RADIOLOGICAL IMPACT ON MAN AND THE ENVIRONMENT FROM THE OIL AND GAS INDUSTRY: RISK ASSESSMENT FOR THE CRITICAL GROUP

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ABSTRACT:

Radiation exposure of workers in the oil-gas industry can occur by inhalation of high-levels of radon gas; increased gamma dose rates; increased gamma dose rate due to ^{226}Ra, ^{210}Pb, ^{228}Ra, and ^{228}Th. The waste also has elevated contents of long-lived radionuclides. Finally, the recycling of waste originating within the oil-gas industry can pose a contamination problem. The various exposure pathways and a regulatory framework are discussed with regard to their applicability to the conditions in the Caspian Region.

Keywords: Radon, radium, radiation protection, contamination, risk assessment, oil and gas.

INTRODUCTION:

Technologically Enhanced Natural Radiation (TENR) means radiation from naturally occurring isotopes to which exposure would not occur by (or would be increased by) some technological activity not expressly designed to produce radiation. TENR and the oil and gas industry had a strained relationship. For almost 30 years it has been discussed in the scientific community that some workers in the oil and gas industry are exposed to echnologically enhanced levels of natural radioactivity [1,2]. However, this industry was rather reluctant to acknowledge its employees as potentially occupationally exposed to radiation.

Since 1991 the situation has improved to some extent because the International Commission for Radiological Protection (ICRP) has recommended that the full system of radiation protection should also apply for these workers, provided the TENR exposure scenario in average dose values exceeds 1 mSv/yr [3]. The International Atomic Energy Agency (IAEA), recommending to its member states to adopt the ICRP recommendation [4], further expressed the concern over this issue. It is important to recognize that on the one hand, TENR exposure in terms of individual dose of a worker in the oil and gas industry is truly a global issue due to the global distribution of reserves. On the other hand, these figures clearly show that the impact on the collective dose is not uniform, i.e. the number of workers subject to TENR exposure is significantly higher in the Middle East and Central Asia as compared to the number of workers of all other regions combined. For example, the contribution to the total world oil production by the different regions is as follows (approximate figures):

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- Asia Pacific region: 10%
- Europe: 10%
- The Americas: 20%
- Middle East, Central Asia (incl. former Soviet Union): 60%

In Azerbaijan, both oil and gas exploration is continuing to expand. From January to July 2003, the national State Oil Company (SOCAR) produced 5,196,000 tons of oil, exceeding the production of the same period in 2002 by 15,400 tons. The national gas industry produced in the same period of 2003 almost 3 billion m^3 of natural gas (an increase of 77.5 million m^3 over the forecast [5].

It is emphasized that in many countries the oil and gas industry represents a powerful concentration of capital and is frequently one of the main providers of a large number of jobs. Therefore this industry is able to exert also significant lobbying power at the political level. For example, in Brazil until recently a single company had the monopoly to extract oil in all of Brazil, making it the largest Brazilian commercial and industrial enterprise. Such a concentration of power can pose a significant hurdle in enforcing the implementation of any TENR-relevant legislation, as in the case of Brazil. The situation is still worse in many other countries with large oil and gas extraction industries, which have not even yet finished their internal discussion on how to adopt a common regulatory structure with regard to TENR. This is the current situation for: Argentina, Azerbaijan, Australia, Bolivia, China, Ecuador, India, Indonesia, Kazakhstan, Malaysia, Mexico, Saudi Arabia, United Arab Emirates, and Venezuela.

Exposure pathways

Exposure to the TENR in the oil-gas industry can occur as occupational exposure for the workers at various stages of the exploration processing, but also result in an environmental impact due to radioactive releases along various pathways. International databases on radionuclide concentrations in the environment of oil-gas extraction/processing facilities are scarce [6,7].

Incorporation

Workers employed in the vicinity of oil and gas-drilling operations will be exposed to radon gas (^{220}Rn, ^{222}Rn). The radon isotopes are contained in the natural gas, or they are dissolved in the different fluids resulting from the production process. Particularly at working areas adjacent to the well heads outdoor radon values have been found to average 500 Bq/m^3, at some processing plants radon flow reached up to 6.2 GBq per day. Also high radon concentration values have been detected at gas storage tanks and compressor facilities. The radon concentration (in Bq/kg) at different stages of production facilities can reach significant values [7]:

- Demethaniser 438
- Depropaniser reflux 633
- Deethaniser vapour 1,393
- Block oil 1,797

A second inhalation exposure pathway occurs by using the oil shale as a source of oil. Oil shale is a sedimentary rock, which contains kerogen. Oil shale is used to produce synthetic shale oil. Since oil shale contains on average about 250% of the ^{238}U content of coal, raw and spent shale particles released to the atmosphere during mining and processing can represent a significant pathway via inhalation and ingestion. Retort gases resulting from the processing of oil shale can have a ^{222}Rn concentration up to 18 kBq/m^3. Leaching of radionuclides from spent shale piles can contaminate the ground water, since the ^{226}Ra concentration can reach up to 42 kBq/m^3 [6].

