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Decontamination of equipment with oil and gas NORM: the need for internal individual monitoring

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ABSTRACT

In the oil field, Naturally Occurring Radioactive Material - NORM is present in petroleum-forming rocks and this is related to the presence of radioactive decay series of ^{238}U and ^{232}Th, mainly the daughter radionuclides ^{226}Ra and ^{228}Ra. These radionuclides are detected during the process of production and extraction of oil and gas. They migrate from the reservoir rock and flow through the production lines until the operating areas, forming sludge and scale. The presence of ^{226}Ra and ^{228}Ra can be found in many pieces of equipment on the platforms, and NORM concentrations may increase due to different extraction processes. When this accumulation of NORM occurs inside the equipment, it is necessary to decontaminate them. Depending on the decontamination technique, workers can be exposed to radioactive materials contained in sludge and scale, which are released in the form of aerosols. The existing radiological risk during decontamination is based on external irradiation and internal contamination of workers, this is why an individual monitoring program covering both external and internal dosimetry is necessary. External monitoring is widely used during the routine work of decontamination of equipment, but for internal monitoring, the real importance has not been given, despite the probability of being the greatest contribution to radiological risk for workers. This article presents the need for internal individual monitoring for a comprehensive assessment of radiological risk and a general description of how it is being done in several countries to assist in the implementation of a complete individual monitoring program, mainly in Brazil.

Keywords: internal individual monitoring, decontamination, oil and gas, NORM

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1. INTRODUCTION

1.1. Oil Formation

The formation of petroleum is characterized by the accumulation of organic matter under specific conditions of pressure and isolation in subsoil layers of sedimentary basins, transformed in thousands of years. In addition to being in a sedimentary basin, the primary requirement for eventually locating an oil reservoir is the presence of some type of reservoir rock (usually porous) covered by a cap rock (which prevents oil from escaping to the surface, eventually dissipating) [1].

In the rocks of the reservoir, the oil accumulates on the saline domes, which remains in an equilibrium position with the residual water. This equilibrium is obtained by the equality of oil and water pressures in the pores [2].

An oil field is usually made up of several producing wells, whose flow rates can vary from very low to a few tens of thousands of barrels per day. The different producing wells of a field can produce oil with different characteristics, which depends on the formations found and their depth [2].

1.2. NORM – Naturally Occurring Radioactive Material

Over the years and with the advancement of studies, the presence of NORM (Naturally Occurring Radioactive Material), which are radionuclides naturally contained in the rocks that form oil and gas were detected [3].

NORMs are detected in rock formations and their distribution depends on the geological environment from which they are derived and the processes by which they were concentrated there [3].

The presence of NORM in the Earth's crust is known by the ^{238}U, ^{235}U, and ^{232}Th series and they are particularly important because contain quantities of radionuclides found in petroleum products and natural gas [4]. The most important daughter radionuclides present in sludges and scales are ^{226}Ra and ^{228}Ra, belonging to the natural radioactive series of ^{238}U and ^{232}Th, respectively [5].

In an oil and gas reservoir, which has not yet produced or extracted oil, the ^{232}Th and ^{238}U decay series are in secular equilibrium. For producing reservoirs, the chemical partitioning equilibrium between naturally occurring radionuclides present in reservoir rock and reservoir fluids will depend on some elemental properties of the Th, U and Ra [6]:

a) Th and U: The oil and gas reservoir is a reducing environment, so Th and U remain in the solid rock phase and do not dissolve in the oily aqueous phase (because they are insoluble in the aqueous phase). As a result, they remain in the reservoir rock and, only during drilling, the natural concentrations of these radionuclides on the surface are detected.

