

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protective equipment (PPE) such as overalls, gloves, boots, hearing protection, helmets, and HEPA filter masks, with workers being monitored via external $H_p(10)$ individual dosimetry

Figure 1: Illustration of the activities performed by company A



Source: Illustrative image generated by AI

Following the workflow, Company B (Figure 2: Illustration of the activities performed by company B) specializes in radiometric analysis, acting directly in the characterization of NORM to determine radionuclide concentrations. Its core activities include gamma spectrometry to identify and quantify isotopes in secular equilibrium, such as ^{226}Ra and ^{228}Ra, as well as the verification of drum filling levels for compliance purposes. With a group of

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two participants, work is conducted in a laboratory located within a well-ventilated NORM drum management warehouse. Consistent with the previous company, the safety protocol requires the use of overalls, gloves, boots, hearing protection, helmets, and HEPA filter masks, supplemented by constant external $H_p(10)$ individual dosimetry monitoring.

Figure 2: Illustration of the activities performed by company B



Source: Illustrative image generated by AI

Finally, Company C (Figure 3: Illustration of the activities performed by company C) focuses on packaging verification and management, specifically regarding the physical integrity and repacking of NORM drums. Its responsibilities include the rigorous inspection of packaging to prevent leaks and, if damage is identified, the execution of the repacking

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process into new secure containers. The team consists of three participants operating in either well-ventilated warehouses or open environments within the management facility. Due to direct contact with the packaging, in addition to standard PPE (boots, gloves, helmets, hearing protection, and HEPA filter masks), employees utilize waterproof Tyvek suits. External $H_p(10)$ individual monitoring is also applied to all professionals in this sector, completing the scope of the study's sample group.

Figure 3: Illustration of the activities performed by company C



Source: Illustrative image generated by AI

Stage 2: Data collection and evaluation of individual external monitoring.

This stage consisted of the evaluation of the personal dose equivalent, $H_p(10)$, recorded on the workers' individual monitors. The dose history for each worker was shared by the respective companies for analysis and inclusion in the dose calculation. It should be

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noted that this study exclusively utilizes the results provided; the operationalization and technical responsibility for individual monitoring, conducted on a monthly basis and restricted to the premises of the companies in question, remain entirely with each institution.

Stage 3: Sample collection and preparation, and evaluation of individual internal monitoring.

This stage consisted of the 24-hour urine collection from each worker, the radiochemical procedure, and source preparation for liquid scintillation counting.

The collection of urine samples for internal contamination analysis was performed using 24-hour accumulated urine in containers provided by the Institute of Radioprotection and Dosimetry (IRD), following the provided instructions, once a month for three months. The 24-hour urine samples were collected in 2-liter plastic containers. The workers perform the same operational tasks throughout their daily shifts, characterizing a routine function, which justifies the monthly urine sample collection.

The study did not collect urine samples from unexposed local individuals; therefore, the impact of radium intake via diet and environmental exposure could not be addressed.

The radiochemical analysis followed the methodology of Fernandes (2010) [10], centered on the precipitation of radium-bearing barium sulfate ($BaSO_4$). Over a three-day process, the sample underwent digestion, pH adjustments (from basic to acidic), and the addition of chemical reagents including H_2O_2, HNO_3, and EDTA to isolate and purify the precipitate. On the final day, the $Ra(Ba)SO_4$ was filtered, dried at 180 °C, and the radiochemical yield was determined gravimetrically using barium as a carrier. The resulting source was then prepared for counting by mixing the filter with a specific 2:1:2 ratio of water, Ultima Gold AB® and Insta-Gel Plus® scintillation cocktails.

The samples were counted in a Quantulus 1220 low-background liquid scintillation spectrometer (PerkinElmer/Wallac) for 400 minutes. Based on previous studies, plastic scintillation vials were used [10]. The measurement system was calibrated using certified

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standard solutions of ^{226}Ra and ^{228}Ra (originally provided by LNMRI/IRD). From these standards, efficiency curves for both isotopes were obtained over time to ensure the accuracy of the liquid scintillation counting (LSC) results [11].