Occupational radiation exposure for oil- and gas workers can also occur during maintenance of plant facilities. Maintenance workers opening valves or working with used pipes are likely to incorporate ^{226}Ra, ^{210}Pb, ^{228}Ra, and ^{228}Th from deposits formed on metal surfaces (scales). These scales result from the partial solubility of ^{226}Ra and ^{228}Ra in water. They can be found in the fluids present in the oil and gas reservoir, such as water, gas, oil or condensates. Subsequently the radium isotopes mix with barium, calcium and strontium, present in the rock formation of the deposit. Along the pathway from the oil and gas reservoir to the aboveground production facilities, the various treatment processes decrease the dissolution characteristics of the fluids for radium isotopes. This leads to the deposition of radium isotopes as radium carbonate or radium sulphate in the form of scales or sludge.

High dust levels occur in the breathing area of such workers sandblasting the inside of tanks, or brushing of surfaces for grinding the metal. The scales removed in this manner contain ^{226}Ra up to 1,000 kBq/kg (average: about 5 kBq/kg), and in addition (maximum values each in kBq/kg): ^{210}Pb (72), ^{228}Ra (360), ^{228}Th (360). ^{210}Pb exposure (and of its decay products) can also occur for workers whenever they touch internal surfaces (e.g., in pumps; [8]. These lead deposits can contain ^{210}Pb up to 3,000 kBq/kg [9].

Also non-occupational exposure via the incorporation of radionuclides can result due to practices associated indirectly with the oil and gas industry, such as:

- The use of sewage sludge from oil processing plants in agriculture. Since this waste can contain long-lived radionuclides (e.g. ^{226}Ra), this can lead to an undesirable contamination of agricultural products. Typically the total ^{226}Ra activity brought to the surface equals about 918 GBq/yr [10];
- Disposal of large amounts of contaminated wastes (scales, sludge) in so-called “lagoons” near platforms. This practice occurs frequently in remote desert areas, not necessarily subject to stringent environmental control. The average sludge and scale generated by an oil-producing well amounts to 2.25 t/yr [10];
- Spent oil-shale piles are frequently located in regions with increased precipitation (e.g., Scandinavia). Leaching of these piles has the potential for groundwater contamination, since the leachate can contain ^{226}Ra up to 42 Bq/l.

A special issue is the reuse of contaminated metal, which originated within the oil and gas industry. This has been found to represent a serious contamination problem for the operator of such a recycling facility. Dismantled metal equipment can contain: ^{226}Ra in the scales deposited on the inside of the tanks, and the inner surface of pipes, short-lived ^{222}Rn-decay products deposited on the inside of various equipment components; this itself leads eventually to the contamination with ^{210}Pb and the growth of ^{210}Po. Total activity values for the scale range typically from 500 to 800 kBq/kg [11].

In the first stage of the recycling the pipes are cleaned by high-pressure water jets (pressure up to 2,500 bar) to remove the scales from the inside of the pipes. Subsequently the metal is cut and molten in an electric furnace. The melting process separates the natural radionuclides and leads to an enrichment process in the slag and to a much lesser degree in dust (predominantly ^{226}Ra, which accumulates to about 98% in slag and only 2% in dust).[2]

External radiation: Workers on platforms or near rigs, exposed to increased gamma dose rate due to external radiation in the vicinity of vessels and tanks filled with brines raised to the surface. Both, workers as well as members of the public can be exposed to external radiation from the storage and transport of radioactive contaminated materials and waste products.

The magnitude of the environmental issue becomes apparent when taking into account that even in countries with a relatively small oil and gas exploration large amounts of brines are raised to the surface as an unwanted by-product; for example in Germany, almost 30 million t of brines annually [12]. The United Kingdom has about 80 offshore platforms, disposing routinely of radioactive TENR wastes from its production facilities [13].

Doses for critical groups

Critical groups are: members of the public, exposed to incorporation of radium via the food chain or through inhalation of radium containing dust, workers inhaling radon at the workplace, respectively incorporating radon, radium and lead. Actual release data are rare and therefore the doses have to be calculated, assuming different exposure scenarios as input data for dose models, such as BIOS (National Radiological Protection Board, Chilton, Didcot, United Kingdom).