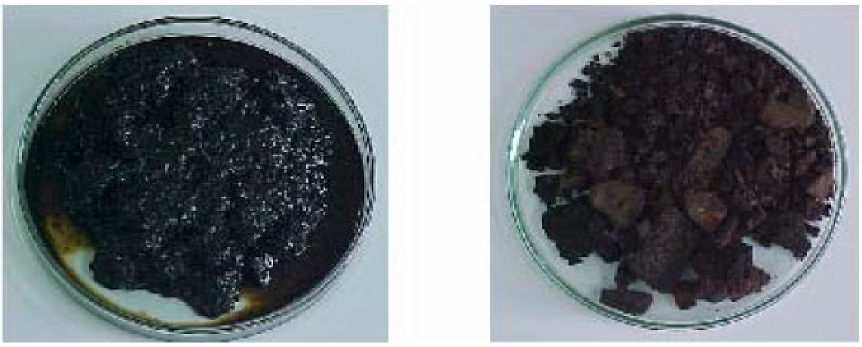
b) Ra: The decomposition of Ra into ^{228}Ra, ^{226}Ra, and ^{224}Ra is special since they are formed by alfa (α) decay of their parent. Ra prefers the aqueous phase, causing concentrations to rise naturally. Therefore, after production, the Ra will follow the flow of produced water. Because it is chemically like barium (Ba), strontium (Sr), calcium (Ca), and magnesium (Mg), radium is incorporated into sulphate or carbonate deposits and scales. Once deposited inside the facilities or produced on the surface due to their radiation characteristics, the three radioisotopes exhibit different behaviours.

1.3. Types of NORM in the Oil and Gas Industry

Sludge and scale are two types of NORM can be detected in the oil and gas industry.

Sludge (Figure 1) is the accumulation of heavy hydrocarbons and sediments that are brought to the surface during the oil extraction process. On the other hand, the incrustation (Figure 2) is the result of mineral impurities that accumulate due to the injection of little incompatible water, evaporation in a few gases, changes in pressure, and/or temperature drops. The material is a precipitate of barium/strontium sulphate ($BaSO_4$/$SrSO_4$) or calcium carbonate ($CaCO_3$) [7].

Figure 1: *Sludge of oil and gas NORM*



Source: Araújo, 2005 [5]

Figure 2: *Pipes with Scale of oil and gas NORM*

Source: IBP, 2019 [20]

NORM accumulation, either in the form of sludge or scale, occurs at various points on the platform, such as valves, pipes, vessels, and tanks. When this accumulation is detected, it is necessary to clean and decontaminate this equipment, in order to maintain the processing flow of the platform, as well as the safety and health of the worker [8].

1.4. Decontamination Methods

The removal of NORM containing scale and sludge from facilities and equipment, whether for production and safety reasons or during decommissioning, should be carried out with appropriate radiation protection measures and with due regard to other safety, waste, and relevant environmental aspects [3].

There are 5 decontamination methods used [9]:

a) Manual cleaning or vacuuming: The method does not involve any machinery or involves only simple machinery. It is commonly used to remove sand and sludge from equipment. Aspiration can be wet or dry to remove loose particulate contamination or to transfer sludge solids from equipment to transport or storage tanks (Figure 3).

Figure 3: *Manual cleaning*

Source: IAEA, 2010 [9]

b) Mechanical removal: Drilling or reaming is commonly used to remove scale (hard deposits) from surface-contaminated pipes and other types of equipment. If dry drilling processes are used, the extractors must be installed in a closed system to prevent the spread of radioactive dust. Wet drilling processes will reduce or avoid the generation of radioactive dust. The wet process must also be shut down to contain contaminants and the wash water must be filtered to remove scale (Figure 4).

Figure 4: *Mechanical removal*

Source: IAEA, 2010 [9]

c) Chemical descaling: Chemical methods are applied and developed for downhole scale removal and scale prevention. If scale prevention fails and the extent of scale interferes with production and/or safety, chemical methods are also applied to remove scale from the production system.

The chemicals used are based on mixtures of acids or combinations of acids and complexing agents. Chemical methods should be applied when the surfaces to be decontaminated are not accessible for mechanical treatment when the mechanical treatment causes unacceptable damage to the components being restored, and when the contaminating material cannot be removed mechanically (Figure 5).