Both the chemical preparation of the samples and the counting and analysis steps were carried out entirely within the facilities of the Internal Dosimetry Laboratory (DIDOS), linked to the Institute of Radiation Protection and Dosimetry (IRD/ANSN).

3. RESULTS AND DISCUSSIONS

The results of the external and internal dose assessments for the 10 monitored employees are presented, categorized by company and job function, as established in the methodology.

3.1. External Monitoring: Personal Dose Equivalent, $H_p(10)$

The data obtained from the thermoluminescent dosimetry (TLD) reports provided by the companies reflect the exposure to gamma radiation emitted by NORM. Table 1 presents the monthly doses accumulated during the 3-month study period.

Table 1: Monthly External Monitoring Results

Company	Employee	$H_p(10)$ Month 1 (mSv)	$H_p(10)$ Month 2 (mSv)	$H_p(10)$ Month 3 (mSv)	Monthly Mean (mSv)
Company A	Employee 1	LD*	LD*	-	0
	Employee 2	LD*	LD*	-	0
	Employee 3	0.1	-	LD*	0.1
	Employee 4	LD*	-	LD*	0
	Employee 5	-	LD*	LD*	0
Company B	Employee 1	-	LD*	LD*	0
	Employee 2	-	LD*	LD*	0

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Company	Employee	$H_p(10)$ Month 1 (mSv)	$H_p(10)$ Month 2 (mSv)	$H_p(10)$ Month 3 (mSv)	Monthly Mean (mSv)
Company C	Employee 1	-	LD*	LD*	0
	Employee 2	-	LD*	LD*	0
	Employee 3	-	LD*	LD*	0

Legend: LD = doses below 0.1 mSv

During the observation period, workers wore dosimeters while performing their activities. The dosimeter was positioned on the chest and remained in place throughout the workday.

Although employee 3 from company A received a dose of 0.1 mSv/month, all values from the individual external dosimetry results demonstrate that the monitored exposures are Below or equal to the investigation level of 0.1 mSv/month.

The prevalence of undetectable values in the samples analyzed confirms that the doses received by the workers were technically negligible for numerical recording purposes.

3.2. Internal Monitoring: ^{226}Ra and ^{228}Ra Activity in Urine

The radiochemical analysis by liquid scintillation counting (LSC) aimed to identify the urinary excretion of radium, which is indicative of incorporation via inhalation or accidental ingestion.

The activity concentrations (mBq/L) of the results are detailed in Tables 2 and 3. In these tables, the monthly columns (Month 1 to 3) report the measured activities, while the LD columns specify the detection limits established for the respective samples.

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Table 2: Results of radiochemical analysis by liquid scintillation counting for ^{226}Ra

Company	Employee	Month 1 (mBq/L)	LD (mBq/L)	Month 2 (mBq/L)	LD (mBq/L)	Month 3 (mBq/L)	LD (mBq/L)
Company A	Employee 1	<LD*	3	<LD*	3	-	-
	Employee 2	<LD*	2	<LD*	2	-	-
	Employee 3	<LD*	3	-	-	<LD*	3
	Employee 4	<LD*	3	-	-	<LD*	1
	Employee 5	-	-	<LD*	2	<LD*	2
Company B	Employee 1	-	-	<LD*	3	<LD*	3
	Employee 2	-	-	<LD*	2	<LD*	2
Company C	Employee 1	-	-	<LD*	2	<LD*	2
	Employee 2	-	-	<LD*	3	<LD*	3
	Employee 3	-	-	<LD*	3	<LD*	3

Legend: LD = limit of detection

Table 3: Results of radiochemical analysis by liquid scintillation counting for ^{228}Ra

Company	Employee	Month 1 (mBq/L)	LD (mBq/L)	Month 2 (mBq/L)	LD (mBq/L)	Month 3 (mBq/L)	LD (mBq/L)
Company A	Employee 1	<LD*	22	<LD*	35	-	-
	Employee 2	<LD*	30	<LD*	33	-	-
	Employee 3	<LD*	34	-	-	<LD*	34
	Employee 4	<LD*	38	-	-	<LD*	18
	Employee 5	-	-	<LD*	26	<LD*	34
Company B	Employee 1	-	-	<LD*	35	<LD*	40
	Employee 2	-	-	<LD*	21	<LD*	24
Company C	Employee 1	-	-	<LD*	28	<LD*	33
	Employee 2	-	-	<LD*	40	<LD*	45
	Employee 3	-	-	<LD*	34	<LD*	43

Legend: LD = limit of detection

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In all samples analyzed, the activities of ^{226}Ra and ^{228}Ra were below the limit of detection (LD).