Committed effective doses due to inhalation of radioactive aerosols (e.g., during the removal of scales in a tank) are summarized in Table 1. These values are based on the dose conversion coefficients as recommended in the EURATOM Basic Safety Standards [14]

Table 1: Committed effective doses due to inhalation and ingestion (mSv/g of incorporated material) for scales[1]

Radionuclide	Specific activity [kBq/kg]	Inhalation AMAD 1 μm	Ingestion
^{226}Ra	500	1.6	0.1
^{228}Ra	300	13.5	0.2
^{210}Pb	300	1.2	0.3

[2] ^{210}Pb is gaseous at the typical operating temperatures up to 1 400 C and is accumulated to about 93% in the dust of the air cleaning system of the melter

[1] based on measurements of scales with the maximally observed activities in the soil and gas industry

It can be seen that the inhalation exposure exceeds in all cases the exposure due to ingestion by at least 400%. By comparison, external radiation due to radon and its decay products is rather low: assuming a ^{222}Rn flow of 6 GBq/d and an exposure for 20 h/week, this will result in an external gamma exposure of 0.15 mSv/yr.

The dose rate due to external radiation is a function of the activity concentration of the radium isotopes contained in the scales, the amount of scales, the irradiation geometry, and the shielding characteristics of the wall material contaminated on the inside with radium (e.g., of the contained filled with brines). The external dose rate is predominantly due to radium isotopes, since the ^{210}Pb deposits do not contribute significantly to the external irradiation due to the low energy of the gamma radiation (46 keV). The resulting dose rate values can reach up to several tens of µSv/h [9]. If the employee is engaged in a dust-laden atmosphere due to the removal of scales, the additional respiratory tract-relevant doses are about 0.5 mSv/yr.
Assuming the lack of any precautionary actions during routine operations the following range of dose values can be expected [9]:

- Maintenance: 0.03 to 0.5 mSv/yr
- Revision: 0.3 to 7 mSv/yr

For comparison, the absorbed dose rate in air, inclusive cosmic and terrestrial exposure, ranges from 0.02 to 30 µGy/h in areas of high natural background rates [15].

Regulatory control

In the European Union EURATOM recommends that all workplaces with a potential exposure to natural radioactivity must be evaluated. If a value of 1 mSv/yr is exceeded, appropriate measures have to be taken to control – and if necessary – to reduce the occupational radiation exposure.

In case an industrial activity results in NORM waste materials below 500 kBq/kg these materials are not subject to control, provided the above listed dose limit and nuclide-specific upper values are adhered to; for example, in case of ^{226}Ra this corresponds to a specific activity of 65 kBq/kg. In this situation there are no requirements for records to be kept of disposals made. If the limit of 500 kBq/kg is exceeded, a Member State can exempt this type of activity only if the individual dose of 10 µSv, respectively the collective dose of 1 man-Sv is not exceeded. An alternative approach can be the demonstration that the exemption is indeed the optimum solution in terms of radiation protection, e.g. by applying an optimisation process.

The practical application of such regulatory approach for a smaller oil and gas producing country, such as Azerbaijan, is demonstrated in the case of UK offshore operations. For wastes resulting from the UK oil and gas exploration carried out under the terms of the Radioactive Substances Exemption Order, there is an exemption rule in place, which covers phosphatic substances, rare earths, etc. Otherwise, disposal of scale and other wastes is granted under the terms of the Radioactive Substances Act (1993), which indeed requires records of actual discharges made under the authorization to be archived.

CONCLUSIONS:

Globally there is still inadequate awareness in oil and gas industry about the necessity to address the issue of radiation protection for workers and controlling the discharge of radioactive wastes into the environment. Numerical data on the activity concentration and mass flow of radionuclides involved in the different stages of the oil and gas exploration and production are insufficient and subject to large uncertainties. This is specially the case for oil and gas exploration in developing countries.

Based on the few currently available data, critical groups in the workforce can be defined (e.g., workers engaged in revision) who may receive – under adverse conditions – significantly elevated doses exceeding the currently applicable dose limits for non-occupationally exposed persons. Therefore a worldwide initiative is recommended to improve the currently inadequate lack of statistically representative data for the radiation exposure of the workforce in order to a) identify critical groups, b) apply an adequate system of radiation protection for them. In addition, representative surveys of the environmental impact resulting from the waste disposal practices should be intensified to derive at cost-effective sustainable solutions with regard to an environmentally friendly waste management system.

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