Figure 5: *Chemical descaling*

Source: IAEA, 2010 [9]

d) Abrasive methods: Wet and dry abrasive methods using handheld devices can be applied to remove scale from easily accessible component surfaces. Normally, dry sanding, milling, grinding, and polishing should be avoided due to the risks of spreading airborne radioactive contamination. With wet abrasive methods, this risk is greatly reduced. Consequently, the application of dry abrasive methods requires extensive protection measures for workers and the environment, which in practice can only be provided by specialized companies or organizations. High-Pressure Water Jetting (HPWJ) has been shown to be effective for the decontamination of oil and gas production components. In principle, it can be applied on site, offshore, and on land, but its effective and radiologically safe application requires knowledge and dispositions to achieve the correct blast impact, contain flashback mist, and collect and remove water and fouling. (Figure 6).

Figure 6: *Abrasive methods*

Source: IAEA, 2010 [9]

e) Fusion: Melting of NORM-contaminated metal components separates the metals from the NORM radionuclides. The latter end up in slag or dust and gas vapours. Fusion decontamination is being applied in dedicated fusion facilities (Figure 7).

Figure 7: *Fusion*

Source: IAEA, 2010 [9]

1.5. Oil and Gas NORM Radiological Hazard

In the absence of adequate radiation protection measures, NORM in the oil and gas industry could cause external exposure during production due to the accumulation of gamma emitting radionuclides and internal exposures of workers and others, particularly during maintenance, the transport of waste and contaminated equipment, decontamination of equipment, the processing and disposal of waste, and also the decommissioning of oil and gas production facilities [3]. Therefore, during the cleaning and decontamination of equipment contaminated with NORM, the worker will be exposed to ionizing radiation from these materials.

Internal exposure to NORM may result from ingestion or inhalation of radionuclides. This may occur when working in open facilities and equipment, handling debris and contaminated surface objects, and cleaning contaminated equipment. Ingestion can also occur if precautions are not taken before eating, drinking, smoking etc. [3].

Effective precautions are necessary during the aforementioned operations to contain radioactive contamination and prevent its transfer to areas where other people may also be exposed. Cleaning contaminated surfaces during repair, replacement, renovation, or other work can generate airborne radioactive material, especially if dry abrasive techniques are used. Inhalation exposure can become significant if effective personal protective equipment (including respiratory protection) and/or engineering controls are not used [3].

As a consequence of this accumulation, it is necessary to clean and decontaminate the equipment. This practice can release aerosols containing radionuclides present in sludge and scale, exposing workers performing this function to ionizing radiation [3].

The existing radiological risk during decontamination can be due to irradiation from external sources and internal contamination by ingestion, inhalation and dermal contact [3].

The potential committed dose by inhalation depends on the physical and chemical characteristics of NORM. It is important to consider the radionuclide composition and activity concentrations, the activity aerodynamic size distribution of the particles (quantified by the activity mean aerodynamic diameter, or AMAD), and the chemical forms of the elements and substances. corresponding types of lung absorption [3].

Radionuclides ^{226}Ra and ^{228}Ra are of more concern because radium belongs to the same family as calcium on the periodic table and can lodge in the same places as bones and lungs. In addition, both have as their descendants ^{222}Rn and ^{220}Rn, which are gaseous elements that can be dispersed in the air and inhaled [6].

In general, many researchers have studied the risks of radiation exposure from the oil and gas industry in different parts of the world. Oil and gas production areas may be contaminated with NORM, but generally low. But, over time, the accumulation of oil and gas residues under improper handling can produce radiation doses that are harmful to humans and the environment. The higher the level of radioactivity in the waste, the greater the radiation effects, especially when considering the possibility of exposure of operators by internal contamination from dust absorption during waste treatment and cleaning [10].

1.6. Individual Monitoring of Internal Contamination

Due to the radiological risk, it is necessary to have an adequate individual monitoring program that evaluates not only the external dose but also the internal dose of the workers.

Intake can occur by inhalation, ingestion, or skin lesions. Once incorporated, the radionuclide is transferred to the blood and then distributed among the organs and tissues of the body [11].