The detection limit of the method ranged from 1 to 3 mBq/L for ^{226}Ra and 18 to 45 mBq/L for ^{228}Ra. According to ICRP 37, the detection limit of the liquid scintillation technique for urine analysis is 3 mBq/L for ^{226}Ra and 50 mBq/L for ^{228}Ra. Therefore, the detection limit found in this study is in accordance with the parameters indicated by the ICRP.

Furthermore, the data validates the effectiveness of the radiological safety protocols implemented in each company:

Company A Workers (Radiation Protection and Advisory): This result proves that, even during NORM management activities, there was no inhalation of aerosols or accidental ingestion. Correct signaling and adherence to safety distances were fundamental in keeping workers free from internal contamination and external exposure.

Company B Workers (Radiometric Analysis): In the laboratory environment, where NORM material is processed by gamma spectrometry, the risk lies in sample handling. Results below the LD confirm that good laboratory practices, such as the use of well-ventilated areas, gloves, masks, and rigorous hand hygiene control, prevented any material from entering the body.

Company C Workers (Packaging Management): Among the participating companies, this group represented the greatest radiation protection challenge, as activities involving integrity verification and the repacking of damaged drums have a high potential for particle suspension (NORM-laden dust). The absence of detection in urine demonstrates that the use of appropriate respiratory protection and disposable clothing was entirely effective, ensuring that the material, although exposed during drum replacement, was not incorporated through the respiratory or digestive tracts.

Therefore, the fact that all participants yielded results below the detection limit reinforces the premise that the risk of internal contamination during NORM handling, under

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these logistical configurations, is controllable. Maintaining a clean and well-ventilated work environment, combined with discipline in the use of Personal Protective Equipment (PPE), reduced the risk of incorporation, keeping the exposure profile limited to doses below the individual public limit for the activities studied.

The IAEA recognizes that the risks of internal contamination through inhalation or ingestion are inherent to the handling of radioactive materials. Therefore, while the use of PPE minimizes these risks, it does not eliminate them entirely. To ensure good practices and validate the effectiveness of protective barriers, annual internal monitoring of workers via urine analysis is recommended. This ensures rigorous control of radiological safety and serves as a real-world verification of the effectiveness of the adopted protection protocols.

4. CONCLUSIONS

The present research allowed for the evaluation of occupational exposure among workers involved with NORM across different operational fronts.

The results of individual monitoring, regarding both external dose ($H_p(10)$) and internal monitoring (analysis of ^{226}Ra and ^{228}Ra in urine), demonstrated that there was no significant exposure above the natural background radiation levels. The absence of detectable internal contamination and the external dose values evidence that good radiation protection practices and the rigorous use of Personal Protective Equipment (PPE) were decisive factors in minimizing risks.

The use of physical barriers, exposure time control, and proper donning of protective gear proved effective in protecting the physical integrity of the employees in the companies studied, ensuring that activities were performed safely.

It is important to emphasize that, given the nature of the activities, measurable exposures were expected in companies specializing in cleaning and decontamination of

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components. In these scenarios, the direct handling of sludge and scales during cleaning and decontamination offers a much higher exposure potential than the activities performed by the other companies participating in this research.

In conclusion, this study confirms the safety of the current protocols in monitored companies. Continuous monitoring remains an indispensable tool to ensure that, even in low-dose activities, the ALARA (As Low As Reasonably Achievable) philosophy continues to be upheld.

For the purposes of regulatory compliance and to ensure the health and safety of workers and the environment, an annual internal monitoring frequency is suggested.

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CONFLICT OF INTEREST

All authors declare that they have no conflicts of interest.

DATA AVAILABILITY STATEMENT

The authors declare that the data supporting the results of this study are available within the article. Derived data supporting the findings of this study that are not found in the article may be requested from the corresponding author.

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