Individual monitoring of internal contamination due to the incorporation of radionuclides can be carried out on the basis of aerosol analysis procedures, *in vitro* and *in vivo* bioassays [11]:

a) Aerosols Analysis Procedures: Aerosol properties, such as aerosol viscosity, density, and concentration, depend on the particles and the suspended medium and are different from the properties of the air and the particles present in the aerosol. To assess the risks due to inhalation of particles, it is necessary to determine the size of the particles to which the element is associated, since this parameter determines the place of deposit of the particle in the respiratory tract, the inhaled fraction deposited in each compartment of the respiratory tract and the kinetics of the particles as they enter the respiratory tract, the chemical form, which determines the solubility of the particle in lung fluid, and the biokinetic behaviour of the element. The biokinetic behaviour of the particles depends on the physical and morphological and physiological properties of the airways.
b) *In Vivo* Bioassays: The use of *in vivo* techniques in internal dosimetry consists of the qualitative and quantitative determination of radioactive substances deposited internally, through direct measurements in the human body. This type of procedure is normally performed in laboratories generically called whole body counters. The direct radionuclide monitoring technique is recognized as a valuable tool in the field of radiation protection and dosimetry. This technique basically consists of placing radiation detectors near previously defined regions of the body and acquiring the spectrum during a standard time, which is a function of the type of measurement to be carried out. Subsequently, spectrum analysis makes it possible to identify, quantify and locate the radionuclides present in the body at the time of measurement.
c) *In Vitro* Bioassays: The determination of the concentration of radionuclides in biological samples is an indirect method for the evaluation of the incorporation. The main sources of bioassay data

are usually faces, urine, exhaled breath, and blood, although other sources such as hair, teeth, and nose swabs may be used in special cases. The choice of the biological sample will depend on the primary route of excretion of the radionuclide in question, as well as factors such as ease of collection, analysis, and interpretation.

Based on experimental data and information from the scientific literature, this article presents the need to perform internal individual monitoring of workers for a global assessment of the radiological risk during the decontamination of NORM oil and gas equipment. It also presents an overview of the decontamination methods of NORM performed in many countries to support the implementation of an efficient individual monitoring program, especially in Brazil.

2. MATERIALS AND METHODS

The qualitative research method and the case study were used. The bibliographic research was done in 3 steps: 1) NORM radiological risk for occupational workers; 2) Brazilian and international companies that decontaminate oil and gas NORM equipment and their decontamination methods; 3) Recommendations and regulations of many countries for oil and gas NORM.

The bibliographic research was done using mainly the publication of international organizations, such as, IAEA, UNSCEAR and ICRP. Some scientific articles from indexed journals and publications in international congresses were also used. Brazilian and international regulations were also surveyed.

Some analyses were done comparing the decontamination methods of the companies, the radiological risk from NORM during the decontamination and the status of some recommendations and regulations.

3. RESULTS AND DISCUSSION

The results obtained after extensive research are presented in three fundamental aspects: an overview of companies that perform the decontamination of equipment containing oil and gas NORM, the legal aspects of radiation protection regulations and recommendations and experimental results of the annual effective dose of workers performing equipment decontamination with NORM. These results demonstrated the need for a more effective internal individual monitoring control.

3.1. Oil and Gas NORM Decontamination Companies

There are several companies that offer the service of decontamination of equipment containing oil and gas NORM, as shown in Table 1.

Table 1: Some companies that perform the decontamination of equipment containing NORM oil and gas.

Companies	Local	Decontamination Method
ASCO	UK	Ultra-High-Pressure Water Jetting
Elite Offshore Pvt	India	Ultra-High-Pressure Water Jetting
Maqshan	Middle East	Ultra-High-Pressure Water Jetting Chemical Decontamination Dry Mechanical Decontamination
Solutient Technologies	USA	Chemical Decontamination Mechanical Decontamination
C-Tank (Ambipar)	Latin America	Ultra-High-Pressure Water Jetting Chemical Decontamination Mechanical Decontamination
Lince Radioproteção	Brazil	Ultra-High-Pressure Water Jetting Chemical Decontamination Mechanical Decontamination
NRC US Ecology	USA and UK	Ultra-High-Pressure Water Jetting

Companies have more than one decontamination method that can be used. The choice of the technique can vary for some reasons, such as, the environmental condition of the work, the equipment to be decontaminated (pipes, valves, tanks, etc.) and the types of NORM material (sludge or scale).

The decontamination method with ultra-high-pressure water jetting is the most widely used because it minimizes the dispersion of radioactive particles in the air, once these particles mix and precipitate with water. However, spite of this situation, the radiological risk is still presented and does not exclude the need for internal individual monitoring.

3.2. Radiation Protection Recommendations and Regulations

Many international organizations have published several recommendations and studies on occupational radiation protection, such as International Atomic Energy Agency (IAEA), International Commission on Radiological Protection (ICRP) and United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

Based on these international recommendations the countries, such as Australia, Canada, the United States of America, the Middle East, Japan and Brazil have prepared their regulations related to radiation protection to NORM.

Some of these international recommendations demonstrate the importance and necessity of an effective control of internal individual monitoring, such as:

a) IAEA - Radiological Protection and Safety of Radiation Sources: International Basic Safety Standards [12]: it is recommended that the regulatory body establishes and enforces requirements for safety assessment and that the person or organization responsible for a facility or activity giving rise to radiation hazards conduct a security assessment at that facility or activity (Requirement 13: Safety Assessment), and that registrants, licensees, and employers conduct monitoring to verify compliance with security and safety requirements (Requirement 14: Compliance Monitoring).

b) IAEA - Occupational Radiation Protection [13]: that cites the monitoring program, it was evidenced that the evaluation of the doses received by workers due to exposure through ingestion of radionuclides can be based on the results of individual monitoring that involves one or more of the following types of measurement: sequential measurements of radionuclides throughout the body or in specific organs, such as the thyroid or lungs; measurements of radionuclides in biological samples, such as excreta or respiration; measurement of activity concentrations in air samples that are collected using personal air sampling devices worn by the worker and that are representative of the air that worker breathes (Item 7: Monitoring and evaluation of occupational exposure).

c) IAEA - Radiological Protection and Management of Radioactive Waste in the Oil and Gas Industry [3]: it presents that indoor exposure to NORM can result from ingestion or inhalation of radionuclides and this can occur while working in open facilities and equipment, handling debris and objects from contaminated surfaces, and cleaning contaminated equipment. Therefore, as the oil and gas production sectors meet the requirement to have regulatory control, they could have a proper monitoring program for workers. It also shows the dose per inhaled unit of the radionuclides ^{226}Ra and ^{228}Ra, for an activity concentration of 10 Bq/g, as presented in Table 2.

Table 2: Dose per unit of incorporation by inhalation of particulate radionuclides on the NORM scale [3]

Radionuclides	Committed effective dose per unit of intake (Sv/Bq)		
	5 µm AMAD		1 µm AMAD
	Slower Lung Absorption Type	Slow absorption type (S)	Slower Lung Absorption Type
Ra-226	2.2×10^{-6}	3.8×10^{-5}	3.2×10^{-6}
Ra-228	1.7×10^{-6}	1.2×10^{-5}	2.6×10^{-6}

To minimize this internal radiation exposure, the use of respiratory protective equipment should be mandatory, but this use does not exclude the need for individual internal control of workers, including to demonstrate the effectiveness of the protection and to assess the ingestion of radioactive materials during equipment decontamination.

It is important to observe that although the values of effective doses at table 2 are not very high, there are in Brazil some activity concentrations up to 3500 Bq/g [13] that take very high committed effective doses.

d) ICRP - Radiological Protection from Naturally Occurring Radioactive Material (NORM) in Industrial Processes [15]: The ICPR shows that the characterisation to determining who is exposed, when, where, and how, is an important starting point for the protection of workers. It includes characterisation of the source, with the aim of identifying the distribution of NORM radionuclides and their activity concentrations throughout the industrial process, radiological protection from naturally occurring radioactive material (NORM) in industrial processes including mode of exposure, chemical and physical characteristics of particulates, NORM distribution, and activity concentrations at all stages of the industrial process in both operational and maintenance conditions.

An assessment of the exposure of workers is required as part of the initial characterisation. Where doses are well above a few mSv per year, individual dose assessments should be undertaken. For external radiation, this should be done with personal dosimeters (passive or electronic). Assessment of internal exposures from dust inhalation is much more challenging; however, in very dusty NORM workplaces, there may already be a dust monitoring programme which can be adapted to provide estimates of radiation dose. If not, and if internal doses are high, arrangements with a suitable internal dosimetry service will need to be considered. It should be noted, however, that such exposures are unlikely to be considered optimised, and that suitable protective actions should be more than capable of reducing internal exposures [15].

So, the protection of workers in industries involving NORM should be based on a graded approach to control radiation exposures, according to the annual effective dose (due to the activities involving NORM) that is likely to be received and the scope for dose reduction that may be achievable through optimisation (Item 4 Implementation of the system of radiological protection to industrial processes involving NORM) [15].

3.3. Experimental results obtained in the scientific literature

The lack of research and experiment on the internal individual monitoring of these workers in this area raises a concern about their job's performance. With this gap is not possible to guarantee the health and safety of these workers without knowing if they are being exposed to radiological risks. Despite this, two studies on the internal individual monitoring of the workers, who perform the decontamination of equipment with NORM of oil and gas, were published. These articles showed the annual effective doses received by workers and reinforce that it is really necessary to perform the individual internal and external monitoring of workers.

First study: The authors Hamilton and UNSCEAR (2004, 2022) presented an assessment of effective dose of maintenance personnel due to decontamination of NORM carried out under controlled conditions. Personal air samplers and personal dosimeters, along with a significant number of area samplers were used, and external exposure and internal exposure from inhalation and ingestion were determined. This research was based on the workload of cleaning 20 tubes per day for 250 days per year (5000 tubes) done by occupational radiation workers, the operator and helper [14,21].

The specific activity samples of the pipe scale were obtained from three sites: the Lake Sand, Mud Lake, and West Delta. The samples were analysed by gamma spectroscopy with a progeny ingrowth method and the specific activities were shown at Table 3.

Table 3 : Pipe scale specific activities fron aggregate samples [14]

Radionuclides	Lake Sand	Mud Lake	West Delta
^{228}Ra and progeny	14.6 ± 0.2 Bq.g^{-1}	26.6 ± 0.3 Bq.g^{-1}	81.4 ± 8.5 Bq.g^{-1}
^{226}Ra and progeny	33.6 ± 0.4 Bq.g^{-1}	65.5 ± 0.7 Bq.g^{-1}	57.7 ± 0.4 Bq.g^{-1}

For internal dose estimation, two aspects were taken into consideration: the inhalation dose component based on the suspended pipe scale and the radon inhalation, that is, the radon emanates from stored pipes awaiting cleaning and diffuses from the pipe scale dispersed around the machine; and the incidental ingestion, assuming that the dust available to be incidentally ingested comes exclusively from contaminated pipes.

For external dose two exposure pathways were included : “groundshine” from large pieces of pipe scale ejected from the pipes during the rattling process and the finer, airborne particulates that deposit on the ground during and shortly after the rattling operation; and “pipeshine,” or the gamma rays from pipe scale inside pipes that await cleaning. The external annual effective dose equivalent was calculated for a 2,000 h work year using the hazard indices UNSCEAR.

The authors showed (table 5) the assessment of effective dose of maintenance personnel due to decontamination of NORM oil and gas.

Table 5: Estimated annual dose to oil field pipe rattler operator and helper (mSv) [14]

Dose pathway	Operator	Helper
Inhalation	0.45	0.45
Ingestion	0.097	0.097
Pipeshine	0	0.28
Groundshine	2.8	4.1
Total	3.3	4.9

The highest annual effective dose received by the helper is higher than the dose postulated by the regulatory order for the public individual (1 mSv), so this worker must fit into an occupationally exposed individual (IOE) and be subject to the rules and recommendations of the regulatory body of your country. The table 5 shows that the effective dose (internal and external) of 4.9 mSv comes from the exposure to the sample containing concentrations of activities of 65.5 Bq/g for ^{226}Ra. In Brazil, in the exploration field of the Sergipe and Alagoas Basin [22] the activity concentration values for scale are about 3500 Bq/g, that is, 54 times higher than that presented in the first study references. As the concentration of activity of a sample is a factor that influences the dose [13] receive by the worker, higher doses can be expected than those presented in the first study references.

Second study: The ICRP and IAEA (2004, 2022) showed that work activities involving NORM can give rise to external and internal radiation exposures.

External exposures can arise from extended exposures to low (gamma) dose rates; shorter exposures to high (gamma and sometimes beta) dose rates from performing maintenance on internals of equipment, slag, scale, and sludge; or a combination of these.

The potential for internal exposure is governed mostly by the way NORM appears in the workplace, and the personal protective equipment (PPE) worn by workers. The airborne dust is an industrial hazard, and internal exposures from inhalation of NORM can be significant, especially where higher activity concentrations are present.

Very large numbers of workers in the world may be exposed to all types of NORM, and although the data are more limited than those for occupational exposures to manmade sources, the worldwide level of exposure for workers exposed to natural sources of radiation has been estimated at 30000 man/Sv annually (approximately 13 million workers).

Table 5 shows ranges of employee exposures involving NORM specifically for oil and gas. It was observed that the main problems of radiological protection are associated to the scale are the external gamma exposure of the workers, especially where the scale is deposited, and internal staff display when removing scale during maintenance and decommissioning [15, 23].

Table 5: Examples of dose assessments for workers for oil and gas NORM (external and internal from dust, excluding exposure to radon) [15, 23]

Activities	Radionuclides with highest activity concentrations	Annual effective dose (mSv)		
		Minimum	Mean	Maximum
Oil production, cleaning of pipes	^{226}Ra (scale/sludge)	-	0.6	3

Similar to the first study, the highest annual effective dose received by workers is higher than the dose postulated by the regulatory order for the public individual (1 mSv), so these workers must fit into an occupationally exposed individual (IOE) and be subject to the rules and recommendations of the regulatory body of your country.

With respect to the NORM regulations of the countries, some of them present specific aspects for radiological protection of workers, such as, (1) Canada presents Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM) [16], (2) the USA presents the NRC Regulations Title 10, Code of Federal Regulations, Chapter I - Nuclear Regulatory Commission part 20 about standards for protection against radiation [17], (3) Australia presents the Management of Naturally Occurring Radioactive Material (NORM) [18] and (4) the Brazil presents the CNEN Resolution 288 [19] that "establishes the necessary requirements for the registration of oil and gas exploration and production facilities to carry out activities for cleaning and packaging waste containing naturally occurring radionuclides".

So, it was observed that some countries don't emphasize the radiation protection of workers exposed to oil and gas NORM during, specifically, the activity of decontamination of equipment. This is worrying, as these workers could be exposed to external and internal radiation from NORM material due to gamma radiation as well as a great number of radioactive particles in the air (Figure 8). This situation shows the need to assess the exposure level of these workers in order to implement a more adequate radiological protection policy.

Figure 8: *Ultra High-Pressure Water Jetting*

Source: IAEA, 2010 [9]

4. CONCLUSION

There are currently five techniques to decontaminate equipment with oil and gas NORM, but the most widely used method worldwide is ultra-high-pressure water jetting abrasive decontamination. Despite being used to minimize the dispersion of particles due to forced precipitation with the use of water, the dispersion of radioactive particles in the air is still observed (Figure 8), and it will require an individual internal monitoring for an effective evaluation of the radiological risk of these workers.

Although internal monitoring is very important, the lack of published scientific articles involving NORM oil and gas decontamination makes very difficult the discussion about this area. Despite having few articles, two were found that provide information on the decontamination of NORM oil and gas equipment and showed the real need for internal monitoring of workers.

Since radiation exposure and activity concentrations of oil and gas NORM are very different from other NORM industries (e.g. coal, mineral sands, fertilizers, construction, etc.), internal individual monitoring will become necessary to assess potential doses to organs and tissues, especially during equipment decontamination work.

With the implementation of a fully radiological risk assessment for equipment decontamination work, the companies would perform a correct radiological monitoring of their employees. This will be one of an important action to ensure the health and safety conditions to workers involved.

Furthermore, countries, with their regulatory authorities, would develop specific regulations to ensure full radiological protection for workers exposed to oil and gas NORM during equipment decontamination.

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